

Daniel K. Resnick, MD

University of Wisconsin School of Medicine and Public Health, Department of Neurosurgery, Madison, Wisconsin

Correspondence:

Daniel K. Resnick, MD,
University of Wisconsin School of Medicine and Public Health,
Department of Neurosurgery,
600 Highland Avenue,
Madison, WI 53792.
E-mail: resnick@neurosurg.wisc.edu

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On behalf of the AANS/CNS Joint Guidelines Committee, I am pleased to introduce the updated *Guidelines for the Management of Acute Cervical Spine and Spinal Cord Injury*. This work describes the “state of the literature” with regard to the treatment of patients with cervical spine and spinal cord injuries and is a useful guide to help clinicians make important decisions in the care of these patients. As with all evidence-based guidelines, recommendations made cannot exceed the strength of the literature, and where there is a lack of evidence or disagreement in the literature, strong recommendations cannot be made. These recommendations represent a foundation for one leg of the “three-legged stool” of evidence-based practice. Having a well-described and vetted summary of the available medical evidence helps to structure decisions also dependent upon clinical judgment and patient desires.

In some cases, the guidelines can provide firm and easily applicable guidance—the (non)use of steroids is an example of such a recommendation in this volume. The authors present a compelling case from high-quality clinical studies demonstrating a greater propensity for such medication to harm rather than benefit patients with spinal cord injuries. In most cases, however, the use of guidelines requires further reflection. Application of clinical judgment to the use of guidelines begins with the determination of whether a guideline applies to your patient. For example, fracture patterns at the craniocervical junction may be complex, may be influenced by congenital abnormalities, and may not fit into the neat boxes selected by the authors for classification. Similarly, application of clinical practice guidelines needs to be balanced against the cost of the application—is aggressive blood pressure augmentation appropriate for an elderly patient with limited cardiac

reserve? Is the evidence for benefit really strong enough to warrant the risk in an individual patient? What about routine imaging for vertebral artery injuries—how many asymptomatic patients need to be exposed to radiation and potentially anticoagulated for radiographic findings that may or may not have clinical importance? These decisions cannot be made by a writing panel, no matter how expert—they require “boots on the ground” judgment, often made with incomplete information. Guidelines provide the best evidence, but only the evidence that exists.

Additionally, application of guidelines needs to be mitigated by patient desires when such desires can be assessed. A decision regarding collar vs halo vs surgical immobilization of odontoid fractures may be substantially guided by patient-related factors and preferences—the same radiographic fracture may be treated differently depending on patient age, community, and preference.

This update of the *Guidelines for the Management of Acute Cervical Spine and Spinal Cord Injury* is an impressive accomplishment. The evolution of skill in evidence-based review in neurosurgery is evident throughout the document, as every process has been improved over the last decade. The authors have not only updated the guidelines based on new literature, but they have improved the applicability of the guidelines to clinical practice through better question formulation, illustrated graphically the evolution of evidence to allow readers to appreciate what has been learned over the past decade, and incorporated a more sophisticated discussion of the literature to explain areas of continued uncertainty. The reader is encouraged to critically read the supporting evidence for the recommendations in order to appreciate the context of the recommendations as well as the limitations. The authors are congratulated on an outstanding piece of work.

These revised guidelines are an outstanding achievement, and neurosurgeons should be proud of these authors who have taken the time and effort to create this work. Overall, the methodology is sound and the results are solid. I congratulate the authors for not being tempted to comment on popular but yet inadequately studied topics such as hypothermic treatment of acute spinal cord injury just because this topic appears in the newspapers.

Some of the recommendations in this volume are repeated in different chapters. For example, the first two recommendations in the paper on the management of acute traumatic central cord syndrome (ATCCS) are also found in the paper dealing with cardio-pulmonary management of spinal cord injury.

The paper on transportation of patients with acute traumatic cervical spine injuries raises some interesting policy questions for providers. In this paper, the second recommendation is that, whenever possible, patients with acute cervical spine or spinal cord injuries be transported to specialized acute spinal cord injury treatment centers. But what makes an institution a “specialized acute spinal cord injury treatment center”? Are these centers designated by a governmental agency/regulatory body, or are they self-designated? If the answer is that an acute spinal cord injury center is any institution that can provide acute critical care and surgical care, then isn’t it the care itself that is important and not the designation of the institution?

What about care of the acute spinal cord injury patient that is provided within all the recommendations for critical care and surgical care published in these guidelines but provided in an institution that does not choose to call itself an “acute spinal cord injury treatment center”? Is the care inadequate because of the lack of designation or recognition? This is not a trivial issue from a medical-legal standpoint.

There is a concern shared by a number of healthcare providers that a recommendation like the second recommendation in this particular paper is the result of a conflict of interest from large medical centers that are often self-

designated specialty care centers (ie, “we can do it better so you should send all your cases to us”).

Finally, the summary Table in the introduction is incomplete. It lists many of the recommendations listed in this volume but does not list all of them. A complete and comprehensive tabulation of all the recommendations would be very helpful.

Jeffrey W. Cozzens
Springfield, Illinois

In this newest edition of the *Guidelines for the Management of Acute Cervical Spine and Spinal Cord Injury*, the author group has updated the 2002 guidelines in a number of ways, incorporating the newest available studies as well as scrutinizing existing studies. The review process for this edition has included additional review by the AANS/CNS Joint Guidelines Committee, and this has prompted several refinements of the recommendations that have resulted in a work that is very tightly tied to the available evidence in the literature. Features such as a summary of changes between the two sets of guidelines, and evidence tables that are easy to cross-reference with text and recommendations make this edition more accessible than ever before.

As a community neurosurgeon, it can sometimes be difficult to glean practical rules from many of the EBM practice guidelines currently available; I believe this set will be an aid not only to academicians and those with backgrounds in epidemiology and evidence-based medicine, but also to the vast majority of neurosurgeons who are extremely skilled in patient care and who look to these types of published practice guidelines for changes in current thinking about what is—and is not—supported in the neurosurgical literature. The more accessible and transparent these guidelines efforts are, the more readily they will be embraced both by our colleagues in neurosurgery and well as in other disciplines, including emergency medicine and trauma surgery; the use of the same sets of guidelines by multiple specialties will surely foster better communication

and collaboration in the care of many patients. The author group should be congratulated on another excellent effort.

J. Adair Prall

Littleton, Colorado

In recent years, there has been a growing national interest in enhancing the quality of patient care. One of the commonly used methods is standardization, which has been associated with increased quality of care in various health care settings. In the setting of spinal trauma, rigid standardization is frequently impractical and difficult, as there are often subtle differences between patient characteristics, injury patterns, and other clinical considerations that may result in two similarly presenting patients receiving different, yet appropriate treatment. Another method to enhance quality is to provide practitioners with factual, evidenced-based information that may validate established consensus opinion, or, in some cases, may even shift treatment paradigms. The 2012 *Guidelines for the Management of Acute Cervical Spine and Spinal Cord Injury* is likely to improve the quality of patient care through both mechanisms.

Students of the 2002 *Guidelines for the Management of Acute Cervical Spine and Spinal Cord Injury* will be very pleased with the current offering. The present rendition provides a balanced, evidenced-based assessment of the available literature regarding a broad swath of management strategies ranging from underappreciated topics such as the transportation of acute SCI patients, to more provocative subjects such as the use of steroids in acute spinal injury. The authors provide an easy to use table that contrasts the 2002 and 2012 recommendations for each of the

investigated topics. Although this table is handy and informative, the reader should not use this as a substitute for reading the individual chapters in detail, as the material provided allows for a better understanding of the genesis of the recommendations.

All of the topics are thoroughly investigated and presented, yet I must make special mention of the chapter entitled “Pharmacological Therapy for Acute Spinal Cord Injury.” The use of steroids in acute SCI is a very controversial subject, with practitioners falling on either side of the treatment line. To many, the literature has previously lacked clarity on this subject. One of the few criticisms of the 2002 guidelines is that the role of methylprednisolone was not clearly defined: “Treatment with methylprednisolone for either 24 or 48 hours is recommended as an option in the treatment of patients with acute spinal cord injuries...” The present day usage of methylprednisolone is fueled by both a desire to do everything humanly possible for these tragically injured patients, as well as medicolegal concerns, which can be quite significant in some communities. The 2012 guidelines clearly state that methylprednisolone is not recommended in the management of acute SCI, and that there is no Class I or II evidence to support its use. In stark contrast, there is Class I–III evidence that this treatment is associated with harmful side effects. This powerful and well-written chapter will provide an immediate and beneficial impact on patient care.

The authors should be congratulated for their excellent work. This was an arduous and challenging task that was completed in an elegant and outstanding fashion.

Langston Holly

Los Angeles, California



American
Association of
Neurological
Surgeons



CNS

Guidelines Author Group

Joint Section on Disorders of the Spine and Peripheral Nerves
of the American Association of Neurological Surgeons
and the Congress of Neurological Surgeons

Lead Authors

Mark N. Hadley

Division of Neurological Surgery
University of Alabama at Birmingham

Beverly C. Walters

Division of Neurological Surgery
University of Alabama at Birmingham

Bizhan Aarabi

Department of Neurosurgery
University of Maryland

Sanjay S. Dhall

Department of Neurosurgery
Emory University

Daniel E. Gelb

Department of Orthopaedics
University of Maryland

Mark R. Harrigan

Division of Neurological Surgery
University of Alabama at Birmingham

R. John Hurlbert

Department of Clinical Neurosciences
University of Calgary

Curtis J. Rozzelle

Division of Neurological Surgery, Children's Hospital of Alabama
University of Alabama at Birmingham

Timothy C. Ryken

Iowa Spine & Brain Institute
University of Iowa

Nicholas Theodore

Division of Neurological Surgery
Barrow Neurological Institute

Administrative Support

Debbie Mielke

Administrative Associate & Residency Coordinator
Division of Neurological Surgery
University of Alabama at Birmingham

Introduction to the Guidelines for the Management of Acute Cervical Spine and Spinal Cord Injuries

Mark N. Hadley, MD*

**Beverly C. Walters, MD, MSc,
FRCSC‡**

*Co-Lead Author, Guidelines Author Group; Charles A. & Patsy W. Collat Professor of Neurosurgery and Program Director, University of Alabama Neurosurgical Residency Training Program, Division of Neurological Surgery, University of Alabama at Birmingham, Birmingham, Alabama; ‡Co-Lead Author, Guidelines Author Group; Professor of Neurological Surgery and Director of Clinical Research, University of Alabama at Birmingham, Birmingham, Alabama; Professor of Neurosciences, Virginia Commonwealth University - Inova Campus and Director of Clinical Research, Department of Neurosciences, Inova Health System, Falls Church, Virginia; Affiliate Professor of Molecular Neurosciences, George Mason University, Fairfax, Virginia

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Medical evidence-based guidelines, when properly produced, represent a contemporary scientific summary of accepted management, imaging, assessment, classification, and treatment strategies on a focused series of medical and surgical issues.¹⁻³ They are an evidence-based hierarchical ranking of the scientific literature produced to date. They record and rank the collective experiences of scientists and clinicians and are a comprehensive reference source on a given topic or group of topics.

Medical evidence-based guidelines are not meant to be restrictive or to limit a clinician's practice. They chronicle multiple successful treatment options (for example) and stratify the more successful and the less successful strategies based on scientific merit. They are not absolute, "must be followed" rules. This process may identify the most valid and reliable imaging strategy for a given injury, for example, but because of regional or institutional resources, or patient co-morbidity, that particular imaging strategy may not be possible for a patient with that injury. Alternative acceptable imaging options may be more practical or applicable in this hypothetical circumstance.

Guidelines documents are not tools to be used by external agencies to measure or control the care provided by clinicians. They are not medical-legal instruments or a "set of certainties" that must be followed in the assessment or treatment of the individual pathology in the individual patients we treat. While a powerful and comprehensive resource tool, guidelines and the recommendations contained therein do not necessarily represent "the answer" for the medical and surgical dilemmas we face with our many patients.

This second iteration of *Guidelines for the Management of Acute Cervical Spine and Spinal Cord Injuries* represents 15 months of diligent volunteer effort by the Joint Section on Disorders of the Spine and Peripheral Nerves author group to provide an up-to-date review of the medical literature on 22 topics germane to the care, assessment, imaging and treatment of

patients with acute cervical spine and/or spinal cord injuries. The medical evidence summarized within each guideline has been painstakingly analyzed and ranked according to rigorous evidence-based medicine criteria, and have been linked to 112 evidence-based recommendations for these topics.¹⁻³

There are many important differences in this iteration of these Guidelines compared to those we published 10 years ago. Regrettably, however, for some of the topics considered and included in this medical evidence-based compendium, little new evidence beyond Class III medical evidence has been offered in the last 10 years by investigators and surgeons who treat patients with these disorders. Our specialties and our patients desperately need comparative Class I and Class II medical evidence derived from properly designed analytical clinical studies to further our understanding on the best ways to assess, diagnose, image and treat patients with these acute traumatic injuries.

Good progress has been made in several clinical research areas since the original Guidelines publication in 2002. One hundred twelve evidence-based recommendations are offered in this contemporary review, compared to only 76 recommendations in 2002. There are 19 Level I recommendations in the current Guidelines; each supported by Class I medical evidence.

- Assessment of Functional Outcomes (1)
- Assessment of Pain After Spinal Cord Injuries (1)
- Radiographic Assessment (7)
- Pharmacology (2)
- Diagnosis of AOD (1)
- Cervical Subaxial Injury Classification Schemes (2)
- Pediatric Spinal Injuries (1)
- Vertebral Artery Injuries (1)
- Venous Thromboembolism (3)

There are an additional 16 Level II recommendations based on Class II medical evidence and 77 Level III recommendations based on Class III medical evidence.

TABLE. Comparison of Cervical Spine and Spinal Cord Injury Guidelines Recommendations Between 2 Iterations Where Differences in Recommendations Have Occurred. All Other Recommendations Remain as Previously Stated

Topic	Previous Level of Recommendation	Recommendation 2002	Current Level of Recommendation	Recommendation 2012
Immobilization	Option	<ul style="list-style-type: none"> All trauma patients with a cervical spinal column injury or with a mechanism of injury having the potential to cause cervical spine injury should be immobilized at the scene and during transport by using 1 of several available methods. 	Level II	<ul style="list-style-type: none"> Spinal immobilization of all trauma patients with a cervical spine or spinal cord injury or with a mechanism of injury having the potential to cause cervical spinal injury is recommended.
		<ul style="list-style-type: none"> A combination of a rigid cervical collar and supportive blocks on a backboard with straps is effective in limiting motion of the cervical spine and is recommended. 		<ul style="list-style-type: none"> Triage of patients with potential spinal injury at the scene by trained and experienced EMS personnel to determine the need for immobilization during transport is recommended. Immobilization of trauma patients who are awake, alert, and are not intoxicated, who are without neck pain or tenderness, who do not have an abnormal motor or sensory examination and who do not have any significant associated injury that might detract from their general evaluation is not recommended.
	None	Not addressed	Level III	<ul style="list-style-type: none"> Spinal immobilization in patients with penetrating trauma is not recommended due to increased mortality from delayed resuscitation.
Transportation	None	Not addressed	Level III	<ul style="list-style-type: none"> Whenever possible, the transport of patients with acute cervical spine or spinal cord injuries to specialized acute spinal cord injury treatment centers is recommended.
Clinical Assessment: Neurological status	Option	<ul style="list-style-type: none"> The ASIA international standards are recommended as the preferred neurological examination tool. 	Level II	<ul style="list-style-type: none"> New Class II medical evidence.
Clinical Assessment: Functional status	Guideline	<ul style="list-style-type: none"> The Functional Independence Measure is recommended as the functional outcome assessment tool for clinicians involved in the assessment and care of patients with acute spinal cord injuries. 	Level I	<ul style="list-style-type: none"> The Spinal Cord Independence Measure (SCIM III) is recommended as the preferred Functional Outcome Assessment tool for clinicians involved in the assessment, care, and follow-up of patients with spinal cord injuries.
	Option	<ul style="list-style-type: none"> The modified Barthel index is recommended as a functional outcome assessment tool for clinicians involved in the assessment and care of patients with acute spinal cord injuries. 	N.A. (Not included in current iteration)	N.A. (Not included in current iteration)
Clinical Assessment: Pain	None	Not addressed	Level I	<ul style="list-style-type: none"> The International Spinal Cord Injury Basic Pain Data Set (ISCI-PDS) is recommended as the preferred means to assess pain including pain severity, physical functioning and emotional functioning among SCI patients.

(Continues)

TABLE. Continued

Topic	Previous Level of Recommendation	Recommendation 2002	Current Level of Recommendation	Recommendation 2012
Radiographic Assessment: Asymptomatic Patient	Standard	<ul style="list-style-type: none"> Radiographic assessment of the cervical spine is not recommended in trauma patients who are awake, alert, and not intoxicated, who are without neck pain or tenderness, and who do not have significant associated injuries that detract from their general evaluation. 	Level I	<ul style="list-style-type: none"> In the awake, asymptomatic patient who is without neck pain or tenderness, who has a normal neurological examination, is without an injury detracting from an accurate evaluation, and who is able to complete a functional range of motion examination; radiographic evaluation of the cervical spine is not recommended.
				<ul style="list-style-type: none"> Discontinuance of cervical immobilization for these patients is recommended without cervical spinal imaging.
	Option	<ul style="list-style-type: none"> It is recommended that cervical spine immobilization in awake patients with neck pain or tenderness and normal cervical spine x-rays (including supplemental CT as necessary) be discontinued after either a) normal and adequate dynamic flexion/extension radiographs, or b) a normal magnetic resonance imaging study is obtained within 48 hours of injury. 	Level III	<ul style="list-style-type: none"> In the awake patient with neck pain or tenderness and normal high-quality CT imaging or normal 3-view cervical spine series (with supplemental CT if indicated), the following recommendations should be considered:
				1) Continue cervical immobilization until asymptomatic,
				2) Discontinue cervical immobilization following normal and adequate dynamic flexion/extension radiographs,
				3) Discontinue cervical immobilization following a normal MRI obtained within 48 hours of injury (limited and conflicting Class II and Class III medical evidence), or,
		<ul style="list-style-type: none"> Cervical spine immobilization in obtunded patients with normal cervical spine x-rays (including supplemental CT as necessary) may be discontinued after dynamic flexion/extension studies performed under fluoroscopic guidance, or b) after a normal magnetic resonance imaging study is obtained within 48 hours of injury, or c) at the discretion of the treating physician. 		4) Discontinue cervical immobilization at the discretion of the treating physician.

(Continues)

TABLE. Continued

Topic	Previous Level of Recommendation	Recommendation 2002	Current Level of Recommendation	Recommendation 2012
Radiographic Assessment: Symptomatic Patient	Standard	<ul style="list-style-type: none"> A 3-view cervical spine series (anteroposterior, lateral, and odontoid views) is recommended for radiographic evaluation of the cervical spine in patients who are symptomatic after traumatic injury. This should be supplemented with computed tomography (CT) to further define areas that are suspicious or not well visualized on the plain cervical x-rays. 	Level I	<ul style="list-style-type: none"> In the awake, symptomatic patient, high-quality computed tomographic (CT) imaging of the cervical spine is recommended.
				<ul style="list-style-type: none"> If high-quality CT imaging is available, routine 3-view cervical spine radiographs are not recommended. If high-quality CT imaging is not available, a 3 view cervical spine series (AP, lateral, and odontoid views) is recommended. This should be supplemented with CT (when it becomes available) if necessary to further define areas that are suspicious or not well visualized on the plain cervical x-rays.
	Option	<ul style="list-style-type: none"> It is recommended that cervical spine immobilization in awake patients with neck pain or tenderness and normal cervical spine x-rays (including supplemental CT as necessary) be discontinued after either a) normal and adequate dynamic flexion/extension radiographs, or b) a normal magnetic resonance imaging study is obtained within 48 hours of injury. 	Level III	<ul style="list-style-type: none"> In the awake patient with neck pain or tenderness and normal high-quality CT imaging or normal 3-view cervical spine series (with supplemental CT if indicated), the following recommendations should be considered: <ol style="list-style-type: none"> 1) Continue cervical immobilization until asymptomatic, 2) Discontinue cervical immobilization following normal and adequate dynamic flexion/extension radiographs, 3) Discontinue cervical immobilization following a normal MRI obtained within 48 hours of injury (limited and conflicting Class II and Class III medical evidence), or, 4) Discontinue cervical immobilization at the discretion of the treating physician.

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TABLE. Continued

Topic	Previous Level of Recommendation	Recommendation 2002	Current Level of Recommendation	Recommendation 2012
Radiographic evaluation in obtunded (or unevaluable) patients	Option	<ul style="list-style-type: none"> Cervical spine immobilization in obtunded patients with normal cervical spine x-rays (including supplemental CT as necessary) may be discontinued a) after dynamic flexion/extension studies performed under fluoroscopic guidance, or b) after a normal magnetic resonance imaging study is obtained within 48 hours of injury, or c) at the discretion of the treating physician. 	Level I	<ul style="list-style-type: none"> In the obtunded or un-evaluable patient, high-quality CT imaging is recommended as the initial imaging modality of choice. If CT imaging is available, routine 3-view cervical spine radiographs are not recommended.
				<ul style="list-style-type: none"> If high-quality CT imaging is not available, a 3 view cervical spine series (AP, lateral, and odontoid views) is recommended. This should be supplemented with CT (when it becomes available) if necessary to further define areas that are suspicious or not well visualized on the plain cervical x-rays.
Closed Reduction	Option	<ul style="list-style-type: none"> Early closed reduction is recommended. 	Level III	No changes in recommendations
Cardiopulmonary Management	Option	<ul style="list-style-type: none"> Management of patients with acute SCI in a monitored setting is recommended. Maintain mean arterial BP 85 to 90 mm Hg after SCI is recommended. 	Level III	No changes in recommendations
Pharmacology Management: Corticosteroids	Option	<ul style="list-style-type: none"> Treatment with methylprednisolone for either 24 or 48 hours is recommended as an option in the treatment of patients with acute spinal cord injuries that should be undertaken only with the knowledge that the evidence suggesting harmful side effects is more consistent than any suggestion of clinical benefit. 	Level I	<ul style="list-style-type: none"> Administration of methylprednisolone (MP) for the treatment of acute SCI is not recommended. Clinicians considering MP therapy should bear in mind that the drug is not FDA approved for this application. There is no Class I or Class II medical evidence supporting the clinical benefit of MP in the treatment of acute SCI. Scattered reports of Class III evidence claim inconsistent effects likely related to random chance or selection bias. However, Class I, II, and III evidence exists that high-dose steroids are associated with harmful side effects including death.
Pharmacology Management: GM-1 Ganglioside	Option	<ul style="list-style-type: none"> Treatment of patients with acute spinal cord injuries with GM-1 ganglioside is recommended as an option without demonstrated clinical benefit. 	Level I	<ul style="list-style-type: none"> Administration of GM-1 ganglioside (Sygen) for the treatment of acute SCI is not recommended.
Occipital Condylar Fractures: Diagnostic	Guidelines (CT)	<ul style="list-style-type: none"> CT recommended to diagnose OCF. 	Level II (CT)	No changes in recommendation
	Option (MRI)	<ul style="list-style-type: none"> MRI recommended to assess ligaments. 	Level III (MRI)	

(Continues)

TABLE. Continued

Topic	Previous Level of Recommendation	Recommendation 2002	Current Level of Recommendation	Recommendation 2012
Occipital Condylar Fractures: Treatment	Option	<ul style="list-style-type: none"> Treatment with external cervical immobilization is recommended. 	Level III	<ul style="list-style-type: none"> External cervical immobilization is recommended for all types of occipital condyle fractures. More rigid external immobilization in a halo vest device should be considered for bilateral OCF. Halo vest immobilization or occipitocervical stabilization and fusion are recommended for injuries with associated AO ligamentous injury or evidence of instability.
AOD: Diagnostic	None	Not addressed	Level I	<ul style="list-style-type: none"> CT imaging to determine the CCI in pediatric patients with potential AOD is recommended.
	Option	<ul style="list-style-type: none"> If there is clinical suspicion of atlanto-occipital dislocation, and plain x-rays are non-diagnostic, computed tomography or magnetic resonance imaging is recommended, particularly for the diagnosis of non-Type II dislocations. 	Level III	<ul style="list-style-type: none"> If there is clinical or radiographic suspicion of AOD, and plain radiographs are non-diagnostic, CT of the craniocervical junction is recommended. The Condyle-C1 interval (CC1) determined on CT has the highest diagnostic sensitivity and specificity for AOD among all radiodiagnostic indicators.
AOD: Treatment	Option	<ul style="list-style-type: none"> Traction may be used in the management of patients with atlanto-occipital dislocation, but it is associated with a 10% risk of neurological deterioration. 	Level III	<ul style="list-style-type: none"> Traction is not recommended in the management of patients with AOD, and is associated with a 10% risk of neurological deterioration.
Atlas Fractures	Option	<ul style="list-style-type: none"> Treatment based on specific fracture type and integrity of transverse ligament. 	Level III	No changes in recommendations
Odontoid Fracture	Guideline	<ul style="list-style-type: none"> Treatment of Type II odontoid fractures based on 50 years of age. 	Level II	No change in recommendations
Axis Fractures: Odontoid	None	Not addressed	Level III	If surgical stabilization is elected, either anterior or posterior techniques are recommended.
Axis Fractures: Hangman's	Option	<ul style="list-style-type: none"> External immobilization is recommended. Surgery is recommended for angulation, instability. 	Level III	No changes in recommendations
Axis Fractures: Miscellaneous Body	Option	<ul style="list-style-type: none"> External immobilization is recommended for treatment of isolated fractures of the axis body. 	Level III	<ul style="list-style-type: none"> External immobilization for the treatment of isolated fractures of the axis body is recommended. Consideration of surgical stabilization and fusion in unusual situations of severe ligamentous disruption and/or inability to achieve or maintain fracture alignment with external immobilization is recommended. In the presence of comminuted fracture of the axis body, evaluation for vertebral artery injury is recommended.

(Continues)

TABLE. Continued

Topic	Previous Level of Recommendation	Recommendation 2002	Current Level of Recommendation	Recommendation 2012
Atlas/Axis Combination Fractures	Option	<ul style="list-style-type: none"> Treatment based on characteristics of axis fracture. 	Level III	No changes in recommendations
Os Odontoideum: Diagnostic	Option	<ul style="list-style-type: none"> Plain radiographs with flex/ext \pm CT or MRI is recommended. 	Level III	No changes in recommendations
Os Odontoideum: Management	Option	<ul style="list-style-type: none"> Occipital-cervical fusion with or without C1 laminectomy may be considered in patients with os odontoideum who have irreducible dorsal cervicomedullary compression and/or evidence of associated occipital-atlantal instability. Transoral decompression may be considered in patients with os odontoideum who have irreducible ventral cervicomedullary compression. 	Level III	<ul style="list-style-type: none"> Occipital-cervical internal fixation and fusion with or without C1 laminectomy is recommended in patients with os odontoideum who have irreducible dorsal cervicomedullary compression and/or evidence of associated occipital-atlantal instability.
				<ul style="list-style-type: none"> Ventral decompression should be considered in patients with os odontoideum who have irreducible ventral cervicomedullary compression.
Classification of Subaxial Injuries	None	Not addressed	Level I	SLIC and CSISS
			Level III	Harris and Allen
Subaxial Cervical Spinal Injuries	None	Not addressed	Level III	<ul style="list-style-type: none"> The routine use of CT and MR imaging of trauma victims with ankylosing spondylitis is recommended, even after minor trauma.
				<ul style="list-style-type: none"> For patients with ankylosing spondylitis who require surgical stabilization, posterior long segment instrumentation and fusion, or a combined dorsal and anterior procedure is recommended. Anterior stand-alone instrumentation and fusion procedures are associated with a failure rate of up to 50% in these patients.
Central Cord Syndrome	Option	<ul style="list-style-type: none"> Aggressive multimodality management of patients with ATCCS is recommended. 	Level III	No changes in recommendations
Pediatric Injuries: Diagnostic	None	Not addressed	Level I	<ul style="list-style-type: none"> CT imaging to determine the condyle-C1 interval for pediatric patients with potential AOD is recommended.
	Guideline	<ul style="list-style-type: none"> In children who have experienced trauma and are alert, conversant, have no neurological deficit, no midline cervical tenderness, and no painful distracting injury, and are not intoxicated, cervical spine x-rays are not necessary to exclude cervical spine injury and are not recommended. 	Level II	<ul style="list-style-type: none"> Cervical spine imaging is not recommended in children who are <u>greater than</u> 3 years of age and who have experienced trauma and who:

(Continues)

TABLE. Continued

Topic	Previous Level of Recommendation	Recommendation 2002	Current Level of Recommendation	Recommendation 2012
		<ul style="list-style-type: none"> In children who have experienced trauma and who are either not alert, non-conversant, or have neurological deficit, midline cervical tenderness, or painful distracting injury, or are intoxicated, it is recommended that anteroposterior and lateral cervical spine x-rays be obtained. 		
				1) are alert,
				2) have no neurological deficit,
				3) have no midline cervical tenderness,
				4) have no painful distracting injury,
				5) do not have unexplained hypotension,
				6) and are not intoxicated.
				<ul style="list-style-type: none"> Cervical spine imaging is not recommended in children who are <u>less than 3 years of age</u> who have experienced trauma and who:
				1) have a GCS > 13,
				2) have no neurological deficit,
				3) have no midline cervical tenderness,
				4) have no painful distracting injury,
				5) are not intoxicated,
				6) do not have unexplained hypotension,
				7) and do not have motor vehicle collision (MVC),
				8) a fall from a height greater than 10 feet,
				9) or non-accidental trauma (NAT) as a known or suspected mechanism of injury.
				<ul style="list-style-type: none"> Cervical spine radiographs or high resolution computed tomography (CT) is recommended for children who have experienced trauma and who do not meet either set of criteria above.
				<ul style="list-style-type: none"> Three-position CT with C1-C2 motion analysis to confirm and classify the diagnosis is recommended for children suspected of having atlanto-axial rotatory fixation (AARF).
	Options	<ul style="list-style-type: none"> In children younger than age 9 years who have experienced trauma, and who are non-conversant or have an altered mental status, a neurological deficit, neck pain, or painful distracting injury, are intoxicated, or have unexplained hypotension, it is recommended that anteroposterior and lateral cervical spine x-rays be obtained. 	Level III	<ul style="list-style-type: none"> AP and lateral cervical spine radiography or high-resolution CT is recommended to assess the cervical spine in children less than 9 years of age.

(Continues)

TABLE. Continued

Topic	Previous Level of Recommendation	Recommendation 2002	Current Level of Recommendation	Recommendation 2012
		<ul style="list-style-type: none"> In children age 9 years or older who have experienced trauma, and who are non-convulsant or have an altered mental status, a neurological deficit, neck pain, or painful distracting injury, are intoxicated, or have unexplained hypotension, it is recommended that anteroposterior, lateral, and open-mouth cervical spine x-rays be obtained. 		<ul style="list-style-type: none"> AP, lateral, and open-mouth cervical spine radiography or high-resolution CT is recommended to assess the cervical spine in children 9 years of age and older.
		<ul style="list-style-type: none"> Computed tomographic scanning with attention to the suspected level of neurological injury to exclude occult fractures or to evaluate regions not seen adequately on plain x-rays is recommended. 		<ul style="list-style-type: none"> High resolution CT scan with attention to the suspected level of neurological injury is recommended to exclude occult fractures or to evaluate regions not adequately visualized on plain radiographs.
		<ul style="list-style-type: none"> Flexion/extension cervical x-rays or fluoroscopy may be considered to exclude gross ligamentous instability when there remains a suspicion of cervical spine instability after static x-rays are obtained. 		<ul style="list-style-type: none"> Flexion and extension cervical radiographs or fluoroscopy are recommended to exclude gross ligamentous instability when there remains a suspicion of cervical spinal instability following static radiographs or CT scan.
		Magnetic resonance imaging of the cervical spine may be considered to exclude cord or nerve root compression, evaluate ligamentous integrity, or provide information regarding neurological prognosis.		<ul style="list-style-type: none"> Magnetic resonance imaging (MRI) of the cervical spine is recommended to exclude spinal cord or nerve root compression, evaluate ligamentous integrity, or provide information regarding neurological prognosis.
Pediatric Injuries: Treatment	None	Not addressed	Level III	<ul style="list-style-type: none"> Reduction with manipulation or halter traction is recommended for patients with acute AARF (less than 4 weeks duration) that does not reduce spontaneously. Reduction with halter or tong/halo traction is recommended for patients with chronic AARF (greater than 4 weeks duration). Internal fixation and fusion are recommended in patients with recurrent and/or irreducible AARF. Operative therapy is recommended for cervical spine injuries that fail non-operative management.
SCIWORA: Diagnosis	Option	<ul style="list-style-type: none"> Plain spinal x-rays of the region of injury and computed tomographic scanning with attention to the suspected level of neurological injury to exclude occult fractures are recommended. 	Level III	<ul style="list-style-type: none"> Magnetic resonance imaging (MRI) of the region of suspected neurological injury is recommended in a patient with SCIWORA.

(Continues)

TABLE. Continued

Topic	Previous Level of Recommendation	Recommendation 2002	Current Level of Recommendation	Recommendation 2012
		<ul style="list-style-type: none"> Magnetic resonance imaging of the region of suspected neurological injury may provide useful diagnostic information Plain X-rays of the entire spinal column may be considered. 		<ul style="list-style-type: none"> Radiographic screening of the entire spinal column is recommended.
				<ul style="list-style-type: none"> Assessment of spinal stability in a SCIWORA patient is recommended, using flexion-extension radiographs in the acute setting and at late follow-up, even in the presence of a MRI negative for extra-neural injury.
SCIWORA: Treatment	Option	<ul style="list-style-type: none"> External Immobilization is recommended until spinal stability is confirmed by flexion/extension x-rays. 	Level III	<ul style="list-style-type: none"> External immobilization of the spinal segment of injury is recommended for up to 12 weeks.
		External immobilization of the spinal segment of injury for up to 12 weeks may be considered.		<ul style="list-style-type: none"> Early discontinuation of external immobilization is recommended for patients who become asymptomatic and in whom spinal stability is confirmed with flexion and extension radiographs.
		<ul style="list-style-type: none"> Avoidance of "high risk" activities for up to 6 months after spinal cord injury without radiographic abnormality may be considered. 		<ul style="list-style-type: none"> Avoidance of "high-risk" activities for up to 6 months following SCIWORA is recommended.
SCIWORA: Prognosis	Option	<ul style="list-style-type: none"> Magnetic resonance imaging of the region of neurological injury may provide useful prognostic information about neurological outcome after spinal cord injury without radiographic abnormality. 	None	Not addressed (see Diagnosis)
Vertebral Artery Injury: Diagnostic	Option	<ul style="list-style-type: none"> Conventional angiography or magnetic resonance angiography is recommended for the diagnosis of vertebral artery injury after nonpenetrating cervical trauma in patients who have complete cervical spinal cord injuries, fracture through the foramen transversarium, facet dislocation, and/or vertebral subluxation. 	Level I	<ul style="list-style-type: none"> Computed tomographic angiography (CTA) is recommended as a screening tool in <u>selected</u> patients after blunt cervical trauma who meet the modified Denver Screening Criteria for suspected vertebral artery injury (VAI).
			Level III	<ul style="list-style-type: none"> Conventional catheter angiography is recommended for the diagnosis of VAI in <u>selected</u> patients after blunt cervical trauma, particularly if concurrent endovascular therapy is a potential consideration, and can be undertaken in circumstances in which CTA is not available.
				<ul style="list-style-type: none"> Magnetic resonance imaging is recommended for the diagnosis of VAI after blunt cervical trauma in patients with a complete spinal cord injury or vertebral subluxation injuries.

(Continues)

TABLE. Continued

Topic	Previous Level of Recommendation	Recommendation 2002	Current Level of Recommendation	Recommendation 2012
Vertebral Artery Injury: Treatment	Option	<ul style="list-style-type: none"> Anticoagulation with intravenous heparin is recommended for patients with vertebral artery injury who have evidence of posterior circulation stroke. 	Level III	<ul style="list-style-type: none"> It is recommended that the choice of therapy for patients with VAI, anticoagulation therapy vs antiplatelet therapy vs no treatment, be individualized based on the patient's vertebral artery injury, their associated injuries and their risk of bleeding.
		<ul style="list-style-type: none"> Either observation or treatment with anticoagulation in patients with vertebral artery injuries and evidence of posterior circulation ischemia is recommended. 		<ul style="list-style-type: none"> The role of endovascular therapy in VAI has yet to be defined; therefore no recommendation regarding its use in the treatment of VAI can be offered.
		<ul style="list-style-type: none"> Observation in patients with vertebral artery injuries and no evidence of posterior circulation ischemia is recommended. 		
Venous Thromboembolism: Prophylaxis	None	Not addressed	Level II	<ul style="list-style-type: none"> Early administration of VTE prophylaxis (within 72 hours) is recommended.
	Option	<ul style="list-style-type: none"> Vena cava filters are recommended for patients who do not respond to anticoagulation or who are not candidates for anticoagulation therapy and/or mechanical devices. 	Level III	<ul style="list-style-type: none"> Vena cava filters are not recommended as a routine prophylactic measure, but are recommended for select patients who fail anticoagulation or who are not candidates for anticoagulation and/or mechanical devices.
Nutritional Support	Option	<ul style="list-style-type: none"> Nutritional support of patients with spinal cord injuries is recommended. Energy expenditure is best determined by indirect calorimetry in these patients because equation estimates of energy expenditure and subsequent caloric need tend to be inaccurate. 	Level II	<ul style="list-style-type: none"> Indirect calorimetry as the best means to determine the caloric needs of spinal cord injury patients is recommended.
			Level III	<ul style="list-style-type: none"> Nutritional support of SCI patients is recommended as soon as feasible. It appears that early enteral nutrition (initiated within 72 hours) is safe, but has not been shown to affect neurological outcome, the length of stay or the incidence of complications in patients with acute SCI.

The Table shows the differences in the recommendations between the 2 sets of guidelines. One key change is that in nomenclature: “Standards” has been replaced by “Level I,” “Guidelines” has been replaced by “Level II,” and “Options” has been replaced by “Level III,” as described in detail in the Methodology section of these guidelines. Not every recommendation is listed since some have not changed, and the statement “No changes in recommendations” indicates that. When they have

changed, the recommendations previously made are compared to those being made currently. Where we have introduced new recommendations not included in the previous iteration of the guidelines, a statement is found indicating what the recommendations are alongside “None” and “Not addressed,” which represents the lack of previous recommendations on a particular aspect or topic. This summary table highlighting the changes in the guidelines is not a substitute for reading and understanding this

new version of the recommendations that reviews and evaluates extant literature in detail.

This comprehensive guidelines update does not contain an evidence-based summary or recommendation on several topics important to the care of our patients, our profession, and our disciplines, simply because there is not enough definitive medical evidence in the literature on those topics to allow such a review. Emerging science in the repair and regeneration of spinal cord injuries,⁴ emerging technology in imaging, the use of electrophysiological monitoring during surgery for spinal cord injury, new engineering technology in surgical implants,⁵ hypothermia in the care of the spinal cord injured patient⁶ and new science on the issue of the timing of surgery after acute traumatic cervical spinal injury,^{7,8} are examples of topics we simply do not have enough meaningful or convincing medical evidence in our literature to be included in this scientific review of acute cervical spine and spinal cord injuries.

The author group and the Joint Section leadership hope that these guidelines will serve their intended valuable purpose. The issues addressed in this scientific compendium are germane to the assessment, management, treatment, and study of the growing population of acute traumatic cervical spine and spinal cord injury patients we see daily in our practices. These patients, their injuries, their care, and in many cases, their losses, personally and to society,

are a major and growing societal and healthcare burden in the United States and around the world.⁹

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Methodology of the Guidelines for the Management of Acute Cervical Spine and Spinal Cord Injuries

Beverly C. Walters, MD, MSc, FRCSC

Division of Neurological Surgery, University of Alabama at Birmingham, Birmingham, Alabama, and Department of Neurosciences, Inova Health System, Falls Church, Virginia

Correspondence:

Beverly C. Walters, MD, MSc, FRCSC, FACS,
UAB Division of Neurological Surgery,
510 - 20th St S, FOT 1008,
Birmingham, AL, 35294-3410.
E-mail: bcwmd@uab.edu

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The original publication of guidelines dealing with the care of acutely injured cervical spine and spinal cord patients occurred within a few years of organized neurosurgery embracing the concept of producing evidence-based recommendations.¹ Much has been learned as a result of the careful critical evaluation of the medical literature pertaining to neurosurgical patients, and the methodology used in formulating practice parameters (or recommendations) has undergone further change and development. The methodology used in this iteration of these recommendations is a product of contributions from many sources, including multiple guidelines produced by neurosurgery and other specialty organizations.

BACKGROUND OF METHODOLOGY FOR EVIDENCE-BASED RECOMMENDATIONS

In the 1990s, professional and governmental organizations such as the American Medical Association, the American College of Physicians, the Institute of Medicine, the former Agency for Health Care Policy and Research, and others recognized that clinical decision making had to be founded in scientific discovery and that the best clinical trials provided the best evidence for treatment. While not ignoring clinical experience, they recognized that expert opinion could result from conformity in practice as easily as from science, noting the superiority of the latter. In 1993, under the leadership of the American

Association of Neurological Surgeons (AANS), a move was made away from consensus-based, potentially biased, “review criteria” to use of a more formalized system to classify and grade extant medical literature for creating recommended clinical maneuvers. This was heavily influenced by the American Academy of Neurology’s approach to the same task, explained and proposed by Rosenberg and Greenberg.² In this paradigm, the recommendations regarding the overall process include the following, modified from recommendations by the Institute of Medicine³:

- Practice parameters should be developed in conjunction with physician organizations.
- Reliable methodologies that integrate relevant research findings and appropriate clinical expertise should be used to develop practice parameters.
- Practice parameters should be as comprehensive and specific as possible.
- Practice parameters should be based on current information.
- Practice parameters should be widely disseminated.

In the spirit of compliance with the above recommendations, the AANS, later joined by the Congress of Neurological Surgeons (CNS), moved forward with embracing the production of evidence-based practice recommendations, or parameters, under the generic rubric of “guidelines.” Topics were chosen for their controversies, their weight in terms of burden of illness to society, and the (sometimes wide) variability in practice across the country. These topics were comprehensively specific, covering treatment, prognosis, clinical assessment, diagnosis, and, more recently, economic analysis and clinical decision-making. Recommendations were based on the most current information available and used careful methodology that focused on the quality of a given study’s design, awarding more

ABBREVIATIONS: AANS, Association of Neurological Surgeons; CNS, Congress of Neurological Surgeons

TABLE 1. Classification of Evidence and Subsequent Recommendations by Woolf¹⁶ and Based on Canadian Recommendations¹⁵

Canadian Task Force Classification of Recommendations and Study Designs: 1992 (Modified)	
Category	Description
Recommendations	
A	There is good evidence to support the recommendation
B	There is fair evidence to support the recommendation
C	There is poor evidence to support use, but recommendations can be made on other grounds
D	There is fair evidence to support the recommendation that the treatment NOT be used
E	There is good evidence to support the recommendation that the treatment NOT be used
Study design	
I	Evidence obtained from at least 1 properly designed randomized controlled trial
II-1	Evidence obtained from well-designed controlled trials without randomization
II-2	Evidence obtained from well-designed cohort or case-control analytic studies, preferably from > 1 center or research group
II-3	Evidence obtained from comparisons between times or places with or without intervention; dramatic results from uncontrolled experiments (such as the results of treatment with penicillin in the 1940s) could also be included in this category
III	Opinions of respected authorities, based on clinical experience, descriptive studies (such as case series), or reports of expert committees

weight to those studies with the least methodological flaws. The development of this methodology has its roots in critical evaluation of the medical literature and weighting that evidence in a way that the robustness of the evidence supporting the recommendations could be inferred by the nomenclature used in classifying the recommendations. The original and subsequent early guidelines produced in neurosurgery used a 3-tier classification system in which literature was qualified as **Class I**, **Class II**, and **Class III** medical evidence.⁴ This reflected a decreasing certainty in the appropriateness of the conclusions of the literature and therefore the strength of the recommendations. In this classification, quality of evidence was indicated as follows:

- **Class I:** Evidence from 1 or more well-designed randomized controlled clinical trials, including overviews of such trials.
- **Class II:** Evidence from 1 or more well-designed comparative clinical studies, such as nonrandomized cohort studies, case-

control studies, and other comparable studies, including less well-designed randomized controlled trials.

- **Class III:** Evidence from case series, comparative studies with historical controls, case reports, and expert opinion, as well as significantly flawed randomized controlled trials.

It is this designation that was used in the previous iteration of these guidelines, as well as several other neurosurgical guideline documents.⁵⁻¹² The levels of recommendations as used in the previous iteration of the “Guidelines for the Management of Acute Cervical Spine and Spinal Cord Injuries,” which are derived from the classes of evidence listed above, are related to the certainty that a clinician has that the evidence is strong enough to support the recommendation(s) as follows:

- **Standards:** Reflection of a high degree of clinical certainty
- **Guidelines:** Reflection of a moderate degree of clinical certainty
- **Options:** Reflection of unclear clinical certainty

TABLE 2. Integrating Evidence Quality Appraisal With an Assessment of the Anticipated Balance Between Benefits and Harms if a Policy Is Carried Out Leads to Designation of a Policy as a Strong Recommendation, Recommendation, Option, or no Recommendation

AMERICAN ACADEMY OF PEDIATRICS CLASSIFYING RECOMMENDATIONS FOR CLINICAL PRACTICE GUIDELINES³		
Evidence Quality	Preponderance of Benefit or Harm	Balance of Benefit and Harm
A. Well-designed, randomized controlled trials or diagnostic studies on relevant populations	Strong	Option
B. Randomized controlled trials or diagnostic studies with minor limitations; overwhelmingly consistent evidence from observational studies	Recommendation	
C. Observational studies (case-control or cohort design)	Recommendation	
D. Expert opinion, case reports, reasoning from first principles	Option	No Recommendation
X. Exceptional situation in which validating studies cannot be performed and there is a clear preponderance of benefit or harm	Strong	
	Recommendation	
	Recommendation	

This 3-tiered system was originally suggested by David Eddy in 1990,¹³ embraced by the American Academy of Neurology,² and subsequently became policy for the AANS/CNS Guidelines Committee.¹⁴ However, during the years that professional societies have taken on the responsibility for practice recommendation development for their specialties, many different paradigms with different nomenclature have been suggested and used for guideline designation. For example, the Canadian Task Force on the Periodic Examination proposed a more extensive schema very early on in the history of guideline development.¹⁵ This 5-tiered system was modified and further proposed by Steven Woolf, from the Office of Disease Prevention and Health Promotion in the Public Health Service in Washington, DC (Table 1).¹⁶ A similar 5-tiered system is being used by the North American Spine Society.¹⁷ The American Academy of Pediatrics proposed a 4-tiered system, shown in Table 2.¹⁸ More simply, the American Thoracic Society generated recommendations for a 2-tiered system that indicated whether recommendations were “strong” or “weak.”¹⁹ In this context, the neurosurgical 3-tiered system appears to be appropriate and easy to implement and understand.

As noted in Table 2, the pediatricians added an “X” category for those situations when there is clear evidence that some action should (or should not) be taken, and no formal comparative study could (or should) be done. An example of an “X” category in neurosurgery would be a circumstance in which a patient with an acute intracranial epidural hematoma demonstrates a unilateral dilated pupil; no one would suggest randomizing that patient to a “no treatment” arm of a randomized controlled trial. The most that one could obtain is a case-control study of a population of patients, some of whom received treatment and some of whom did not (for whatever reason—delay in transport, unavailability of a neurosurgeon, failure of diagnosis, etc). This would provide Class II medical evidence but has never been carried out. This was the very struggle faced by the author group of the Guidelines for

the Surgical Management of Traumatic Brain Injury.¹⁰ In that publication, the group wrestled with the paucity of evidence that could make evacuation of an intracranial epidural hematoma in the scenario of impending brainstem compression a practice Standard, instead of being required to relegate it to the category of practice Option. Because this categorization would be completely inappropriate, the group decided to abandon the Standards, Guidelines, and Options nomenclature that had been adhered to for many years (including the previous iteration of these guidelines), switching instead to the categories of **Level I** (for Standards), **Level II** (for Guidelines) and **Level III** (for Options), with the same classes of evidence that had been used previously in the old nomenclature. It is this categorization that is being used in this iteration of the “Guidelines for the Management of Acute Cervical Spine and Spinal Cord Injuries,” continuing with the 3-tier system that has always been used in neurological surgery, and continues to be consistent with the policy of the AANS/CNS.¹² There is an underlying belief in the simplicity of this system compared with one that may be more sensitive to nuances in quality of medical publications but more unwieldy in the context of evaluation of the neurosurgical literature (Table 3).²⁰

GUIDELINES METHODOLOGY USED IN THE CURRENT VERSION OF THESE RECOMMENDATIONS

For the purposes of these guidelines, the author group has chosen to use a modification of the North American Spine Society criteria for evaluation of the medical literature¹⁷ (Table 4). There are significant differences in the original North American Spine Society criteria and those being used in these guidelines. The obvious, and most notable, difference is that there are 3 classes of evidence, as described above, consistent with other neurosurgical guidelines, for

TABLE 3. Detailed Levels of Evidence Recommended by Oxford⁴

Oxford Center for Evidence-Based Medicine Levels of Evidence	
1a	Systematic reviews (with homogeneity) of randomized controlled trials Systematic review of randomized trials displaying worrisome heterogeneity
1b	Individual randomized controlled trials (with narrow confidence interval) Individual randomized controlled trials (with a wide confidence interval)
1c	All or none randomized controlled trials
2a	Systematic reviews (with homogeneity) of cohort studies Systematic reviews of cohort studies displaying worrisome heterogeneity
2b	Individual cohort study or low-quality randomized controlled trials (< 80% follow-up) Individual cohort study or low-quality randomized controlled trials (< 80% follow-up/wide confidence interval)
2c	“Outcomes” research; ecological studies
3a	Systematic review (with homogeneity) of case-control studies Systematic review of case-control studies with worrisome heterogeneity
3b	Individual case-control study
4	Case series (and poor-quality cohort and case-control studies)
5	Expert opinion without explicit critical appraisal or based on physiology, bench research, or “first principles”

TABLE 4. Rating Scheme for the Strength of the Evidence: Modified North American Spine Society Schema⁵ to Conform to Neurosurgical Criteria as Previously Published and for Ease of Understanding and Implementation: Levels of Evidence for Primary Research Question^a

Class	Therapeutic Studies: Investigating the Results of Treatment	Diagnostic Studies: Investigating a Diagnostic Test	Clinical Assessment: Studies of Reliability and Validity of Observations, Including Clinical Examination, Imaging Results, and Classifications
I	High-quality randomized controlled trial with statistically significant difference or no statistically significant difference but narrow confidence intervals	Testing of previously developed diagnostic criteria on consecutive patients (with universally applied reference "gold" standard)	Evidence provided by 1 or more well-designed clinical studies in which interobserver and intraobserver reliability is represented by a κ statistic ≥ 0.60 or an intraclass correlation coefficient of ≥ 0.70
	Systematic review ^b of Class I randomized controlled trials (and study results were homogeneous ^c)	Systematic review ^b of Class I studies	
II	Lesser-quality randomized controlled trial (eg, < 80% follow-up, no blinding, or improper randomization)	Development of diagnostic criteria on consecutive patients (with universally applied reference "gold" standard)	Evidence provided by 1 or more well-designed clinical studies in which interobserver and intraobserver reliability is represented by a κ statistic of 0.40-0.60 or an intraclass correlation coefficient of 0.50-0.70
	Prospective ^d comparative study ^e	Systematic review ^b of Class II studies	
	Systematic review ^b of Class II studies or Class I studies with inconsistent results	Study of nonconsecutive patients; without consistently applied reference "gold" standard	
	Case-control study ^d	Systematic review ^b of Class III studies	
	Retrospective ^f comparative study ^e	Case-control study	
	Systematic review ^b of Class II studies		
III	Case series ^h	Poor reference standard	Evidence provided by 1 or more well-designed clinical studies in which interobserver and intraobserver reliability is represented by a κ statistic of < 0.40 or an intraclass correlation coefficient of < 0.50.
	Expert opinion	Expert opinion	

^aA complete assessment of quality of individual studies requires critical appraisal of all aspects of the study design.

^bA combination of results from 2 or more prior studies.

^cStudies provided consistent results.

^dStudy was started before the first patient enrolled.

^ePatients treated 1 way (eg, halo vest orthosis) compared with a group of patients treated in another way (eg, internal fixation) at the same institution.

^fThe study was started after the first patient was enrolled.

^gPatients identified for the study on the basis of their outcome, called "cases" (eg, failed fusion), are compared with those who did not have outcome, called "controls" (eg, successful fusion).

^hPatients treated 1 way with no comparison group of patients treated in another way.

ease of understanding. Second, the case-control study has been retained with its Class II designation, as in previous guidelines and because they are, in most other suggested guideline schema (eg, Tables 1-3), differentiated from case series, case reports, and expert opinion. The reasons are that there is a comparison group and that case-control studies can be strengthened with robust study design to be comparable to nonrandomized cohort studies.²¹

Attention must be brought to the fact that all of the above discussion has focused on therapeutic effectiveness as studied in randomized controlled trials, comparative cohort studies, case-control studies, and case series. However, these guidelines also discuss diagnostic tests, which are largely imaging studies of various kinds, as well as clinical assessment such as neurological scoring and classification of injury. Investigation of these aspects

of clinical study does not use the same trial designs as those used for therapeutic effectiveness. The methodology for evaluating these 2 types of studies are outlined in detail in the last iteration of these guidelines,¹ including rationale for the rating schema, and remain relatively unchanged. However, because there have been new and improved studies in clinical assessment and because these studies use different statistical evaluations, the older recommended criteria have been broadened, as depicted in Table 4.

PROCESS FOR GUIDELINES DEVELOPMENT

The current author group was selected for its expertise in spinal surgery (both neurosurgical and orthopedic), neurotrauma,

clinical epidemiology, and, in several cases, prior experience with guideline development. The topics chosen for inclusion in this iteration of these guidelines are contemporary and pertinent to the assessment, evaluation, care, and treatment of patients with acute cervical spine and/or spinal cord injuries. A National Library of Medicine (PubMed) search of the literature published from 1966 through 2011 was accomplished using the search terms defined in each guideline manuscript. The search was limited to human subjects and included English language literature for all but one of the chapters. Additional articles were found through the reference lists in the articles found, as well as from other sources known to the authors. Articles were rejected on the basis of irrelevance to the clinical question at hand. Case reports were included if there was insufficient material from case series. On occasion, the assessed quality of the study design was so contentious and the conclusions so uncertain that we assigned a lower medical evidence classification than might have been expected without such a detailed review. In every way, adherence to the Institute of Medicine's criteria for searching, assembling, evaluating, and weighing the available medical evidence and linking it to the strength of the recommendations presented in this document was carried out.

Selected articles were carefully reviewed by the authors. Evidentiary tables were created that reflected the strengths and weaknesses of each article. Articles that did not achieve immediate consensus among the author group were discussed extensively until a consensus was reached. Very few contributions required extensive discussion. Most articles were easily designated as containing Class I, II, or III medical evidence using the criteria set forth by the author group at the initiation of the literature evaluation process as described above.

SUMMARY

Efforts on the part of neurosurgical specialty societies to remain involved and active in the development of practice recommendations are commendable and completely necessary. The development of practice policies for control of healthcare costs is not a new movement and has been gaining momentum over the last 20 years. In 1990, David Eddy described the (then) recent changes in the view and use of practice policies²²:

...Practice policies now are being designed explicitly as instruments for quality assurance, pre-certification, utilization review, accreditation, coverage, and cost containment... But the greatest concern pertains to control. It is not stretching things too far to say that whoever controls practice policies controls medicine. That control used to lie exclusively, if diffusely, within the medical profession. However, as policies are designed and used as management tools, control could shift outside the profession... As non-physician organizations develop policies to use as management tools, physician groups must race to develop their own policies, lest they lose control.

Spinal surgeons, including neurosurgeons and orthopedic surgeons, must continue to wrestle with defining the best treatment possible for their patients. This includes generating the best possible

evidence to support treatment paradigms and summarizing that evidence periodically in evidence-based recommendations. This publication is an example of the latter; it remains an unavoidable responsibility of spinal specialists to pursue the former.

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Prehospital Cervical Spinal Immobilization After Trauma

Nicholas Theodore, MD*

Mark N. Hadley, MD‡

Bizhan Aarabi, MD, FRCSC¶

Sanjay S. Dhall, MD||

Daniel E. Gelb, MD#

R. John Hurlbert, MD, PhD, FRCSC**

Curtis J. Rozzelle, MD‡‡

Timothy C. Ryken, MD, MS§§

Beverly C. Walters, MD, MSc, FRCSC‡§

*Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona; ‡Division of Neurological Surgery; and ‡‡Division of Neurological Surgery, Children's Hospital of Alabama, University of Alabama at Birmingham, Birmingham, Alabama; §Department of Neurosciences, Inova Health System, Falls Church, Virginia; ¶Department of Neurosurgery and; #Department of Orthopaedics, University of Maryland, Baltimore, Maryland; ||Department of Neurosurgery, Emory University, Atlanta, Georgia; **Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada; §§Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa

Correspondence:

Mark N. Hadley, MD, FACS, UAB
Division of Neurological Surgery, 510 –
20th St S, FOT 1030, Birmingham, AL
35294-3410.
E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS

Level II

Spinal immobilization of all trauma patients with a cervical spine or spinal cord injury or with a mechanism of injury having the potential to cause cervical spinal injury is recommended.

- Triage of patients with potential spinal injury at the scene by trained and experienced emergency medical services personnel to determine the need for immobilization during transport is recommended.
- Immobilization of trauma patients who are awake, alert, and are not intoxicated; who are without neck pain or tenderness; who do not have an abnormal motor or sensory examination; and who do not have any significant associated injury that might detract from their general evaluation is not recommended.

Level III

- A combination of a rigid cervical collar and supportive blocks on a backboard with straps is effective in limiting motion of the cervical spine and is recommended.
- The longstanding practice of attempted spinal immobilization with sandbags and tape is insufficient and is not recommended.
- Spinal immobilization in patients with penetrating trauma is not recommended because of increased mortality from delayed resuscitation.

ABBREVIATIONS: EMS, emergency medical services; HAINES, high arm in endangered spine; ICP, intracranial pressure

RATIONALE

The early management of a patient with a potential cervical spinal cord injury begins at the scene of the accident. The chief concern during the initial management of patients with potential cervical spinal injuries is that neurologic function may be impaired as a result of pathologic motion of the injured vertebrae. It is estimated that 3% to 25% of spinal cord injuries occur after the initial traumatic insult, either during transit or early in the course of management.^{1–6} Multiple cases of poor outcome from mishandling of cervical spinal injuries have been reported.^{5–8} As many as 20% of spinal column injuries involve multiple noncontinuous vertebral levels; therefore, the entire spinal column is potentially at risk.^{9–12} Consequently, complete spinal immobilization has been used in prehospital spinal care to limit motion until injury has been ruled out.^{11–19} Over the last 30 years, there has been a dramatic improvement in the neurologic status of spinal cord-injured patients arriving in emergency departments. During the 1970s, the majority (55%) of patients referred to regional spinal cord injury centers arrived with complete neurological lesions. In the 1980s, however, the majority (61%) of spinal cord-injured patients arrived with incomplete lesions.²⁰ This improvement in the neurologic status of patients has been attributed to the development of emergency medical services (EMS) in 1971 and the prehospital care (including spinal immobilization) rendered by EMS personnel.^{13,20–22} Spinal immobilization is now an integral part of prehospital management and is advocated for all patients with potential spinal injury after trauma by EMS programs nationwide and by the American College of Surgeons.^{13,23–29}

Recently, the use of spinal immobilization particularly for those patients with a low

likelihood of traumatic cervical spinal injury has been questioned. It is unlikely that all patients rescued from the scene of an accident or site of traumatic injury require spinal immobilization.³⁰⁻³³ Some authors have developed and advocate a triage system based on clinical criteria to select patients for prehospital spinal immobilization.^{27,34,35}

Several devices are available for prehospital immobilization of the potential spine-injured patient. However, the optimal device has not yet been identified by careful comparative analysis.^{15,36-42} The recommendations of the American College of Surgeons consist of a hard backboard, a rigid cervical collar, lateral support devices, and tape or straps to secure the patient, the collar, and the lateral support devices to the backboard.^{23,24} A more uniform, universally accepted method for prehospital spinal immobilization for patients with potential spinal injury after trauma may reduce the cost and improve the efficiency of prehospital spinal injury management.^{27,34,35} Although spinal immobilization is typically effective in limiting motion, it has been associated with morbidity in a small percentage of cases, particularly when concomitant head injury exists, in patients with ankylosing spondylitis, and in the setting of delayed resuscitation.^{18,24,43-49}

The guidelines author group of the Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and Congress of Neurological Surgeons produced a medical evidence-based guideline on this topic in 2002.⁵⁰ The purpose of the current review is to update the medical evidence on the spinal immobilization since that early publication.

SEARCH CRITERIA

A National Library of Medicine computerized literature search from 1966 to 2011 was conducted with the terms “spinal injuries” and “immobilization.” The search was limited to human subjects and the English language and yielded no articles. A second search combining the terms “spinal injuries” and “transportation of patients” yielded 81 articles. A third search combining the terms “spinal injuries” and “emergency medical services” produced 331 articles. Additional references were culled from the reference lists of the remaining papers. Finally, the author group was asked to contribute articles known to them on the subject matter that were not found by other search criteria. Duplicate references were discarded. The abstracts were reviewed and articles unrelated to the specific topic were eliminated. This process yielded a total of 109 articles for this review, which are listed in the bibliography. Thirty pertinent publications used to formulate this medical evidence-based guideline are summarized in Evidentiary Table format (Table).

SCIENTIFIC FOUNDATION

Pathologic motion of the injured cervical spine may create or exacerbate cervical spinal cord or cervical nerve root injury.^{9-11,16,51,52} This potential has led to the use of spinal immobilization for trauma patients who have sustained a cervical vertebral column injury or

experienced a mechanism of injury that could result in cervical spinal column injury.^{11,12,15-17,19,24,27,30,35,53}

Kossuth^{54,55} is credited with pioneering the currently accepted methods of protection and immobilization of the cervical spine during extrication of acute injury victims. Farrington^{56,57} championed the concept of prehospital immobilization. Dick and Land⁵⁸ note in their review of spinal immobilization devices that techniques of prehospital spinal immobilization appeared in standard EMS texts and in the American Academy of Orthopedic Surgeons Committee on Injuries Emergency text as early as 1971.¹³ Initially, the preferred method to immobilize the cervical spine was the use of a combination of a soft collar and a rolled-up blanket.³⁷ This was followed by the introduction of a more rigid extrication collar by Hare in 1974. Hare’s contribution launched an era of innovation for devices for spinal immobilization.¹⁵

Currently, spinal immobilization is one of the most frequently performed procedures in the prehospital care of acute trauma patients in North America.^{9,11-13,15-17,19,25,53,59} Although clinical and biomechanical evidence demonstrates that spinal immobilization limits pathologic motion of the injured spinal column, there is no Class I or Class II medical evidence to support spinal column immobilization in all patients after trauma. Although immobilization of an unstable cervical spinal injury makes good sense and Class III medical evidence reports exist of neurological worsening with failure of adequate spinal immobilization, there have been no randomized trials or case-control studies that address the impact of spinal immobilization on clinical outcomes after cervical spinal column injury.^{3,4,6,11,12,15,16,27,31,32,53} The issue of who should be immobilized is important; tens of thousands of trauma victims are treated with spinal immobilization each year, yet few actually have spinal column injuries or instability.^{10,35,60}

Other considerations in the use of prehospital spinal immobilization include the cost of equipment, the time and training of EMS personnel to apply the devices, and the unnecessary potential morbidity for patients who do not need spinal immobilization after trauma.^{15,18,24,45-49,53,61,62} As with many interventions in the practice of medicine, spinal immobilization has been instituted in the prehospital management of trauma victims with potential spinal injuries based on the principles of neural injury prevention and years of clinical experience but without supportive scientific evidence from rigorous clinical trials. For a variety of both practical and ethical reasons, it is likely impossible to obtain this information in prospective, randomized clinical trials in contemporary times.

In 1989, Garfin et al¹⁶ stated, “No patient should be extricated from a crashed vehicle or transported from an accident scene without spinal stabilization.” In that review, they credited stabilization of the cervical spine as a key factor in the decline in the percentage of complete spinal cord injury lesions from 55% in the 1970s to 39% in the 1980s and in the significant reduction in the mortality of multiple injury patients with cervical spinal injuries. Unfortunately, there is no Class I medical evidence to support these claims.

TABLE. Evidentiary Table: Immobilization^a

Author, Reference	Description of Study	Data Class	Conclusions
Haut et al, ¹⁰³ <i>The Journal of Trauma</i> , 2010	The assessment of spinal immobilization in patients with cervical spine injury associated with penetrating trauma	III	Prehospital spine immobilization is associated with higher mortality in the settings of penetrating trauma and should not be routinely used.
Burton et al, ⁷⁰ <i>The Journal of Trauma</i> , 2006	Evaluation of the practice and outcomes associated with statewide EMS protocol for trauma patient spine assessment and selective prehospital immobilization	II	EMS providers were able to evaluate injured prehospital trauma patients with a 4-step clinical assessment protocol and to accurately discriminate between patients likely to benefit from immobilization and patients with unstable spine injury.
Del Rossi et al, ¹⁰⁵ <i>The Spine Journal</i> , 2004	Biomechanical study testing 3 cervical collars on a cadaveric model of cervical spine injury	II	When transferring patients to a spine board, the key remains the combination of manual stabilization and the controlling effect of the cervical collar.
Domeier et al, ¹⁰⁶ <i>The Journal of Trauma</i> , 2002	Evaluation of clinical criteria to identify prehospital trauma patients who may safely have rigid spine immobilization withheld	II	Altered mental status, focal neurologic deficit, evidence of intoxication, spine pain or tenderness, or suspected extremity fracture were clinical criteria that identified the presence of spine injury, therefore justifying immobilization.
Stroh and Braude, ⁶⁸ <i>Annals of Emergency Medicine</i> , 2001	Determination of the sensitivity of Fresno/Kings/Madera EMS selective spine immobilization protocol in identifying patients with potential cervical injuries	II	Fresno/Kings/Madera protocol is 99% sensitive in identifying patients with cervical surgeries for immobilization, suggesting that selecting immobilization may be safely applied in the out-of-hospital setting.
Markenson et al, ³⁹ <i>Pre-Hospital Emergency Care</i> , 1999	Evaluation of the Kendrick extrication device for pediatric spinal immobilization.	III	Kendrick extrication device provides excellent static and dynamic immobilization.
Perry et al, ³³ <i>Spine</i> , 1999	Laboratory evaluation of 3 immobilization devices compared during simulated vehicle motion	III	Substantial amounts of head motion can occur during simulated vehicle motion regardless of the method of immobilization.
	Neck motion was judged by 3 physicians.		Movement of trunk can have an effect equal to head motion on motion across the neck.
Bauer and Kowalski, ⁴⁴ <i>Annals of Emergency Medicine</i> , 1998	Effect of spinal immobilization devices on pulmonary function in 15 men	III	Significant restriction of pulmonary function was seen.
Mawson et al, ⁹⁹ <i>American Journal of Physical Medicine and Rehabilitation/Association of Academic Physiatrists</i> , 1998	Evaluation of risk factors for pressure ulcers after spinal cord injury	III	Time spent on a backboard is significantly associated with pressure ulcers developing within 8 d.

(Continues)

TABLE. Continued

Author, Reference	Description of Study	Data Class	Conclusions
Hauswald et al, ³¹ <i>Academic Emergency Medicine</i> , 1998	A 5-year retrospective chart review at 2 university hospitals. All patients with acute blunt traumatic spinal or spinal cord injuries transported directly from the injury site to the hospital were entered. None of the 120 patients at the University of Malaya had spinal immobilization with orthotic devices during transport; all 334 patients at the University of New Mexico did. The hospitals were comparable. Neurological injuries were assigned to 2 categories, disabling or not disabling, by 2 blinded physicians. Data were analyzed using multivariate logistic regression. There was less neurological disability in the Malaysian patients (odds ratio, 2.03; 95% confidence interval, 1.03-3.99; $P = .04$). Results were similar when the analysis was limited to patients with cervical injuries (odds ratio, 1.52; 95% confidence interval, 0.64-3.62; $P = .34$).	III	Out-of-hospital immobilization has little effect on neurological outcome in patients with blunt spinal injuries.
Blaylock, ¹⁰⁰ <i>Ostomy Wound Management</i> , 1996	Evaluation of pressure ulcers resulting from cervical collars	III	The association between spinal column movement and the potential for spinal cord injury remains unclear.
Johnson et al, ⁷⁵ <i>American Journal of Emergency Medicine</i> , 1996	Measured immobilization and comfort on 10-point scale; vacuum splint was compared with backboard	III	Vacuum splints are more comfortable and faster to apply than backboards and provide a similar degree of immobilization. Vacuum splints are not rigid enough for extrication and are more expensive.
Rodgers and Rodgers, ⁶² <i>Journal of Orthopaedic Trauma</i> , 1995	Marginal mandibular nerve palsy resulting from compression by a cervical hard collar	III	
Chan et al, ⁴⁶ <i>Annals of Emergency Medicine</i> , 1994	Prospective study of the effects of spinal immobilization on pain and discomfort in 21 volunteers after 30 min; all subjects developed pain	III	Duration of time on backboard was minimized.
Liew and Hill, ¹⁰⁷ <i>The Australian and New Zealand Journal of Surgery</i> , 1994	Complication of hard cervical collars in multitrauma patients	III	
Mazolewski and Manix, ⁴⁰ <i>Annals of Emergency Medicine</i> , 1994	Tests the effectiveness of strapping techniques in reducing lateral motion on a backboard in the laboratory in adults	III	Strapping should be added to the torso to reduce lateral motion on a backboard.
Plaisier et al, ⁷⁸ <i>Journal of Trauma Injury Infection and Critical Care</i> , 1994	Prospective evaluation of craniofacial pressure of 4 different cervical orthoses	III	
Raphael and Chotai, ¹⁰⁸ <i>Anaesthesia</i> , 1994	Effects of the cervical collar on cerebrospinal fluid pressure	III	
Chandler et al, ⁷¹ <i>Annals of Emergency Medicine</i> , 1992	Compared rigid cervical extrication collar with Ammerman halo orthosis in 20 men	III	Ammerman halo orthosis and spine board provided significantly better immobilization, equivalent to halo vest.

(Continues)

TABLE. Continued

Author, Reference	Description of Study	Data Class	Conclusions
Rosen et al, ⁸⁹ <i>Annals of Emergency Medicine</i> , 1992	Compares 4 cervical collars in 15 adult volunteers by goniometry	III	Vacuum splint cervical collar restricted the range of motion of the cervical spine most effectively.
Schafermeyer et al, ¹⁰⁹ <i>Annals of Emergency Medicine</i> , 1991	Respiratory effects of spinal immobilization in children	III	Mean reduction in FVC to 80% of baseline
Schriger et al, ⁸⁴ <i>Annals of Emergency Medicine</i> , 1991	Compares flat backboard with occipital padding in achieving neutral position in 100 healthy volunteers	III	Occipital padding places the cervical spine in more neutral alignment
Cohen, ⁹¹ <i>Paraplegia</i> , 1990	A new device for the care of acute spinal injuries: the Russell extrication device	III	Russell extrication device is an effective spinal immobilization device.
Toscano, ⁵² <i>Paraplegia</i> , 1988	Prevention of neurological deterioration before admission to hospital	III	Appropriate handling of patients with spinal injury after trauma can reduce major neurological deterioration caused by pathological motion of the vertebral column.
Graziano et al, ⁹⁰ <i>Annals of Emergency Medicine</i> , 1987	Retrospective review of 123 patients, 32 of 123 sustained major neurological deterioration from injury to admission A radiographic comparison of prehospital cervical immobilization methods with the short board in 45 volunteers	III	The short board proved to be significantly better ($P < .05$).
Linares et al, ⁹⁸ <i>Orthopedics</i> , 1987	Evaluation of pressure sores and immobilization.	III	Strong association between 1 to 2 h of immobilization and the development of pressure sores.
McGuire et al, ⁹³ <i>Spine</i> , 1987	Radiographic evaluation of motion of the thoracolumbar spine in a cadaver with an unstable thoracolumbar spine and a patient with a T12-L1 fracture dislocation	III	Extreme motion at an unstable thoracolumbar spine segment can occur during the logroll maneuver. The backboard and the Scoop stretcher offered adequate stabilization for thoracolumbar spine instability.
McCabe and Nolan, ⁷⁶ <i>Annals of Emergency Medicine</i> , 1986	Radiographic comparison of the 4 cervical collars in 7 adults	III	Polyethylene-1 provides the most restriction in flexion.
Cline et al, ³⁷ <i>Journal of Trauma</i> , 1985	A radiographic comparison of 7 methods of cervical immobilization in 97 adults	III	The short-board technique appeared to be superior to all the 3 collars studied. The collars provided no augmentation of immobilization over that provided by the short board alone.
Podolsky et al, ⁸⁶ <i>Annals of Emergency Medicine</i> , 1983	Static trial using goniometry	III	Hard foam and plastic collars were superior to soft collars.
			Sandbags and tape provide an advantage in addition to the cervical collar.

^aEMS, emergency medical services; FVC, forced vital capacity.

Few articles have directly evaluated the effect of prehospital spinal immobilization on neurological outcome after injury. Several Class III medical evidence reports cite the lack of immobilization as a cause of neurological deterioration among acutely injured trauma patients transported to medical facilities for

definitive care.^{5,7,16,21,63} The most pertinent study is the retrospective case series of Toscano et al,⁵² who in 1988 reported that 32 of 123 trauma patients (26%) they managed sustained major neurological deterioration in the period of time between injury and admission. The authors attributed neurological

deterioration to patient mishandling and cited the lack of spinal immobilization after traumatic injury as the primary cause. Their report supports the need for prehospital spinal immobilization of trauma patients with potential spinal column injuries.

In contrast, a collaborative 5-year retrospective chart review reported by the University of New Mexico and the University of Malaya challenges this position. Hauswald et al³¹ analyzed only patients with acute blunt spinal or spinal cord injuries. At the University of Malaya, none of the 120 patients they managed were treated with spinal immobilization during transport. All 334 patients managed at the University of New Mexico were initially treated with spinal immobilization. Both hospitals were reportedly comparable with respect to physician training and clinical resources. Two independent physicians blinded to the participating hospital characterized the neurological injuries into 2 groups: disabling and nondisabling. Data were analyzed with logistic regression techniques, with hospital, patient age, sex, anatomic level of injury, and injury mechanism as variables. Neurological deterioration after injury was less frequent in Malayan patients with spinal injuries who were not treated with formal spinal immobilization during transport (odds ratio, 2.03; 95% confidence interval, 1.03-3.99; $P = .04$) compared with patients in New Mexico who were managed with spinal column immobilization techniques. Even when the analysis was limited to cervical spine injuries, no significant protective effect from spinal immobilization was identified. For multiple reasons, the conclusions drawn by the authors of this study are considered spurious at best.^{15,31,33}

Evidence in the literature evaluating the effectiveness of prehospital spinal immobilization is sparse. Ethical and practical issues preclude the execution of a contemporary, randomized clinical trial designed to study the effectiveness of prehospital spinal immobilization compared with no immobilization, primarily because spinal immobilization for trauma patients is perceived as essential with minimal risk and is already widely used. Intuitively, the use of prehospital spinal immobilization is a rational means of limiting spinal motion in spine-injured patients in an effort to reduce the likelihood of neurological deterioration resulting from pathological motion at the site(s) of injury.

The medical evidence (Class III) derived from all of the articles reviewed for the first iteration of this guideline published in 2002 supports that, from an anatomic and biomechanical perspective and from time-tested clinical experience with traumatic spinal injuries, all patients with cervical spinal column injuries or those with the potential for a cervical spinal injury after trauma should be treated with cervical spinal cord immobilization until an injury has been excluded or definitive management has been initiated.

Orledge and Pepe¹⁷ in their commentary on the Hauswald et al findings point out some limitations of their article but also suggest that it raises the issue of a more selective evidence-based protocol for spinal immobilization. Should all trauma patients be managed with spinal immobilization until spinal injury has been excluded, or should immobilization be selectively used for patients with potential spinal injury based on well-defined clinical criteria? Which clinical criteria should be used? Since the Hauswald

et al report, prospective studies in support of the use of clinical findings as indicators for the need for prehospital spinal immobilization after trauma have been reported.^{27,30,64} Several EMS systems now use clinical protocols to help guide which patients should be managed with spinal immobilization after trauma.^{65,66}

In 2002, Domeier et al,^{27,30} in a multicenter prospective study of 6500 trauma patients, found that the application of clinical criteria (altered mental status, focal neurologic deficit, evidence of intoxication, spinal pain or tenderness, or suspected extremity fracture) was predictive of the majority of patients who sustained cervical spinal injuries requiring immobilization. The predictive value of their criteria held for patients with high- or low-risk mechanisms of injury. Their study offers Class II medical evidence suggesting that clinical criteria, rather than the mechanism of injury, be evaluated as the standard by which spinal immobilization should be used.

Brown et al³⁴ examined whether EMS providers could accurately apply clinical criteria to clear the cervical spines of trauma patients before transport to a definitive care facility. The criteria included the presence of pain or tenderness of the cervical spine, the presence of a neurological deficit, an altered level of consciousness, evidence of drug use or intoxication (particularly alcohol, analgesics, sedatives, or stimulants), and/or the presence of other significant trauma that might act as a distracting injury. Immobilization of the cervical spine was initiated if any 1 of 6 criteria was present. The clinical assessment of trauma patients by EMS providers was compared with the clinical assessment provided by emergency physicians. The providers (emergency medical technicians and emergency room physician) were blinded to each other's assessments. Agreement between EMS staff and physicians was analyzed by the κ statistic. Five hundred seventy-three patients were included in the study. The assessments matched in 79% of the cases ($n = 451$). There were 78 patients (13.6%) for whom the EMS clinical assessment indicated spinal immobilization, but the physician assessment did not. There were 44 patients (7.7%) for whom the physician's clinical assessment indicated spinal immobilization, but the EMS assessment did not. The κ for the individual components ranged from 0.35 to 0.81. The κ value for the decision to immobilize was 0.48. The EMS clinical assessments were generally more in favor of immobilization than the physician clinical assessments. The authors concluded that EMS and physician clinical assessments to rule out cervical spinal injury after trauma have moderate to substantial agreement. The authors recommended, however, that systems that allow EMS personnel to decide whether to immobilize patients after trauma should provide attentive follow-up of those patients to ensure appropriate care and to provide immediate feedback to the EMS providers.³⁴ Meldon et al,⁶⁷ in an earlier study, found significant disagreement between the clinical assessments and subsequent spinal immobilization of patients between EMS technicians and physicians. They recommended further research and education before widespread implementation of this practice.

Clinical criteria to select appropriate patients for spinal immobilization have been studied in Michigan⁶⁵ and have been

implemented in Maine⁶⁶ and San Mateo County, California.⁴⁵ In Fresno, California, there has been a selective spine immobilization clearance protocol in place since 1990.⁴⁵ EMS Policy Number 530, as it is known, calls for spinal immobilization in the following circumstances:

1. Spinal pain or tenderness, including any neck pain with a history of trauma
2. Significant multiple system trauma
3. Severe head or facial trauma
4. Numbness or weakness in any extremity after trauma
5. Loss of consciousness caused by trauma
6. If mental status is altered (including drugs, alcohol, trauma) and no history is available, or the patient is found in a setting of possible trauma (eg, lying at the bottom of stairs or in the street); or the patient experienced near drowning with a history or probability of diving
7. Any significant distracting injury

In 2001, Stroth and Braude⁶⁸ reported a retrospective series of all cases of cervical spine trauma in a 6-year period from 1990 to 1996 at 5 trauma-receiving hospitals in Fresno County, California. There were 861 patients with cervical injuries during this period, 504 of whom were transported to the hospital by EMS personnel. Of those, 495 arrived with cervical spine immobilization. Of the 9 remaining patients, 2 refused immobilization and 2 could not be immobilized. Three injuries were missed by the protocol criteria and 2 secondary to protocol violations. Of the last 5 patients, only 1 patient had an adverse outcome; 2 patients were considered unstable, 4 patients were > 67 years of age, and 1 patient was 9 months old. The protocol was found to be 99% sensitive in identifying trauma patients with cervical injuries requiring immobilization (95% confidence interval, 97.7-99.7).⁶⁸ The criteria for immobilization are similar to those used to identify patients who require imaging of the cervical spine after trauma.⁶⁹ The authors' retrospective review of prospectively collected data provides convincing Class II medical evidence that prehospital criteria to select which patients need spinal immobilization after trauma can be successfully applied by EMS personnel in the field. The authors pointed out that the missed injuries identified in their series occurred in very old and very young patients; therefore, caution should be exercised in these age ranges.

In 2004, Burton et al⁷⁰ reported a prospective series of trauma patients in Maine who were evaluated by EMS personnel in the field with a "NEXUS-like" decision instrument, originally designed for physicians in the evaluation of trauma patients to determine which trauma patients require imaging of the cervical spine. This included an algorithmic approach excluding patients from immobilization if they were reliable (no alcohol or drugs, loss of consciousness, or altered sensorium), had no distracting injuries, had no normal motor and sensory examinations, and had no spinal tenderness. If any 1 of the 4 criteria was present, the patient was immobilized.⁷⁰

Before the study was initiated, all EMS personnel underwent training on the evaluation system. The protocol was initiated in

2002, and the first year's data were reported in 2004. During that period, there were 207 545 EMS encounters with 41 885 transports to an emergency department. There were 12 988 patients transported with spinal immobilization (41%). Acute spinal fractures were identified in 154 patients; 20 patients were transported without spinal immobilization (13%). Of these 20 patients, 19 patients had stable fractures and 1 patient had an unstable thoracic injury. The sensitivity for immobilization was 87% (95% confidence interval, 81.7-92.3), with a negative predictive value of 99.9% (95% confidence interval, 99.8-100). The only missed injury was in the thoracic spine; there were no missed cervical injuries. The protocol ensured that more than half of the trauma patients evaluated did not unnecessarily receive spinal immobilization.⁷⁰

On the basis of the report by Domeier et al⁶⁴ and the more recent experiences in Fresno and Maine, both of which have robust protocols in place guiding EMS personnel in the application of spinal immobilization, it appears that these criteria can safely and effectively be applied to predict which patients require cervical spinal immobilization after blunt trauma. There have been no subsequent reports of significant missed spinal injuries in settings where these protocols are used. These 3 studies provide Class II medical evidence on this subject.

EMS personnel who make the assessments to immobilize trauma victims require intensive education and vigilant, quality-assurance scrutiny to ensure that trauma patients with potential spinal injuries are appropriately triaged and managed. Available studies support the use of selective "NEXUS-like" criteria to guide EMS personnel in the field to determine the need for spinal immobilization in patients with potential cervical spinal injuries after trauma.

METHODS OF PREHOSPITAL SPINAL IMMOBILIZATION

Prehospital spinal immobilization is effective in limiting spinal motion during patient transport.²⁵ Various devices and techniques exist to provide immobilization of the cervical spine. Attempts to define the best method of spinal immobilization for prehospital transport have been hampered by physical and ethical constraints.^{15,36,38-42}

The methods of measuring the efficacy of spinal immobilization devices vary among investigators. Comparative studies of the various devices have been performed on normal human volunteers, but none has been tested in a large number of patients with spinal injuries. It is difficult to extrapolate normative data to injured patients with potential spinal instability.^{15,36,38,41,42,59,61,71-78}

Several methods have been used to measure movement of the cervical spine. They range from clinical assessment to plumb lines, photography, radiography, cinematography, and computed tomography and magnetic resonance imaging. Roozmon et al⁷⁹ and Bourn et al⁸⁰ summarized the problems inherent in each method and concluded that there was no satisfactory noninvasive means of studying neck motion, particularly if one is to quantify movement between individual vertebral segments.

The position in which the injured spine should be placed and held immobile, the “neutral position,” is poorly defined.^{15,45,80-82} Schriger⁸³ defined the neutral position as “the normal anatomic position of the head and torso that one assumes when standing and looking ahead.” This position correlates to 12° cervical spine extension on a lateral radiograph. The extant radiographic definition of neutral position was based on the radiographic study of patients who were visually observed to be in the neutral position.⁸³ Schriger et al⁸⁴ used this position in their evaluation of occipital padding on spinal immobilization backboards. De Lorenzo,¹⁵ in a magnetic resonance imaging study of 19 adults, found that a slight degree of flexion equivalent to 2 cm occiput elevation produces a favorable increase in spinal canal/spinal cord ratio at levels C5 and C6, a region of frequent unstable spinal injuries. Backboards have been used for years for extrication and immobilization of spine-injured patients. Schriger et al⁸⁴ questioned the ability of a flat board to allow neutral positioning of the cervical spine. They compared spinal immobilization with the flat backboard with and without occipital padding in 100 adults. Clinical observation and assessment were used to determine the neutral position of the cervical spine. The authors found that the use of occipital padding in conjunction with a rigid backboard places the cervical spine in the optimal neutral position compared with positioning on a flat backboard alone.^{83,84} McSwain²⁸ determined that > 80% of adults require 1.3 to 5.1 cm of padding to achieve neutral positioning of the head and neck with respect to the torso and noted that body habitus and muscular development alter the cervical-thoracic angle, thus affecting positioning. These variables make it impossible to dictate specific or routine recommendations for padding.

In general, spinal immobilization consists of a cervical collar, supports on either side of the head, and either long or short backboards with associated straps to attach and immobilize the entire patient's body to the board.¹⁵ Garth⁸⁵ proposed performance standards for cervical extrication collars, but these standards have not been uniformly implemented. There are a variety of different cervical collars. Several studies compare collars alone or in combination with other immobilization devices using a wide range of assessment criteria.^{36,41,42,46,71,72}

In 1983, Podolsky et al⁸⁶ evaluated the efficacy of cervical spine immobilization techniques using goniometric measures. Twenty-five healthy volunteers lying supine on a rigid emergency department resuscitation table were asked to actively move their necks as far as possible in 6 ways: flexion, extension, rotation to the right and left, and lateral bending to the right and left. Control measurements were made with no device, and measurements were repeated after immobilization in a soft collar, hard collar, extrication collar, Philadelphia collar, bilateral sandbags joined with 3-in-wide cloth tape across the forehead attached to either side of the resuscitation table, and the combination of sandbags, tape, and a Philadelphia collar. Hard foam and hard plastic collars were superior at limiting cervical spine motion compared with soft foam collars. Neither collars alone nor sandbags and tape in combination provided satisfactory restriction of cervical spine motion. Immo-

bilization with sandbags and tape was significantly better than with any of the other methods used alone for all 6 cervical spinal movements. The authors found that the combination of sandbags and tape with a rigid cervical collar was the best means of those evaluated to limit cervical spine motion. The addition of a Philadelphia collar was significantly more effective in reducing neck extension ($P < .01$), from 15° to 7.4°, a change of 49.3%. Collar use had no significant additive effect for any other motion of the cervical spine.

Sandbags as adjuncts to cervical spine immobilization require more rather than less attention from care providers.⁸⁷ Sandbags are heavy, and if the extrication board is tipped side to side during evacuation and transport, the sandbags can slide, resulting in lateral displacement of the patient's head and neck with respect to the torso. Sandbags can be taped to the extrication board, but because they are small compared with the patient, this can be difficult and/or ineffective. Finally, sandbags must be removed before initial lateral cervical spine x-ray assessment because they can obscure the radiographic bony anatomy of the cervical spine. For these reasons and because of the findings of Podolsky et al,⁸⁸ the use of sandbags and tape alone to attempt to immobilize the cervical spine is not recommended.

In 1985, Cline et al³⁷ compared methods of cervical spinal immobilization used in prehospital transport. They found that strapping the patient to a standard short board was superior to cervical collar use alone. They noted no significant differences between the rigid collars they tested. McCabe and Nolan⁷⁶ compared 4 different collars for their ability to restrict motion in flexion-extension and lateral bending using radiographic assessment. They found that the polyethylene-1 collar provided the most restriction of motion of the cervical spine, particularly with flexion. Rosen et al⁸⁹ in 1992 compared the limitation of cervical spinal movement of 4 rigid cervical collars in 15 adults using goniometric measurements. The vacuum splint cervical collar provided the most effective restriction of motion of the cervical spine of the 4 devices they tested.

Graziano et al⁹⁰ compared prehospital cervical spine immobilization methods by measuring cervical motion radiographically in the coronal and sagittal planes in 45 immobilized adults. The Kendrick extrication device and the Extrication Plus-One device were nearly as effective in limiting cervical motion as the short immobilization board in their study. Both devices were superior to a rigid cervical collar alone.

In 1990, Cohen⁹¹ described the Russell extrication device for immobilization of patients with potential spine injuries. The Russell extrication device was comparable to the short immobilization board for prehospital spinal immobilization. Chandler et al⁷¹ compared a rigid cervical extrication collar with the Ammerman halo orthosis in 20 male patients. The Ammerman halo orthosis combined with a rigid spine board provided significantly better cervical spinal immobilization than a cervical collar and spine board. The Ammerman halo orthosis and spine board was equivalent to the standard halo vest immobilization device.

Perry et al³³ evaluated 3 cervical spine immobilization devices during simulated vehicle motion in 6 adults. Neck motion was

assessed by 3 neurologists and neurosurgeons as to whether motion was “clinically significant.” They found that substantial head motion occurred during simulated vehicle motion regardless of the method of immobilization. They observed that the efficacy of cervical spine immobilization was limited unless the motion of the head and the trunk was also controlled effectively. Mazolewski and Manix⁴⁰ tested the effectiveness of strapping techniques to reduce lateral motion of the spine of adults restrained on a backboard. Subjects were restrained on a wooden backboard with 4 different strapping techniques. The backboard was rolled to the side, and lateral motion of the torso was measured. The authors found that additional strapping securing the torso to the backboard reduced lateral motion of the torso. Finally, the traditional method of moving a patient onto a long backboard has typically involved the logroll maneuver. The effectiveness of this transfer technique has been questioned.^{89,92} Significant lateral motion of the lumbar spine has been reported to occur.^{93,94} Alternatives to the logroll maneuver include the HAINES (high arm in endangered spine) method and the multihand or fireman lift method.^{14,23} In the HAINES method, the patient is placed supine, the upper arm away from the kneeling rescuer is abducted to 180°, the near arm of the patient is placed across the patient’s chest, and both lower limbs are flexed. The rescuer’s hands stabilize the head and neck and the patient is rolled away onto an extrication board or device.⁹⁵ The multihand or fireman lift method involves several rescuers on either side of the patient, each of whom slides his or her arms underneath the patient and lifts the patient from 1 position to the other onto an extrication board or device.

The above review describes the evolution of and underscores the diversity of techniques available for providing prehospital spinal immobilization of spine-injured patients during transport. These studies are limited by the fact that none of the studies evaluates the full range of available devices using similar criteria. Overall, it appears that a combination of rigid cervical collar immobilization with supportive blocks on a rigid backboard with straps to secure the entire body of the patient is most effective in limiting motion of the cervical spine after traumatic injury.¹⁴ The longstanding practice of attempted spinal immobilization with sandbags and tape with a rigid backboard is insufficient and is not recommended.

SAFETY OF PREHOSPITAL SPINAL IMMOBILIZATION DEVICES

Despite obvious benefits, cervical spinal immobilization has a few potential drawbacks. Immobilization can be uncomfortable; it can be difficult to apply properly; it takes time to apply; application may delay transport; and it is associated with modest morbidity.^{14,18,44-48}

Chan et al⁴⁶ studied the effects of spinal immobilization on pain and discomfort in 21 uninjured adults. Subjects were placed in backboard immobilization for 30 minutes, and symptoms were chronicled. All subjects developed pain, which was described as

moderate to severe in 55% of volunteers. Occipital headache and sacral, lumbar, and mandibular pain were the most frequent complaints. In a later study, Chan and others⁴⁷ compared spinal immobilization on a backboard with immobilization with a vacuum mattress-splint device in 37 normal adults. They found that the frequency and severity of occipital and lumbosacral pain were significantly greater during backboard immobilization than on the vacuum mattress-splint device. Johnson et al⁷⁵ performed a prospective, comparative study of the vacuum splint device and the rigid backboard. The vacuum splint device was significantly more comfortable than the rigid backboard and was faster to apply. The vacuum splint device provided better immobilization of the torso. The rigid backboard with head blocks was slightly better at immobilizing the head. Vacuum splint devices, however, are not recommended for extrication because they are reportedly not rigid enough, and they are more expensive. At a cost of approximately \$400, the vacuum splint device is roughly 3 times more expensive than a rigid backboard.

Hamilton and Pons⁷⁴ studied the comfort level of 26 adults on a full-body vacuum splint device compared with a rigid backboard with and without cervical collars. Subjects graded their immobilization and discomfort. No statistically significant difference was found between the vacuum splint device–collar combination compared with the backboard–collar combination for flexion and rotation. The vacuum splint–collar combination provided significantly superior immobilization in extension and lateral bending than the backboard–collar combination. The vacuum splint device alone provided superior cervical spinal immobilization in all neck positions except extension compared with the rigid backboard alone. A statistically significant difference in subjective perception of immobilization was noted, with the backboard alone less effective than the other 3 alternatives. In conclusion, the vacuum splint device, particularly when used with a cervical collar, is an effective and comfortable alternative to a rigid backboard (with or without a collar) for cervical spinal immobilization.

Barney et al⁹⁶ evaluated pain and discomfort during immobilization on rigid spine boards in 90 trauma patients and found that rigid spine boards cause discomfort. Padding the rigid board improves patient comfort without compromising cervical spine immobilization.⁹⁷ Minimizing the pain of immobilization may decrease voluntary movement and therefore decrease the likelihood of secondary injury.⁴⁶

Cervical collars have been associated with elevations in intracranial pressure (ICP). Davies et al⁴⁸ prospectively analyzed ICP in a series of injured patients using the Stifneck rigid collar. ICP rose significantly ($P < .001$; mean, 4.5 mm Hg) when the collar was firmly in place. They cautioned that because head-injured patients may also require cervical spinal immobilization, it is essential that secondary insults producing raised ICP are minimized. Kolb and coinvestigators⁴⁹ also examined changes in ICP after the application of a rigid Philadelphia collar in 20 adult patients. ICP averaged 176.8 mm H₂O initially and

increased to an average of 201.5 mm H₂O after collar placement. Although the difference in ICP of 24.7 mm H₂O was statistically significant ($P = .001$), it remains uncertain that it has clinical relevance. Nonetheless, this modest increase in pressure may be important in patients who already have elevated ICP. Plaisier et al⁷⁸ in 1994 prospectively evaluated craniofacial pressure with the use of 4 different cervical orthoses. They found small changes in craniofacial pressure (increases) but no significant differences between the 4 collar types.

Spinal immobilization increases the risk of pressure sores. Linares and associates⁹⁸ found pressure sores were associated with immobilization (patients who were not turned during the first 2 hours after injury). The development of pressure sores was not related to mode of transportation to hospital or the use of a spinal board and sandbags during transportation. Mawson et al⁹⁹ prospectively assessed the development of pressure ulcers in 39 spinal cord-injured patients who were immobilized immediately after injury. The length of time on a rigid spine board was significantly associated with the development of decubitus ulcers within 8 days of injury ($P = .01$). Rodgers and Rodgers⁶² reported a marginal mandibular nerve palsy resulting from compression by a hard collar. The palsy resolved uneventfully during the next 2 days. Blaylock¹⁰⁰ found that prolonged cervical spinal immobilization may result in pressure ulcers. Improved skin care (keeping the skin dry), proper fitting (avoiding excessive tissue pressure), and the appropriate choice of collars (those that trap or do not absorb moisture or that exert significant tissue pressure) can reduce this risk.^{100,101} Skin breakdown is another potential complication of spinal immobilization. This can occur within 48 hours of application of a cervical collar.¹⁰²

Cervical spinal immobilization may also increase the risk of aspiration and may limit respiratory function. Bauer and Kowalski⁴⁴ examined the effect of spinal immobilization with the Zee Extrication Device and the long spinal board on pulmonary function. They tested pulmonary function in 15 healthy, nonsmoking men using forced vital capacity (FVC), forced expiratory volume in 1 second (FEV₁), the FEV₁:FVC ratio, and forced midexpiratory flow (25%-75%). They found a significant difference ($P < .05$) between preimmobilization strapping and poststrapping values for 3 of the 4 functions tested when on the long spinal board. Similarly significant differences were found for 3 of the 4 parameters using the Zee Extrication Device. These differences reflect a marked pulmonary restrictive effect of appropriately applied entire-body spinal immobilization devices.

Totten and Sugarman⁶ evaluated the effect of whole-body spinal immobilization on respiration in 39 adults. Respiratory function was measured at baseline, once immobilized with a Philadelphia collar on a rigid backboard, and when immobilized on a Scandinavian vacuum mattress with a vacuum collar. The comfort levels of each of the 2 methods were assessed on a visual analog scale. Both immobilization methods restricted respiration by an average of 15%. The effects were similar with the 2 methods, although the FEV₁ was lower on the vacuum mattress. The vacuum mattress was significantly more comfortable than the wooden backboard.

Haut et al¹⁰³ conducted a retrospective analysis comparing patients with and without prehospital spine immobilization after penetrating trauma (knife stab and gunshot). Their study revealed that patients with penetrating injuries to the spine rarely have spinal instability even when the penetrating trauma specifically injures the spine and that spine-immobilized penetrating trauma patients were twice as likely to die as those who were not treated with spinal immobilization. They estimated that the number of patients with a penetrating spinal injury needed to treat with spinal immobilization to potentially benefit 1 patient was 1032. They estimated that the number of patients needed to harm 1 patient with the use of spinal immobilization, potentially contributing to death, was 66. The time required for the proper application of spinal immobilization devices in patients who have suffered stab and gunshot wounds delays patient resuscitation, resulting in increased morbidity and mortality.

Other potential problems with spinal immobilization have been reported in patients with ankylosing spondylitis. In 1 series, 15 patients with ankylosing spondylitis were followed up after sustaining spinal trauma. Twelve of the 15 patients deteriorated neurologically after presentation. In more than one of these patients, neurological deterioration was felt to be secondary to spinal immobilization protocols.¹⁰⁴

In conclusion, cervical spine immobilization devices are generally effective at limiting spinal motion but may be associated with increased morbidity in certain instances. Cervical spinal immobilization devices should be used to achieve the goals of safe extrication and transport yet should be removed as soon as it is safe to do so. Spinal immobilization for patients with penetrating injuries does not appear to be efficacious.

SUMMARY

Spinal immobilization can reduce untoward movement of the cervical spine and can reduce the likelihood of neurological deterioration in patients with unstable cervical spinal injuries after trauma. Immobilization of the entire spinal column is necessary in these patients until a spinal cord injury (or multiple injuries) has been excluded or until appropriate treatment has been initiated. Although immobilization of the cervical spine after trauma is not supported by Class I or II medical evidence, this effective, time-tested practice is based on anatomic and mechanical considerations in an attempt to prevent spinal cord injury and is supported by years of cumulative trauma and triage clinical experience.

Not all trauma patients must be treated with spinal immobilization during prehospital resuscitation and transport. Many patients do not have spinal injuries and therefore do not require such intervention. The development of specific selection criteria for those patients for whom immobilization is indicated remains an area of investigation. Current publications on the use of contemporary, well-defined EMS triage protocols provide Class II medical evidence for their utility.

The variety of techniques used and the lack of definitive evidence to advocate a uniform device for spinal immobilization

make immobilization technique and device recommendations difficult. It appears that a combination of a rigid cervical collar with supportive blocks on a rigid backboard with straps and tape to immobilize the entire body is effective at achieving safe, effective spinal immobilization for transport. The longstanding practice of attempted spinal immobilization with sandbags and tape with the patient strapped to a rigid backboard is not sufficient and is not recommended.

Cervical spine immobilization devices are effective but can result in patient morbidity. Spinal immobilization devices should be used to achieve the goals of spinal stability for safe extrication and transport. They should be removed as soon as a definitive evaluation is accomplished and/or definitive management is initiated. Spinal immobilization of trauma patients with penetrating injuries is not recommended.

KEY ISSUES FOR FUTURE INVESTIGATION

The optimal device for immobilization of the cervical spine after traumatic vertebral injury should be studied in a prospective fashion.

A sensitive, reliable, and valid in-field triage protocol to be applied by EMS personnel for patients with potential cervical spine injuries after trauma should be studied in greater detail.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Transportation of Patients With Acute Traumatic Cervical Spine Injuries

Nicholas Theodore, MD*

Bizhan Aarabi, MD, FRCSC‡

Sanjay S. Dhall, MD§

Daniel E. Gelb, MD¶

R. John Hurlbert, MD, PhD,
FRCSC||

Curtis J. Rozzelle, MD#

Timothy C. Ryken, MD, MS**

Beverly C. Walters, MD, MSc,
FRCSC‡‡§§

Mark N. Hadley, MD‡‡

*Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona; ‡Department of Neurosurgery and ¶Department of Orthopaedics, University of Maryland, Baltimore, Maryland; §Department of Neurosurgery, Emory University, Atlanta, Georgia; ||Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada; #Division of Neurological Surgery, Children's Hospital of Alabama and ‡‡Division of Neurological Surgery, University of Alabama at Birmingham, Birmingham, Alabama; **Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa; §§Department of Neurosciences, Inova Health System, Falls Church, Virginia

Correspondence:

Mark N. Hadley, MD, FACS,
UAB Division of Neurological Surgery,
510 – 20th St S, FOT 1030,
Birmingham, AL 35294-3410.
E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS

Level III:

- Expeditious and careful transport of patients with acute cervical spine or spinal cord injuries is recommended from the site of injury by the most appropriate mode of transportation available to the nearest capable definitive care medical facility.
- Whenever possible, the transport of patients with acute cervical spine or spinal cord injuries to specialized acute spinal cord injury treatment centers is recommended.

RATIONALE

Complete and accurate care of the patient with an acute traumatic cervical spinal injury cannot be provided at the accident scene. Proper care for patients with spinal injuries includes immobilization, extrication, initial resuscitation, and early transport of the patient to a medical center with the capability for diagnosis and treatment.^{1–5} Less favorable outcome, longer hospitalizations, and increased costs are associated with delayed transportation of spinal injury patients to a definitive treatment center.^{5–7}

Selecting the most appropriate mode of transportation from the site of injury to a definitive treatment facility for an individual patient depends on the patient's clinical circumstances, distance, geography, and availability. Land (ambulance) and air (helicopter or fixed-wing plane) are the primary modes available to trans-

port the spinal injury patient. The goal is to expedite safe and effective transportation without an unfavorable impact on patient outcome. These factors provide the rationale to establish medical evidence-based guidelines for the transportation of patients with acute traumatic cervical spine and spinal cord injuries (SCIs). The guidelines author group of the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons have previously produced a medical evidence-based guideline on this topic.⁸ The current review is undertaken to update the medical evidence on the transport of acute SCI patients since that 2002 publication.

SEARCH CRITERIA

A National Library of Medicine (PubMed) computerized literature search from 1966 to 2011 was completed using Medical Subject Headings in combination with “spinal injury” and “transport.” The search was limited to the English language and yielded 10 008 citations for the first search term and 71 323 articles for the second. A search combining both search terms provided 259 articles. All 259 abstracts were reviewed. Additional references were culled from the reference lists of the remaining articles. Finally, members of the author group were asked to contribute articles known to them on the subject matter that were not found by other search means. A total of 16 articles directly relevant to the subject of transportation of spine-injured patients were identified. All provided Class III medical evidence. The 11 most pertinent publications are summarized in Evidentiary Table format (Table).

ABBREVIATIONS: ASCIU, Acute Spinal Cord Injury Unit; SCI, spinal cord injury

SCIENTIFIC FOUNDATION

Safe, rapid, and careful transport of the spinal injured patient to a medical facility for definitive care has long been a fundamental concept of emergency medical service care delivery. No reported Class I medical evidence clinical studies have established the requirement or effectiveness of this strategy. A search of the literature has provided only Class III medical evidence in support of this practice.

One of the basic principles of prehospital spinal care is the early transfer of the injured patient to a center with the resources and expertise to manage acute cervical spine injuries or SCIs.¹⁻⁵ Better neurological outcomes with fewer complications have been reported when early transfer to a specialized SCI center is accomplished.^{3,5} Limiting untoward spinal motion during transportation of patients with cervical spine injuries is considered essential to preserve neurological function and to limit further injury from spinal instability.⁹ The transport of injured patients to the closest definitive care facility can be provided with a variety of transportation methods. Choosing the mode of transportation depends on the patient's overall medical status, the distance to the nearest capable facility, and the availability of resources.

In 1974, Hachen³ described the creation of a nationwide emergency transportation protocol for spinal injury patients implemented in Switzerland in 1968. All SCI patients in Switzerland were immediately transported to The National Spinal Injuries Centre in Geneva by the Swiss Air Rescue Organization. In the 10-year follow-up of this protocol published in 1977, Hachen reported that early transport from the site of the accident to the SCI center under close medical supervision was associated with no patient death during transport. Before 1968, multiple deaths occurred during transport secondary to acute respiratory failure before definitive care could be provided. After 1968, patients were transported rapidly with an onboard anesthesiologist who provided respiratory, cardiac, and hemodynamic monitoring, resuscitation, and nasotracheal intubation as necessary. The average time for the rescue operation was reduced from 4.5 hours to 50 minutes. There was a significant reduction in cardiovascular and respiratory morbidity and mortality. The mortality rate for complete quadriplegic patients dropped from 32.5% in 1966 to 6.8% in 1976 and that for incomplete cervical cord injury patients from 9.9% to 1.4% during the same time period. Hachen concluded that survival and outcome of patients with acute SCIs were enhanced by a well-organized medical system and rapid medically supervised transfer by helicopter to a specialized center, followed by definitive care in a SCI facility for aggressive management in the intensive care unit setting.^{3,10}

Zäch et al¹¹ in 1976 described their experience with 117 acute SCI patients managed per prospective protocol in the Swiss Paraplegic Centre in Basel, Switzerland. All patients were treated in the intensive care unit setting with aggressive medical management and cardiac and blood pressure support. Outcome was stratified by initial injury and time of admission after injury. Sixty-two percent of cervical SCIs managed in this fashion

improved at the last follow-up. No patient with a cervical level injury worsened; 38% were unchanged. Of patients who arrived within 12 hours of injury, 67% improved compared with their initial neurological condition. Fifty-nine percent of patients admitted between 12 and 48 hours of injury showed neurological improvement. When admission occurred after 48 hours of injury, improvement was seen in only 50% of patients. The authors concluded that early transport and "immediate medical specific treatment of the spinal injury" appeared to facilitate neurological recovery.

In 1984, Tator et al⁵ reported their experience with 144 patients with acute SCIs treated between 1974 to 1979 at the Acute Spinal Cord Injury Unit (ASCIU) at Sunnybrook Medical Centre in Toronto, Ontario, Canada. They found a marked reduction in both morbidity and mortality after acute SCI for the group of patients managed from 1974 to 1979 compared with a similar group of patients managed from 1947 to 1973, before the creation of a dedicated, regional spinal cord injury unit. Reasons cited for these improvements included earlier transport to the ASCIU after trauma and better definitive management on arrival.

In a subsequent 1993 publication comparing ASCIU patients managed from 1974 to 1981 with their historical population of patients managed from 1947 to 1973, Tator and colleagues¹² noted a statistically significant difference in duration of time from injury to arrival, 5 hours for ASCIU patients compared with 13 hours for the pre-ASCIU group. They found a significant decrease in the severity of SCI (65% complete cervical lesions compared with 46% for ASCIU patients) and noted fewer complications, shorter hospital stays, and lower expenses for patients managed under the new ASCIU paradigm. Their findings support the advantages of early transport to a regional, specialized SCI center for definitive comprehensive care of patients with SCIs.

Burney et al¹ reviewed the means of transport and type of stabilization used for all patients with acute SCIs transferred to the University of Michigan Medical Center from 1985 to 1988 to determine the effect of these variables on impairment and neurological improvement. Sixty-one patients were reviewed. Twenty-five patients were transported by ground ambulance (41%), 33 by helicopter (54%), and 3 by fixed-wing aircraft (5%). Forty-three patients (70.5%) had cervical spinal injuries, 11 patients (18%) had thoracic spine injuries, and 7 patients (11.5%) had lumbar spinal injuries. Fifty-one patients (84%) were transferred within 24 hours of injury. A variety of standard methods of stabilization were used during transport. No patient suffered an ascending injury as a result of early transport. Level of function improved before discharge in 26 of 61 patients (43%). Patients transported to the medical center within 24 hours of injury were more likely to show improvement (25 of 51) than those transported after 24 hours (1 of 10). There was no significant difference in the probability of improvement between ground (8 of 25 patients) and air (18 of 36 patients) transportation. The authors concluded that acute SCI patients could

TABLE. Evidentiary Table: Transportation^a

Citation	Description of Study	Evidence Class	Conclusions
Crandall et al, ¹⁸ <i>Archives of Surgery</i> , 2010	Retrospective review trauma patients who underwent interfacility transfer and those who did not	III	Although the majority of transfers occur at greater than the mandated 2-h interval, the most seriously injured patients are reaching definitive care within 2 h. Markers of acuity for patients transferred at > 2 h parallel those of the general trauma patient population. These data suggest that, in this system, provider-determined transfer time that exceeds 2 h has no adverse effect on patient outcome.
Bagnal, ¹⁷ <i>Cochrane Database System Review</i> , 2008	To answer the question: Does immediate referral to a spinal injury center result in a better outcome than delayed referral?	III	The current evidence does not enable conclusions to be drawn about the benefits or disadvantages of immediate referral vs late referral to spinal injury centers. Well-designed, prospective, experimental studies with appropriately matched controls are needed.
Bernhard et al, ¹⁹ <i>Resuscitation</i> , 2005,	Review of prehospital management on spinal cord injury	III	Careful movement and the use of appropriate extrication techniques are crucial in all trauma patients with cervical column injury or in mechanisms of injury with the potential to cause spinal injury.
Tator et al, ¹² <i>Surgical Neurology</i> , 1993	201 ASCI patients, ICU care, hemodynamic support compared with 351 prior patients	III	Less severe cord injuries resulted from immobilization, resuscitation, and early transfer to and ICU setting.
Armitage et al, ¹⁴ <i>BMJ</i> , 1990	Case reports of 4 patients who developed respiratory problems during airplane transport	III	Airplane air is less humid, and measures to optimize humidity and pulmonary function travel in patients with high cervical injury may be required.
Boyd et al, ¹³ <i>Journal of Trauma</i> , 1989	A prospective cohort study to determine the effectiveness of air transport for major trauma patients when transferred to a trauma center from a rural emergency room	III	Patients with severe multiple injury from rural areas fare better with helicopter emergency medical service than ground emergency medical service.
Burney et al, ¹ <i>Journal of Trauma</i> , 1989	Retrospective review of the means of transport and type of stabilization used for all patients with ASCIs	III	ASCI patients can be safely transported by air or ground when standard precautions are used.
			Distance and extent of associated injury are the best determinants of the mode of transport.
Tator et al, ⁵ <i>Canadian Journal of Surgery</i> , 1984	Retrospective review of results of innovations between 1974 and 1979 at Sunnybrook Medical Centre in Toronto; the unit achieved a marked reduction in both mortality and morbidity	III	Patients were transferred to the SCI unit earlier, with a consequent marked reduction in complications and cost of care.
Hachen, ¹⁰ <i>Journal of Trauma</i> , 1977	188 patients with ASCI managed in the ICU; aggressive treatment of hypotension and respiratory insufficiency	III	Morbidity and mortality were reduced with early transfer, attentive ICU care and monitoring, and aggressive treatment of hypotension and respiratory failure.
Zäch et al, ¹¹ <i>Paraplegia</i> , 1976	117 patients with ASCI at a Swiss center, ICU setting; aggressive blood pressure and volume therapy	III	Neurological outcome was improved with aggressive medical treatment. Outcome was better for early referrals.
	Rheomacrodex for 5 d Dexamethasone for 10 d		
Hachen, ³ <i>Paraplegia</i> , 1974	Retrospective review of effectiveness of emergency transportation of spinal injury patients in Switzerland. Between 1965 and 1974, all SCI patients were immediately transported by air to SCI center. Mortality reduced to zero during transport. Average time for the rescue operation reduced from 4.5 h to 50 min. Significant reduction in cardiovascular and respiratory morbidity.	III	Mortality and morbidity of patients with acute spinal injury is reduced by a well-organized medical response with smooth and rapid transfer by helicopter to a specialized SCI center.

^aASCI, acute spinal cord injury; ICU, intensive care unit.

be safely transported by air or ground when standard precautions are used. They found that distance and the extent of the patient's associated injuries were the best determinants of the mode of transport.

Rural areas reportedly account for 70% of fatal accidents, and rural mortality rates for victims of motor vehicle accidents are 4 to 5 times greater than those in urban areas. A prospective cohort study by Boyd et al¹³ examined the effectiveness of air transport of major trauma patients when transferred to a trauma center from a rural emergency room. The study consisted of 872 consecutive trauma patients admitted after long-distance transfer. The authors found a 25.4% reduction in predicted mortality ($Z = 3.95$; $P < .001$). The benefit of helicopter emergency medical service transport was realized only in major trauma victims with a probability of survival of $< 90\%$. Thus, the benefits identified with early helicopter emergency medical service transport were directly related to injury severity. It is unclear whether these findings can be extrapolated to spine-injured and/or SCI patients because the authors did not stratify injuries by body systems in their report.

Neither land nor air transport has been reported in the literature to negatively affect the outcome of spine-injured patients when properly executed. One note of caution was offered by Armitage et al.¹⁴ They described 4 spine-injured patients who developed respiratory distress or failure during airplane transport. They noted that because patients with cervical SCIs may have severely reduced pulmonary performance, measures to optimize oxygenation, humidification, and pulmonary function in cervical SCI patients should be undertaken.

The role that specialized centers play in the care of patients with SCIs has long been a topic of debate. In 1990, DeVivo et al¹⁵ compared patients admitted to their multidisciplinary SCI center at the University of Alabama within 1 day of injury with a group of similar SCI patients who received their acute care outside of their facility and were transferred later, solely for rehabilitation. The demographics of the 2 SCI patient groups were similar. The authors reported statistically significant reductions in length of care in acute care and total length of hospitalization, coupled with a highly significant reduction in the incidence of pressure ulcers among patients admitted within 1 day of injury.

Further support for the transport of SCI patients to specialized SCI centers for acute care was offered by Swain and Grundy¹⁶ in 1994. They compared the outcomes of 420 SCI patients who underwent spinal surgery after acute SCI with a cohort of similar patients operated on at other facilities and later transferred to their center. They noted that "complications were more frequent in patients undergoing spinal surgery before transfer to the center. Furthermore, the longer the delay in transfer, the higher the incidence of pressure sores."

Since the publication of the previous medical evidence-based guidelines on this issue in 2002,⁸ 2 contemporary articles germane to the issue of transportation/transfer of seriously injured patients have been published. In 2004, Jones and Bagnall¹⁷ addressed the issue of to which type of facility should acute SCI patients be

transferred. In contrast to prior studies that suggest that SCI patients have better outcomes when treated at specialized centers, their Cochrane Review concluded that there is not sufficient evidence to support either the immediate or delayed transfer of SCI patients to a specialized facility. Their summary is predictable given that there is no Class I or Class II medical evidence on this topic.

In 2010, Crandall et al¹⁸ reported the timing of transfer data from a state-wide trauma registry in Illinois from 1999 to 2003. During that period, there were 22 447 interfacility transfers. The overall transfer rate was 10.4%. Only 20% of the transfers occurred within the arbitrary yet mandated 2-hour transfer interval. Measured outcomes included the Injury Severity Score, mortality, and the time interval to the operating room at the receiving facility. They found that even though most transfers exceeded the recommended 2-hour window limit, there were no adverse effects on patient outcome. The authors concluded that the most seriously ill patients were being transferred expeditiously and that there was no need for a mandated 2-hour transfer interval.

SUMMARY

The patient with an acute cervical spinal injury or SCI should be expeditiously and carefully transported from the site of injury to the nearest capable definitive care medical facility. The mode of transportation chosen should be based on the patient's clinical circumstances, distance from target facility, and geography to be traveled and should be the most rapid means available. Immobilization of patients with acute cervical spinal cord and/or spinal column injuries is recommended. Cervical SCIs have a high incidence of airway compromise and pulmonary dysfunction; therefore, respiratory support measures should be available during transport. Several studies cited suggest improved morbidity and mortality of spinal cord-injured patients after the advent of sophisticated transport systems to dedicated SCI treatment centers. These studies all provide Class III medical evidence on this issue.

KEY ISSUES FOR FUTURE INVESTIGATION

Development and refinement of transportation protocols for patients with cervical spine and SCI should be undertaken and could be accomplished with a large prospectively collected data set. From these data, additional case-control or comparative cohort studies could be structured to generate Class II evidence.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Clinical Assessment Following Acute Cervical Spinal Cord Injury

Mark N. Hadley, MD*

Beverly C. Walters, MD, MSc,
FRCSCT[‡]

Bizhan Aarabi, MD, FRCSCT

Sanjay S. Dhall, MD[¶]

Daniel E. Gelb, MD^{||}

R. John Hurlbert, MD, PhD,
FRCSCT

Curtis J. Rozzelle, MD**

Timothy C. Ryken, MD, MS^{‡‡}

Nicholas Theodore, MD^{§§}

*Division of Neurological Surgery and

**Division of Neurological Surgery, Children's Hospital of Alabama, University of Alabama at Birmingham, Birmingham, Alabama; [‡]Department of Neurosciences, Inova Health System, Falls Church, Virginia; [§]Department of Neurosurgery and ^{||}Department of Orthopaedics, University of Maryland, Baltimore, Maryland; [¶]Department of Neurosurgery, Emory University, Atlanta, Georgia; [#]Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada; ^{‡‡}Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa; ^{§§}Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona

Correspondence:

Mark N. Hadley, MD, FACS,
UAB Division of Neurological Surgery,
510 – 20th St S, FOT 1030,
Birmingham, AL 35294-3410.
E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS

Neurological Examination:

Level II:

- The American Spinal Injury Association international standards for neurological and functional classification of spinal cord injury are recommended as the preferred neurological examination tool for clinicians involved in the assessment and care of acute spinal cord injury patients.

Functional Outcome Assessment:

Level I:

- The Spinal Cord Independence Measure III is recommended as the preferred functional outcome assessment tool for clinicians involved in the assessment, care, and follow-up of patients with spinal cord injuries.

Pain Associated With Spinal Cord Injury:

Level I:

- The International Spinal Cord Injury Basic Pain Data Set is recommended as the preferred means to assess pain, including pain severity, physical functioning, and emotional functioning, among SCI patients.

RATIONALE

Acute traumatic spinal cord injury (SCI) affects 12 000 to 15 000 people in North America each year. The functional conse-

quences of an acute SCI are variable; therefore, the initial clinical presentation of patients with an acute SCI is a key factor in determining triage, defining therapy, and predicting prognosis. The patient must be assessed with an accurate, consistent, and reproducible neurological assessment scale to define the acute SCI patient's neurological deficits and to facilitate communication about patient status to caregivers. The early neurological status of an injury victim as described by an ideal neurological assessment scale should also have prognostic value for that patient's neurological future. The comprehensive clinical assessment of the SCI patient should both accurately describe the patient's neurological function (motor and sensory examinations) and generally predict that patient's future relative abilities and/or impairment given the patient's neurological status. Prognostic information provided by comparing current injury victims and the functional outcomes of historical patients with similar injuries is of value to patients and families. The evaluation of new therapies proposed for the treatment of acute SCI requires the use of accurate, reproducible neurological assessment scales and reliable functional outcome measurement tools to measure potential neurological improvement after therapy and, importantly, to determine its functional significance.

Pain of the spinal cord, spinal column, or other orthopedic origin is often of clinical significance following acute SCI. Pain can be horribly debilitating, hindering patient performance and limiting functional abilities beyond that predicted by the patient's neurological deficits. These 3 topics (neurological assessment, functional outcome, and pain associated with SCI) are the focus of this contemporary update on the Clinical Assessment Following Acute Spinal Cord Injury, previously produced and published by the Joint Section on Disorders of the Spine

ABBREVIATIONS: ASIA, American Spinal Injury Association; FIM, Functional Independence Measure; ISCI BPDs, Spinal Cord Injury Basic Pain Data Set; QIF, Quadriplegic Index of Function; SCI, spinal cord injury; SCIM, Spinal Cord Independence Measure

and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons.¹

SEARCH CRITERIA

A computerized search of the database of the National Library of Medicine (PubMed) of the literature published from 1966 to 2011 was performed for each of the 3 subtopics reviewed in this guideline: neurological assessment, function outcome, and pain following SCI. The search was limited to the English language, the human literature, and reviews, case series, meta-analyses, and randomized clinical trials of adult patients published between 1966 and 2011. The term “spinal cord injury” was combined with the term “neurological assessment,” yielding 1444 references. A second search using the terms “spinal cord injury” and “assessment scales” yielded 81 references. A third search employing the terms “spinal cord injury” and “assessment scores” revealed 178 publications. A search using “ASIA impairment scale” yielded 351 citations. A search using the terms “ASIA classification” and “spinal cord” yielded 113 references (total, 2167).

For functional outcome, each PubMed database search was limited to the English language, the human literature, and reviews, case series, meta-analyses, and randomized clinical trials published between 2000 and 2010. Search terms “spinal cord injury” and “functional outcomes assessment” yielded 448 references. Search terms “spinal cord injury” and “functional outcome scales” yielded 28 citations. A search for “functional independence measure” resulted in 1132 references. A search for “spinal cord independence measure” revealed 190 citations (total, 1798).

For pain following SCI, each PubMed database search was limited to the English language, the human literature, and reviews, case series, meta-analyses, and randomized clinical trials published between 1966 and 2010. Search terms “spinal cord injury” and “pain” resulted in 2093 references. Search terms “spinal cord injury” and “pain classification” yielded 91 citations. A search using the terms “spinal cord injury” and “pain assessment scales” produced 26 references. Search terms “spinal cord injury” and “pain assessment scale” resulted in 121 references (total 2331).

The 733 references for neurological assessment, the 520 references for functional outcome, and the 1050 citations for pain following SCI were imported into a database, and duplicates were eliminated. Articles germane to each of the 3 topics were selected by reviewing their titles and abstracts. Additional references were culled from the reference lists of the remaining papers. Finally, members of the author group were asked to contribute articles known to them on the subject matter that were not found by other search means. The citations critical to the formulation of this guideline on each of the 3 topics are provided in Evidentiary Table format (Tables 1-3).

SCIENTIFIC FOUNDATION

A variety of neurological assessment systems/scales have been utilized for the documentation of the neurological status of

patients following SCI. They include the Frankel Scale; the modified Frankel Scale; the Lucas and Ducker Neurotrauma Motor Index; the Sunnybrook, the Botsford, and the Yale scales; the NASCIS scale; the American Spinal Injury Association (ASIA) scale; and the ASIA/International Medical Society of Paraplegia international standards for neurological and functional classification of SCI scale, now referred to as the American Spinal Injury Association Classification Standards.²⁻²¹

Several of these assessment scales have been refined through serial iterations.^{2,4,8-11,17,19,20,22} A few are widely used, while others have not attained general acceptance and recognition. Ideally, the clinical neurological assessment of acute SCI victims should be uniform, reproducible, and thorough yet easy to use. The assessment tool must be detailed and precise to specifically document a given patient's injury and must provide descriptive measurement scales that allow determination of loss or gain of function with time and therapy. Nearly simultaneously, there must be correlation of the patient's functional abilities relative to their neurological examination to document whether losses or gains have meaningful significance to the patient and to accurately determine outcome. This is typically accomplished using a scale to quantify Functional Outcome in conjunction with a Neurological Assessment scale. Whatever assessment system(s) is/are used, it/they must be consistent and accurate and have interrater reliability. Difficulties exist when clinicians utilize poorly defined measurement tools or different methods of neurological assessment to describe the same patient, hindering the definition (potentially the management) of that patient by different clinicians and the comparison of that patient with other patients with similar injuries. The accurate assessment of both the neurological status and the functional skills of acute SCI patients is essential for patient management, the conduct of research studies, and comparisons of clinical therapeutic trials.

Numerous assessment scales have been used to evaluate patients with SCI. Scales may be divided into 2 general types. The first type is examination-specific and focuses on the neurological deficits suffered as a result of SCI. These scales use the motor and sensory examination primarily (or exclusively) to assign a numerical value or letter grade.^{4,8,9,12,15,17-20,23} The second type of scale focuses on functional skills, including a patient's ability to care for himself or herself, participate in personal hygiene, transfer, or ambulate.^{10,11,22,24-34} In general, the first type of scale is used for the acute assessment of patients with SCI, whereas both assessment scales are used to define the chronically injured patient. The contemporary assessment of SCI patients incorporates both neurological examination scales and functional outcome/assessment scales to most accurately describe individual patients.^{10,11,35} Finally, the clinical assessment of patients with acute SCI should include an assessment of pain severity, physical functioning, and emotional functioning experienced by that patient. Several pain classification systems have been developed, and 13 pain intensity instruments have been designed and utilized to describe pain among SCI patients.³⁶⁻³⁸

NEUROLOGICAL EXAMINATION SCALES

A comprehensive medical evidence-based review of neurological assessment scales used to assess acute adult SCI patients was published in 2002.¹ In 2002, based on the best medical evidence in the literature to that point, the guidelines author group concluded that the 1996 ASIA standards was the most valid and reliable neurological assessment scale available to clinicians who care for these patients. This recommendation was offered as an Option Level or Level III recommendation.

Since the 2002 guideline publication, several investigators have further studied the reliability and validity of the ASIA standards as a neurological examination scale for adult patients following acute SCI. Kirshblum et al compared the revised 2000 ASIA Classification Standards with the previous 1996 ASIA standards. Ninety-four subjects with SCI who were assessed with the 1996 standards at 1 week and 1 year after injury were retrospectively reassessed using the revised 2002 ASIA Standards. They found nearly perfect agreement between the 2 scales (weighted κ scores between 0.995 and 0.91; confidence intervals between 0.79 and 1.0). Three of 17 ASIA C categorized patients based on the 1996 standards were categorized as ASIA B using the 2000 standards, a distinction that had no impact on prognosis at 1 year follow-up examination.

In 2003, Burns and colleagues³⁹ retrospectively discovered that 5 of 81 acute SCI patients (6%) initially scored as ASIA A injuries at their institution were reclassified as ASIA B within the first week of injury. They used 1-year follow-up assessments for comparison. They cited closed head injury, drug effects, mechanical ventilation, and psychological disorders as factors that could potentially interfere with the ability to accurately examine a patient. They concluded that these factors could diminish the reliability of the initial examination on admission.

Marino and Graves³ reported on the metrics of the ASIA motor score in correlation with functional activities and functional impairment in 2004. They used item response theory methods to determine the value of the use of ASIA motor score/subscores to predict motor Functional Independence Measure (FIM) instrument scores among a database of 4338 SCI patients discharged from inpatient rehabilitation between 1994 and 2003. They concluded that functional impairment following SCI is more accurately described by the use of separate upper- and lower-extremity ASIA motor scores rather than a single, total ASIA motor score. Similarly, in 2006, Graves et al²¹ concluded that the use of upper- and lower-extremity motor scales will reduce measurement error when the ASIA motor score is used as a predictor of outcome. In an assessment of the ASIA motor score scales in 6116 SCI patients, they found that the use of 2 scales was more accurate and could distinguish between complete paraplegia and incomplete SCI (in both instances the ASIA motor score could equal 50) more reliably than the use of a single total ASIA motor scale score.

In 2007, Slavic et al² reported on the interrater reliability of the ASIA standards motor and sensory examinations performed by 2 experienced examiners in a prospective observational study and

assessment of 45 SCI patients. The total ASIA score showed a very strong correlation between the 2 examiners with Pearson correlation coefficients and intraclass correlation coefficients exceeding 0.99 for total motor and light touch scores and 0.97 for pinprick scores. Weighted κ values for myotome determination when a sufficient number of observations allowed statistical analysis were 0.785 to 0.981, indicating substantial to almost perfect agreement. Level of agreement between the 2 examiners for level of injury ranged between 73% and 80%. The unweighted κ coefficient for agreement in motor and sensory levels ranged from 0.68 to 0.78, indicating substantial agreement (Class II medical evidence). There was no difference in ASIA impairment grades between the 2 examiners' results.

Furlan et al^{40,41} performed 2 similar but separate literature reviews and have produced 2 publications on the psychometric properties of the ASIA Standards, one in 2008 and the other in 2010. There is no accepted "gold standard" neurological assessment examination against which to compare all others. They reported that the ASIA standards have not been evaluated adequately with respect to several of the 8 quality criteria for psychometric properties of instruments as proposed by Terwee and colleagues.⁴² Convergent construct validity, reliability, and responsiveness have been the criteria of the ASIA standards most rigorously scientifically studied. There are recognized minor variances noted among investigators in each criterion as summarized above. There is the potential for floor effects on the motor score assessment among paraplegic patients (no measure of motor function between T1 and L1) and a ceiling effect among the quadriplegic patients (injury above measurable motor units), which can affect scoring scale accuracy and hinder comparison to other similarly injured SCI patients. The ASIA standards cannot be accurately applied to SCI patients who cannot be accurately examined owing to confounding factors³⁹ (This is not a failure/weakness of the scoring scale) and are not applicable to adolescents and children.^{43,44} Despite these few, but real, potential problematic features, the 2000 American Spinal Injury Association (ASIA) Standards is the most consistent, reliable, valid and responsive scoring system for the Neurological Assessment of adult patients with acute SCI, to a high degree of scientific certainty.^{2,4,40,41}

FUNCTIONAL OUTCOME SCALES

Functional outcome scales are measures of human performance and ability/disability typically defined during medical rehabilitation, ie, how a person functions with activities of everyday life after injury/impairment/debilitating illness. Several scales have been employed or developed in an effort to accurately characterize an injury victim's functional skills and disabilities after SCI in order to quantify his or her functional independence.^{10,11,22,24,25,27-31,34,45-53} They attempt to determine a patient's ability or inability to function and/or live independently. Scales for functional rating include the Barthel Index, the modified Barthel Index, the FIM, the Quadriplegic Index of Function (QIF), the Spinal Cord Independence Measure (SCIM), the Walking Index for SCI, the Spinal

TABLE 1. Evidentiary Table: Clinical Neurological Assessment: Neurological Examination^a

Reference	Description of Study	Evidence Class	Conclusions
Savic et al, ² <i>Spinal Cord</i> , 2007	Assessment of interrater reliability of motor/sensory examinations of ASIA standards	II	κ Values for agreement in motor and sensory examinations, 0.68-0.78, indicating substantial agreement.
Graves et al, ²¹ <i>Journal of Spinal Cord Medicine</i> , 2006	Comparison of total ASIA motor score with separate upper- and lower-extremity scales to describe SCI	III	Use of upper- and lower-extremity scores will reduce measurement error compared to total ASIA motor score.
Marino and Graves, ³ <i>Archives of Physical Medicine and Rehabilitation</i> , 2004	IRT methods to assess total ASIA motor score vs ASIA subscores for upper/lower extremity to predict FIM	III	Impairment from SCI is more accurately characterized using upper-/lower-extremity ASIA subscores.
Burns et al, ³⁹ <i>Journal of Neurotrauma</i> , 2003	Assessment of early ASIA grade with one week and one year follow-up.	III	Earliest ASIA grade assignment may be inaccurate due to confounding features that limit examination.
Kirshblum et al, ⁴ <i>American Journal of Physical Medicine and Rehabilitation</i> , 2002	Comparison of 2000 ASIA standards to 1996 ASIA standards	I	There was near-perfect agreement between 1996 and 2000 ASIA standards.
Jonsson et al, ¹⁰⁸ <i>Spinal Cord</i> , 2008	To determine the interrater reliability of the ISCSCI-92	III	This study indicates a weak interrater reliability for scoring incomplete SCI lesions using the ISCSCI-92.
Cohen et al, ¹⁰⁹ <i>Spinal Cord</i> , 1998	A test of the ISCSCI-92	III	Further revisions of the 1992 ASIA standards and more training are needed to ensure accurate classification of SCI.
El Masry et al, ²⁶ <i>Spine</i> , 1996	Validation of the ASIA motor score and the NASCIS motor score	III	The ASIA and NASCIS motor scores can both be used for the neurological quantification of motor deficit and motor recovery.
Wells and Nicosia, ³⁵ <i>Journal of Spinal Cord Medicine</i> , 1995	Comparison of Frankel Scale, Yale Scale, Motor Index Score, modified Barthel Index, and Functional Independence Measure	III	The best assessment tool is a combination of 2 scales, one based on impairment and the other on disability.
Waters et al, ¹¹⁰ <i>Archives of Physical Medicine and Rehabilitation</i> , 1994	ASIA compared with motor scores based on biomechanical aspects of walking	III	ASIA motor score strongly correlates with walking ability.
Davis et al, ¹¹¹ <i>Spine</i> , 1993	Reliability of Frankel and Sunnybrook scales	III	Demonstrated high inter-rater reliability of Frankel and Sunnybrook scales.
Bednarczyk and Sanderson, ¹¹² <i>Journal of Rehabilitation Research and Development</i> , 1993	Compared several classification systems within the same group of spinal cord-injured subjects	III	ASIA scale showed the greatest discrimination in grouping subjects with SCI.
Botsford and Esses, ¹³ <i>Orthopedics</i> , 1992	Description of a new functionally oriented scale with assessment of motor and sensory function, rectal tone, and bladder	III	Scale was more sensitive for the detection of improvement in function.
Priebe and Waring, ¹¹³ <i>American Journal of Physical Medicine and Rehabilitation</i> , 1991	Interobserver reliability of the 1989 revised ASIA standards for neurological classification of spinal injury patients	III	The interobserver reliability for the revised ASIA standards is improved but continues to be less than optimal. They recommended changes.
Bracken et al, ¹¹⁴ 1990, <i>New England Journal of Medicine</i>	Multicenter North American trial examining effects of methylprednisolone or naloxone in ASCI (NASCIS II)	III for neuro assessment	Motor scores of 14 muscles on 5-point scale, right side of body only. Sensory scores of pinprick and light touch, 3-point scale, bilateral. No interrater reliability comparison.
Lazar et al, ¹¹⁵ <i>Archives of Physical Medicine and Rehabilitation</i> , 1989	Relationship between MIS and the modified Barthel Index	III	The MIS is useful in predicting function during rehabilitation, although individual differences in ambulation limit its predictive utility.
Bracken et al, ⁶ 1984, <i>JAMA</i>	Methylprednisolone in SCI	III for neuro assessment	Description of NASCIS motor score.

(Continues)

TABLE 1. Continued

Reference	Description of Study	Evidence Class	Conclusions
Tator et al, ²⁰ <i>Early Management of Acute Spinal Cord Injury</i> , 1982	Description of a 10-grade numerical neurological assessment scale	III	Improvement from the Frankel scale. Motor grading is not very sensitive.
Chehrizi et al, ¹⁵ <i>Journal of Neurosurgery</i>	Description of Yale scale	III	Provides assessment of the severity of SCI and the prognosis for recovery.
Lucas and Ducker, ¹⁸ <i>American Surgeon</i> , 1979	A motor classification of patients with SCI injuries with statistically discrete subdivisions; the patients in each of the subdivisions of the classification can be mathematically summarized with numerical indices, which can be accurately analyzed statistically	III	Allows the clinical researcher to evaluate current treatments and assess the potential of new treatments and to assess the potential of new treatment regimens.
Bracken et al, ⁷ <i>Paraplegia</i> , 1978	Description of 133 ASCI patients classified using motor and sensory scales developed by Yale SCI Study Group	III	Considerable discrepancy between motor and sensory impairment scales among patients with greater motor than sensory loss.
Frankel et al, ¹⁷ <i>Paraplegia</i> , 1969	5-Category scale used in a large study to assess neurologic recovery in patients treated with postural reduction of spinal fractures	III	Present results in terms of defined degrees of neurological involvement.

^aASCI, acute spinal cord injury; ASIA, American Spinal Injury Association; FIM, Functional Independence Measure; IRT, item response theory; ISCSI-92, International Standards Classification of Spinal Cord Injury 1992; MIS, Motor Index Score; NASCIS, National Acute Spinal Cord Injury Study; SCI, spinal cord injury.

Cord Injury Functional Ambulation Inventory, and the recently proposed SCI Computer Adaptive Test.^{10,11,22,24,25,27-34,45,47-57} They are applicable to a wide range of nervous system disorders; however, the QIF, the Spinal Cord Injury Functional Ambulation Inventory, and the SCIM were developed specifically for patients with SCI and are reportedly more specific and sensitive for patients with SCI.^{24,27,32,48,53,58,59} All of these scales have been successfully used to characterize the functional abilities of SCI patients.^{10,11,22,24,25,27-31,45,47-52,54} A comprehensive medical evidence-based review of functional outcome scales was published in 2002.¹ On the basis of the best medical evidence published in the English language literature through 2001 on adult SCI patients, the guidelines author group advocated the use of the FIM as the functional outcome assessment tool of choice for SCI patients at a Guideline Level (Level II) recommendation.¹

As described in the original guideline on the topic, FIM has proven to be a reliable, valid tool to assess the functional abilities of compromised patients with respect to activities of daily living and to assess the burden of care of those patients for a variety of medical disorders.^{32,60} Several investigator groups have been critical of FIM and its applicability to patients with neurological dysfunction following SCI.^{32,61} While widely used, FIM was not developed specifically for patients with SCI. It has been cited for its lack of sensitivity, particularly in locomotion, mobility, respiration, and bladder/bowel sphincter function items among patients with SCI.⁶¹ To address the shortcomings of FIM in documenting patient disability and the degree of functional recovery among SCI patients, 3 SCI-specific functional assessment scales were developed. The QIF, developed in 1980 to

describe the functional skills and abilities of tetraplegic patients (complete high cervical SCI patients), has poor applicability to the whole of the adult SCI population.^{27,32,62} The same is true of the Spinal Cord Injury Functional Ambulation Inventory, proposed in 2001, and the Walking Index for SCI. Both are tools to assess the walking abilities of patients with incomplete SCI.^{34,48,56,63}

SCIM was proposed in 1997 as a new disability scale specific for patients with spinal cord pathology.²⁴ An international collaborative author-investigator group has twice revised SCIM.^{33,64} In its current iteration, the SCIM III has been studied in detail and is reported to be sensitive, specific, valid, and reliable for the assessment of disability among SCI patients, both early and late after SCI.^{32,58,64,65} The SCIM instrument focuses on the patient's ability to perform everyday tasks and captures the economic burden of disability, as well as the impact of their disability on the patient's overall medical condition and comfort. It consists of 3 subscales that cover the related but distinct subsets of self-care (6 items; score range, 0-20), respiration and sphincter management (4 items; score range, 0-40), and mobility (9 items; score range, 0-40). The total score ranges from 0 to 100. The mobility subset is further subdivided into 2 subscales: room and toilet, and indoors and outdoors. Individual item scores range from 2 to 9 points. SCIM scores a task higher in patients who accomplish it with less assistance, aids, or medical compromise than other patients.

SCIM was introduced by Catz et al²⁴ in 1997. This author group described the assessment of 30 patients with spinal cord pathology using SCIM. They assessed the interrater reliability

TABLE 2. Evidentiary Table: Clinical Neurological Assessment: Functional Outcome Assessment^a

Reference	Description of Study	Evidence Class	Conclusions
Ackerman et al, ⁵³ <i>Spinal Cord</i> , 2010	Assessment of SCIM III as functional outcome tool after acute rehabilitation	III	SCIM III is sensitive, effective for outcome after rehabilitation. Floor/ceiling effects identified in some subgroups.
Bluvshstein et al, ⁵⁸ <i>Spinal Cord</i> , 2010	Analysis of reliability and validity of SCIM III	I	κ Values of 0.649-0.858 for all SCIM III tasks. SCIM III more responsive than FIM.
Glass et al, ⁶⁰ <i>Journal of Rehabilitation Medicine</i> , 2009	Analysis of SCIM III and FIM in SCI patients in the United Kingdom	III	SCIM III valid and reliable. Both SCIM III and FIM valid, SCIM III more sensitive than FIM.
Rudhe and van Hedel, ⁶⁸ <i>Neurorehabilitation and Neural Repair</i> , 2009	Comparison of 261 patients upper-extremity SCIM III scores with arm and hand muscle strength and hand function in tetraplegic patients	II	SCIM III accurately reflects upper-extremity function in tetraplegia.
Wirth et al, ⁵⁹ <i>Neurorehabilitation and Neural Repair</i> , 2008	Analysis of sensitivity of SCIM III vs ASIA scores as late functional outcome tool	III	SCIM II sensitive tool for outcome at one-year follow-up. Floor/ceiling effects noted in some subgroups.
Catz et al, ⁶⁵ <i>Spinal Cord</i> , 2007	Rasch analysis of SCIM III	I	SCIM III and SCIM III subscales reliable/valid.
Itzkovich et al, ⁶⁴ <i>Disability and Rehabilitation</i> , 2007	Assessment of reliability and validity of SCIM III, 2 raters	I	κ Values of 0.631-0.823 for all SCIM III tasks. SCIM III much more sensitive than FIM.
Itzkovich et al, ⁶⁷ <i>American Journal of Physical Medicine and Rehabilitation</i> , 2003	Comparison of reliability of SCIM II by interview and comparison with observation	III	Reliability of SCIM II by interview good but not as good as observation.
Itzkovich et al, ⁶⁶ <i>Spinal Cord</i> , 2002	Rasch analysis of SCIM II	III	Confirms validity and reliability of SCIM II.
Catz et al, ³³ <i>Disability and Rehabilitation</i> , 2001	Introduction of revised SCIM (SCIM II) with comparison to SCIM and FIM	III	SCIM II supersedes SCIM.
Catz et al, ⁶¹ <i>Spinal Cord</i> , 2001	Comparison of SCIM to FIM	III	SCIM more sensitive than FIM for spinal cord lesions. Needs further refinement.
Field-Fote, ⁴⁸ <i>Journal of Rehabilitation Medicine</i> , 2001	Spinal Cord Injury Functional Ambulation Inventory as functional assessment scale for gait assessment.	III	Reliable and relatively sensitive measure of walking ability in patients with ASCI. Interrater reliability good, no κ values offered.
Küçükdeveci et al, ²⁹ <i>Scandinavian Journal of Rehabilitation Medicine</i> , 2000	To determine the reliability and validity of the modified Barthel Index in Turkey	III	Adaptation of the modified Barthel Index has been successful and can be used in Turkey as long as its limitations are recognized.
Ditunno et al, ⁴⁵ <i>Spinal Cord</i> , 2000	Walking Index for SCI offered as index for ambulation skills after SCI in pilot study	III	Good reliability and excellent interrater reliability but needs assessment in clinical setting.
Yavuz et al, ⁶² <i>Spinal Cord</i> , 1998	Assessment of the relationship of the 2 functional tests, the FIM and the QIF, to ASIA scores	III	Good, strong correlations between the FIM and the QIF to ASIA scores.
Catz et al, ²⁴ <i>Spinal Cord</i> , 1997	SCIM as new disability scale for spinal cord lesions; 30 patients assessed with SCIM and FIM	III	SCIM more sensitive than FIM.
Hamilton et al, ¹¹⁶ <i>Scandinavian Journal of Rehabilitation Medicine</i> , 1994	FIM interrater reliability in the clinical setting	III	FIM is reliable when used by trained/tested inpatient medical rehabilitation clinicians.
Dodds et al, ⁴⁷ <i>Archives of Physical Medicine and Rehabilitation</i> , 1993	Assessment of reliability of FIM in characterizing 11 102 UDS rehabilitation patients	III	FIM has high internal consistency and adequate discriminative capabilities and was a good indicator of burden of care.
Hamilton et al, ¹¹⁷ <i>Archives of Physical Medicine and Rehabilitation</i> , 1991	Interrater agreement assessment of FIM in 263 patients in 21 UDS hospitals	III	κ Values for 7-level FIM ranged from 0.61-0.76; mean, 0.71.

(Continues)

TABLE 2. Continued

Reference	Description of Study	Evidence Class	Conclusions
Shah et al, ³¹ <i>Journal of Clinical Epidemiology</i> , 1989	Description of modified Barthel Index	III	The modified Barthel Index has greater sensitivity and improved reliability than the original version, without additional difficulty or affecting the implementation time.
Gresham et al, ²⁷ <i>Paraplegia</i> , 1986	Test of the QIF	III	The QIF was more sensitive than the Barthel Index.

^aASIA, American Spinal Injury Association; FIM, Functional Independence Measure; QIF, Quadriplegic Index of Function; UDS, Uniform Data System; SCI, spinal cord injury; SCIM, Spinal Cord Independence Measure.

and sensitivity of SCIM and compared their SCIM results with FIM assessments for each patient. The authors found remarkable consistency between each pair of raters (2 trained raters for each of 3 subsets) for all tasks assessed, with a κ coefficient between 0.66 and 0.98. Total agreement was > 85%. The authors found the SCIM more sensitive than FIM to changes in the functional abilities of spinal cord lesion patients over time: SCIM detected all functional changes detected by FIM, but FIM missed 26% of changes detected by SCIM scoring. The authors concluded that SCIM is a useful instrument for assessing functional changes in patients with lesions of the spinal cord. The same author group described similar results in a comparison between SCIM assessment and FIM assessment scores in 22 patients with spinal cord lesions in 2001 but suggested revision of the functional subgroups of self-care and mobility.⁶¹

Catz and colleagues³³ reported these revisions in 2001. SCIM II included new scales for the activities of bathing, dressing, bowel care, and mobility in bed. The correlations between the paired scores for these functional categories were $r = 0.90$ to 0.96 (statistically significant improvement, $P < .001$). The authors recommended that SCIM II supersede SCIM as an SCI-related functional assessment tool. Itzkovich and colleagues⁶⁶ performed a Rasch analysis of the revised SCIM assessment tool (SCIM II) and reported it in 2002. They concluded that SCIM II was a valid and reliable assessment tool and had an acceptable goodness of fit to the Rasch model (in-fit mean square = 0.8-1.2; outfit mean square = 0.6-1.4). Nonetheless, their analysis identified a few item categories that should be revised or removed to further improve SCIM. Itzkovich and coauthors⁶⁷ later demonstrated that SCIM II was also remarkably reliable when applied after interview (only) of SCI patients compared with observed examinations of the same patients by skilled examiners.

Wirth and associates⁵⁹ evaluated 64 patients with complete paraplegia and 36 with complete quadriplegia with SCIM II and compared SCIM II data to ASIA motor scores at 1, 3, 6, and 12 months after injury. They reported that median ASIA motor scores remained stable in the paraplegic group at 1-year follow-up. The quadriplegic group demonstrated significant improvement in median ASIA motor scores at 1 year, from

a median of 14 points initially to 19 points 12 months after injury. They noted a floor effect on motor recovery among the paraplegic patients (no measure of motor function between T1 and L1) and a ceiling effect among the quadriplegic patients (injury above measurable motor units). Paraplegic patients had significant increases in SCIM II scores over time (median improvement, 41 points). Quadriplegic patients also demonstrated significant improvements in SCIM II scores (median improvement, 11 points) but less improvement than paraplegic patients. The functional recovery rate of patients with paraplegia was significantly higher than that of quadriplegic patients in the first 3 months after injury; however, the annualized functional recovery rate was comparable between the 2 groups of patients. Floor and ceiling effects previously described with ASIA motor scores were identified with SCIM II scores as well. There was no correlation between functional and motor recovery in paraplegic patients; however, a fair correlation was observed with quadriplegic patients. These authors concluded that functional recovery is a continuous process in the first year after SCI and that SCIM II is a sensitive, responsive, valuable assessment tool complementary to the ASIA standards for monitoring rehabilitation outcome in SCI.

A new and improved SCIM scale (SCIM III) was reported by Itzkovich et al in 2007. Four hundred twenty-five patients with spinal cord lesions from 13 centers in 6 countries were evaluated with SCIM III and FIM on admission to rehabilitation and upon discharge. SCIM III was tested for interrater reliability (agreement between raters, κ coefficients, Pearson correlation, and interclass correlation coefficients) and the internal consistency of scale (Cronbach coefficient). Total agreement between raters ranged between 74.5% and 96.2%; total agreement was > 80% in 13 of the 18 tasks. The κ coefficients ranged between 0.631 and 0.823 ($P < .001$). Pearson coefficients of the 3 SCIM III subscales and total SCIM III were > 0.9 ($P < .001$). Interclass correlation values were > 0.94 for total SCIM III and all SCIM III subscales. Cronbach α values for SCIM III were 0.847 and 0.849. Pearson correlation coefficients between SCIM III and FIM were 0.790 and 0.779 for the 2 raters, respectively. The responsiveness of SCIM III was statistically significantly better than that of FIM in the respiration and sphincter management and mobility indoors

TABLE 3. Evidentiary Table: Clinical Neurological Assessment: Pain Associated With SCI^a

Reference	Description of Study	Evidence Class	Conclusions
Jensen et al, ¹⁰⁷ <i>Spinal Cord</i> , 2010	Assessment of Spinal Cord Injury Basic Pain Data Set in 184 SCI patients with pain	I	Excellent internal consistency (reliability) (Cronbach's $\alpha = .94$). Validity statistically significant, $P < .01$.
Dijkers, ⁹¹ <i>Journal of Spinal Cord Medicine</i> , 2010	Comparison of quantification of SCI pain by Verbal Rating Scale and Numeric Rating Scale	III	Considerable variation in patient interpretation and use of Verbal Rating Scale and Numeric Rating Scale to describe pain.
Attal et al, ⁹⁰ <i>Pain</i> , 2008	Characterization and quantification of neuropathic pain from nerve, spinal cord, and brain lesions with NPSI	III	NPSI revealed several positive correlations but not specific or reliable.
Hanley et al, ⁸¹ <i>Journal of Pain</i> , 2008	Assessment of pain catastrophizing and beliefs on pain after SCI	III	Pain catastrophizing associated with greater pain interference and poorer psychological functioning.
Felix et al, ⁷⁴ <i>Journal of Rehabilitation Research and Development</i> , 2007	Assessment of chronic pain after SCI with descriptions, Numeric Rating Scale, IASP taxonomy	III	Sharp pain most disturbing, more frequently interferes with activities and sleep.
Budh and Osteräker, ⁸⁰ <i>Clinical Rehabilitation</i> , 2007	Assessment of self-reported life satisfaction after SCI; questionnaire with Lisat-9 and Verbal Rating Scale	III	SCI pain negatively affects life satisfaction compared to SCI patients without pain.
Wollaars et al, ⁸³ <i>Clinical Journal of Pain</i> , 2007	Comprehensive questionnaire assessment of psychological factors on SCI and impact of SCI pain on quality of life	III	Chronic SCI pain and poor quality of life associated with pain catastrophizing and SCI helplessness.
Hanley et al, ⁹² <i>Clinical Journal of Pain</i> , 2006	Assessment of change in pain intensity in patients with SCI or limb amputation	III	An approximate 33% decrease in pain is considered a reasonable standard for meaningful change in chronic pain.
Hanley et al, ¹⁰¹ <i>Journal of Pain</i> , 2006	Classification of SCI pain; mild, moderate, and severe	III	Classification of SCI pain may be useful for applying clinical treatment guidelines and for interpreting results of future clinical trials.
Bryce et al, ³⁶ <i>Journal of Spinal Cord Medicine</i> , 2006	Assessment of Bryce/Ragnarsson SCI pain taxonomy using clinical vignettes	II	"Substantial" interrater agreement in determining subtypes of pain, κ Values between 0.55 and 0.91. Not applied to patients.
Raichle et al, ⁹⁷ <i>Journal of Pain</i> , 2006	Survey assessment of reliability and validity of Graded Chronic Pain Disability Scale Disability and Brief Pain Inventory of Wisconsin Interference scales	III	Graded Chronic Pain Disability Scale Disability and Brief Pain Inventory of Wisconsin Interference scales appear reliable and valid.
Widerstrom-Noga et al, ¹⁰⁵ <i>Archives of Physical Medicine and Rehabilitation</i> , 2006	Assessment of consistency, stability, and validity of the Multidimensional Pain Inventory	III	Multidimensional Pain Inventory appears to be a reasonable measure for evaluating chronic pain and its impact after SCI.

(Continues)

TABLE 3. Continued

Reference	Description of Study	Evidence Class	Conclusions
	Moderate to substantial reliability: 8 of 10 subscales		
	High construct validity in 9 of 10 subscales		
Salisbury et al, ⁹⁹ <i>Spinal Cord</i> , 2006	Assessment of shoulder pain following tetraplegia using Wheelchair Users Shoulder Pain Index, McGill Pain Questionnaire, and Numeric Rating Scale	III	High incidence of shoulder pain after SCI even among those patients not confined to wheelchairs.
Cruz-Almeida et al, ⁷¹ <i>Journal of Rehabilitation Research and Development</i> , 2005	Questionnaire assessment of self-reported pain and pain interference with sleep and daily activities; confirmatory factor analysis	III	Chronic nociceptive and neuropathic pain are consistent after SCI and have negative impact on sleep and activities of daily living.
Lund et al, ⁹³ <i>BMC Medical Research Methodology</i> , 2005	Comparison of Visual Analog Scale and Verbal Rating Scale in cross-sectional study of chronic pain (not isolated SCI pain)	III	Visual Analog Scale and Verbal Rating Scale not interchangeable. Visual Analog Scale may overestimate or underestimate perceived pain.
Samuelsson et al, ¹⁰⁰ <i>Spinal Cord</i> , 2004	Assessment of shoulder pain in paraplegic SCI patients using CMS, Wheelchair Users Shoulder Pain Index, and COPM	III	Shoulder pain in this population mostly related to wheelchair activities. No correlation between assessment measures.
Roth et al, ⁹⁸ <i>American Journal of Physical Medicine and Rehabilitation</i> , 2004	Assessment of pain and its relation to affective distress, depression, and pain catastrophizing in patients with chronic wounds/injury	III	McGill pain questionnaire more sensitive to pain in 69 patients (12 with SCI).
Putzke et al, ¹⁰³ <i>Spinal Cord</i> , 2003	Assessment of test-retest reliability of Donovan SCI pain classification	III	Adequate test-retest reliability, interrater agreement low.
Putzke et al, ⁹⁴ <i>Spinal Cord</i> , 2002	Assessment of verbal descriptors to distinguish between pain types after SCI	III	Verbal descriptors of SF-McGill Pain Questionnaire offered marginal utility.
Turner et al, ⁸² <i>Pain</i> , 2002	Assessment of catastrophizing with pain intensity, psychological distress, and pain-related disability in patients with chronic pain after SCI	III	Catastrophizing was strongly and independently associated with poor outcome/disability after SCI.
Richards et al, ¹⁰⁴ <i>Archives of Physical Medicine and Rehabilitation</i> , 2002	Assessment of Donovan SCI pain classification	III	Considerable variability among raters using the Donovan system to classify SCI pain.
Cardenas et al, ³⁷ <i>Archives of Physical Medicine and Rehabilitation</i> , 2002	Evaluation of interrater reliability of Cardenas Pain Classification System, questionnaires, with or without interviews	II	"Substantial" interrater reliability, κ values between 0.66 and 0.68. Interviews did not improve interrater reliability. Small numbers in subgroups prohibit qualitative analysis.

(Continues)

TABLE 3. Continued

Reference	Description of Study	Evidence Class	Conclusions
Putzke et al, ⁹⁵ <i>Journal of Spinal Cord Medicine</i> , 2001	Assessment of Short Form-12 to assess pain interference in daily activities	III	Age and occupational status were predictors of pain interference in activities of daily living.
Finnerup et al, ⁷⁵ <i>Spinal Cord</i> , 2001	Questionnaire survey of pain of SCI origin, use of McGill Pain Questionnaire	III	Pain and dysesthesias are common and disruptive consequences after SCI.
Defrin et al, ⁷³ <i>Pain</i> , 2001	Characterization of pain and somatosensory function after SCI	III	Damage to the spinothalamic tract is necessary for the occurrence of chronic pain.
Widerstrom-Noga et al, ⁷⁷ <i>Arch Phys Med Rehab</i> , 2001	Questionnaire assessment of chronic pain after SCI, interference with sleep, and activities of daily living	III	Pain of SCI origin interferes with sleep, activities of daily living.
Defrin et al, ⁷² <i>Pain</i> , 1999	Assessment of pain thresholds in patients with chronic pain after SCI	III	Nocioceptive thresholds for pain elevated in patients with complete SCI.
Kennedy et al, ⁷⁶ <i>Spinal Cord</i> , 1997	Analysis of acute and chronic pain after SCI	III	60% of patients with pain from SCI improved in short-term follow-up, 38% improved in long-term follow-up.
Quigley and Veit, ⁹⁶ <i>SCI Nursing</i> , 1996	Use of McGill-Melzack Pain Questionnaire to assess pain of SCI origin	III	McGill-Melzack Pain Questionnaire provides systematic framework for assessment of pain.

^aCMS, Constant Murley Scale; COPM, Canadian Occupational Performance Measure; IASP, International Association for the Study of Pain; NPSI, Neuropathic Pain Symptom Inventory; SCI, spinal cord injury.

and outdoors subscales ($P < .001$). Their report provides Class I medical evidence on the reliability and validity of SCIM III and the superior sensitivity of SCIM III compared to FIM. Catz et al⁶⁵ subjected these data and these results to a stringent Rasch analysis. The authors concluded that the SCIM III subscales were reliable and quantitative (average in-fit mean square indices of 0.79-1.06) as a specific construct of independence after a spinal cord lesion. These 2 publications offer Class I medical evidence in support of the validity, reliability, and sensitivity of SCIM III.^{64,65}

Anderson and colleagues³² reported the consensus analysis of a multinational work group in 2008. Experts in the field of SCI rehabilitation evaluated 4 measures of functional recovery after SCI: the modified Barthel Index, FIM, QIF, and SCIM III. They concluded that the QIF and SCIM III were spinal cord-specific measures of functional abilities and recovery. QIF applies only to tetraplegic patients and has not been widely used or studied. Both FIM and SCIM III were given high consensus marks for validity and reliability. FIM was considered of value in measuring the burden of care; SCIM III was considered the best measure of an individual's global disability specific to an SCI.

In 2009, Rudhe and van Hedel⁶⁸ examined the relationship among SCIM III, arm and hand muscle strength, and hand function tests in 29 patients with tetraplegia. They found that SCIM III sum score correlated very well with the sum scores of the 3 tests (Spearman correlation coefficient ≥ 0.76). They

concluded that the SCIM III self-care category in particular reflects upper-extremity performance as it contains especially useful and valid items that relate to upper-extremity and capacity tests (Spearman correlation coefficient ≥ 0.80). Their analysis offers Class II medical evidence for the sensitivity, validity, and reliability of SCIM III for tetraplegic patients.

Glass et al⁶⁰ published on the applicability of SCIM III to SCI patients in the United Kingdom in 2009. Eighty-six SCI patients were evaluated consecutively over a 12-month period at 4 regional SCI rehabilitation centers. Patients were assessed with SCIM III and with FIM upon admission and within a week of discharge. The Pearson correlation values between SCIM III and FIM scores for each of the 2 raters were 0.798 ($P < .01$) and 0.782 ($P < .01$) respectively, indicating superior validity for both functional assessment tools. The ability to identify a 1-point change within the 4 areas of SCIM III in comparison with the total FIM score was analyzed using the McNemar test. SCIM III detected more numerous changes than FIM in 3 of the 4 subscale areas. The reliability of SCIM III as described by κ coefficients ranged from 0.491 (stair management) to 0.835 (mobility outdoors), indicating moderate (3 tests) to substantial agreement (15 tests). A floor effect was noted for 1 item: transfers ground/wheelchair. The authors concluded that both conventional inferential statistical and Rasch analyses justify the use of SCIM III for assessment of SCI patients and SCI research in the United Kingdom.

Ackerman et al⁵³ reported the use of SCIM III to assess the functional recovery of 114 patients with complete SCI at the Shepherd Center in Atlanta, Georgia. Their 2010 publication documented statistically significant improvements in SCIM III scores at discharge. The greatest improvements were among C6 and C7-8 injury level patients. The least improvement was observed in the C1-4 and C5 subgroup patients. In the C1-4 injury level patients, a floor effect was observed. Ceiling effects were noted (as expected) for the T1-6 and T7-12 injury level patients because of their fully functional upper extremities upon admission. The authors concluded that despite these modest potential drawbacks owing to injury level, SCIM III is sensitive to changes in individuals with SCI, particularly with injury levels between C5 and T12.

Bluvstein et al⁵⁸ offered their assessment of SCIM III in the evaluation of 261 patients with spinal cord lesions. The results of this multicenter international study were published in 2010. Total agreement between paired raters was > 80% for virtually all SCIM III tasks. The κ coefficients for all SCIM III tasks were all > 0.6 and statistically significant (range, 0.649 to 0.858), indicating substantial to almost perfect agreement. Pearson coefficients of correlation between the paired raters exceeded 0.9, and the interclass correlation coefficients were > 0.95. Cronbach α values for the entire SCIM III scale were 0.833 to 0.835. When compared to FIM, entire SCIM III scores correlated well ($r = 0.84$, $P < .001$). SCIM III was more responsive to changes than FIM. In all subscales, SCIM III identified more changes in function than FIM, and in 3 of the 4 subscales, differences in responsiveness were statistically significant ($P < .02$). The authors concluded that SCIM III is reliable and valid in assessing functional recovery among adult patients with traumatic spinal cord lesions. Their report offers Class I medical evidence on the sensitivity, validity, and reliability of SCIM III for patients with spinal cord lesions.

PAIN ASSOCIATED WITH SCI

Pain following SCI is common. Several reviews and case series suggest that the prevalence of chronic pain after SCI ranges between 25% and 80% of injured patients.⁶⁹⁻⁷⁸ It has been classified as nociceptive (musculoskeletal and visceral) and neuropathic (above, at, and below the level of cord injury).^{38,70,78,79} There are a variety of psychological and psychosocial factors that interface with the pain of SCI origin that influence its management and treatment.^{74,76,80-83} The importance of pain symptoms to patients with SCI cannot be understated. Patients with severe pain syndromes consistently have poor outcome scores in quality of life assessments, have functional impairment beyond that expected from the neurological injury, and often suffer from debilitating depression.^{77,84-88} Westgren and Levi⁸⁹ have suggested that the impact of pain on quality of life after SCI may be more significant than the original SCI in selected patients.

Thirteen pain intensity instruments have been utilized to assess pain following SCI, including the McGill Pain Questionnaire, the McGill-Melzack Pain Questionnaire, the Zung Pain and Distress

Index, the Graded Chronic Pain Disability Scale, the Constant Murley Scale, the Short Form-12, the Multidimensional Pain Inventory, the Brief Pain Inventory of Wisconsin, the Verbal Rating Scale, the Neuropathic Pain Symptom Inventory, the Visual Analog Scale (0-10 points and scales of 0-100 points), the Wheelchair Users Shoulder Pain Index, and an 11-point (0-10 points) Numeric Rating Scale.^{36,37,41,69,72,76,77,79,90-101} The Visual Analog Scales have been used most frequently. These instruments use descriptors to categorize pain. Verbal pain descriptors are difficult to apply to the characterization of the different types of pain associated with SCI. For example, the verbal description “burning” can be used by patients to describe nociceptive and neuropathic pain symptoms, at above and below the level of SCI. Different patients with similar injuries and symptoms may use different verbal descriptors depending on their use of language. These confounding variations and variables hinder the ability of investigators to devise valid and reliable pain intensity instruments.

Five pain classification system instruments have been generated and used as assessment tools for patients following acute SCI: the Tunks SCI pain classification, the Donovan Classification Scheme, the Cardenas pain classification, the Siddall/International Association for the Study of Pain classification, and the Bryce/Ragnarsson SCI pain taxonomy.^{37,41,69,70,78,79,84,97,101-104} They are difficult to compare because of varying formats, numbers of items assessed, and different rating scales. Despite these issues, interrater reliability (the degree of agreement between 2 raters using the same pain classification system/instrument to characterize that patient’s pain), a means to assess system/instrument validity, has been reported to be “substantial” for 2 of the 5 pain classification systems (κ values between 0.61 and 0.80) (Table 4).^{36,37,84}

In 2006, Widerstrom-Noga et al¹⁰⁵ applied a modified version of the Multidimensional Pain Inventory to SCI patients to assess their pain. The Multidimensional Pain Inventory included a means to assess pain severity, physical functioning, and emotional functioning, the 3 key domains “considered important for capturing the multidimensionality of the pain experience.” It was brief and easy to administer, and patients felt it was appropriate and applicable. Internal consistency and test-retest reliability were moderate to substantial in 8 of the 10 test

TABLE 4. Pain Assessment^{a,b}

SCI Pain Classification System/Instrument*	κ Coefficient
Bryce/Ragnarsson spinal cord injury pain taxonomy	0.70
Cardenas pain classification	0.68
Donovan classification scheme	0.55
Siddall/International Association for the Study of Pain classification	0.49
Tunks spinal cord injury pain classification	0.49

^aFrom: Ullrich PM. Pain following spinal cord injury. *Phys Med Rehabil Clin N Am*. 2007;18:217-233.

^bSCI, spinal cord injury.

subscales. Construct validity had high Pearson correlation coefficients in 9 of 10 subscales. The authors concluded that the Multidimensional Pain Inventory is a useful measure for evaluating chronic pain and its impact after SCI.

In 2008, Widerstrom-Noga and additional collaborators¹⁰⁶ developed the International Spinal Cord Injury Pain Data Set to standardize the collection and reporting of pain in the SCI population. It included the 3 essential domains or outcomes of pain severity and physical and emotional functioning. It is meant to evaluate and report the diverse pains in persons affected with SCI. It was designed to be feasible and applicable across varied clinical settings, languages, and countries. It is meant to be used in conjunction with the ASIA impairment scale, which documents the extent of neurological injury following SCI.

Jensen et al¹⁰⁷ in 2010 reported the use of the Spinal Cord Injury Basic Pain Data Set (ISCIBPDS) among 184 SCI patients with pain. The internal consistency of the data set (as an indicator of reliability) was excellent (Cronbach $\alpha = .94$). The validity of the ISCIBPDS was statistically significant at the $P < .001$ level for 23 of the 27 pain interference items and scales and was statistically significant at the $P < .01$ level for 26 of the 27 pain interference items and scales. The authors concluded that the ISCIBPDS is useful and valid as a self-report means for assessing pain and its impact in individuals with SCI. Their report provides Class I medical evidence on the utility of the ISCIBPDS to assess pain of SCI origin and is recommended for use in both the clinical and research settings.

SUMMARY

A variety of injury classification schemes have been utilized to describe patients who have sustained spinal cord injuries. There are 2 general types of assessment scales, neurological examination scales and functional outcome scales. The most accurate and meaningful description of SCI patients, in the acute setting and in longitudinal follow-up, is that accomplished by using a neurological scale in conjunction with a functional outcome scale. Based on a contemporary evaluation and ranking of the medical evidence, the 2000 American Spinal Injury Association (ASIA) Standards is the most consistent, reliable, valid, and responsive scoring system for the neurological assessment of adult patients with acute SCI, to a high degree of scientific certainty. This recommendation is supported by Class II medical evidence.

The SCIM III, designed specifically to assess the functional abilities and impairment of patients with spinal cord lesions and SCI, is the functional outcome assessment tool with the greatest scientific validity, reliability, and sensitivity. This recommendation is supported by Class I medical evidence.

The assessment of pain among patients with SCI is important and should include an evaluation of pain severity, physical functioning, and emotional functioning. There are a number of pain assessment classification instruments that have been used in this patient population. The ISCIBPDS has the highest reliability and validity of any of the pain classification instruments and is recommended on the basis of Class I medical evidence.

KEY ISSUES FOR FUTURE INVESTIGATION

Clinical trials in which all 3 clinical assessment parameters (neurological examination, functional outcome assessment and pain assessment) are studied as an integral part of outcome measurements are needed to more completely describe the clinical status of patients following acute SCIs.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Radiographic Assessment

Timothy C. Ryken, MD, MS*

Mark N. Hadley, MD‡

Beverly C. Walters, MD, MSc, FRCS‡§

Bizhan Aarabi, MD, FRCS¶

Sanjay S. Dhall, MD||

Daniel E. Gelb, MD#

R. John Hurlbert, MD, PhD, FRCS**

Curtis J. Rozzelle, MD‡‡

Nicholas Theodore, MD§§

*Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa; ‡Division of Neurological Surgery, and ‡‡Division of Neurological Surgery, Children's Hospital of Alabama, University of Alabama at Birmingham, Birmingham, Alabama; §Department of Neurosciences, Inova Health System, Falls Church, Virginia; ¶Department of Neurosurgery, and #Department of Orthopaedics, University of Maryland, Baltimore, Maryland; ||Department of Neurosurgery, Emory University, Atlanta, Georgia; **Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada; §§Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona

Correspondence:

Mark N. Hadley, MD, FACS,
UAB Division of Neurological Surgery,
510 – 20th Street South,
FOT 1030,
Birmingham, AL 35294-3410.
E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS

Awake, Asymptomatic Patient

Level 1

- In the awake, asymptomatic patient who is without neck pain or tenderness, who has a normal neurological examination, is without an injury detracting from an accurate evaluation, and who is able to complete a functional range of motion examination; radiographic evaluation of the cervical spine is not recommended.
- Discontinuance of cervical immobilization for these patients is recommended without cervical spinal imaging.

Awake, Symptomatic Patient

Level 1

- In the awake, symptomatic patient, high-quality computed tomography (CT) imaging of the cervical spine is recommended.
- If high-quality CT imaging is available, routine 3-view cervical spine radiographs are not recommended.
- If high-quality CT imaging is not available, a 3-view cervical spine series (anteroposterior, lateral, and odontoid views) is recommended. This should be supplemented with CT (when it becomes available) if necessary to further define areas that are suspicious or not well visualized on the plain cervical x-rays.

ABBREVIATIONS: CCR, Canadian C-Spine Rule; CCT, cervical computed tomography; CSR, cervical spine radiographs; EAST, Eastern Association for the Surgery of Trauma; NEXUS, National Emergency X-Radiography Utilization Study Group; NLC, NEXUS low risk category; NPV, negative predictive value; PPV, positive predictive value

Level III

- In the awake patient with neck pain or tenderness and normal high-quality CT imaging or normal 3-view cervical spine series (with supplemental CT if indicated), the following recommendations should be considered:
 1. Continue cervical immobilization until asymptomatic,
 2. Discontinue cervical immobilization following normal and adequate dynamic flexion/extension radiographs,
 3. Discontinue cervical immobilization following a normal magnetic resonance imaging (MRI) obtained within 48 hours of injury (limited and conflicting Class II and Class III medical evidence), or,
 4. Discontinue cervical immobilization at the discretion of the treating physician.

Obtunded or Unevaluable Patient

Level 1

- In the obtunded or unevaluable patient, high-quality CT imaging is recommended as the initial imaging modality of choice. If CT imaging is available, routine 3-view cervical spine radiographs are not recommended.
- If high-quality CT imaging is not available, a 3-view cervical spine series (anteroposterior, lateral, and odontoid views) is recommended. This should be supplemented with CT (when it becomes available) if necessary to further define areas that are suspicious or not well visualized on the plain cervical x-rays.

Level II

- In patients in whom there is a high clinical suspicion of injury yet have a normal high-

quality CT imaging study, it is recommended that the decisions for further patient management involve physicians trained in the diagnosis and management of spinal injuries.

Level III

- In the obtunded or unevaluable patient with a normal high-quality CT or normal 3-view cervical spine series, the following recommendations should be considered:
 1. Continue cervical immobilization until asymptomatic,
 2. Discontinue cervical immobilization following a normal MRI study obtained within 48 hours of injury, (limited and conflicting Class II and Class III medical evidence), or,
 3. Discontinue cervical immobilization at the discretion of the treating physician.
- In the obtunded or unevaluable patient with a normal high-quality CT, the routine use of dynamic imaging appears to be of marginal benefit and is not recommended.

RATIONALE

Spinal cord injury is a potentially devastating consequence of acute trauma and can occur with/be exacerbated by improper immobilization of an unstable cervical spinal injury. Immobilization of an injury victim's cervical spine following trauma is a universal standard practiced by Emergency Medical Services systems and is now based on pre-hospital clinical criteria. Immobilization of the potentially injured cervical spine is maintained until spinal column injury is ruled out by clinical assessment and/or radiographic survey. Radiographic study of the cervical spine of every trauma patient is costly and results in significant radiation exposure to a large number of patients, very few of whom will have a spinal column injury. Asymptomatic trauma patients, defined by rigid clinical criteria, require no radiographic assessment irrespective of the mechanism of potential injury.

Trauma patients who are symptomatic, that is complain of neck pain, have cervical spine tenderness, have symptoms or signs of a neurological deficit associated with the cervical spine, and trauma patients who cannot be assessed for symptoms or signs (those who are unconscious, uncooperative or incoherent, intoxicated, or who have associated traumatic injuries that distract from their assessment) require radiographic study of the cervical spine prior to the discontinuation of cervical spine immobilization. Many investigators have proposed strategies and imaging techniques to accomplish x-ray clearance of the cervical spine after trauma, particularly in the symptomatic or the obtunded patient.

In 2002, the guidelines author group of the Joint Section on Disorders of the Spine of the American Association of Neurological Surgeons (AANS) and the Congress of Neurological Surgeons (CNS) published 2 medical evidence-based guidelines on the

topic of imaging the cervical spine following acute blunt trauma entitled, "Radiographic Assessment of the Cervical Spine in Asymptomatic Trauma Patients" and "Radiographic Assessment of the Cervical Spine in Symptomatic Trauma Patients."¹⁻² The purpose of the current review is to build on that foundation, adding pertinent new evidence on these issues generated over the past decade.

SEARCH CRITERIA

A computerized search of the database of the National Library of Medicine (PubMed) between 1966 and 2011 was conducted using the search terms "spinal cord injury" or "spinal fractures" or "spinal injuries" and resulted in 30 238 references. A similar search was conducted with search terms "clearance" or "diagnosis" or "radiographs" that provided 23 005 577 citations. Combining these 2 searches using "and" gave 6399 references. The search was limited to the English language and human subjects. This resulted in 4942 citations. The titles and abstracts of these references were reviewed. Studies that investigated the diagnostic potential of an imaging technique to assess cervical trauma were selected. Additional articles were obtained from the bibliographies of selected manuscripts. Thirty-two manuscripts were identified that provided either direct or supporting medical evidence on the diagnostic potential of cervical spinal imaging modalities. In general, priority was given to large (greater than 100 patients) prospective studies, meta-analyses, and articles published since the previous iteration of this guideline. Fifteen articles addressing cervical spinal imaging in asymptomatic trauma patients, 25 references addressing imaging in symptomatic patients, and 20 references addressing imaging in the obtunded patient are summarized in Evidentiary Table format (Tables 3-5).

SCIENTIFIC FOUNDATION

In 2002, the guidelines author group of the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons published 2 medical evidence-based guidelines on the topic of radiographic assessment of the cervical spine following acute trauma.^{1,2} Based on 8 Class I medical evidence studies, diagnostic standards (Level I) were recommended at a high level of medical certainty that for asymptomatic patients, the "Radiographic assessment of the cervical spine is not recommended for trauma patients who are awake, alert, and not intoxicated, who are without neck pain or tenderness, and who do not have significant associated injuries that detract from their general evaluation." For all other patients (symptomatic) medical evidence-based diagnostic standards (Level I) recommendations were offered: "A 3-view cervical spine series (AP, lateral, and odontoid views) is recommended for the radiographic evaluation of the cervical spine in patients who are symptomatic after traumatic injury. This should be supplemented with CT to

further define areas that are suspicious or not well visualized on the plain cervical x-rays.” Further, option or Level III recommendations based on Class III medical evidence were offered suggesting that “cervical spine immobilization in awake patients with neck pain or tenderness and normal cervical spine x-rays (including supplemental CT as necessary) be discontinued after either, (1) normal and adequate dynamic flexion/extension radiographs, or (2) a normal MRI study obtained within 48 hours of injury. For obtunded patients, Class III medical evidence supported the recommendation that “Cervical spine immobilization in obtunded patients with normal cervical spine x-rays (including supplemental CT as necessary) may be discontinued (1) after dynamic flexion/extension studies performed under fluoroscopic guidance, (2) after a normal MRI study is obtained within 48 hours of injury, or (3) at the discretion of the treating physician.” These 3 clinical scenarios following trauma (asymptomatic, symptomatic, and the obtunded patient) are the focus of this update on the medical evidence on this important topic.

In 2009, the Eastern Association for the Surgery of Trauma (EAST) published an updated medical evidence review on the identification of cervical spinal injuries following trauma.³ The authors utilize a 3-tiered system of medical evidence and linked their recommendations to the quality of the medical evidence reported in the world’s literature. Fifty-two articles were selected for inclusion. The EAST author group concluded that Class I medical evidence indicates CT has become superior to plain radiography as the primary imaging modality of the cervical spine for acute trauma patients who required cervical imaging. A detailed review of the updated EAST recommendations suggest that the methodology used by the EAST author group is better suited to assess a therapeutic intervention, rather than to evaluate the validity and accuracy of a diagnostic test, which requires a different set of medical evidence criteria.^{4,5} The current effort to update the medical evidence of these 2 guidelines consider radiographic imaging of the cervical spine in acute trauma patients to be a diagnostic test. Appropriate, distinct, and specific medical evidence grading criteria for a diagnostic test have been applied.

Since the original evidence-based medicine guideline produced on the issue of radiographic assessment of the asymptomatic patient in 2002, four clinical studies and a recent meta-analysis have been published. These citations provide Class I and Class II medical evidence in support of the original Level I recommendation that truly asymptomatic patients require no cervical spinal imaging after trauma.

In 2001, Stiell et al⁶ published a study of 8924 awake blunt trauma patients treated in 10 large Canadian medical centers. The investigators evaluated 20 different standardized clinical findings in an attempt to create a valid decision-making rule sensitive for detecting acute cervical spinal injuries, therefore allowing the selective use of radiography in alert trauma patients. The reported incidence of a significant cervical spinal injury was 1.7%. The resultant Canadian C-Spine Rule (CCR) utilizes 3 questions: (1) presence of a high-risk factor that mandates radiography (ie: age 65 years or older, dangerous mechanism of

injury, or paresthesias in extremities), (2) presence of a low-risk factor allowing safe assessment of range of motion (ie: simple rear-end motor vehicle collision, sitting position in ED, ambulatory at any time following injury, delayed onset of neck pain, or absence of midline C-spine tenderness), and (3) ability to actively rotate neck 45° to the left and right. Use of the CCR resulted in 100% sensitivity for a significant cervical spinal injury, (95% confidence interval [CI], 98%-100%) and 42.5% specificity (95% CI, 40%-44%).⁶

The largest series referenced in the previous version of this guideline was published by Hoffman et al⁷ in 2000 and generated decision-making rules subsequently referred to as the NEXUS (National Emergency X-Radiography Utilization Study Group) criteria. This study involved the prospective study of 34 069 blunt trauma patients of which 4309 were asymptomatic. All patients underwent standard 3 view cervical spinal radiographs supplemented with CT as needed. Five criteria had to be met in order to be classified as having a low probability of injury: no midline cervical tenderness, no focal neurologic deficit, normal alertness, no intoxication, and no painful, distracting injury. These criteria correctly identified 810 of the 818 patients who had a cervical spinal injury (true positives), resulting in a sensitivity of 99.0%, a specificity of 12.9%, a negative predictive value (NPV) of 99.8% and a positive predictive value (PPV) of 2.7%. Only 2 patients were misclassified as unlikely to have an injury and had a clinically significant injury (false negatives) for a calculated sensitivity of 99.6%, a specificity of 12.9%, a NPV of 99.9% and a PPV of 1.9%. Only 1 of these 2 patients required surgical treatment for a C6 laminar fracture with delayed onset paresthesias. The other missed injury required no treatment.

In 2003, Stiell et al⁸ conducted a prospective cohort study comparing the Canadian C-spine rule (CCR) vs the NEXUS criteria. Three hundred and ninety-four physicians evaluated 8283 patients prior to radiographic imaging, 169 of which had clinically significant cervical spinal injuries (2%). Application of the CCR resulted in 1 missed patient injury. Use of the NEXUS low risk criteria (NLC) resulted in 16 missed cervical spinal injuries, 4 of which were unstable. In this Class I medical evidence study, Stiell et al⁸ found the CCR was statistically significantly more sensitive than the NEXUS criteria in the detection of a significant cervical spinal injury. Of interest, the application of the CCR rather than the NEXUS criteria would have resulted in significantly lower radiography rates (55.9% vs 66.6%, $P < .001$, see Table 1).

In 2010, Anderson et al⁹ produced a meta-analysis of 14 Class I medical evidence studies published between 1966 and 2004.^{6-8,10-20} The authors’ inclusion criteria were: (1) a prospectively applied protocol; (2) reported outcomes to allow calculation of sensitivity, specificity, NPV, and PPV; and (3) follow-up to determine the status of potential missed injuries with minimum of a 2-week telephone call or a follow-up CT scan. The 3 senior authors each independently confirmed the validity of the included articles and independently verified each publication’s analysis as well as extraction of true-positive, true-negative, false-

positive, and false-negative numbers. Original scale and log odds meta-analysis were performed. Sensitivity, specificity, PPV, and NPV were calculated using random effects methodology. The 14 studies that met these rigid inclusion criteria correctly identified the 3.7% of alert trauma patients who had confirmed cervical spinal injuries (PPV, 3.7%). They missed the 0.2% of patients who had acute injuries who should have had cervical radiography performed (NPV, 99.8%). The random effects model used in the meta-analysis resulted in a collective sensitivity of 0.981 (98.1%) and a specificity of 0.354. The authors concluded that the alert, asymptomatic patient without a neurologic deficit who can complete a functional range-of-motion examination and is free from other major distracting injury may safely be released from cervical spine immobilization without radiographic evaluation, with a sensitivity of 98.1% and a NPV of 99.8%. Additional supporting data is provided in Table 3.⁷⁷⁻⁸¹

Awake Symptomatic Patient

In the previously produced 2002 guideline on the topic of Radiographic Assessment of the Symptomatic Patient, the author group concluded that a 3-view cervical spine series (AP, lateral, and odontoid views) was recommended for radiographic evaluation of the cervical spine in patients who are symptomatic after traumatic injury (Standard or Level I recommendation based on Class I medical evidence). Class I medical evidence suggests that those studies should be supplemented with CT as necessary, to define areas that are suspicious or not well-visualized on the plain cervical x-rays. These recommendations were based in part on a series of high quality articles considered to provide Class I medical evidence for diagnostic testing. The combined series of Berne et al,²¹ Ajani et al,²² Davis et al,²³ and MacDonald et al²⁴ included 1049 trauma patients evaluated with 3-film radiography. The sensitivity of the 3-film technique for fracture detection in these series ranged from 60% to 84%. The NPV ranged from 85% to 98%, increasing to 100% with the addition of dynamic studies. The current update on the topic of radiographic assessment of the symptomatic patient following acute trauma will focus on the increasing reliance on CT rather than plain radiography to assess the cervical spine (see Table 2 for comparison).

In 2005, Holmes and Akkinepalli²⁵ published a meta-analysis of studies comparing CT and plain radiographs in detecting cervical spinal injuries in patients predetermined to require imaging by clinical criteria. The authors included 7 studies, including 5 graded to provide Class III medical evidence and 2 to provide Class IV medical evidence on a 4-tiered evidence grading scale.^{21,26-31} They failed to utilize an appropriate assessment scheme for a diagnostic test, and instead attempted to find randomized studies to provide Class I medical evidence. They did prioritize prospective data collection, an adequate study population, and the use of gold standards. The pooled sensitivity of plain radiographs for detecting cervical spinal injury in their analysis was 54% compared to 98% for CT. This study provides supporting Class III medical evidence

that CT may be superior to plain radiographs to detect cervical spinal injury following trauma.

In 2009, Bailitz et al³² published a prospective, comparative study of cervical spine radiographs (CSR) with cervical CT (CCT) to detect cervical spinal injury after trauma. The study assessed awake adult patients who had sustained blunt trauma who met 1 or more of the NEXUS criteria for spinal assessment following acute trauma. Three-view CSR and CCT were obtained in a standard protocol. Each CSR and CCT study was interpreted independently by a different blinded radiologist. Clinically significant injuries were defined as those requiring 1 or more of the following interventions: operative procedure, halo application, and/or rigid cervical collar. The entire data set included 1583 patients, but 78 patients (4.9%) were excluded due to lack of complete studies. The remaining 1505 patient data set contained 78 with a cervical spinal injury determined by 1 or both radiographic assessment methods. The sensitivity of CCT was 100% compared to 36% for CSR. The authors conclude that CT is significantly superior to plain film radiography for the initial evaluation of cervical spinal injuries following trauma and should be the imaging modality of choice. Their study provides Class I medical evidence for a diagnostic test.

In 2007, Mathen et al³³ published a prospective Class I medical evidence study of 667 acute trauma patients including 60 patients with cervical spine injuries (9% of total) all evaluated with both cervical spine films and CT. CT had a sensitivity of 100% and a specificity of 99.5%. Plain films had a sensitivity of 45% and a specificity of 97.4%. Plain films missed 15 of 27 clinically significant cervical spinal injuries (55.5%). The authors concluded that CT is superior to plain spine films in the acute setting, and that plain films add no significant information to a high quality CT.

Griffen et al²⁸ in 2003 studied a series of 1199 acute trauma patients at risk for a cervical spinal injury who had both plain films and CT studies. There were 116 cervical spine injuries detected. All were identified by CT (sensitivity = 1.00, 100%; NPV = 1.00). Plain radiographs detected only 75 of the injuries (sensitivity = 0.64, 64%; NPV = 0.96). The authors summarized previous published studies comparing the sensitivity of CT to the sensitivity of plain films to detect cervical injury after blunt trauma.

Combining the patients from these series resulted in a total patient population of 3034. Ten percent were found to have cervical spinal injuries (309). The combined sensitivity of plain films was 53%. The combined sensitivity of CT was of 98%. This study and review provides Class I medical evidence on the superiority of CT for the assessment of cervical spinal injuries after trauma.

In 2001, Schenarts et al³⁰ published a large prospective series evaluating the role of cervical CT in their blunt trauma population. They reported on 2690 consecutive blunt trauma admissions. They applied the EAST recommendations to determine which patients should be studied radiographically to assess for potential cervical spinal injuries. This latter group consisted of 1356 patients who had experienced blunt trauma, many of whom were going to have CT studies performed on other body regions (ie, head injury, abdominal injury). All were assessed with 5-view cervical spine

x-rays. There were 70 cervical spine injuries detected (incidence 5.2%). CT detected 67 of the 70 injuries (sensitivity 96%). Five-view plain films detected 38 of the 70 injuries (sensitivity 54%). The authors concluded that the use of the EAST guidelines for clearance of the cervical spine correctly identified all injuries in their study population. They found CT was superior to plain films in the evaluation of acute cervical trauma.

Daffner et al³⁴ published a retrospective analysis of 5172 trauma admissions and identified 297 cervical fractures (5.4%). Of these, 245 were identified to have had both plain films and CT performed. CT identified 243 of the 245 fractures (sensitivity 0.992, 99.2%). Comparatively, plain films identified only 108 fractures (sensitivity 0.441, 44.1%). Their 2006 study is considered to provide Class III medical evidence due to the loss of subjects (17.5%) and its retrospective nature. Of note is that the 2 fractures missed on CT were readily identified on plain films. The authors recommended that lateral plain films be included with CT to assess for cervical spinal injury after trauma. Both fractures missed by CT involved the C2 spinous process; 1 was obscured by dental work and the other was in the plane of the scan. The Daffner et al study highlights the need for ensuring that the cervical imaging utilized to assess the cervical spine adequately visualizes the region of interest, regardless of the specific imaging modality employed, but fails to provide medical evidence for the utility of plain films to supplement CT in this setting.

In addition to CTs superior sensitivity in fracture detection, authors have reported on other advantages of CT over plain radiography in the acute trauma setting. Daffner et al^{35,36} published a series of studies evaluating the efficiency of plain radiographs compared to CT, and found that the average time involved to obtain a cervical CT scan was 11 to 12 minutes, approximately half the time required to obtain a full radiographic series of the cervical spine. Blackmore et al³⁷ performed a cost-effectiveness analysis for high risk subjects and concluded that the higher short-term cost of CT would be offset by the increased sensitivity of CT for fracture detection, the shortened time required for the evaluation, and a decreased need for additional imaging.

Symptomatic Patient With Negative Initial Imaging.

The author group of the previous guideline published on this topic in 2002 recommended that cervical spinal immobilization could be discontinued in the awake but symptomatic patient with normal radiographic studies supplemented by thin section CT as indicated, following either normal flexion and extension radiographs or a normal MRI obtained within 48 hours of injury. Based on Class III medical evidence, the NPV of normal 3-view plain films supplemented with flexion and extension x-rays ranged from 93% to 100%,^{23,24,38-41} and the NPV of an MRI obtained within 48 hours of injury ranged from 90% to 100%. Several studies evaluating cervical MRI in the acute trauma setting suggested that no significant injuries occurred in the setting of a normal MRI.^{21,22,42-44} Isolated cases in which significant injuries were not detected by MRI have raised concerns and prompted additional study.^{45,46}

Studies published since the previous guidelines have focused on the role of dynamic imaging and/or MRI in assessment of

symptomatic trauma patients with negative initial radiographs or CT imaging, in an attempt to define which patients require continued spinal immobilization. The studies are varied in their comparison groups and in the level of medical evidence they provide. The report by Duane et al⁴⁷ provides Class II medical evidence that MRI is significantly more sensitive than dynamic films, but the Class III medical evidence study by Schuster et al⁴⁸ concludes that the routine use of MRI is of minimal benefit in detecting additional injury. Class II evidence published by Pollack et al⁴⁹ and Class III medical evidence offered by Insko et al⁵⁰ indicate that dynamic films are of limited benefit in detecting additional injuries when the clinical exam and CT imaging are normal.

In 2010, Duane et al⁴⁷ published the only investigation to date directly comparing dynamic imaging to MRI in this patient population. Their study evaluated 22 929 trauma patients, among whom 271 patients were studied with dynamic imaging, 49 of whom were also assessed with MRI. MRI identified 8 patients with ligamentous injury. Flexion and extension radiographs failed to identify any of the 8 ligamentous injuries identified on MRI. When comparing dynamic studies to MRI (these authors considered MRI to be the gold standard for ligamentous injuries), the sensitivity of dynamic films was 0.0%, the specificity was 98%, the PPV was 0%, and the NPV was 83%. Flexion and extension studies were incomplete in over 20.5% of the patients and ambiguous in another 9.2%. The authors concluded that due to the often incomplete or ambiguous results with dynamic imaging and the inability of flexion and extension radiographs to identify many potential ligamentous injuries, MRI be used in the relatively infrequent situation of a suspected cervical spinal ligamentous injury following trauma when the initial radiographs or CT images did not identify a fracture injury. This study offers a select few patients for comparison. The choice of MRI as the “gold standard” for ligamentous injury likely leads to a false endpoint. MRI has not been proven to represent the gold standard for ligamentous injury in the literature, and is associated with a high number of false-positive findings.

In 2005, Schuster et al⁴⁸ reported a prospective study examining the role of MRI in excluding significant injury in the symptomatic patient with a normal motor exam and a normal CT evaluation of the cervical spine following acute trauma. The study population included 2854 patients. Ninety-three patients had a normal admission motor examination yet persistent cervical spine pain. All underwent MRI examination and all were negative for a clinically significant injury. Seventeen patients had MRI studies that revealed pre-existing degenerative cervical spondylosis, and 6 had spinal canal stenosis secondary to ossification. The authors concluded that patients with a normal motor exam and normal CT of the cervical spine do not require MRI imaging in order to exclude a significant cervical spinal injury. The Class II medical evidence offered in this publication is in conflict with the Class II medical evidence provided by Duane et al⁴⁷ in 2010.

TABLE 1. Comparison of Canadian C-Spine Rule With the National Emergency X-Radiography Study Group Criteria for Low-Risk Criteria^a

	Sensitivity	Specificity	
CCR	99.4%	45.1%	$P < .001$
NLC	90.7%	36.8%	$P < .001$

^aCCR, Canadian C-Spine Rule, NLC, National Emergency X-Radiography Utilization Study Group low risk criteria.

Pollack et al⁴⁹ reported a large multicenter prospective study evaluating the role of dynamic plain films to supplement the standard 3-view radiographic evaluation of the cervical spine in the acute trauma setting. Twenty-one centers participating in the NEXUS project entered patients who had standard 3-view radiographs, as well as any other imaging deemed necessary by their physicians. Eight hundred and eighteen patients were diagnosed with a cervical spinal injury, of which 86 (10.5%) underwent dynamic imaging. Two patients (2.3%) had injuries detected only on dynamic imaging. The authors concluded that dynamic imaging added little to the acute evaluation of patients suspected to have sustained cervical spinal trauma. This study provides Class II medical evidence on this topic.

In 2002 Insko et al⁵⁰ published a retrospective review of 106 consecutive trauma patients in whom flexion and extension radiographs were obtained in the acute trauma setting. Nine patients were identified who had cervical spinal injuries. Only 74 patients (70%) had a range of flexion and extension felt to be adequate for diagnostic purposes. Five of the 74 patients with acceptable range of motion had cervical spinal injuries (6.75%). There were no missed ligamentous injuries in this group. Thirty-two of the flexion and extension examinations (30%) were inadequate because of limited motion. Four of the 32 patients with inadequate range of motion on dynamic x-rays were diagnosed with a significant injury either by CT or MRI (12.5%). The authors stressed the need for adequate and complete dynamic studies if they are to be used for diagnostic purposes. If adequate range of motion is not possible, they suggest MRI should be considered to assess for ligamentous injury.

Sanchez et al⁵¹ instituted a single institution protocol to assess and image patients as indicated following trauma. They performed

TABLE 2. Detection of Cervical Spinal Injury Following Blunt Trauma

Author Group	Sensitivity of Plain Films	Sensitivity of Computed Tomography
Nuñez et al ²⁹	37.5%	100%
Berne et al ²¹	60%	90%
Schenarts et al ³⁰	54%	96%
Griffen et al ²⁸	64%	100%

cervical helical CT imaging on patients who could not be cleared clinically. Patients with a neurological deficit underwent MRI, but patients with no focal deficit and a normal CT scan were cleared. Prospective data were collected on 2854 trauma patients. One hundred patients had cervical spine or spinal cord injuries, of which 99 were identified by their sequential protocol. The 1 missed patient had pre-existing syringomyelia. Fifteen percent of patients with neurological deficits of spinal cord origin had no imaging abnormality. The authors reported that their combination protocol of clinical exam, helical CT, and MRI had a sensitivity of 99% and a specificity of 100%. Their study provides a rational approach to the assessment for the potential of a cervical spinal injury following trauma, and provides Class II medical evidence. Additional supporting data is provided in Table 4.⁸²⁻⁸⁵

Obtunded or Unevaluable Patient

The previous guideline author group recommended that in the obtunded or unevaluable patient who had normal radiographic studies of the cervical spine, cervical immobilization could be discontinued under the following conditions: normal dynamic imaging, normal MRI within 48 hours of injury, or at the discretion of the treating physician. These recommendations were based on Class III medical evidence provided in the literature through 2001 that indicated that in the obtunded patient with a normal 3-view x-ray series of the cervical spine supplemented with CT (as necessary), the incidence of a significant cervical spinal injury was less than 1%.²¹ Flexion/extension studies could be performed under fluoroscopy safely, and could effectively rule out a significant ligamentous injury (reported NPV of over 99%).²³ A negative MRI within 48 hours of injury appeared to exclude the presence of a significant ligamentous injury. In selected patients, based upon normal radiographic imaging, the mechanism of injury, and clinical judgment, the cervical spine could be considered stable without further study.³⁹

Of all the clinical issues associated with the radiographic assessment of the cervical spine, the issue of clearing the cervical spine in the obtunded or unevaluable patient has received the most attention and remains the issue of the greatest uncertainty. The role of CT as a replacement for plain radiographs has been the subject of active research in this select patient population, as has the role of dynamic imaging. The increasing use of MRI to exclude significant cervical ligamentous injury in the otherwise unevaluable patient has also been an active area of investigation. The following section will review the recent literature on plain films, CT, dynamic imaging, and MRI and their application to the obtunded/unexaminable acute trauma patient.

Plain Films and CT

In 2003, Diaz et al²⁷ published a prospective series of 1006 trauma patients with altered mental status evaluated with both plain films and CT imaging scanning. One hundred seventy-two cervical spinal injuries were identified. CT had a sensitivity of 97.4%, a specificity of 100%, a PPV of 100%, and a NPV of

TABLE 3. Evidentiary Table: Radiographic Assessment: Asymptomatic^a

Citation	Description of Study	Evidence Class	Conclusions
Anderson, ⁹ <i>J Orthop Trauma</i> , 2010	Meta-analysis of 14 articles that addressed asymptomatic patients and discontinuance of cervical spine immobilization without radiographic evaluation.	I	Sensitivity 98.1%
	Inclusion criteria: prospective study, outcomes reported to allow calculation of sensitivity, specificity, NPV, and PPV, and included clinical follow-up.		NPV 99.8%
			Alert, asymptomatic patient with no distracting injury, no neurologic deficit and able to complete a functional range-of-motion examination can safely have cervical spine immobilization precautions removed without radiographic evaluation
Duane, ⁷⁷ <i>J Trauma</i> , 2007	Prospective study 534 blunt trauma patients comparing the reliability of the clinical examination (CE) with CT to identify cervical spine fracture.	II	The authors concluded that even with a normal Glasgow Coma Score, the CE alone does not provide sufficient sensitivity or NPV to exclude cervical spine fracture
			Downgraded to Class II medical evidence
			CE is not known to be reliable or valid. A smaller more restricted population involved in this study than other similar studies. This article stands alone in contrast to other larger studies addressing criteria for imaging in the asymptomatic patients.
Stiell, ⁸ <i>N Engl J Med</i> , 2003	Prospective study of 8283 alert stable trauma patients including 169 with cervical spine injuries comparing CCR and the NEXUS Low-Risk Criteria (NLC) in 9 Canadian emergency departments.	I	Sensitivity for injury: CCR 99.4%, NLC 90.7% ($P < 0.001$)
			Specificity for injury: CCR 45.1%, NLC 36.8%, $P < 0.001$.
			For alert stable trauma patients, the CCR is significantly more sensitive and specific than the NLC.
Stiell, ⁶ <i>JAMA</i> , 2001	Prospective cohort study of 8924 stable awake adult trauma patients including 151 with a cervical spine injury evaluating 20 standardized clinical findings prior to radiographic imaging to determine those findings most sensitive in identifying cervical spine fracture. This study defines the CCR.	II	The CCR is a highly sensitive decision rule for determining the need for imaging in suspected cervical spine trauma
			Class II because validation is not included in this study
Hoffman, ⁷ <i>N Engl J Med</i> , 2000	Prospective study of 34 069 patients including 4309 asymptomatic and 2 with clinically significant injuries.	I	NPV of 99.9%
			Radiographs not necessary in asymptomatic patients

(Continues)

TABLE 3. Continued

Citation	Description of Study	Evidence Class	Conclusions
Gonzalez, ¹² <i>J Am Coll Surg</i> , 1999	Prospective diagnostic study of 2176 patients including 33 with a significant cervical spine injury evaluating the diagnostic potential of clinical exam and lateral radiography.	I	Clinical examination of the neck can reliably rule out significant cervical spine injury in the awake and alert blunt trauma patient
			Addition of lateral c-spine x-ray does not improve the sensitivity of clinical examination in the diagnosis of significant cervical spine injury
Roth, ¹⁸ <i>Arch Surg</i> , 1994	Prospective study of 682 patients admitted to ED with trauma; 96 were asymptomatic, none had injury.	I	NPV of asymptomatic exam: 100%
			PPV of symptomatic exam: 2.7
			Radiographs not necessary in asymptomatic patients
Hoffman, ¹³ <i>Ann Emerg Med</i> , 1992	Prospective study of 974 blunt trauma patients including 353 alert, asymptomatic patients.	I	NPV of asymptomatic exam: 100%
			PPV of symptomatic exam: 4.5%
			Asymptomatic patients do not require cervical spine films
Ross, ⁷⁸ <i>Injury</i> , 1992	Prospective study of 410 patients	I	NPV: 100%
			PPV: 6.1%
	Including 196 asymptomatic patients.		Radiography not mandatory for asymptomatic patients
			Mechanism of injury is not a valuable predictor of injury
McNamara, ⁷⁹ <i>J Emerg Med</i> , 1990	Retrospective review of 286 patients judged to be "high risk" by mechanism of injury: • 178 were asymptomatic • 108 were symptomatic	III	NPV for asymptomatic exam was 100%
			PPV for symptomatic exam was 4.9%
			CSR not necessary in asymptomatic patients
			Class III because many patients excluded
Bayless, ⁸⁰ <i>Am J Emer Med</i> , 1989	Prospective study of 211 patients, including 122 alert asymptomatic patients.	I	NPV of asymptomatic exam: 100%
			PPV of symptomatic examination: 3%
			Asymptomatic patients do not require cervical spine films
Kreipke, ¹⁴ <i>J Trauma</i> , 1989	Prospective study of 860 patients including 324 asymptomatic.	I	NPV of asymptomatic exam: 100%
			PPV of symptomatic exam: 4%
			Radiographs not necessary in asymptomatic patients
Mirvis, ⁸¹ <i>Radiology</i> , 1988	Prospective study of 408 patients comparing radiographs and CT.	II	NPV of asymptomatic exam 99.3 to 100%
			PPV of symptomatic exam 12.6%
			Radiographs may not be unnecessary in asymptomatic patients
			Class II due to unclear "gold standard"
Neifeld, ¹⁵ <i>J Emerg Med</i> , 1988	Prospective study of 886 patients	I	NPV 100%
			PPV: 6.2%
	Including 244 asymptomatic patients.		Asymptomatic patients do not require radiographs
Roberge, ¹⁷ <i>J Trauma</i> , 1988	Prospective study of 467 trauma including 155 asymptomatic patients.	I	NPV of asymptomatic exam: 100%
			PPV of symptomatic exam: 2.5%
			Asymptomatic patients do not require radiographs

TABLE 4. Evidentiary Table: Radiographic Assessment: Symptomatic^a

Citation	Description of Study	Evidence Class	Conclusions
Duane, ⁴⁷ <i>Am Surg</i> , 2010	22 929 trauma patients identifying 271 patients with dynamic imaging 49 of which were also imaged with MRI. Only study identified that directly compares dynamic imaging with MRI. Evaluated flexion/extension as a diagnostic test.	I	Sensitivity was 0.0% Specificity was 98% PPV was 0% NPV was 83%
	Gold standard for ligamentous injury was MRI.		MRI is more sensitive and specific than flexion/extension films for detecting ligamentous injury
	Flexion/extension films failed to identify any of the 8 ligamentous injuries.		Class III medical evidence. MRI not "gold standard," likely false endpoint
Bailitz, ³² <i>J Trauma</i> 2009	Prospective study of 1505 patients including 50 with clinically significant injuries comparing plain film with CT in blinded fashion. Blinded comparison of 3-view radiographs and cervical CT.	I	CT 100% sensitive
	NEXUS criteria used for initial diagnosis.		Plain films 36% sensitive ($P < 0.05$) CT is significantly more sensitive than three view plain films for detecting clinical significant cervical spine injury
Mathen, ³³ <i>J Trauma</i> , 2007	Prospective study of 667 trauma patients including 60 patients with cervical spine injuries comparing plain films and CT.	I	CT
			Sensitivity 100%
			Specificity 99.5%
			Plain films:
			Sensitivity 45%
			specificity 97.4%
			Plain films add no significant information to a high quality CT study
Daffner, ³⁴ <i>Injury</i> , 2006	Retrospective cohort study of 5172 trauma admissions including 297 cervical fractures comparing plain films and CT.	II	Sensitivity:
			CT 99.2%
			Plain film 44.1%
			Lateral plain films can identify fractures not noted on CT
			Class II due to number of patients excluded and incomplete data
Holmes, ²⁵ <i>J Trauma</i> , 2005	Meta-analysis of studies addressing 3-view radiographs and cervical CT.	Meta-analysis Class III	Sensitivity:
			CT 98%
			Plain films 52%
			CT more sensitive for detection of significant cervical spine injury
Sanchez, ⁵¹ <i>J Trauma</i> , 2005	Prospective study of 2854 trauma patients imaged per protocol with exam, CT and MRI.	II	Sensitivity was 99%
			Specificity was 100%
			Protocol of exam, CT and MRI has high sensitivity and specificity

(Continues)

TABLE 4. Continued

Citation	Description of Study	Evidence Class	Conclusions
Schuster, ⁴⁸ <i>Arch Surg</i> , 2005	Prospective study of 2854 patients including 93 symptomatic with a normal exam comparing CT and MRI.	II	Patients with a normal motor exam and normal CT of the cervical spine do not require MRI imaging in order to exclude significant injury Class II as limited population and number excluded not stated
Griffen, ²⁸ <i>J Trauma</i> , 2003	Prospective study comparing plain films and CT.	I	Sensitivity: CT 100%, Plain radiographs 64% NPV: CT 100%, Plain films 96%. CT is superior to plain films
Insko, ⁵⁰ <i>J Trauma</i> , 2002	Retrospective review of 106 patients evaluated with flexion/extension films	III	Flexion/extension films were of limited value due to inadequate motion on a significant number of studies
Schenarts, ³⁰ <i>J Trauma</i> , 2001	Prospective study evaluating the role of cervical CT scanning in their trauma population.	I	Sensitivity: CT 96%, Plain films 54% CT was superior to plain films in the evaluation of early cervical trauma
Pollack, ⁴⁹ <i>Ann Emerg Med</i> , 2001	Prospective study of 818 patients evaluating the role of dynamic plain films supplementing standard 3 view radiographic evaluation in the acute trauma setting.	II	Dynamic imaging adds little to the acute evaluation of cervical trauma
Berne, ²¹ <i>J Trauma</i> , 1999	Prospective study comparing plain films and CT.	I	Plain films: Sensitivity 60%, PPV of 100%, NPV of 85% CT: Sensitivity 90%, Specificity 100%, PPV of 100%, NPV of 95% CT more sensitive and more specific than plain films
Katzberg, ⁸² <i>Radiology</i> , 1999	Prospective study of 199 patients who underwent MRI in addition to standard radiographic study.	III	MRI detected injuries in a higher fraction of these patients than did conventional radiographs and CT Class III as no Gold Standard and inclusion criteria not clear
Klein, ⁴⁴ <i>Spine</i> , 1999	Retrospective review of 32 patients with 75 known spine fractures evaluating MRI.	II	MRI not good for evaluating bony pathology Class II as a restricted population.
Tan, ⁸³ <i>J Spinal Disord</i> , 1999	Retrospective review of 360 patients treated for blunt injury who underwent 3 view C-spine films supplemented with CT.	III	CT able to detect fractures missed by plain films
Ajani, ²² <i>Anaesth Intensive Care</i> , 1998	Prospective study of 100 consecutive patients evaluating 3-view radiographs.	I	PPV 45% NPV 98.9% Three-view radiographs have a high NPV
Emery, ⁴³ <i>J Spinal Disord</i> , 1998	Prospective study of 37 patients with known spine injuries evaluated with MRI.	II	Sensitivity 89.5% PPV 100%

(Continues)

TABLE 4. Continued

Citation	Description of Study	Evidence Class	Conclusions
Davis, ²³ <i>J Trauma</i> , 1995	Prospective study of 116 patients with GCS<13 and normal radiographs evaluated with flexion/extension views under fluoro evaluating plain films vs flexion/extension films as Gold standard for injury.	I	NPV 90% Class II as a restricted population NPV 100%
Borock, ⁸⁴ <i>J Trauma</i> , 1991	Prospective study of 179 symptomatic patients with equivocal screening underwent CT to evaluate cervical spine.	II	Flexion/extension films able to exclude significant injury PPV of 72%
Cohn, ⁸⁵ <i>J Trauma</i> , 1991	Prospective study of 60 patients prospectively studied with lateral film and full 5-view series.	II	NPV of 97.6% Class II as questionable false endpoint Lateral view PPV 100%NPV 94%Sensitivity 57%
Lewis, ⁴⁰ <i>Ann Emerg Med</i> , 1991	Retrospective review of 141 patients with flexion/extension films performed after 3-view series was normal.	II	Class II as questionable false endpoint Plain films vs flexion/extension vs plain films:
MacDonald, ²⁴ <i>J Trauma</i> , 1990	Prospective study of 775 patients with 3 views compared to Gold standard of all other studies performed and clinical outcome.	I	Sensitivity 71% vs 99%, Specificity 89% vs 89%, NPV 93% vs 93%, PPV 67% vs 99% Three view series:
Freemyer, ⁸⁶ <i>Ann Emerg Med</i> , 1989	Prospective study of symptomatic patients imaged with 5-view series compared to 3 with CT as Gold standard.	II	Sensitivity: 83% Specificity: 97% PPV: 81% NPV: 98% Three views adequate to visualize fractures in symptomatic patients Class II due to restricted population

99.7%. By comparison, plain cervical spine films had a sensitivity of 44.0%, a specificity of 100%, a PPV of 100%, and a NPV of 93.2%. Five-view plain films failed to identify 52% of the cervical spine fractures identified by CT imaging.

Widder et al³¹ conducted a prospective blinded study in obtunded ventilated patients comparing the role of plain radiography and CT. In their 2004 report, the sensitivity of plain films in detecting cervical spinal injuries was 39% compared to 100% sensitivity of CT imaging.

In 2005, Brohi et al⁵² reported on 437 unconscious intubated patients, including 61 with cervical spinal injuries, 31 of which were considered unstable (7%). The sensitivity of CT was 98.1%, with a specificity of 98.8%, and a NPV of 99.7%. CT detected all unstable injuries. In contrast, lateral cervical spine films detected only 14 unstable injuries and had a sensitivity of 53.3%.

Dynamic Imaging

The role of dynamic imaging in the obtunded patient remains controversial. In a recent study, Hennessey et al⁵³ in 2010 described a prospective study of consecutive trauma admissions over a 4-year period. Included in their analysis were 402 patients who underwent both CT and dynamic imaging of the cervical spine for suspected cervical spinal injuries. The authors identified 1 case (0.25%) that was negative on CT imaging yet positive on flexion and extension x-rays. Flexion and extension x-rays were used as the comparative gold standard. The reported sensitivity of CT was 99.75%. The authors concluded that routine flexion/extension studies were not necessary in the presence of normal CT imaging. The use of flexion/extension as a gold standard (likely false endpoint) and the lack of rigorously defined inclusion

TABLE 5. Evidentiary Table: Radiographic Assessment: Obtunded^a

Citation	Description of Study	Evidence Class	Conclusions
Duane, ⁴⁷ <i>Am Surg</i> , 2010	Retrospective review of 22x2009;929 blunt trauma patients who had both FE and MRI of the cervical spine performed.	II	MRI imaging should be used rather than flexion/extension radiographs to diagnose ligamentous injury. MRI should be used when there is high clinical suspicion of injury
Hennessy, ⁵³ <i>J Trauma</i> , 2010	Prospective study of 402 obtunded trauma patients comparing CT vs dynamic radiographs.	II	Class II as inclusion for imaging not defined Sensitivity of CT 99.75%
	Only 1/402 (0.25%) missed fracture by CT that was detected by FE films.		CT is more sensitive than flexion/extension films Class II as inclusion criteria not clear
Menaker, ⁷⁴ <i>Am Surg</i> , 2010	Retrospective review of 213 trauma patients evaluated with 40-slice CT vs MRI.	III	MRI changed clinical practice in 17.8% of all patients
	Determine how often MRI altered the management of patients with a negative CT.		MRI still required despite advancements in CT technology
Schoenfeld, ⁶⁹ <i>J Trauma</i> , 2010	Meta-analysis of 11 studies considered Class I by authors including 1550 patients with a negative cervical CT scan subsequently imaged with MRI.	II	Reliance on CT imaging alone to "clear the cervical spine" after blunt trauma can lead to missed injuries
			The addition of MRI in evaluating patients who are obtunded, or unexaminable, despite a negative CT scan is recommended
	Q-statistic <i>P</i> value for heterogeneity was 0.99.		Class II as studies not all with same endpoints and variability in study design
Simon, ⁷³ <i>J Trauma</i> , 2010	Retrospective study of 708 trauma patients undergoing CT scanning for cervical spine trauma including 91 patients with scans read as negative by radiologists and subsequently underwent MRI. The imaging was reviewed subsequently by 2 fellowship trained spine surgeons.	II for involving spine expertise in evaluation.	Excluding the presence of significant cervical injury in patients without the ability participate in a clinical examination is best determined by experts in spine trauma management
		III in support of MRI in algorithm.	A multidisciplinary, algorithmic approach generally yields the most consistent results. Reliance on a single imaging modality may lead to missed injuries
Schoenwaelder, ⁶⁸ <i>Emerg Radiol</i> , 2009	Retrospective study in intubated trauma patients, evaluating the utility of MRI in intubated multitrauma patients with normal CT.	III	NPV 82% for discoligamentous injury and 100% for unstable injury
			A normal single-slice helical CT with sagittal reformats of the cervical spine in intubated trauma patients excludes unstable injuries
Muchow, ⁷⁰ <i>J Trauma</i> , 2008	Meta-analysis of 5 Class I studies including 464 patients addressing the imaging of obtunded blunt trauma patients with negative radiographs or CT.	II	False negatives 0%
			NPV 100%
			PPV 94.2%
			Sensitivity 97.2%

(Continues)

TABLE 5. Continued

Citation	Description of Study	Evidence Class	Conclusions
			Specificity 98.5%
			Negative MRI conclusively excludes cervical spine injury
			Class II as the studies reviewed not Class I and had variability in design and address a relatively restricted population
Tomycz, ⁶⁷ <i>J Trauma</i> , 2008	Retrospective review of 690 patients with both CT and MRI of the cervical spine in a level I trauma center from January 2003 to December 2006 were retrospectively analyzed.	III	MRI is unlikely to identify a significant injury in the setting of a negative CT
Como, ⁶¹ <i>J Trauma</i> , 2007	Prospective evaluation of 115 CT negative trauma patients.	II	MRI did not add significantly to the evaluation
Mathen, ³³ <i>J Trauma</i> , 2007	Prospective, unblinded, consecutive series of trauma patients requiring c-spine evaluation comparing plain radiographs to CT for cervical spine evaluation.	II	All clinically significant injuries were detected by CT. Plain films failed to identify 55.5% of clinically significant fractures
			CT is superior to plain radiography as a screening modality for the identification of acute traumatic cervical spine injury
Sarani, ⁶⁴ <i>J Trauma</i> , 2007	Retrospective study of 254 adults including 53 obtunded patients. All study patients underwent both CT and MRI scanning of the cervical spine.	III	A cervical spine MRI should be obtained in trauma patients who are either unexamined or symptomatic with a normal CT scan
Stelfox, ⁶⁶ <i>J Trauma</i> , 2007	Prospective study of intubated trauma patients imaged with CT and either clinical examination or MRI to discontinue c-spine immobilization.	II	Discontinuation of c-spine precautions based on a normal CT decreases the duration of immobilization and is associated with fewer complications, fewer days of mechanical ventilation, and shorter hospital admissions
Adams, ⁶⁰ <i>Am Surg</i> , 2006	Prospective evaluation of CT scanning in the blunt trauma patient.	II	CT:
			Sensitivity 94%
			Specificity 91%
			NPV 98%
			PPV 78%
			CT scanning identifies the presence of cervical injury with a high sensitivity
			Downgraded due to small size and unclear inclusion criteria
Stassen, ⁶⁵ <i>J Trauma</i> , 2006	Retrospective review of 52 obtunded trauma patients having both cervical CT and MRI.	III	CT combined with MRI provides efficient evaluation for cervical spine injury. CT alone misses a statistically significant number of cervical spine injuries
Brohi, ⁵² <i>J Trauma</i> , 2005	Prospective study of 437 trauma patients including 61 patients with significant spine injury evaluating CT.	I	CT:
			Sensitivity of 98.1%, specificity of 98.8%
			NPV 99.7%
			CT excludes significant cervical spine trauma with a high sensitivity and specificity
Hogan, ⁶² <i>Radiology</i> , 2005	Retrospective study of CT and MRI in obtunded patients.	III	CT for ligamentous injury

(Continues)

TABLE 5. Continued

Citation	Description of Study	Evidence Class	Conclusions
			NPV 98.9% for and CT for unstable cervical spine injury
			NPV 100%
			A normal cervical CT scan in the obtunded blunt trauma patient can exclude an unstable cervical spine injury
Schuster, ⁴⁸ <i>Arch Surg</i> , 2005	Prospectively collected registry data of 2854 trauma patients including 100 with cervical spine injuries with normal motor examination results and normal cervical spine helical CT scans	II	A normal exam and normal cervical CT excludes significant injury without additional imaging
Horn, ⁷⁵ <i>J Neurosurg Spine</i> , 2004	Retrospective review of patients imaged with MRI compared with either plain films or CT.	III	MRI is not helpful in determining cervical stability and may lead to un-necessary testing
Diaz, ²⁷ <i>J Trauma</i> , 2003	Prospective study of adults with altered mental status imaged with both CT and plain films.	I	CT:
			Sensitivity 97.4%
			Specificity 100%
			Prevalence of 11.5%
			PPV 100%
			NPV 99.7%
			Plain films:
			Sensitivity 44.0%
			Specificity 100%
			Prevalence 11.5%
			PPV 100%
			NPV 93.2%
			CT outperformed 5-view plain films in identifying cervical spine injury in obtunded patients
Albrecht, ⁷¹ <i>World J Surg</i> , 2001	Retrospective review of 150 obtunded patients evaluating the role of MRI to exclude significant cervical trauma.	III	MRI identified all significant cervical spine injuries

^aCCR, Canadian C-Spine Rule; CT, computed tomography; MRI, magnetic resonance imaging; NEXUS, National Emergency X-Radiography Utilization Study Group; NLV, NEXUS low risk category; NPV, negative predictive value; PPV, positive predictive value.

criteria limit the evidence reported in this study to Class III medical evidence.

In 2006, Padayachee et al⁵⁴ published a prospective analysis of 276 obtunded patients who were assessed with CSR, CT, and flexion/extension studies. The authors reported that flexion/extension studies had 94% (260/276) true negatives, 2.2% (6/276) false positives, and 0.4% (1/276) false negative results, with no true positives. In 9 patients, the dynamic films were deemed inadequate upon review. The authors concluded that in this prospective cervical spine clearance protocol for unconscious traumatic brain injury patients, flexion/extension studies under fluoroscopy failed to identify any patient with a significant cervical injury that was not already identified either by plain radiographs or high-definition CT.

Spiteri et al⁵⁵ published a retrospective review of 839 trauma patients for unstable cervical spine injuries and any cases missed by CT but identified by dynamic imaging. The authors identified 87 patients with unstable cervical spinal injuries. CT imaging missed 2 injuries (sensitivity 97%, specificity 100%). Flexion and extension films identified 1 case of atlanto-occipital dislocation missed on CT (sensitivity 98.8%, specificity 100%). No injuries or neurological worsening were attributable to dynamic imaging. The authors concluded that dynamic imaging is safe but adds little if anything to plain radiographs and/or CT of the cervical spine in the assessment of acute traumatic injury.

Freedman et al⁵⁶ studied all unconscious patients admitted over a 1-year period who failed to clear cognitively within 48 hours. In 2005 they reported on 123 patients who had normal 3-view cervical radiographs who subsequently underwent passive

dynamic imaging when they were able to participate. Final injury status at follow-up served as the gold standard. Dynamic imaging resulted in a 57% false negative rate (missed 4 of 7 injuries). None suffered an adverse neurologic outcome as a result of dynamic imaging. The authors concluded that passive flexion and extension imaging fails to provide adequate sensitivity for detecting occult cervical spinal injuries.

Griffiths et al⁵⁷ retrospectively reviewed 447 trauma patients examined with flexion and extension x-rays in evaluation for cervical spinal injuries. The outcome of interest was worsened neurological deficit as a result of the dynamic imaging procedure. There were no cases identified of neurological worsening following forced flexion and extension imaging. Of 447 patients evaluated with dynamic imaging, 29 were identified who had cervical spinal abnormalities, either fracture or ligamentous injury. In 80% of the patients with injuries (23 of 29), no change in diagnosis was made following forced flexion and extension studies. In 6 patients (20%), an alteration in diagnosis was made based on positive dynamic studies. Of the 497 dynamic imaging studies, 285 (59%) were found to be inadequate either due to inadequate motion (31%) or inadequate visualization (40%).

In 2004, Bolinger et al⁵⁸ reported a retrospective study of 56 consecutive comatose head-injured patients. All patients had 3-view radiographs and CT imaging performed and reviewed by the attending neurosurgeon and a radiologist. If these studies were felt to be normal, flexion/extension fluoroscopic studies were performed. In only 4% of the cases were the studies felt to be adequate to visualize the full cervical spine. Clinical outcome served as the gold standard. Occult instability was identified in 1 patient with a Type II odontoid fracture, and significant instability at C6-7 was identified in 1 patient despite normal dynamic films. The authors concluded that flexion and extension fluoroscopy was almost always inadequate for visualizing the lower cervical spine in obtunded patients.

Davis et al⁵⁹ evaluated the efficacy of flexion/extension studies under fluoroscopy in obtunded patients who had normal cervical spine plain films. Over a 7-year period, 301 patients were evaluated. Ligamentous injury was identified in 2 patients (0.7%). There were 297 true negative, 2 true positive, 1 false negative, and 1 false positive examinations. One patient was rendered quadriplegic by the dynamic evaluation. This study does not provide evidence to support the routine use of dynamic fluoroscopy in assessing the cervical spine in the obtunded patient and demonstrates the rare, but devastating complications that may occur with dynamic imaging.

MRI

In 2010, Schoenfeld et al^{27,33,48,60-69} performed and reported a meta-analysis of 11 studies comparing CT alone to CT plus MRI in identifying occult cervical spine injuries following acute trauma. The authors attempted to address the question: Does adding MRI provide useful information that alters treatment when a CT scan of the cervical spine reveals no evidence of injury? The study included 1550 patients with a negative cervical CT study who were subsequently imaged with MRI. Abnormalities

were detected by MRI in 182 patients (12%). Ligamentous injuries were found in 47% of the patients and bony abnormalities in 2% of patients. Significantly, MRI identified an injury that altered management in 96 patients (6%). Twelve patients (1%) required surgical stabilization and 84 patients (5%) required immobilization for injuries identified on MRI but not on CT imaging. The Q-statistic *P* value for heterogeneity was 0.99, supporting the validity of the study. The pooled sensitivity of MRI for detecting a clinically significant injury was 1.00 (100%) (95% CI = 95-100). The pooled specificity was 0.94 (94%) (95% CI = 93-95). The pooled NPV for MRI was 1.00 (100%) (95% CI = 95-100). There were no false negatives in any of the studies included in their meta-analysis. The pooled false-positive rate was 0.06 (6%) (95% CI = 1-11). The likelihood ratio of a clinically significant injury in the setting of a positive MRI was 17 (95% CI = 13.8-20.8). The authors advocate the use of MRI to evaluate patients who are obtunded or unexamined despite a negative CT study of the cervical spine. Their report provides Class II medical evidence on this issue. The authors' meta-analysis included 6 retrospective studies. Study designs varied and had different criteria. There is no imaging gold standard for cervical spinal instability, or for ligamentous injury; therefore, several studies the authors included likely had false endpoints.

An earlier meta-analysis was published by Muchow et al⁷⁰ in 2008, and included studies by Albrecht et al,⁷¹ Benzel et al,⁴² D'Alise et al, Keiper et al,⁷² and Schuster et al.⁴⁸ The authors considered these 5 studies to provide Class I medical evidence in the assessment of MRI in the setting of negative plain films or CT of the cervical spine following trauma. The authors used the following inclusion criteria: minimum 30 patients with clinically suspicious or unevaluable cervical spines, clinical follow-up as the gold standard, data reported to allow the collection of true positives, true negatives, false positives, and false negatives, MRI obtained within 72 hours of injury, and plain radiographs that disclosed nothing abnormal of the cervical spine with or without a CT scan that disclosed nothing abnormal. The pooled sensitivity, specificity, positive, and NPV of MRI were calculated from a log odds meta-analysis. The total number of patients in the combined studies was 464. The NPV of MRI was 100%. There were no false negatives in any of the 5 studies included in the analysis. The pooled sensitivity of MRI in these studies was 97.2% (95% CI 89.5, 99.3), the specificity was 98.5% (95% CI 91.8, 99.7), and the PPV was 94.2% (95% CI 75.0, 98.9). Ninety-seven injuries (20.9%) were identified on MRI that were not diagnosed by either plain film or CT imaging. The authors concluded that a normal MRI study in the setting of normal CSR or a normal CT study excludes cervical spinal injury and establishes MRI as a gold standard for excluding a significant cervical spinal injury in a clinically suspicious or unevaluable acute trauma victim. This analysis by Muchow et al⁷⁰ provides Class II medical evidence in support of the role of MRI in the evaluation of the obtunded or unevaluable patient who has negative plain radiography or CT imaging of the cervical spine. Their review was limited by differences in the imaging protocols, the combination of

negative plain films or CT as a portion of the entry criteria, difficulty ensuring similarity of the patient population across the 5 studies, the inclusion of a primarily pediatric study,⁷² and extrapolating the overall results to an adult evidence-based review.

In 2010, Simon et al⁷³ published a detailed analysis of 708 consecutively admitted trauma patients and identified a subset of 91 patients who had cervical CT imaging interpreted as negative who subsequently were evaluated with cervical MRI imaging. The collective images of these 91 patients were independently re-evaluated by 2 fellowship-trained spine surgeons. Both surgeons agreed that the images of 76 of 91 patients (84%) were adequate to determine the potential for a cervical spinal injury. Both agreed that the images of 7 of the 91 patients (8%) were inadequate (95% CI, 2.3-13.1). Total Observer agreement was 91% (kappa, 0.59). The calculated sensitivity of CT in this study was 77.3%. The specificity of CT for a cervical spinal injury was 91.5% with a NPV of 92.0%. The addition of MRI to CT imaging improved the probability of identifying a significant cervical spinal injury by approximately 8%. When clinicians skilled in the interpretation of cervical spinal imaging and the management of patients with cervical spinal injuries were directly involved in the assessment of obtunded, high risk patients following trauma, fewer injuries were missed compared to an initial single read of the acute images by less experienced clinicians. This study provides Class II medical evidence in support of the involvement of physicians trained in the diagnosis and management of spinal injuries in the assessment of obtunded or unevaluable patients following acute trauma in whom there is a high clinical suspicion of cervical spinal injury yet have a normal high-quality CT imaging study.

Menaker et al⁷⁴ offered a retrospective analysis of 213 patients who had negative CT on a high quality 40 slice CT who had a subsequent MRI. 24% of these patients had an abnormal MRI study (52 of 213). Fifteen (7%) underwent surgery, 23 (11%) were treated with cervical immobilization, and 14 (6.5%) had immobilization collars removed. In total, 8.3% of obtunded patients and 25.6% of symptomatic patients with normal CT studies had a change in management based on MRI findings (combined 17.8%). This 2010 publication is problematic in design and provides, at best, Class III medical evidence on the value of MRI in the acute setting following trauma, but does highlight the increased sensitivity of MRI in detecting cervical spinal injuries.

In 2006, Stassen et al⁶⁵ reported a retrospective analysis of 52 patients studied in a 1-year trauma protocol utilizing CT and MRI. Thirty-one patients (60%) had both a negative CT and MRI. The authors identified that of 44 patients with a negative CT, 13 (30%) had evidence of a potential ligamentous injury on MRI. Eight patients with positive CT findings also had positive MRI findings. There were no missed cervical spine injuries identified by clinical follow-up. The authors concluded that cervical CT, when used in combination with MRI, provides an efficient method for identifying cervical spine injuries following trauma. CT imaging alone, they added, misses a statistically significant number of acute cervical spinal injuries. Their study provides Class III medical evidence on this subject.

Horn et al⁷⁵ in 2004 described a retrospective series of 6328 trauma patients that included a subset of 314 trauma victims that were imaged with a cervical MRI for 1 of the following indications: neurological deficit, fracture, neck pain, and/or indeterminate clinical examination. Based on clinical follow-up, there were 65 patients identified with unstable cervical spinal injuries. In this group, plain films, CT, and MRI were all abnormal. There were 143 patients who had abnormal CT or plain films. Of these, 13 had normal MRI studies. Six of the 13 had dynamic films. All were interpreted as normal. One hundred and sixty-six of the 314 patients had normal CT or cervical plain films. Of these, 70 had abnormal MRI findings. Twenty-three of the 70 had dynamic studies performed as well; they were all normal. The authors concluded that MRI is sensitive to soft tissue image abnormalities but may add little in the detection of a significant cervical spinal injury in the circumstance of either normal plain films or CT study. Study design, lack of follow-up, and the lack of clear comparison groups limit the medical evidence in their report to Class III.

In 2002, Ghanta et al⁷⁶ published a retrospective review of 124 consecutive patients who underwent 3-view plain films (3VPF), a full CT survey (CTS), and MRI of the cervical spine. The study included 51 obtunded patients with normal plain films. Thirty-six of these 51 patients had normal CT and MRI studies. The authors determined that 22% of obtunded patients with normal cervical plain films and CTS had an abnormal MRI. Six percent of these injuries were potentially unstable. The authors concluded that plain films and CT imaging appear effective in detecting bony injury among obtunded patients, but may not be sensitive enough for cervical ligamentous injuries and significant disc herniations.

SUMMARY

Awake Asymptomatic Patient

Class I medical evidence was previously reported on this topic. The current updated review identified additional Class I evidence supporting a Level I recommendation that in the awake, asymptomatic patient who is without neck pain or tenderness, is neurologically intact without an injury detracting from an accurate evaluation, and who is able to complete a functional range of motion examination, radiographic evaluation of the cervical spine is not recommended. The discontinuance of cervical immobilization in this patient population is recommended.

Awake Symptomatic Patient

Class I medical evidence was previously reported on this topic. This current updated review identified additional Class I medical evidence that alters the previous Level I recommendation. High-quality CT imaging of the cervical spine in the symptomatic trauma patient has been proven to be more accurate than CSR with higher sensitivity and specificity for injury following blunt trauma. If high-quality CT is available, 3-view CSR are not necessary. If high quality CT is not available, a 3-view cervical spine series (anteroposterior, lateral, and odontoid views) remains a Level I recommendation.

The question of “what to do?” if anything for the awake patient with neck pain or tenderness and normal high-quality CT or 3-view CSR remains less clear. Only lower level medical evidence is available to guide treatment decisions for these patients. The current literature offers less robust medical evidence in support of the 3 following strategies in the awake but symptomatic patient: (1) continue cervical immobilization until asymptomatic, (2) discontinue cervical immobilization following either normal and adequate dynamic flexion/extension radiographs, or a normal MRI study obtained within 48 hours of injury, or (3) discontinue immobilization at the discretion of the treating physician. Several studies favor the use of MRI (Level II) over dynamic radiographs (Level III) in further study of these patients, but may not be feasible or indicated in all situations.

Obtunded or Unevaluable Patient

A large number of studies have been produced since the previous guideline publication on imaging the obtunded or unevaluable patient in order to clear the cervical spine without the benefit of the clinical examination. The current Level I recommendation, based on Class I medical evidence, is that high-quality CT imaging is recommended as the initial imaging study of choice. If high-quality CT imaging is available, routine 3-view CSR are not necessary, similar to the Level I recommendations in the other categories. If high-quality CT is not available, a 3-view cervical spine series (anteroposterior, lateral, and odontoid views) is recommended. The plain cervical spine x-ray studies should be supplemented with CT (when it becomes available) if necessary, to further define areas that are suspicious or not well-visualized on the plain cervical x-rays.

The most controversial issue in the obtunded/unevaluable patient group is the recommendation on the discontinuation of immobilization. The current recommendation is that in the obtunded or unevaluable patient who has normal high-quality CT imaging or a normal 3-view cervical spine series, 1 of the following strategies be considered: (1) continue cervical immobilization until asymptomatic, (2) discontinue cervical immobilization following a normal MRI study obtained within 48 hours of injury, or (3) discontinue immobilization at the discretion of the treating physician. MRI appears to be the imaging modality of choice in this situation based on limited and conflicting Class II and Class III medical evidence. Class III medical evidence suggests that the routine use of dynamic imaging is of marginal benefit and is not recommended. Class II medical evidence suggests that the decisions for the subsequent patient management of the obtunded/unevaluable patient including whether or not to obtain an MRI study on individual patients involve physicians trained in the diagnosis and management of spinal injuries.

KEY ISSUES FOR FUTURE INVESTIGATION

The issue of discontinuing cervical spinal immobilization after blunt trauma remains the area of most controversy in both the symptomatic patient with negative initial imaging, and in the obtunded or unevaluable patient with normal cervical spinal

imaging. Numerous publications have addressed this issue and several have provided Class II and Class III medical evidence on this topic. Although a challenge, it appears that this issue could be addressed in a multicenter randomized trial. An appropriately designed and conducted prospective multicenter trial has the potential to define the optimum methodology to accurately exclude a significant cervical spinal injury in these patients prior to discontinuing immobilization. While limited and conflicting medical evidence suggests that MRI is recommended to further study these patients, this has yet to be definitely proven. The question of whether there is any role for dynamic imaging in this setting should be determined.

Disclosure

The other authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Initial Closed Reduction of Cervical Spinal Fracture-Dislocation Injuries

Daniel E. Gelb, MD*

Mark N. Hadley, MD‡

Bizhan Aarabi, MD, FRCSC§

Sanjay S. Dhall, MD¶

R. John Hurlbert, MD, PhD,
FRCSC||

Curtis J. Rozzelle, MD#

Timothy C. Ryken, MD, MS**

Nicholas Theodore, MD‡‡

Beverly C. Walters, MD, MSc,
FRCSC§§§

*Department of Orthopaedics and;
§Department of Neurosurgery, University of Maryland, Baltimore, Maryland;
‡Division of Neurological Surgery and;
#Division of Neurological Surgery, Children's Hospital of Alabama, University of Alabama at Birmingham, Birmingham, Alabama; ¶Department of Neurosurgery, Emory University, Atlanta, Georgia;
||Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada; **Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa;
‡‡Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona; §§Department of Neurosciences, Inova Health System, Falls Church, Virginia

Correspondence:

Mark N. Hadley, MD, FACS, UAB
Division of Neurological Surgery,
510 – 20th St S, FOT 1030,
Birmingham, AL 35294-3410.
E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS

Level III

- Early closed reduction of cervical spinal fracture/dislocation injuries with craniocervical traction for the restoration of anatomic alignment of the cervical spine in awake patients is recommended.
- Closed reduction in patients with an additional rostral injury is not recommended.
- Magnetic resonance imaging is recommended for patients with cervical spinal fracture dislocation injuries if they cannot be examined during closed reduction because of altered mental status or before either anterior or posterior surgical procedures when closed reduction has failed. Prereduction magnetic resonance imaging performed in patients with cervical fracture dislocation injuries will demonstrate disrupted or herniated intervertebral disks in one-third to one-half of patients with facet subluxation injuries. These findings do not appear to influence outcome following closed reduction in awake patients, and therefore, the utility of pre-reduction MRI in this circumstance is uncertain.

RATIONALE

In the clinical scenario of traumatic cervical spine fractures and cervical facet dislocation injuries, narrowing of the spinal canal caused by displacement of fracture fragments or subluxation of 1 vertebra over another frequently

produces spinal cord injury. Reduction of the dislocation deformity helps to restore spinal alignment and the diameter of the bony canal by eliminating bony compression of the spinal cord resulting from the vertebral fracture and/or subluxation. By carrying out reduction early after injury, decompression of the spinal cord may lead to improved neurological outcome. Up until 2001, several investigators described positive results with large series of patients treated with initial closed reduction of cervical fractures and facet dislocation injuries with negligible rates of neurological complications. In 2002, the guidelines author group of the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons published a medical evidence-based guideline on this important topic.¹ Concurrently, descriptive series of patients with facet dislocation injuries were reported describing a high incidence of cervical disk herniation (in addition to the fracture/dislocation injury) identified on prereduction magnetic resonance imaging (MRI). In addition, several case reports and small series of patients who worsened neurologically following closed cervical spinal reduction were published. Several of these reports impugned ventral compression of the spinal cord by displaced disk material as causative. The purpose of this updated qualitative medical evidence-based review is to address the following issues:

1. Is closed reduction safe and effective for reducing cervical spinal deformity/spinal cord compression in patients with cervical fractures and/or facet dislocation injuries?
2. What is the risk of neurological injury following closed reduction of acute traumatic cervical fractures/facet dislocation injuries?

ABBREVIATION: MUA, manipulation under anesthesia

SEARCH CRITERIA

To add to and update the previously analyzed medical evidence on this issue, a new National Library of Medicine (PubMed) computerized literature search was performed. Medical subject headings queried included “facet dislocation” or “fracture” or “dislocation” and “cervical spine.” This search resulted in 6705 citations. This search was combined with the term “reduction,” yielding 527 potential citations. English language citations with abstracts limited to human subjects yielded 380 potential references. Restricting the search to 2001 to 2011 further refined the results to 155 citations. The abstracts of each of these citations were reviewed. As before, clinical series dealing with adult patients in the acute setting were selected. Case reports and case collections were included. Additional references were culled from the reference lists of the articles reviewed. Nine additional articles with clinical data germane to the issue of closed reduction of cervical spinal fractures were identified. These articles are summarized in the text, provided in Evidentiary Table format (Table), and included in the bibliography.

As observed in the previous medical evidence-based review, there were no randomized clinical trials, no prospective cohort studies, and no case-control studies. The publications identified consisted of case series of patients with acute or subacute unilateral or bilateral cervical facet dislocation injuries and provide Class III medical evidence. In contrast to the original spinal cord injury guidelines publication, no report of permanent neurological deterioration following or resulting from closed reduction of a cervical spinal fracture injury has been published since 2000.

SCIENTIFIC FOUNDATION

Closed reduction of cervical spinal deformity resulting from facet dislocation by manipulation was first described by Walton² in 1893. Crutchfield³ introduced tongs for inline traction-reduction in 1933, and similar techniques have been successfully used for traction-reduction of cervical deformity by a large number of authors.⁵⁻²² Observations by Evans and Kleyn popularized reduction under anesthesia, although other authors condemned the procedure as potentially dangerous compared to craniocervical traction-reduction. Manipulation under anesthesia (MUA) has been a common technique, usually used following failure of traction-reduction but occasionally used as a primary means of achieving reduction.^{6,15,21,22} Only 1 cohort study has been performed comparing the 2 modalities. Lee et al²³ found a higher rate of success and a lower complication rate with traction-reduction as opposed to MUA. The significance of their results is questionable because of the historical cohort design of the study. Lee et al attributed the higher complication rate in the MUA group to the effects of anesthesia on perfusion of the injured spinal cord. It is possible, however, that advances in the pharmacological and medical management of spinal cord-injured patients over the 10-year period of data accrual accounted for the improved results the authors noted in the traction-reduction

group. For this reason, the evidence provided by this study is considered to be Class III medical evidence.

THE EFFICACY OF CLOSED REDUCTION

In 2002, the guidelines author group of the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons/Congress of Neurological Surgeons published a medical evidence-based guideline on this issue.¹ That review reported the efficacy of closed reduction of acute cervical spinal fracture dislocation injuries derived from combined case series published in the literature to that point; > 1200 patients were treated with closed reduction, 80% (approximately) successfully. The reported neurological complication rate, permanent and transient combined, was low.

Four additional retrospective series and 3 case reports dealing specifically with closed reduction were identified in the current review that were not part of the original guideline publication, adding another 195 reported cases of closed reduction of cervical spinal fracture dislocation injuries for consideration. In 1991, Beyer et al²⁴ described their experience with a series of 34 patients who had acute traumatic unilateral facet dislocations or fracture dislocations of the cervical spine, 28 of whom were treated with attempted closed reduction. Ten of 28 injuries were successfully reduced with halo traction and achieved anatomic realignment. Eleven had improvement in alignment but incomplete anatomic reduction. Three patients had residual neurological deficits following traction reduction, although they did not deteriorate with traction. Seven patients had dislocation injuries that could not be reduced with traction. The authors described increased difficulty with the reduction of unilateral facet dislocation injuries.

O'Connor et al²⁵ in 2003 reported 21 patients with subaxial cervical facet injuries treated with attempted closed reduction. Eleven patients were reduced successfully. Closed reduction was not successful in any patients with a fracture dislocation injury ≥ 5 days old ($n = 5$). One patient had a transient neurological deterioration. Traction up to 36 kg was employed. Koivikko and colleagues²⁶ successfully reduced cervical fracture dislocation injuries in 62 of 85 patients (73%) they treated with craniocervical traction. Their 2004 report cited 1 patient who experienced neurological deterioration following successful reduction. The temporal association of the deterioration with the closed reduction was not clear from the text of the report. Personal communication with the primary author revealed that the patient deteriorated while in traction for definitive treatment, not in association with closed reduction of the fracture dislocation injury.

In the same year, Anderson et al²⁷ reported their retrospective series of 45 patients who underwent reduction of unilateral and bilateral traumatic cervical spinal facet dislocation injuries. Eighty-nine percent of their patients underwent successful closed reduction. The authors found that motor score on presentation and patient age were statistically related to final motor score. Those with preserved neurological function at presentation and

younger patients tended to do better. Time to reduction did not correlate with improved motor score outcome in their study. However, their analysis suffers from the fact that nearly two-thirds of the original cohort were excluded from analysis because of incomplete medical records.

Reindl et al²⁸ in 2006 described their experience with anterior fusion/internal fixation for cervical spinal facet dislocation injuries. Thirty-three of the 41 patients they treated achieved successful closed reduction (80%). One patient had transient neurological deterioration due to closed reduction that resolved at 1 year following surgery. All 41 patients were treated anteriorly, including 8 with dislocation injuries that could not be reduced with traction. Only 2 patients treated anteriorly could not be reduced/stabilized with interbody fusion and internal fixation. Those 2 patients subsequently required posterior reduction, stabilization, and fusion.

Class III medical evidence supports the efficacy of closed reduction of acute traumatic cervical spinal fracture dislocation injuries. A number of investigators have suggested that early reduction of the traumatic cervical spinal deformity/restoration of the spinal canal improves neurological outcome.^{1,10,15,27,29-33} To date, that intuitive supposition has yet to be supported by Class I or Class II medical evidence.

THE RISK OF CLOSED REDUCTION OF CERVICAL SPINAL INJURIES

The incidence of neurological deterioration related to closed reduction remains low. Before 2001, the reported permanent neurological complication rate was < 1.0%.^{5,7,11,13-21,31,34-39} Of the 11 patients reported to develop new permanent neurological deficits with attempted closed reduction, 2 had root injuries, and 2 had ascending spinal cord deficits noted at the time of reduction.^{11,13,14,20} Seven patients were noted to have decreased American Spinal Injury Association motor scores after reduction; however, neither the nature nor the cause of the new deficits in these patients was described.¹⁵ The current literature review failed to uncover any other reports of patients who suffered a permanent neurological deficit related to closed reduction.

Transient neurological deterioration following closed reduction has also been reported with an incidence between 2% and 4%. Before 2001, temporary deficits were described in 20 patients of 1200 reported. These deficits reversed spontaneously or improved following reduction of weight or following open reduction.^{11,13-15,21,31} The causes of neurological deterioration associated with closed reduction in these and other series included overdistraction, failure to recognize a more rostral noncontiguous lesion, disk herniation, epidural hematoma, and spinal cord edema.^{11,13,16,20,31,40-42}

Mahale et al⁴³ reviewed 16 cases of neurological deterioration in patients with cervical spinal cord injuries following reduction of cervical facet dislocation injuries. Seven of the 16 patients developed complete cord injuries, 6 following open reduction and 1 following manipulation under anesthesia. Five patients developed partial injuries, 3 following MUA, 2 following closed

traction-reduction, and 1 following open reduction. Of the 2 patients who deteriorated following closed reduction, 1 patient was found to be overdistraction. Minor injuries were suffered by the remaining 3 patients, including 1 patient who deteriorated when the skull traction pins slipped, 1 patient who deteriorated in a plaster brace, and 1 patient who lost reduction and had neurological worsening. Nine of the 16 patients whom Mahale et al described were investigated with myelography following deterioration, 2 patients with MRI, and 1 patient with CT. A disk protrusion was noted in 1 patient, and a “disk prolapse with hematoma” was noted in another. Both of these patients were treated conservatively. The most common imaging finding in these 9 patients was cord edema.

Four additional retrospective series and 3 case reports dealing specifically with closed reduction for cervical spinal injuries were identified in the current review, adding another 195 reported cases of closed reduction reported since 2001. Four patients in this cohort were reported to suffer transient neurological deterioration in conjunction with closed reduction.^{25,28,44} The cause of the deterioration was not specified in three of the patients and was attributed to ossification of the posterior longitudinal ligament in the fourth. Three of the 4 patients experienced neurological recovery following surgical treatment.

PREREDUCTION MRI

Reports of neurological deterioration following closed or open posterior reduction of cervical fracture/dislocation injuries has led some authors to recommend the use of prerelation MRI to assess for ventral cord compromise caused by traumatic disk disruption. The risk of extruded disk material exacerbating neurological compression is the main concern related to closed reduction. However, prerelation MRI assessment requires the transport of a patient with a potentially unstable cervical spinal fracture/dislocation injury to the MRI suite. The use of prerelation MRI may delay reduction of the spinal deformity and therefore may delay decompression of the compromised spinal cord. If stabilization of the unstable cervical spine protects against additional injury to the cervical spinal cord, the information gained by prerelation MRI must be of sufficient value to warrant the delay in treatment and the associated potential morbidity of transport.

Several authors have reported the prevalence of MRI-documented disk herniation in association with cervical facet injury. Harrington et al¹⁵ reported a series of 37 patients managed with closed reduction. Postreduction imaging revealed a disk herniation in 9 patients, four of whom underwent later anterior decompression. Doran et al⁴⁵ reported a series of 13 patients drawn from 4 institutions over an unspecified time period. All patients underwent MRI evaluation, four of which were performed before reduction. Herniated disks were visualized in 10 patients; bulging disks were identified in 3 patients. No patient treated developed a permanent neurological deficit as a result of attempted closed reduction. Vaccaro et al⁸ studied 11 consecutive patients with prerelation and postreduction MRI. The authors found

a herniated disk in 2 patients in the prereduction group and in 5 of 9 patients who underwent successful closed reduction. Grant et al⁴⁶ obtained postreduction MRI studies on 80 patients treated with closed reduction and found herniated or bulging disks in 46%. Rizzolo et al³⁹ found evidence of disk disruption/herniation in 55% of patients studied with prereduction MRI. Awake and alert patients underwent closed reduction with no neurological deterioration. The authors did not attempt closed reduction in patients who were not awake. The clinical implications of the findings of a disk herniation on a prereduction MRI were questioned by the authors.

In 2006, Daurasut et al⁴⁷ studied the risk of closed reduction using a unique traction device to monitor reduction with MRI. Seventeen nonconsecutive patients were studied; 11 of 17 were successfully reduced with closed craniocervical traction, and 9 of those 11 patients achieved complete spinal cord decompression. One patient had incomplete decompression, and 1 patient had none. Interestingly, all soft disk herniations identified before the initiation of closed reduction were reduced back into the disk space as part of the traction-reduction process.

Despite the paucity of evidence regarding the value of prereduction MRI in the patient who has a cervical spinal dislocation, the topic remains controversial. Lee et al²³ in 2009 published a review on the topic and found no medical evidence-based guidelines for the treatment of the obtunded patient with a cervical dislocation. Arnold et al³⁵ performed a survey of 29 spinal surgeons from The Spine Trauma Study Group asking for their management responses to ten clinical scenarios related to acute unilateral and bilateral cervical facet dislocation injuries. There was substantial variability among surgeons regarding the need for prereduction MRI, depending on the clinical scenario (42%-77%), and little agreement regarding open or closed reduction to reduce the injury or the operative approach to provide definitive surgical treatment. In 2004, Koivikko et al²⁶ reported their experiences with a series of 85 patients treated for cervical fracture/dislocation injuries. Sixty-two experienced successful reduction with closed cervical traction; the others required operative reduction. No patients underwent prereduction MRI, and no patient deteriorated neurologically as a result of closed reduction. All surgical patients were treated with posterior interspinous wiring with fusion. Despite these results, the authors admit to more recent use of prereduction MRI in the management of patients with cervical fracture/dislocations since their publication.

Neurological deterioration from extruded disk material has been reported to occur in conjunction with both anterior and posterior open reduction following failed closed reduction. Eismont et al³⁴ reported a series of 63 patients managed with closed traction-reduction followed by open reduction if closed reduction was unsuccessful. One of these patients worsened following posterior open reduction and fusion. A herniated disk was found ventral to the cord on postprocedure myelography. Herniated disks were found in 3 other patients who failed closed reduction and in 2 patients with static neurological deficits

following fracture/dislocation reduction (1 open, 1 closed). One of these patients deteriorated after subsequent anterior cervical discectomy and fusion. Olerud and Jónsson³² described 2 patients found to have disk herniations on postreduction MRI or computed tomographic myelography. Both patients deteriorated after open reduction following failure of attempted closed reduction. Robertson and Ryan¹⁹ reported 3 patients who deteriorated during management of cervical subluxation injuries. One of their patients worsened during transport to the hospital. That patient's vertebral injury was found to have spontaneously partially reduced. MRI revealed a disk fragment compressing the cord. A second patient deteriorated following posterior open reduction. MRI revealed disk fragments compressing the ventral cord. Mahale et al⁴³ reviewed 16 cases of neurological deterioration in patients with cervical spinal cord injuries following reduction of facet dislocations. Seven of the 16 patients developed complete cord injuries, 6 following open reduction and 1 following manipulation under anesthesia. Preoperative MRI to assess for the presence of a significant disk herniation with the potential to cause spinal cord compression and neurological deficit when closed reduction has failed is recommended on the basis of these reports.

Review of the available literature reveals only 2 documented cases of neurological deterioration associated with attempted closed reduction of cervical spine fracture/dislocation injuries resulting from cord compression from disk herniation.^{13,48} Both of these cases were characterized by deterioration hours to days following closed reduction. A number of large clinical series have failed to establish a relationship between the presence of a prereduction herniated disk and subsequent neurological deterioration with attempted closed traction-reduction in awake patients.

SUMMARY

In the data derived from the literature published to date, closed reduction of fracture/dislocation injuries of the cervical spine by traction-reduction appears to be safe and effective for the reduction of acute traumatic spinal deformity in awake patients. Approximately 80% of patients will have their cervical fracture dislocation injuries reduced with this technique. The overall permanent neurological complication rate of closed reduction is approximately 1%. The associated risk of a transient injury with closed reduction appears to be 2% to 4%. Closed traction-reduction appears to be safer than MUA.

There are numerous causes of neurological deterioration in patients whom harbor unstable cervical spinal injuries. These include inadequate immobilization, unrecognized rostral injuries, overdistraction, loss of reduction, and cardiac, respiratory, and hemodynamic instability. Therefore, an appropriately trained specialist must supervise the treatment, including attempted closed reduction, of patients with cervical spine fracture dislocation injuries.

Although prereduction MRI will demonstrate disk herniation in up to half of patients with acute cervical spinal facet subluxation

TABLE. Evidentiary Table: Closed Reduction^a

Citation	Description of Study	Results	Evidence Class	Conclusions
Tumialán et al, ³³ <i>Spine</i> , 2009	Case report	Successful closed reduction of spondyloptosis of C7 on T1	III	Traction reduction of spondyloptosis is safe.
Cowan et al, ²⁹ <i>New England Journal of Medicine</i> , 2008	Case report	Improvement in neurological deficits with closed reduction	III	Rapid intervention can allow recovery from traumatic spinal cord injury.
Darsaut et al, ⁴⁷ <i>Spine</i> , 2006	17 patients, prospective nonconsecutive series, reduction under MRI	Reduction successful in 11 of 17 patients; 10 of 11 reductions achieved spinal cord decompression	III	Traction reduction achieves spinal canal decompression.
Reindl et al, ²⁸ <i>Spine</i> , 2006	41 patients, retrospective case series of patients treated with anterior fusion for cervical dislocations	33 of 41 cases reduced successfully; 1 patient deteriorated during surgery but recovered at 1 y	III	Closed reduction successful in most cases. Anterior surgery sufficient for stabilization.
Koivikko et al, ²⁶ <i>European Spine Journal</i> , 2004	85 patients, case series with historical control subjects	62 of 85 patients reduced successfully	III	No neurological deterioration during traction reduction.
Anderson et al, ²⁷ <i>Spine Journal</i> , 2004	45 patients (of 132), retrospective study to determine a statistical model to predict neurological outcomes	88% successfully reduced with closed reduction; no patient deteriorated neurologically	III	Age and initial motor score predict neurological outcome. Timing of reduction did not correlate to outcome.
O'Connor et al, ²⁵ <i>International Orthopaedics</i> , 2003	21 patients, retrospective case series	11 of 21 patients reduced successfully; 1 patient with transient neurological deficit	III	Anterior translation correlates to neurological deficit.
Grant et al, ⁴⁶ <i>Journal of Neurosurgery</i> , 1999	82 patients	Successful reduction in 97.6%	III	Closed reduction is effective and safe despite high incidence of MRI-demonstrable disk injuries/herniations.
	Retrospective series	Average time to reduction, 2.1 ± 0.24 h		
	All closed C-spine injuries with malalignment included	Overall ASIA scores improved by 24 h following reduction		
	Unilateral and bilateral locked facets	1 patient deteriorated 6 h after reduction (probable root lesion)		
	Early rapid closed reduction attempted in all patients	46% had disk injury on MRI, 22% had herniation		
	MRI scans obtained after reduction	Disk injury on MRI correlated with cord edema on MRI		
	ASIA and Frankel grades determined on admission and 6 and 24 h	Successful reduction in 97.6%		
	Weight up to 80% of patient's body weight			
Vital et al, ²² <i>Spine</i> , 1998	168 patients, retrospective series, unilateral and bilateral	43% reduced by traction without anesthesia (time < 2 h)	III	Authors promote their protocol as a safe and effective means for reduction and stabilization of fractures.
	Employed manipulation under general anesthesia in minority of cases	30% reduced by manipulation under anesthesia		
	Used relatively light weights (maximum, 8.8 lb plus 2.2 lb per level for maximum of 40 lb)	27% reduced intraoperatively		

(Continues)

TABLE. Continued

Citation	Description of Study	Results	Evidence Class	Conclusions
Lee et al, ³¹ <i>Journal of Bone and Joint Surgery</i> , 1994	All patients operated on immediately after reduction or after failure of reduction	5 patients did not reduce (delayed referral, surgical error)	III	Traction superior to MUA. Both procedures safe and effective.
	MRIs not done before reduction (although disks noted in 7 patients?)	Authors observed no cases of neurological deterioration		
	210 patients	Reduction successful:		
	Rapid traction-reduction in 119	MUA, 66/91 (73%)		
	Manipulation under anesthesia in 91	RT, 105/119 (88%)		
	Retrospective historical cohort study	All failures in RT group were due to associated fractures or delayed referral		
	Groups similar except traction group had longer delay to treatment	Time to reduction (RT), 21 min		
Cotler et al, ³⁹ <i>Spine</i> , 1994	Weights up to 150 lb used	MUA, not reported	III	Reduction with weights up to 140 lb is safe and effective in monitored setting with experienced physicians.
	No MRI done before reduction	No loss of Frankel grade in either group		
		6 MUA and 1 RT had deterioration on ASIA score		
	24 patients (all awake)	All 24 reduced		
	Prospective study	No incidence of neurological deterioration		
	No fractured facets	Manipulation used in addition to weights in 9 patients (when facets perched)		
	All acute injuries	Time required ranged from 8 to 187 min		
Mahale et al, ⁴³ <i>Journal of Bone and Joint Surgery</i> , 1993	Weights up to 140 lb used		III	Numbers of patients subjected to each treatment arm not given. Purely a descriptive article.
	No CT or MRI done			
	341 patients treated for traumatic dislocations of cervical spine	Complete injuries: 6 after OR, 1 after manipulation		
	15 suffered neurological deterioration	Incomplete injuries: 1 after OR, 3 after manipulation, 2 after traction, 1 during application of cast		
	Variety of treatments used to reduce deformity (4.3%)	Radiculopathy: 1 (occurred when tongs slipped during traction)		Only conclusion is that neurological deterioration can occur.
		Deterioration delayed in 11 patients		

(Continues)

TABLE. Continued

Citation	Description of Study	Results	Evidence Class	Conclusions
Hadley et al, ³⁸ <i>Neurosurgery</i> , 1992	68 patients	58% of patients had successful reduction	III	Early decompression by reduction led to improved outcomes based on fact that patients who did best were reduced early (< 5-8 h). No comparison possible between CR and ORIF because of small numbers.
	Retrospective series	Overall, most patients (78%) demonstrated neurological recovery by last follow-up (not quantified)		1.2% permanent deficit (root) related to traction.
	Facet fracture dislocations only	7 patients deteriorated during "treatment" (6 improved following ORIF, 1 permanent root deficit following traction)		
	Unilateral and bilateral locked facets	No MRI data reported		
	66 treated with early attempted closed reduction (2 late referrals)			
	Average weights used for successful reduction were between 9 and 10 lb per cranial level			
Beyer et al, ²⁴ <i>Journal of Bone and Joint Surgery</i> , 1991	34 patients	Reduction successful in 10 of 28 injuries; 3 patients with residual neurological problems	III	Open reduction more successful in maintaining reduction than halo vest treatment.
	Retrospective series			
	24 treated nonsurgically 10 treated with open reduction and posterior fusion			
Star et al, ⁵ <i>Spine</i> , 1990	57 patients	53 of 57 (93%) reduced	III	Closed reduction is safe and effective for decompressing cord and establishing spinal alignment.
	Retrospective series	Mean time to reduction was 8 h		
	Unilateral and bilateral injuries	No patient deteriorated a Frankel grade		
	Early rapid reduction attempted in all patients	2 patients lost root function, 1 transiently		
	No MRI done before reduction	45% improved 1 Frankel grade by time of discharge; 23% improved less substantially		
	1 patient was a delayed transfer	75% of patients required > 50 lb		
	Weights up to 160 lb (began at 10 lb)			
	Frankel grades recorded at admission and discharge			

(Continues)

TABLE. Continued

Citation	Description of Study	Results	Evidence Class	Conclusions
Sabiston et al, ²¹ <i>Journal of Trauma</i> , 1988	39 patients	35 of 39 (90%) patients successfully reduced	III	Closed reduction with up to 70% of body weight is safe and effective for reducing locked facets.
	Retrospective series, unilateral and bilateral injuries	Average weight used, 62.5 lb		Authors state that patients seen in delayed fashion (> 10 d) are unlikely to reduce (no evidence presented).
	Up to 70% of body weight used	No neurological deterioration		
	All acute injuries	Failures due to surgeon unwillingness to use more weight		
Maiman et al, ⁴⁸ <i>Neurosurgery</i> , 1986	No MRI		III	Mixed group of patients and treatments. In general, traction seemed to be safe.
	28 patients	10 of 18 reduced with traction		
	Variety of treatments offered	No patient treated by authors deteriorated		
Kleyn, ⁴² <i>Paraplegia</i> , 1984	No MRI	1 referred patient had an overdistraction injury	III	Traction followed by MUA is safe, usually (80%) effective, and may result in improved neurological function.
	18 patients had attempt at closed reduction (maximum weight, 50 lb)			
	101 patients	82 of 101 successfully reduced (4 open reduction, 6 partial reduction accepted, 9 no further attempt owing to poor condition of patient)		
	Unilateral and bilateral, all with neurological involvement	37 of 45 incomplete lesions improved		
	All treated with traction	7 of 56 complete lesions improved		
	If injury < 24 h, MUA attempted initially; if reduction fails with maximum of 18 kg weight, MUA performed	No neurological deterioration		
Sonntag, ⁷ <i>J Neurosurg</i> , 1981	Before MRI		III	Stepwise algorithm (traction, manual manipulation, operative reduction) is indicated. Closed reduction by weight application is the preferred method for reduction of deformity.
	15 patients	Reduction with traction successful in 10 patients		
	Retrospective analysis	5 failed: 1 with C1 fracture that did not allow traction, 2 with fractured facets, 1 with radicular symptoms worsened by traction (transient), 1 with an ascending spinal cord injury (patient died of pulmonary complications 2 wk later)		
	All bilateral locked facets			
	All acute injuries			

(Continues)

TABLE. Continued

Citation	Description of Study	Results	Evidence Class	Conclusions
Shrosbree, ⁶ <i>Paraplegia</i> , 1979-1980	Manual traction, tong traction, and open reduction used			
	216 patients identified with locked facets	70 of 95 unilaterals reduced (74%)	III	Discarded patients and lack of statistical analysis preclude firm statements. Highly suggestive paper. Conclusions: Traction followed by manipulation is safe and usually effective, and reduction seems to improve outcome (or patients who are reducible do better).
	Used traction (no weight specified) followed by manipulation under anesthesia if traction failed	77 of 121 bilaterals reduced (64%)		
	Before MRI	No neurological morbidity reported		
Burke and Berryman, ¹¹ <i>Journal of Bone and Joint Surgery</i> , 1971	86 died within 3 mo, excluded from series	Patients who were successfully reduced improved more often than patients who were not successfully reduced (41% vs 32% unilateral, 16% vs 0% bilateral)		MUA and traction both safe if proper diagnosis and careful attention paid to radiographs.
	41 patients treated by MUA, light traction followed by induction of anesthesia and intubation, followed by manipulation under anesthesia if necessary (same as Evans)	37 of 41 successfully reduced by MUA	III	
	32 patients treated with traction alone	21 of 25 reduced with traction before anesthetic		
	3 treated by traction after manipulation failed	7 patients were judged too sick for anesthesia and underwent traction for stabilization, not reduced		
	C7-T1 not attempted	2 cases of neurological deterioration: 1 overdistraction, 1 unrecognized injury		
	Before MRI	No neurological deterioration noted	III	
Evans, ³⁰ <i>Journal of Bone and Joint Surgery</i> , 1961	17 patients treated by induction of anesthesia and intubation, sometimes with manipulation under anesthesia			Reduction under anesthesia safe and effective. Small series.
	Before MRI	All successfully reduced, 2 unchanged, 2 died, 13 improved		

^aASIA, American Spinal Injury Association; CT, computed tomography; MRI, magnetic resonance imaging; MUA, manipulation under anesthesia; OR, operating room.

injuries, the clinical importance of these findings is unknown. Only 2 case reports were found that document neurological deterioration caused by disk herniation following successful closed traction-reduction. In addition, several investigators have demonstrated the

lack of correlation between the MRI findings of disk herniation and neurological deterioration in this patient population. The use of prereduction MRI has therefore not been shown to improve the safety or efficacy of closed traction-reduction of patients with acute

cervical fracture dislocation injuries. MRI before fracture/dislocation reduction may unnecessarily delay spinal column realignment for decompression of the spinal cord. There is Class III medical evidence that supports early closed reduction of cervical fracture/dislocation injuries with respect to neurological recovery. Prereduction MRI in this setting is not necessary. The ideal timing of closed reduction of cervical spinal fracture dislocation injuries is unknown, but many investigators favor reduction as rapidly as possible after injury to maximize the potential for neurological recovery.^{10,15,29-32}

Patients who fail attempted closed reduction of cervical fracture injuries have a higher incidence of anatomic obstacles to reduction, including facet fractures and disk herniations. Patients who fail closed reduction should undergo more detailed radiographic study/MRI before attempts at open reduction. The presence of a significant disk herniation in this setting is a relative indication for an anterior decompression procedure, either in lieu of or preceding a posterior procedure.

Patients with cervical fracture dislocation injuries who cannot be examined because of head injury or intoxication cannot be assessed for neurological deterioration during attempted closed reduction. For this reason, an MRI before attempted reduction (open or closed) is recommended as a treatment option on the basis of Class III medical evidence.

KEY ISSUES FOR FUTURE INVESTIGATION

A prospective cohort study of patients with cervical spinal cord injuries resulting from facet fracture-subluxation injuries treated with or without prereduction MRI would provide Class II medical evidence in support of a treatment recommendation on this issue. This type of comparative study could also address issues of timing of closed reduction.

No prospective comparative study of closed reduction vs anterior decompression and stabilization for patients with MRI-documented herniated disks in association with unreduced cervical fracture/dislocation injuries has been performed. A prospective comparative study would provide Class II medical evidence in support of a treatment recommendation on this issue.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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The Acute Cardiopulmonary Management of Patients With Cervical Spinal Cord Injuries

Timothy C. Ryken, MD, MS*

R. John Hurlbert, MD, PhD,
FRCSCT†

Mark N. Hadley, MDS

Bizhan Aarabi, MD, FRCSCT¶

Sanjay S. Dhall, MD||

Daniel E. Gelb, MD#

Curtis J. Rozzelle, MD**

Nicholas Theodore, MD‡‡

Beverly C. Walters, MD, MSc,
FRCSCT§§§

*Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa; †Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada; ‡Division of Neurological Surgery and; **Division of Neurological Surgery, Children's Hospital of Alabama, University of Alabama at Birmingham, Birmingham, Alabama; ¶Department of Neurosurgery and; #Department of Orthopaedics, University of Maryland, Baltimore, Maryland; ||Department of Neurosurgery, Emory University, Atlanta, Georgia; ‡‡Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona; §§Department of Neurosciences, Inova Health System, Falls Church, Virginia

Correspondence:

Mark N. Hadley, MD, FACS, UAB
Division of Neurological Surgery,
510 – 20th St S, FOT 1030,
Birmingham, AL 35294-3410.
E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS

Level III:

Management of patients with an acute cervical spinal cord injury in an intensive care unit or similar monitored setting is recommended.

- Use of cardiac, hemodynamic, and respiratory monitoring devices to detect cardiovascular dysfunction and respiratory insufficiency in patients following acute spinal cord injury is recommended.
- Correction of hypotension in spinal cord injury (systolic blood pressure < 90 mm Hg) when possible and as soon as possible is recommended.
- Maintenance of mean arterial blood pressure between 85 and 90 mm Hg for the first 7 days following an acute spinal cord injury is recommended.

RATIONALE

The intensive care unit (ICU) setting has traditionally been reserved for critically ill patients who require aggressive medical care and exceptional medical attention. Most contemporary medical centers have multiple critical care units, each designed to provide discipline-specific observation and intensive care to patients in need. Select institutions have created Acute Spinal Cord Injury Centers and offer multidisciplinary care including ICU care to patients who have sustained acute spinal cord injuries (SCIs).¹⁻¹⁰ Several reports describe improved patient management and

lower morbidity and mortality following acute SCI with ICU monitoring and aggressive medical management.^{2-4,6-10} Despite this interest in and commitment to more comprehensive care for the patient with an acute SCI, many traumatic SCI patients are not managed in an ICU setting, nor are they routinely monitored for cardiac or respiratory dysfunction. There exist divergent management strategies for acute SCI patients within regions, communities, even institutions, depending on the training and experiences of the clinicians providing care.

Respiratory insufficiency and pulmonary dysfunction are common after traumatic SCI, particularly when the injury occurs at cervical spinal cord levels.^{2,3,6,8,11-14} Severely injured patients demonstrate marked reductions in expected vital capacity and inspiratory capacity and may experience relative hypoxemia, all of which contribute to global hypoxemia and can exacerbate spinal cord ischemia after acute injury.^{6,9,11-14} It appears that the earlier cardiac and/or ventilatory/pulmonary dysfunction is detected, the more likely effective, often life-saving treatment can be initiated. It is for these reasons that the issues of early ICU care and cardiac and pulmonary monitoring for human patients following acute SCI have been raised.

Acute traumatic SCI is frequently associated with systemic hypotension. Hypotension may be due to hypovolemia, direct severe spinal cord trauma itself, or a combination of the two. The presence of hypotension has been shown to be associated with worse outcomes after traumatic injury, including severe head injury.^{1,4,14-17} Although a prospective controlled assessment of the effects of hypotension on acute human SCI has not been performed, laboratory evidence suggests that hypotension contributes to secondary injury after acute SCI by further reducing spinal cord blood flow and perfusion.^{5,6,12,13,15-21}

ABBREVIATIONS: ASIA, American Spinal Injury Association; ICU, intensive care unit; MAP, mean arterial pressure; SCI, spinal cord injury

Hypotension in animal models of SCI results in worse neurological outcome.^{9,11,17,22-25}

Several clinical series of human patients with acute SCI managed in an aggressive fashion with attention to blood pressure, oxygenation, and hemodynamic performance report no deleterious effects of therapy and suggest improved neurological outcome.^{9,11,17,22-25} Despite these observations, many patients with acute SCI treated in contemporary practice are not routinely monitored in an ICU setting or treated with blood pressure augmentation after injury. For these reasons, the issues of routine blood pressure support and threshold levels of mean arterial pressure (MAP) maintenance following acute SCI have been raised.

The previous medical evidence-based guideline effort by the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons addressed the role of systemic blood pressure support and the role of the intensive care setting in 2 separate chapters.^{26,27} The purpose of the current review is to update the medical evidence on the diagnosis and treatment of these issues since the original 2 medical evidence-based guidelines were published in 2002 and to address the following questions:

- Do patients with acute spinal cord injuries benefit from ICU cardiac, hemodynamic, and pulmonary monitoring and care?
- Does blood pressure management influence neurological outcome in patients with acute cervical SCI?

SEARCH CRITERIA

A National Library of Medicine (PubMed) computerized literature search from 2000 to 2011 was undertaken using Medical Subject Headings in combination with “spinal cord injury”: medical management, nonoperative management, hypotension, spinal cord blood flow, respiratory insufficiency, pulmonary complications, and intensive care unit. Approximately 3500 citations were acquired. Non-English-language citations were excluded. Titles and abstracts of the remaining publications were reviewed, and relevant articles were selected to develop the guidelines. We focused on 4 specific topics concerning human patients with acute SCI: management in an ICU, cardiac instability, hypotension, and respiratory/pulmonary dysfunction. Additional citations were extracted from the reference lists of the remaining papers. Finally, members of the author group were asked to contribute articles known to them on the subject matter that were not found by other search means. Articles describing economics, epidemiology, anesthesia, monitoring techniques, penetrating cord injuries, nursing care, infectious or urologic complications, chronic complications, or remote SCIs were excluded. These efforts resulted in 11 articles, which form the foundation for this updated review. All studies provided Class III medical evidence. Twenty-seven articles are summarized in Evidentiary Table format (Table).

SCIENTIFIC FOUNDATION

In 1976, Zäch et al¹⁰ reported on a prospective medical management paradigm in the treatment of 117 consecutive acute

SCI patients in the Swiss Paraplegic Centre of Basel, Switzerland. All patients were treated in the ICU with central venous pressure monitoring and were administered dexamethasone 0.5 mg/kg for 4 days with a tapering dose through 10 days and volume expansion with Rheomacrodex 40 at 500 mL/d for 7 days. Patients were stratified by injury level, degree of deficit (Frankel grade), and time of admission after injury. The authors reported that 62% of cervical-level SCI patients they managed in this way improved at last follow-up, including 8 of 18 Frankel grade A patients, 2 by 2 grades and a third patient by 3 grades. No patient with a cervical injury worsened; 38% were unchanged from admission. Patients with thoracic T1-T10-level SCIs fared less well; 38% improved, none worsened, and 62% were without change, including 22 of 26 Frankel grade A patients. Two Frankel grade A patients experienced a complete recovery. Seventy percent of acute T11-L1-level SCI improved with this treatment paradigm, none worsened, and 30% were unchanged from admission. Of patients who arrived within 12 hours of injury, 67% were improved compared with their admission neurological examination. Of patients admitted between 12 and 48 hours of injury, only 59% improved. When admission occurred after 48 hours of injury, improvement was seen in only 50% of patients. The authors concluded that early transfer and “immediate medical specific treatment of the spinal injury” with attention to maintenance of acceptable blood pressure appeared to improve neurological recovery.

That same year, Hachen³ reported a decade of experience with acute traumatic tetraplegia from the National Spinal Injuries Centre in Geneva. He described 188 acute SCI patients treated in an ICU setting following immediate transfer from the scene of the injury. The center reported a marked reduction in mortality rates following acute cervical SCI compared with annual statistics from 1966. Mortality for complete tetraplegia was reduced from 32.5% to 6.8% over the 10-year period. Mortality for patients with incomplete tetraplegia fell from 9.9% in 1966 to 1.4% in 1976. Most early deaths in the center’s experience were related to pulmonary complications. The likelihood of severe respiratory insufficiency was related to the severity of the cervical SCI. Seventy percent of patients with complete lesions experienced severe respiratory insufficiency in the center’s experience compared with 27% of patients with incomplete lesions. The improvement in mortality rates described was related directly to early monitoring and treatment of respiratory insufficiency in the ICU setting. Hachen stressed that facilities for continuous monitoring of central venous pressure, arterial pressure, pulse, respiration rate and pattern, and oxygenation-perfusion parameters must be available for all patients with neurological injuries following acute SCI, particularly those injuries above the C6 level.

In 1979, Gschaedler et al² described the comprehensive management of 51 patients with acute cervical SCIs in an ICU setting in Colmar, France. Forty percent of patients had multiple organ system injuries. They reported a low mortality rate of 7.8% and described several severely injured patients who made important neurological improvements, including 1 Frankel grade

A patient who improved to grade D and 2 Frankel grade B patients who changed to grade D. They cited early transport after injury and comprehensive intensive medical care with attention to and the avoidance of hypotension and respiratory insufficiency as essential to the improved outcomes their patients experienced.

McMichan et al¹⁴ reported a prospective case series in 1980 of pulmonary complications identified in 22 patients with cervical-level acute SCI managed in an ICU setting. They compared their results with 22 historical controls with similar injuries. Institution of a new, aggressive pulmonary treatment paradigm resulted in zero deaths and fewer respiratory complications compared with those experienced by the retrospective group (9 deaths). They concluded that vigorous pulmonary therapy initiated early after acute SCI was associated with increased survival, a reduced incidence of pulmonary complications, and a decreased need for ventilatory support.

Ledsome and Sharp¹¹ measured pulmonary function in 16 patients with complete cervical SCI and compared initial values with those obtained in the same patients at 1, 3, and 5 weeks and 3 and 5 months after injury. In their 1981 report, they noted profound reduction in forced vital capacity (FVC) and expiratory flow rate immediately after injury. Patients with an FVC < 25% of expected had a high incidence of respiratory failure requiring ventilator support. This was especially true of patients with injuries at C4 or above. FVC was significantly increased at 5 weeks after injury and doubled at 3 months regardless of the level of cervical cord injury. Importantly, hypoxemia ($PO_2 < 80$ mm Hg) was identified through blood gas analyses in 74% of patients who did not require ventilator support despite adequate alveolar ventilation (PCO_2 normal; low FVC). The authors attributed this to a ventilation perfusion imbalance occurring immediately after acute SCI. Systemic hypoxemia responded to treatment with supplemental oxygen in most patients.

Piepmeyer et al⁵ identified cardiovascular instability following acute cervical SCI in 45 patients they managed in an ICU setting in New Haven, Connecticut. Twenty-three patients had Frankel grade A injuries, 8 had grade B, 7 had grade C, and 7 had grade D. They discovered a high incidence of cardiovascular irregularities in these patients and identified a direct correlation between the severity of cord injury and incidence and severity of cardiovascular problems. Three patients returned to the ICU setting during the 2-week observation period of the study because of cardiac dysfunction despite a period of initial stability. Twenty-nine of the 45 patients had an average daily pulse rate of < 55 bpm, and 32 had episodes during which their pulse rate was < 50 bpm for a prolonged period of time. Hypotension was common after acute SCI in their series, but most patients responded well to volume replacement. However, 9 patients required vasopressors ranging over a period from hours to 5 days to maintain systolic pressure > 100 mm Hg. Cardiac arrest occurred in 5 patients (11%). All had Frankel grade A injuries. Three arrests occurred during endotracheal suctioning. The authors found that the first week after injury was the timeframe during which patients were most vulnerable to cardiovascular instability. Patients with the most

severe neurological injuries were most likely to experience cardiovascular instability after acute SCI regardless of autonomic function. They concluded that careful monitoring of severely injured acute SCI patients in the ICU setting reduces the risk of life-threatening emergencies.

In 1984, Tator and colleagues⁸ described their experience with 144 patients with acute SCI managed between 1974 and 1979 at a dedicated SCI unit at Sunnybrook Medical Centre in Toronto, Ontario, Canada. They compared their results with a cohort of 358 SCI patients managed between 1948 and 1973 before the development of the acute care SCI facility. All 144 patients managed from 1974 to 1979 were treated in an ICU setting with strict attention to the treatment of hypotension and respiratory failure. Their medical paradigm was developed on the principle “that avoiding hypotension is one of the most important aspects of the immediate management of acute cord injury.” Hypotension was “treated vigorously” with crystalloid and transfusion of whole blood or plasma for volume expansion. Patients with respiratory dysfunction were treated with ventilatory support as indicated. They reported a reduced mean time from injury to admission and treatment (5 hours) compared with their 1948 to 1973 experience (> 12 hours). Neurological improvement was observed in 41 of 95 patients (43%) managed under the aggressive ICU medical paradigm. Fifty-two patients (55%) demonstrated no improvement. Only 2 patients (2%) deteriorated. The authors reported lower mortality, reduced morbidity, shorter length of stay, and lower cost of treatment compared with the 1948 to 1973 experience a result of this aggressive ICU strategy. They cited improved respiratory management in their ICU as one of the principal factors responsible for reduced mortality and credited the avoidance of hypotension, sepsis, and urologic complications for reduced morbidity after injury. These improved outcomes were realized despite the fact that 28% of the acute SCI patients they treated had additional injuries that increased their risk of morbidity and mortality.

In a 1987, Lehmann et al²⁸ reported on 71 acute SCI patients managed in an ICU at Yale/New Haven Medical Center. Patients were admitted within 12 hours of SCI and stratified by level and severity of neurological injury (Frankel scale). Patients were excluded if they harbored comorbidities such as head injury, diabetes mellitus, preexisting cardiac disease, or a history of cardiac medication use. All were monitored; hypotension was aggressively treated. The authors found that all patients with severe cervical SCIs (Frankel grades A and B) had prolonged bradycardia defined as heart rate < 60 bpm lasting at least 1 day. Thirty-five percent of Frankel grade C and D patients also demonstrated prolonged bradycardia. Only 13% of thoracic and lumbar SCI injuries had this finding. Marked bradycardia (< 45 bpm) was frequent in patients with severe cervical SCI (71%) and less common in patients with more mild cervical (12%) and thoracolumbar (4%) SCI. Sinus node slowing was profound enough to produce hemodynamic compromise and systemic hypotension necessitating bolus injections of atropine or placement of a temporary pacemaker in 29% of the severe cervical SCI

patients. Episodic hypotension unrelated to hypovolemia was identified in 68% of the severe cervical injury group, requiring the use of intravenous pressors in half. Five of 31 patients (16%) in the severe injury group experienced a primary cardiac arrest, three of which were fatal. All 5 patients had Frankel grade A SCI. There were no significant cardiac rate disturbances or spontaneous episodes of hypotension beyond 14 days of injury. The authors concluded that potentially life-threatening cardiac arrhythmias and hypotension regularly accompany acute severe injury to the cervical spinal cord within the first 14 days of injury. These events were not solely attributable to disruption of the autonomic nervous system. Detection and treatment were best accomplished in an ICU setting.

Wolf et al²⁹ in 1991 described their experience with bilateral facet dislocation injuries of the cervical spine at the University of Maryland in Baltimore. Fifty-two patients with acute cervical trauma were reviewed who received ICU care, volume resuscitation, invasive monitoring, and hemodynamic manipulation to maintain mean blood pressure > 85 mm Hg for 5 days. Thirty-four patients had complete neurological injuries, 13 had incomplete injuries, and 5 patients were intact. The authors attempted closed reduction within 4 hours of patient arrival to their center and performed early open reduction on patients who could not be reduced by closed means, including closed reduction under anesthesia. All but 3 patients underwent surgery for stabilization and fusion. The authors reported neurological improvement at discharge in 21% of complete SCI patients and in 62% of patients with incomplete cervical SCI. No intact patient deteriorated. Only 52% 1-year follow-up was provided. The authors concluded that their protocol of aggressive, early medical and surgical management of patients with acute SCI improved outcome following injury. Treatment in the ICU setting, hemodynamic monitoring with maintenance of MAP, and early closed or open decompression of the spinal cord were linked to a reduction of secondary complications.

Levi and coworkers⁴ treated 50 acute cervical SCI patients in the ICU at the University of Maryland in Baltimore according to an aggressive management protocol that included invasive hemodynamic monitoring and volume and pressor support to maintain a hemodynamic profile with adequate cardiac output and mean blood pressure > 90 mm Hg. Their 1993 report described 31 patients with Frankel grade A injuries on admission, 8 patients with Frankel grade B injuries, and 11 patients in Frankel C and D grades. Eight patients had severe hypotension at the time of admission (systolic blood pressure < 90 mm Hg), whereas 82% of patients developed volume-resistant hypotension requiring pressors within the first 7 days of treatment. This was 5½ times more common among patients with complete motor injuries. The authors reported that the overall mean pulmonary vascular resistance index for the 50 patients they studied was less than the normal range, and it was less than the normal value in 58% of patients. Half of their acute SCI patients had a lower-than-normal systemic vascular resistance index. No patient with a complete motor deficit (Frankel grades A and B) and marked

pulmonary vascular resistance index/systemic vascular resistance index deficits experienced neurological recovery at 6 weeks. Forty percent of patients managed by protocol including several with complete injuries had some degree of neurological function improvement, 42% remained unchanged, and 9 patients died (18%). There was minimal morbidity associated with invasive hemodynamic monitoring. The authors concluded that hemodynamic monitoring in the ICU allows early identification and prompt treatment of cardiac dysfunction and hemodynamic instability and can reduce morbidity and mortality following acute SCI.

Vale et al⁹ reported their results in 1997 from a prospective case series in which aggressive medical resuscitation and blood pressure management were performed on 77 patients with acute SCI treated at the University of Alabama in Birmingham. All patients were managed in the ICU with invasive monitoring (Swan Ganz catheters and arterial lines) and blood pressure augmentation to maintain MAP > 85 mm Hg for 7 days after injury. They reported 10 patients with complete cervical SCI (American Spinal Injury Association [ASIA] grade A), 25 with incomplete cervical injuries (ASIA grades B, C, and D), 21 patients with complete thoracic SCI, and 8 patients with incomplete thoracic-level SCI (grades B, C, and D). The average admission MAP for ASIA A cervical patients was 66 mm Hg. Nine of 10 patients required pressors following volume replacement to maintain an MAP of 85 mm Hg. Fifty-two percent of incomplete cervical SCI patients required pressors to maintain MAP at 85 mm Hg. Only 9 of 29 patients with thoracic-level SCI required the use of pressors. The authors reported minimal morbidity with the use of invasive monitoring or with pharmacological therapy to augment MAP. At 1-year follow-up (mean, 17 months), neurological recovery was variable and typically incomplete. Three of 10 cervical ASIA A patients regained ambulatory capacity, and 2 regained bladder function. Incomplete cervical SCI patients fared better. Twenty-three of these patients regained ambulatory function at 12 months of follow-up, only four of whom had initial examination scores consistent with ambulation. Twenty-two of 25 patients (88%) regained bladder control. Thirty-one of 35 cervical SCI patients and 27 of 29 thoracic-level SCI patients were treated surgically. The authors statistically compared selection for and timing of surgery with admission neurological function and compared surgical treatment, early and late, with neurological outcome and found no statistical correlation. They concluded that the enhanced neurological outcome identified in their series after acute SCI was optimized by early and aggressive volume resuscitation and blood pressure augmentation and was in addition to and/or distinct from any potential benefit provided by surgery.

In 2001, Vitaz et al³⁰ described a clinical pathway for SCI management developed in multidisciplinary fashion and compared the results before and after implementation. Thirty-six patients in the study group were compared with 22 control patients. Study group patients had 6.8 fewer ICU days, 11.5 fewer hospital days, 6 fewer ventilator days ($P < .05$), and a lower

rate of complications. The authors concluded that the use of a clinical care pathway for SCIs resulted in improved patient care and fewer complications. Despite the prospective comparison, the groups were not comparable and the study was considered to provide Class III medical evidence.

Aito³¹ prospectively assessed the incidence of complications associated with acute SCI on the basis of the type of facility in which the acute care of the traumatic SCI was provided. In their 2003 publication, nearly all of the described complications they identified occurred in patients not initially admitted to a specialized SCI unit, including respiratory complications, deep-vein thrombosis, pulmonary embolism, trophic skin changes, heterotopic ossification, and urinary complications. The authors concluded that prevention of complications during the acute phase after SCI is best accomplished by early admission to a specialized multidisciplinary SCI unit.

Como et al³² characterized the need for mechanical ventilation in patients with acute cervical SCI and neurological deficits. Their 2005 study included 119 patients, of whom 45 (37%) had complete SCI. Twelve patients (27%) had injury levels from C1 to C4. Nineteen (42%) had a C5 injury level, and 14 (31%) had an injury level of C6 or below. Eight of the complete injury patients died (mortality, 18%). All patients with complete SCI at the C5 level and above required a definitive airway and tracheostomy. Of patients with a complete SCI at C6 or below, 79% required intubation and 50% eventually required tracheostomy. From these results, the authors recommended consideration of early intubation for patients with complete SCI, especially for patients with injuries at the C5 level or above.

Berlly and Shem³³ in 2007 reported on acute respiratory management following acute SCI. They found that respiratory complications were frequent and were the most common cause of morbidity among acute SCI patients (36% of total complications). Respiratory failure was the most common cause of mortality in their series, cited in 86% of deaths following acute SCI. Ventilatory failure occurred on average 4.5 days after acute SCI. The authors concluded that the incidence of respiratory complications can be significantly reduced by transfer of acute SCI patients to an SCI center. Hassid et al³⁴ reviewed nearly 55 000 Level I trauma patients and identified a subgroup of 186 patients with isolated acute cervical SCI. They reported that early intubation for acute complete SCI patients is mandatory. They favor close observation of incomplete SCI patients and immediate airway intervention should the patient manifest any evidence of respiratory failure.

Guly et al³⁵ found an incidence of neurogenic shock (systolic blood pressure < 100 mm Hg and heart rate < 80 bpm) of 19.3% (95% confidence interval, 14.8-23.7) in a series of 490 patients with acute SCI. In 2006, Franga et al³⁶ described an incidence of cardiovascular instability of 17%, including bradyarrhythmias requiring permanent pacemaker placement among 30 acute complete cervical SCI patients. Neumann et al³⁷ performed a retrospective review of mortality following SCI. They found that Glasgow Coma Scale score < 9, the need

for vasopressors to support mean blood pressure, and mechanical ventilation were predictors of mortality among acute SCI patients. All of these investigators favor ICU care for monitoring and treatment of acute SCI patients, particularly those with more severe injuries.

Macias et al³⁸ evaluated the importance of admission to a specialized trauma center on the incidence of paralysis in patients with acute SCI. Their 2009 review included 4121 patients diagnosed with traumatic SCI treated at 100 trauma centers and 601 other local and regional medical facilities. Mortality was 7.5%, and the incidence of paralysis, based on the reported discharge diagnosis, was 16.3%. A designated trauma center provided the initial care in 57.9% of the patients (n = 2378). Multivariate analysis determined that the incidence of paralysis was significantly lower at designated trauma centers compared with local and regional hospitals without trauma center designation (adjusted odds ratio, 0.67; 95% confidence interval, 0.53-0.85; *P* = .001). There was no significant difference in the incidence of mortality between the 2 types of facilities. The authors concluded that early admission to a designated trauma center significantly reduces the incidence of paralysis following acute SCI.

Berney et al³⁹ described their experience with the pulmonary/ventilatory care of 114 acute SCI patients. They described a clinical pathway (classification and regression tree) to assist in clinical decision making regarding airway management in patients following acute cervical SCI. The following variables were considered crucial in predicting the need for aggressive airway management: FVC, the volume of pulmonary secretions, and gas exchange. The use of these variables in their regression tree analysis allowed accurate prediction of the need for airway management in > 82% of their patients and predicted extubation success in the vast majority of ventilated patients (8.7% extubation failure rate).

In a subsequent publication, the same group performed a literature review on respiratory complications associated with acute cervical SCI.⁴⁰ They identified 21 studies including 1263 patients that described definitive protocols for the respiratory management of acute cervical SCI. Although the majority of the reports were case series, the authors discovered that mortality (adjusted risk ratio = 0.4; 95% confidence interval, 0.18-0.61), the incidence of respiratory complications (adjusted risk ratio = 0.36; 95% confidence interval, 0.08-0.58), and the requirement for a tracheostomy (adjusted risk ratio = 0.18; 95% confidence interval, -0.05 to 0.4), were all significantly reduced when care givers/institutions used a respiratory protocol in the management of acute SCI patients. Specifically, the use of a clinical pathway reduced the duration of mechanical ventilation by 6 days (95% confidence interval, -0.56 to 12.56) and ICU length of stay by 6.8 days (95% confidence interval, 0.17-13.77).

SUMMARY

Patients with acute cervical SCI frequently develop hypotension, hypoxemia, pulmonary dysfunction, and cardiovascular instability, often despite initial stable cardiac and pulmonary function. These

TABLE. Evidentiary Table: Cardiopulmonary Management^a

Citation	Description of Study	Evidence Class	Conclusions
Berney et al, ³⁹ <i>Spinal Cord</i> , 2011	Prospective observational study of a clinical pathway for airway management in 114 patients with acute cervical spine injury	III	Forced vital capacity, the volume of pulmonary secretion, and gas exchange were predictive of airway management on 82.3% occasion with an 8.7% extubation failure rate. The authors conclude that a clinical pathway of respiratory management was useful in clinical decision making.
Berney et al, ⁴⁰ <i>Spinal Cord</i> , 2011	Systematic review of acute respiratory management of cervical SCI in the first 6 wk after injury	III	The authors have demonstrated that a clinical pathway with a structured respiratory protocol is effective in reducing respiratory complications, ventilator time, and intensive care unit length of stay.
Casha and Christie, ⁴¹ <i>Journal of Neurotrauma</i> , 2010	Systematic review of intensive cardiopulmonary management following acute SCI	III	Class III as the majority of articles included are case series. Because of the high incidence of cardiopulmonary complications, acute SCI patients should be managed in monitored unit.
Ploumis et al, ⁴² <i>Spinal Cord</i> , 2010	Systematic review of the evidence supporting a role for vasopressor support in acute SCI	III	There is Class III evidence supporting the maintenance of MAP > 85 mm Hg for a period extending up to 1 wk following acute SCI. No statistical difference in neurological improvement with vasopressor support with an MAP of < 85 mm Hg and those with MAP < 90 mm Hg.
Neumann et al, ³⁷ <i>Journal of Trauma</i> , 2009	Retrospective study of risk factors for mortality in traumatic cervical SCI	III	The authors conclude that there is no gold standard on vasopressor support and that cervical cord injuries require vasopressors more frequently than other SCIs ($P < .001$). Independent predictors for mortality were Glasgow Coma Scale score < 9 and vasopressor use.
Guly et al, ³⁵ <i>Resuscitation</i> , 2008	Database review to determine the incidence of neurogenic shock in patients with isolated SCI	III	The authors conclude that Glasgow Coma Scale score < 9, mechanical ventilation, and vasopressor use were predictors of mortality. Incidence of neurogenic shock in cervical cord injuries was 19.3% (95% confidence interval, 14.8-23.7) vs in 7% (95% confidence interval, 3-11.1) in the thoracic or 3% (95% confidence interval, 0-8.85) in the lumbar spine cord.
Hassid et al, ³⁴ <i>Journal of Trauma</i> , 2008	Database review of 54 838 consecutive Level I trauma patients	III	Respiratory complications in SCI are frequent. Early intubation is mandatory for complete SCI patients. For incomplete patients, close observation for any evidence of respiratory failure should prompt immediate airway intervention.
Berly and Shem, ³³ <i>Journal of Spinal Cord Medicine</i> , 2007	Retrospective review of respiratory management during the first 5 d after SCI	III	Morbidity and mortality following acute SCI were 36% and 83%, respectively, with ventilatory failure occurring an average 4.5 d following injury.

(Continues)

TABLE. Continued

Citation	Description of Study	Evidence Class	Conclusions
			The authors recommend transfer to a center specializing in acute management of SCI to reduce the number of respiratory complications.
Franga et al, ³⁶ <i>The American Surgeon</i> , 2006	Retrospective evaluation of recurrent asystole resulting from high cervical SCIs	III	5 of 30 (17%) patients with complete cervical SCIs required placement of permanent cardiac pacemakers for recurrent bradycardia/asystolic events.
Como et al, ³² <i>Journal of Trauma</i> , 2005	Retrospective review evaluating the need for mechanical ventilation following cervical SCI in the presence of neurological deficit	III	The authors recommend considering early intubation, particularly with a complete injury at C5 or above.
Vitaz et al, ³⁰ <i>Journal of Spinal Disorders</i> , 2001	Prospective comparison of patients treated with and without a clinical pathway for treatment of acute SCI	III	The authors demonstrate that the use of a clinical care pathway for SCIs resulted in improved patient care and fewer complications.
Lu et al, ¹² <i>Spine</i> , 2000	Retrospective review of apnea in 36 acute SCI patients	III	Delayed apnea most likely in acute SCI patients with severe, diffuse acute SCI. Apnea most likely within first 7-10 d.
Bötel et al, ¹⁸ <i>Spinal Cord</i> , 1997	225 acute SCI patients treated in ICU; only 87 admitted within 24 h of injury	III	Significant numbers of multiply injured and head-injured patients. The percentage of complete injuries not recorded. Improved outcome when admitted to ICU early after injury
Vale et al, ⁹ <i>Journal of Neurosurgery</i> , 1997	Prospective assessment of 77 acute SCI patient treated in ICU, aggressive hemodynamic support, MAP > 85 mm Hg	III	Improved outcome with aggressive medical care, distinct from potential benefit from surgery at 1-y follow-up.
Levi et al, ²⁰ <i>Neurosurgery</i> , 1993	50 patients treated in ICU, aggressive medical treatment, MAP > 90 mm Hg	III	Improved outcome with aggressive hemodynamic support at 6 wk after injury.
Tator et al, <i>Paraplegia</i> , 1993 ¹⁶	201 acute SCI patients, ICU care, hemodynamic support compared with 351 prior patients	III	Less severe cord injuries resulting from immobilization, resuscitation, and early transfer to ICU setting.
Wolf et al, ²⁹ <i>Journal of Neurosurgery</i> , 1991	52 patients with locked facets reduced within 4 h, ICU care, MAP > 85 mm Hg, 49 operated on: 23 on day 1, 26 delayed (mean, day 8.7)	III	Closed reduction 61%
			52% 1 year follow-up
			In general, improved neurological outcome with hemodynamic therapy.
Lehmann et al, ²⁸ <i>Journal of the American College of Cardiology</i> , 1987	71 consecutive acute SCI patients, ICU care, monitoring of cardiac/hemodynamic parameters	III	Bradycardia, 100%; hypotension (< 90 mm Hg systolic), 68%. Life-threatening bradyarrhythmias, 16% incidence related to severity of SCI.
Reines and Harris, ⁶ <i>Neurosurgery</i> , 1987	123 cases, acute SCI patients in ICU, aggressive pulmonary treatment	III	Respiratory insufficiency major cause of morbidity and mortality after ASCI. Aggressive ICU care, pulmonary treatment reduce incidence.
Piepmeyer et al, ⁵ <i>Central Nervous System Trauma</i> , 1985	45 ASCI patients, all managed in ICU setting with cardiac, hemodynamic monitoring	III	Cardiac dysrhythmia, hypotension, and hypoxia common in first 2 wk after ASCI. Incidence related to severity of injury.
Bose et al, ¹ <i>Neurosurgery</i> , 1984	28 patients with acute SCI, 22 managed in ICU setting	III	Improved neurological outcome at discharge for group 2 but better scores initially. Group 1 with intrinsic cord injury vs Group 2 compression on myelo and/or instability.
	Group 1: medical treatment		
	Group 2: medical/surgical treatment		

(Continues)

TABLE. Continued

Citation	Description of Study	Evidence Class	Conclusions
Tator et al, ⁸ <i>Canadian Journal of Surgery</i> , 1984	144 acute SCI patients, ICU care, hemodynamic support, compared with prior series	III	Improved neurological outcome, less mortality with early transfer, avoidance of hypotension, and ICU care.
Ledsome and Sharp, ¹¹ <i>American Review of Respiratory Disease</i> , 1981	Reassessment of pulmonary function in acute SCI patients, comparison over time	III	Reduced vital capacity, flow rates, and hypoxia after ASCI. Incidence related to severity of SCI. Marked improvement in pulmonary functions 3 mo after injury.
McMichan et al, ¹⁴ <i>Journal of the American Medical Association</i> , 1980	Prospective study of pulmonary complications in 22 acute SCI patients compared with 22 prior patients managed with aggressive ICU care	III	No deaths in series vs 9 of 22 deaths in prior group. ICU care and vigorous pulmonary therapy improves survival, reduces complications.
Gschaedler et al, ² <i>Paraplegia</i> , 1979	51 acute SCI patients managed in ICU, aggressive medical treatment, avoid hypotension	III	Improved morbidity and mortality with early transfer, avoidance of hypotension, respiratory insufficiency.
Hachen, ³ <i>Journal of Trauma</i> , 1977	188 acute SCI patients managed in center's ICU, aggressive treatment of hypotension, respiratory insufficiency	III	Reduced morbidity and mortality with early transfer, attentive ICU care and monitoring, and aggressive treatment of hypotension and respiratory failure.
Zäch et al, ¹⁰ <i>Paraplegia</i> , 1976	117 acute SCI patients at Swiss Center, ICU setting, aggressive blood pressure, volume therapy: Rheomacrodex × 5 d, dexamethasone × 10 d	III	Improved neurological outcome with aggressive medical treatment. Better outcome for early referrals.

^aICU, intensive care unit; MAP, mean arterial pressure; SCI, spinal cord injury.

complications are not limited to patients with complete SCI. Life-threatening cardiovascular instability and respiratory insufficiency may be transient and episodic and may be recurrent in the first 7 to 10 days after injury. Patients with the most severe neurological injuries appear to have the greatest risk of these life-threatening events. Class III medical evidence indicates that ICU monitoring allows the early detection of hemodynamic instability, cardiac disturbances, pulmonary dysfunction, and hypoxemia. Prompt treatment of these events in patients with acute SCI reduces cardiac- and respiratory-related morbidity and mortality.

Management in an ICU or other monitored setting appears to have an impact on neurological outcome after acute cervical SCI. Retrospective studies consistently report that volume expansion and blood pressure augmentation performed under controlled circumstances in an ICU setting are linked to improved ASIA scores in patients with acute SCI compared with historical controls. Class III medical evidence suggests that the maintenance of MAP at 85 to 90 mm Hg after acute SCI for a duration of 7 days is safe and may improve spinal cord perfusion and ultimately neurological outcome.

KEY ISSUES FOR FUTURE INVESTIGATION

The length of stay in the ICU setting necessary to provide optimal management of patients with acute SCI is unknown. The available

evidence suggests that most untoward and potentially life-threatening cardiac and respiratory events occur within the first 2 weeks of injury. Patients with less severe acute SCIs may require less time in a monitored setting than those patients with more severe injuries. Class II medical evidence is needed to guide treatment recommendations in these areas.

The issue of whether or not blood pressure augmentation has an impact on outcome following human SCI is important and deserves further study. If augmentation of MAP is determined to be of potential benefit, the most appropriate threshold levels of MAP and the length of augmentation therapy need definition. These questions may be best analyzed in a multi-institution prospective cohort study or a properly designed multi-institution retrospective case-control study.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Pharmacological Therapy for Acute Spinal Cord Injury

R. John Hurlbert, MD, PhD, FRCS*

Mark N. Hadley, MD‡

Beverly C. Walters, MD, MSc, FRCS‡§

Bizhan Aarabi, MD, FRCS¶

Sanjay S. Dhall, MD||

Daniel E. Gelb, MD#

Curtis J. Rozzelle, MD**

Timothy C. Ryken, MD, MS‡‡

Nicholas Theodore, MD§§

*Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada; ‡Division of Neurological Surgery, and **Division of Neurological Surgery, Children's Hospital of Alabama, University of Alabama at Birmingham, Birmingham, Alabama; §Department of Neurosciences, Inova Health System, Falls Church, Virginia; ¶Department of Neurosurgery, and #Department of Orthopaedics, University of Maryland, Baltimore, Maryland; ||Department of Neurosurgery, Emory University, Atlanta, Georgia; ‡‡Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa; §§Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona

Correspondence:

Mark N. Hadley, MD, FACS,
UAB Division of Neurological Surgery,
510 – 20th Street South, FOT 1030,
Birmingham, AL 35294-3410.
E-mail: mhadley@uabmc.edu.

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RECOMMENDATIONS

Level I

- Administration of methylprednisolone (MP) for the treatment of acute spinal cord injury (SCI) is not recommended. Clinicians considering MP therapy should bear in mind that the drug is not Food and Drug Administration (FDA) approved for this application. There is no Class I or Class II medical evidence supporting the clinical benefit of MP in the treatment of acute SCI. Scattered reports of Class III evidence claim inconsistent effects likely related to random chance or selection bias. However, Class I, II, and III evidence exists that high-dose steroids are associated with harmful side effects including death.
- Administration of GM-1 ganglioside (Sygen) for the treatment of acute SCI is not recommended.

RATIONALE

The search for an effective neuroprotective strategy to prevent secondary injury in the setting of acute SCI remains a priority for basic scientists and clinicians alike. Despite promising results for a number of compounds tested in the laboratory,¹ only 5 pharmaceutical agents have been evaluated in humans with the purpose of improving function after acute SCI. All 5 pharmacological treatments have been evaluated in controlled,

randomized, blinded clinical trials of human patients who have suffered acute SCI. Three substances, naloxone, thyrotropin release hormone, and tirilazad, have been studied less extensively.^{2–4} Further research to define their therapeutic roles in SCI is necessary but because of modest results is unlikely to occur. In 2002, the guidelines author group of the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons (AANS) and the Congress of Neurological Surgeons (CNS) published a medical evidence-based guideline⁵ on the use of MP and GM-1 ganglioside in the setting of acute cervical spinal cord injury. The purpose of the current review is to build on that foundation, adding pertinent new evidence accumulated over the past decade. There have been no new pharmacological agents formally tested for clinical use in SCI through this time period.

SEARCH CRITERIA

A National Library of Medicine (PubMed) computerized literature search from 1966 to 2011 was undertaken using Medical Subject Headings of “steroids,” “methylprednisolone,” and “GM-1 ganglioside” in combination with “spinal cord injury” and “neurological deficit.” Approximately 680 000 citations were acquired. Non-English-language citations were excluded, as were nonhuman experimental studies. Titles and abstracts of 641 manuscripts were reviewed, 589 on the topic of steroids and human SCI and 52 on the topic of GM-1 ganglioside and human spinal cord injury. Additional publications were cross-referenced from the citation lists of the remaining papers. Finally, the members of the author group were asked to contribute articles known to them on the subject matter that were not found by other search means. Duplications,

ABBREVIATIONS: ASIA, American Spinal Injury Association; MP, Methylprednisolone; NASCIS, National Acute Spinal Cord Injury Study; SCI, spinal cord injury

case reports, pharmacokinetic reports, general reviews, editorials, critiques, and manuscripts with mention of one agent or another but without original data were eliminated. Twenty-seven studies on MP and 2 studies on GM-1 ganglioside provide the basis for this review and are summarized in Evidentiary Table format (Tables 1-2).

SCIENTIFIC FOUNDATION

Methylprednisolone

The most research into pharmacotherapy for SCI has been generated by investigation of the potential benefit of MP administration. Certainly the most widely recognized studies are the National Acute Spinal Cord Injury Study (NASCIS) II and III published between 1990 and 1998.^{2,4,6,7} The original NASCIS I trial reported negative results in comparing “high-dose” to “low-dose” MP in 306 patients with acute SCI.⁸ High-dose patients received an MP loading dose of 1000 mg followed by the same dose daily thereafter for a period of 10 days. Low-dose patients received a loading dose of 100 mg followed by a further 100 mg each day for 10 days. Six-month follow up available on 54% of patients demonstrated no difference in motor or sensory outcomes in the high-dose group compared to low-dose patients. Wound infection was 3 times more frequent in the high-dose group ($P = .01$), and 3 times as many patients receiving high-dose MP died within the first 2 weeks of treatment (6% vs 2% mortality). One-year follow up confirmed the absence of a neurological difference between the 2 groups.⁹

The second of the 3 NASCIS studies investigated the effect of MP and naloxone administration in 487 patients with acute SCI.² In this study MP was administered in an initial loading dose of 30 mg/kg followed by 5.4 mg/kg/hour for 23 hours. While the naloxone data was uniformly uninformative, the authors reported a mean improvement of 5 points in motor score (total possible score = 50) and 4 points in sensory scores (total possible score = 58) for patients treated with MP compared to controls at 6 months, as long as they received the drug within 8 hours of injury. Improved motor scores persisted at 1 year ($P = .03$), but the difference in light touch and pinprick sensation between MP and placebo groups was lost.⁷

Although the NASCIS II cohort totaled 487 patients, beneficial effects from MP administration were discernable only after a post-hoc 8-hour therapeutic window was imposed. The rationale for this 8-hour cutoff has never been substantiated.¹⁰ Two hundred and ninety-one patients randomized later than 8 hours from injury were therefore excluded from the analysis, eliminating over half of the study population. The final conclusions from the study were based on a cohort of 66 MP-treated patients compared to 69 controls. Only neurological scores from the right half of the body were reported, although bilateral neurological testing was performed. As mentioned above, sensory improvements were the same in MP and placebo-treated patients 1 year after injury.

Analysis of patients treated beyond the 8-hour window demonstrated MP to have a detrimental effect on neurological outcome. It makes mathematical sense that if (1) an average result encompassing an entire population shows no change and (2) analysis of a subpopulation shows benefit, that (3) the remainder of the population must therefore show harm. As it applies to MP administration in acute SCI, it is at least as likely that these observations represent random chance rather than the possibility a study drug could be of benefit for 8 hours but then have the exact opposite effect over the next 4 hours.

Further post-hoc analyses suggested that MP administration improved neurological function below the level of injury in patients with incomplete SCI, noting that patients with complete SCI demonstrated very little long-tract recovery irrespective of treatment.¹¹ Only 17 patients with incomplete spinal cord injuries received MP within 8 hours of injury and only 22 such patients received placebo.⁷ Hence, while long-tract (as opposed to segmental) recovery was reported in NASCIS II, it was identified in a very small subgroup of patients.

Complications were reasonably distributed between the treatment groups except for a 1.5 times higher incidence of gastrointestinal (GI) hemorrhage, 2 times higher incidence of wound infection, and 3 times higher incidence of pulmonary embolus in MP-treated patients compared to controls. There was a 2.5 times higher incidence of thrombophlebitis in control patients compared to those who received MP. None of these findings were reported as statistically significant, but none of these comparisons were properly powered to avoid Type II error.

NASCIS II was designed as a randomized, controlled, double-blinded clinical study to generate Class I medical evidence on the efficacy of MP and naloxone in the treatment of acute spinal cord injury. However, the strength of medical evidence generated is weakened by omission of data from publication, the arbitrary assignment of an 8-hour therapeutic window, the inconsistency of reported benefit, and the absence of functional outcome measures. The primary positive finding of a 5-point improvement in motor score associated with MP administration compared to placebo control was discovered only in a post-hoc analysis of a partial dataset, constituting a retrospective analysis. Accordingly, the beneficial results of NASCIS II are downgraded to Class III medical evidence. A trend towards more serious complications associated with steroid use is indicated from the original Class I medical evidence dataset.

In 1993, Galandiuk et al¹² reported on 32 patients with cervical or upper thoracic ASCI managed in an urban trauma center. Fourteen patients who received NASCIS II doses of MP within 8 hours of SCI were compared to 18 patients with similar injuries managed without steroids. Forty-seven percent of the cohort was studied retrospectively while 53% were studied prospectively. No difference was observed in neurological outcome for patients treated with MP compared to those untreated. However, patients receiving MP exhibited significant immune response alterations evidenced by a lower percentage and density of monocyte class II antigen expression and lower T-cell helper/suppressor cell ratios.

In addition, MP-treated patients experienced a higher rate of pneumonia (79% vs 50%) and longer hospital stays (44.4 days compared to 27.7 days) compared to their non-MP counterparts.

The same year, Kiwerski et al¹³ published the largest retrospective review of patients with acute SCI to date. Six-hundred and twenty patients were treated over a 15-year period beginning in 1976. Of these, 290 patients were administered MP and 330 were not, based on the discretion of the treating physician. The dose varied according to age, weight, and medical condition, and also at the preference of the attending physician. The most usual dose was 8 mg 3 times a day for several days up to 1 week. Consistently, more patients in the MP group were reported to show some degree of improvement compared to controls. The mortality rate was at least double for patients in the control group compared to those treated with MP, ranging from 18% to 38% depending on age (Figure 1). The authors did not explore the reasons for such high mortality, but the data suggest the control group was more severely injured and therefore less likely to recover.

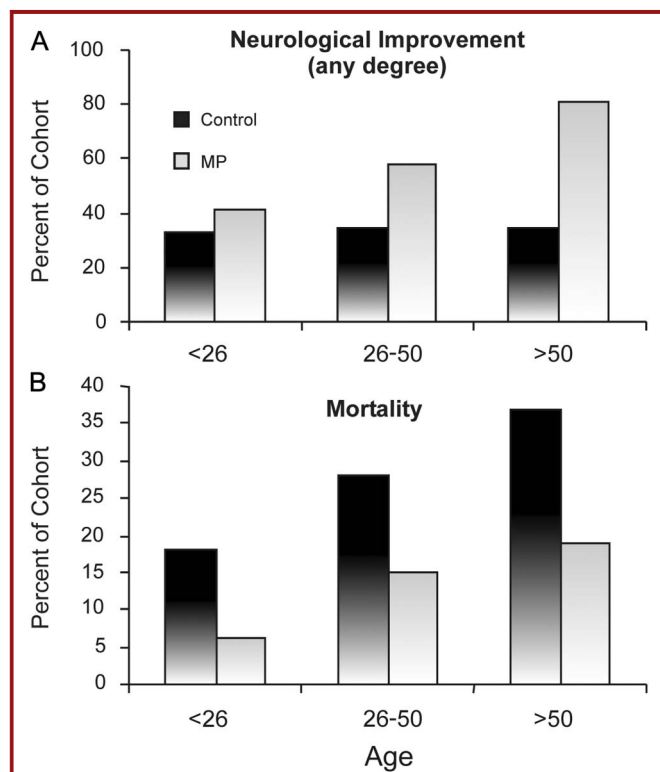


FIGURE 1. A, retrospective data from Kiwerski²² demonstrating the increased proportion of patients showing some degree of neurological recovery who received MP (at their treating physician's discretion). B, corresponding data showing proportionately higher mortality rates in patients not treated with MP for all age groups. This relationship suggests a selection bias for those treated with MP likely based on less severe spinal cord and/or systemic injury.

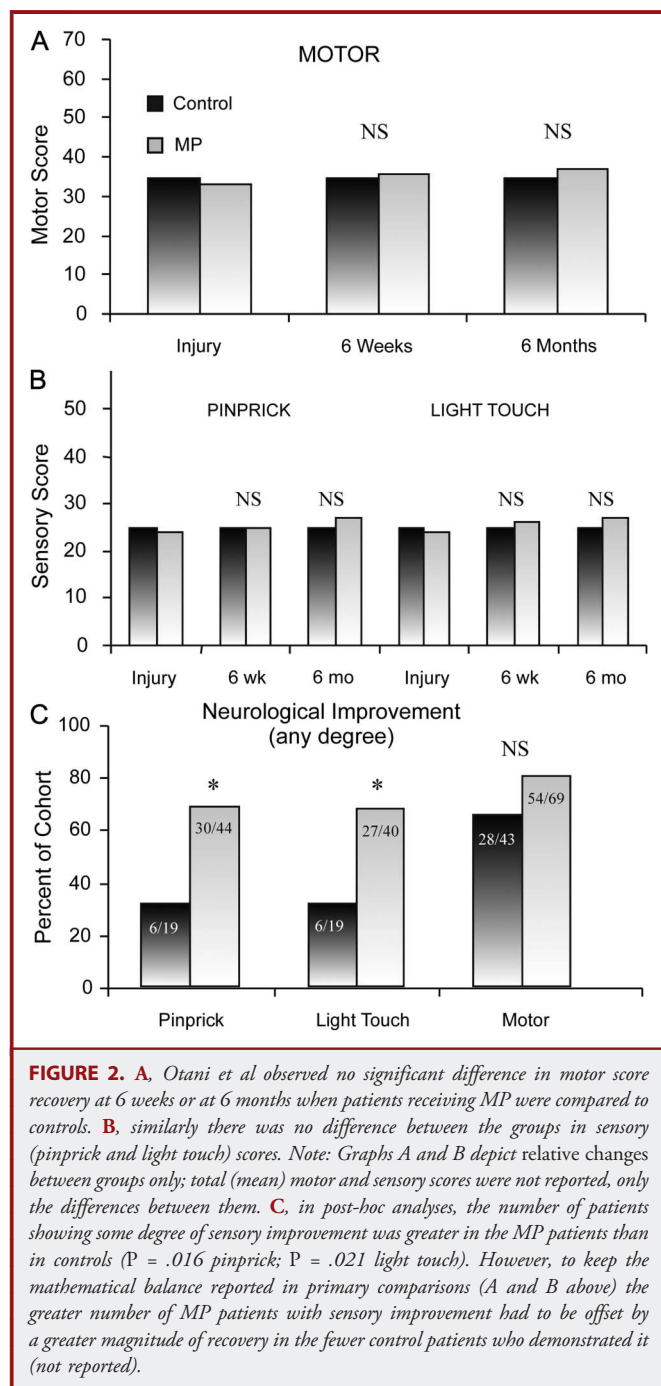
Otani et al¹⁴ reported a prospective randomized (nonblinded) clinical trial investigating the administration of MP at NASCIS II doses within 8 hours of SCI from 11 centers in Japan. Eighty-two MP patients were compared to 76 observational controls (no placebo), randomized over a 14-month period from January 1992 to March 1993. Interestingly, "In the control group, however, use of a corticoid other than MPSS was allowed up to the dose equivalent to 100 mg/day MP for a maximum of 7 days in total. . . if it was judged necessary by the attending physician for the purpose of treating the spinal cord injury."¹⁴ Of the patients entered into the study, only 70 in the treatment group and 47 in the control group were analyzed due to protocol violations. Primary preplanned comparisons of change in motor and sensory scores failed to yield significant differences (Figures 2A and 2B). Post-hoc analyses suggested that significantly more MP patients recovered some degree of sensory function compared to controls ($P = .016$ pinprick; $P = .021$ light touch) (Figure 2C).

However, as discussed in the setting of NASCIS II, mathematical balance dictates that (1) if primary comparisons within the study population show no difference and (2) a subanalysis suggests a treatment effect, then (3) there must be an equal and opposite effect in the remaining patients. In this circumstance, the authors' observation that significantly more MP patients showed sensory recovery is only balanced by considering that within the fewer recovering control patients—magnitude (not frequency) of sensory recovery must have exceeded that observed in the MP-treated group. Taken together, both observations render each other meaningless and irrelevant.

Prendergast et al¹⁵ retrospectively compared patients with SCI before 1990 (the year NASCIS II was published) to patients with SCI after 1990. The latter group ($n = 29$) received MP in NASCIS II doses, whereas the earlier group ($n = 25$) received no steroids (historical control). Of 31 patients who suffered penetrating trauma, 16 received steroids while 15 did not. Throughout a 2-month follow-up period there was no difference in motor or sensory scores for patients with blunt SCI irrespective of steroid administration. However, in those suffering penetrating SCI, MP use was associated with deterioration in motor and sensory function compared to baseline scores on admission. In contrast, recovery was observed in controls. Motor scores were significantly better in control patients compared to those who received MP ($P = .03$).

Gerhart et al¹⁶ retrospectively identified a concurrent cohort of 363 acute SCI patients managed in 1990, 1991, and 1993. Within the study population, 188 (52%) were treated according to NASCIS II protocol, 90 (25%) received no methylprednisolone, and 85 (23%) received other steroid (eg, dexamethasone), an incorrect dose of MP, or had insufficient data. The authors found no significant difference in the outcome assessed by Frankel grade at the time of hospital discharge comparing those who received protocol MP (appropriate dose and timing) to those who did not receive any MP during treatment.

One-hundred and thirty patients suffering acute SCI between 1989 and 1992 were retrospectively analyzed, comparing patients



who received MP to those who did not.¹⁷ Similar to the Prendergast paper, George et al based their comparison on 55 patients treated prior to 1990 (historical controls) and 75 patients treated with MP after 1990 according to NASCIS II dosing within 8 hours of injury. Neurological function was assessed by a 6-point mobility score and through the Functional Independence Measure scale. Mobility was no different between the

groups on admission, but on discharge, despite a lower mean age and lower injury severity score, the MP group fared significantly worse by one-half point compared to controls ($P < .05$). Functional Independence Measure scores did not differ between the 2 groups on discharge or throughout the rehabilitation period.

Medical complications were retrospectively examined by Gerndt et al¹⁸ in 140 SCI patients who received MP according to NASCIS II protocols and compared to a historical control group of 47 patients who received no steroid during treatment. The authors found a 4-fold increase in the incidence of acute pneumonia ($P = .03$), a 3-fold increase in pneumonia of any type ($P = .02$), as well as an increase in ventilated days ($P = .04$) and Intensive Care Unit (ICU) length of stay ($P = .045$) in the MP patients compared to controls. Control patients had a higher incidence of urinary tract infections ($P = .01$). MP patients spent fewer days in regular hospital wards ($P = .02$) and in the rehabilitation unit ($P = .035$). Overall, hospital stay was not different between the 2 groups, leading the authors to conclude that MP may predispose SCI patients to pneumonia, but had no adverse effect on long-term outcome.

Poynton et al¹⁹ retrospectively identified 71 consecutive SCI patients admitted to their rehabilitation facility between June 1991 and December 1994. American Spinal Injury Association (ASIA) motor and sensory scores were recorded at the time of injury, time of transfer to the rehabilitation center, and in follow up after discharge. Thirty-eight patients received NASCIS II MP dosing within 8 hours of injury. Thirty-three patients did not receive MP therapy because they presented beyond the 8-hour cutoff. Outcome was not related to treatment with MP, nor was it related to surgical intervention, although decompression was not distinguished from stabilization.

The third NASCIS study involved 14 centers across the United States and 2 in Toronto, Canada. Six-month and 1-year follow up were published in separate manuscripts.^{4,6} Patients presenting within 8 hours of SCI were enrolled in a prospective double-blind manner and randomized to 1 of 3 treatment arms: (1) MP infusion 5.4 mg/h \times 24 hours; (2) MP infusion 5.4 mg/h \times 48 hours; and (3) tirilazad mesylate 2.5 mg/kg every 6 hours \times 48 hours. Tirilazad mesylate was included as a chemically engineered "super-steroid," created to possess greater antioxidant properties than methylprednisolone. All patients received a loading dose of MP (30 mg/kg) prior to randomization. A placebo control group was not included because of the reported therapeutic effect of MP in NASCIS II. Four hundred ninety-nine patients were entered into the study, 166 in the 24-hour MP group, 166 patients in the 48-hour MP group, and 167 in the 48-hour tirilazad mesylate group.

Within all preplanned comparisons, there were no significant differences in neurological recovery between any groups. Neither tirilazad mesylate nor 48-hour MP showed evidence of a neuro-protective effect compared to 24-hour MP administration; NASCIS III was a negative Class I medical evidence study. Post-hoc analyses suggested motor function to be at least temporarily

improved in patients who received 48-hour MP (n = 80) compared to 24-hour (n = 71) administration, provided the drug was initiated within 3 to 8 hours of injury. A difference of 5 ASIA motor points was found to be significant in favor of 48-hour MP at 6 weeks ($P = .04$) and 6 ASIA points at 6 months ($P = .01$). However, the 5-point ASIA difference became statistically questionable at 1 year follow up ($P = .053$). Even in the post-hoc analysis there was no notable difference between the 3 study groups in ASIA sensory scores, Functional Independence Measure outcomes, or presumably in the unreported left-sided ASIA motor scores. Post-hoc ASIA motor score changes are depicted for both NASCIS II and III in Figure 3.

Similar to NASCIS II, a higher incidence of severe complications seemed to be proportional to steroid administration. There was a 2 times higher incidence of severe pneumonia and a 4 times higher incidence of severe sepsis in the 48-hour MP group compared to patients on MP for 24 hours. Although these differences were not statistically significant, conclusions from statistical testing cannot be drawn, as sample sizes in the order of 600 patients per group would be required to avoid Type II error assuming $\alpha = 0.05$ and $\beta = 0.2$. There were 6 times more deaths observed in the 48-hour group due to pneumonia, respiratory distress syndrome, and respiratory failure ($P = .056$).

Like its predecessors, NASCIS III was designed as a randomized, controlled, double-blinded clinical study to generate Class I medical evidence on the efficacy of MP (and tirilazad mesylate) in the treatment of acute spinal cord injury. However, the strength of the medical evidence generated is weakened by omission of data

from publication, the arbitrary assignment of a 3- to 8-hour therapeutic window, the inconsistency of reported benefit, and the absence of improvement in functional outcome measures. The primary positive finding of a 5-point improvement in motor score associated with 48-MP administration compared to 24-MP was discovered only in a post-hoc analysis of a partial dataset, constituting a retrospective analysis. Accordingly, the beneficial results of NASICS III are downgraded to Class III medical evidence. A trend towards more serious complications associated with prolonged steroid use is indicated from the original Class I medical evidence dataset.

Three years later, Pointillart et al²⁰ reported a single-institution, prospective, randomized clinical trial from France that compared the effect of nimodipine, MP (NASCIS II dosing protocol), and nimodipine + MP against no pharmacological therapy in 106 patients with acute SCI. Blinded neurological assessment evaluated ASIA scores on admission and at 1-year follow up. Time from injury to surgical decompression (where indicated and within 24 hours) was tracked as a confounding variable. One hundred patients were available to assess at 1 year because of 5 deaths and 1 loss to follow up.

Neurological improvement was observed in each group at 1 year compared to admission ($P < .0001$). However, there were no significant differences in ASIA motor or sensory scores between the 4 individual treatment arms. Only the completeness of SCI was linked to prognosis; patients with incomplete injury showed significantly more recovery than those who were complete ($P < .0001$). Improvement among complete injury patients was generally restricted to the level of the lesion and the 2 adjacent caudal levels. Eighty patients underwent surgery within 24 hours, of which 49 had surgery within 8 hours of injury. Neither surgery nor timing of surgery was associated with neurological recovery.

Infectious complications occurred more frequently among patients treated with MP (66%) compared to those who did not receive steroids (45%), which was not statistically significant. Two MP patients suffered upper GI hemorrhage due to ulceration. There were no similar events in patients who did not receive MP. Hyperglycemia requiring insulin administration for up to 3 days was documented in 46% of MP patients but in only 1 of the control patients ($P < .05$).

In 2001, Matsumoto and colleagues reported on 46 patients with acute cervical SCI who were prospectively randomized in a double-blind manner to receive either MP at NASCIS II doses or placebo.²¹ Patients were admitted to a single institution from April 1993 to August 1999. Twenty-three patients received MP, while 23 received placebo. The purpose of the study was to compare complications between the 2 groups from the time of admission throughout the 2-month follow-up period. Despite the prospective nature of the protocol, neurological scores were not reported. However, admission Frankel grades were the same for both groups. MP-treated patients demonstrated a higher propensity towards complications compared to placebo-treated controls (56.5% vs 34.8%; $P = .14$). Eight patients who received MP developed respiratory complications (pneumonia n = 3,

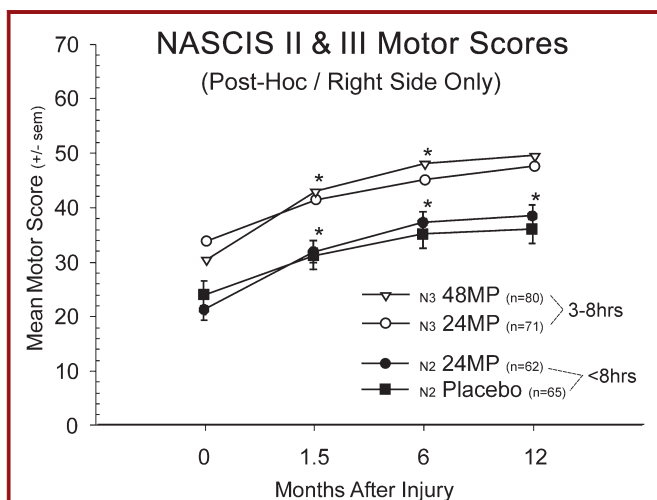


FIGURE 3. Combined 6-week, 6-month, and 1-year post-hoc right-sided motor scores from NASCIS II (N2) and III (N3) reported as favoring 24 MP administration within 8 hours and 48 MP administration between 3 and 8 hours after SCI. Y-axis represents motor function from total quadriplegia (0 points) to normal neurological function (70 points). No difference in post-hoc sensory scores was present at 1 year. **Note:** All primary (preplanned) comparisons negative. Standard error values not published for NASCIS III. * $P < .05$ multiple t-testing.

atelectasis $n = 1$) compared to 1 placebo patient ($P = .009$). Four MP patients developed gastrointestinal complications (GI bleed $n = 3$; ileus $n = 1$). No similar complications were observed in control patients ($P = .036$).

Pollard et al²² retrospectively identified patients who suffered an incomplete cervical SCI and were admitted to a single rehabilitation facility within 90 days of injury over an 18-year period spanning 1982 to 2000. Data were part of a federally funded national database (model systems). Five hundred and forty seven patients were identified, of which 412 met inclusion criteria based on completeness of records and absence of confounding comorbidity (eg, head injury). An analysis of sex, race, age, high vs low energy mechanism of injury, fracture type, cord syndrome, steroid protocol, and definitive surgery less than 24 hours after injury was undertaken to determine which factors were associated with greater improvement in ASIA motor and sensory scores.

Improved neurological recovery was noted in younger patients ($P = .002$) and those with a central cord or Brown-Sequard syndrome ($P = .019$). Administration of MP was not associated with improvement in final ASIA motor score at latest follow-up (MP $n = 104$; No-MP $n = 200$; $P = .66$) or change in ASIA motor score from time of injury (MP $n = 104$; No-MP $n = 201$; $P = .26$). Final mean ASIA sensory scores were no different between patients who received MP and those who did not (MP $n = 86$; No-MP $n = 87$; $P = .904$). An analysis of change in ASIA sensory score suggested steroid-treated patients recovered 11 more points compared to those who did not receive MP ($P = .027$). However, without explanation, the number of patients available for this comparison was a fraction of the original cohort (MP $n = 33$; No-MP $n = 59$).

Patients with SCI sustained from diving accidents were retrospectively reviewed by Aito et al²³ within the experience of a single institution between 1978 and 2002. The primary purpose of the review was to correlate neurological outcome with the level and type of spinal fracture. Sixty-five patients were included in the study, of which 95% were male. Factors associated with improved neurological outcome were: surgical intervention (timing not specified), younger age of the patient, and incomplete SCI. In a subanalysis of 30 patients admitted between 1994 and 2002 (after incorporation of the NASCIS II protocol), 20 patients who received MP within 8 hours of injury were compared to 10 patients who did not receive steroids. Data are not provided, but the authors report their analysis based on the presence or absence of some type of neurological recovery (not specified) in favor of those patients who received MP (Fisher exact test on proportions, $P = .005$). Recovery was mainly restricted to 9 of 10 patients with incomplete SCI, all of whom received MP.

Quian et al²⁴ prospectively analyzed a cohort of 8 SCI patients who were assessed for evidence of acute corticosteroid myopathy (ACM) from 1 to 7 days after their injury. The diagnosis was established directly through muscle biopsy and indirectly through electromyography (EMG) studies sampled above the level of SCI.

Five patients received MP treatment according to NASCIS II dosing. Three patients did not receive MP due to penetrating trauma ($n = 2$) or presentation more than 8 hours from the time of injury ($n = 1$). ACM occurred in a time-dependent manner between 3 to 7 days in the MP group: 1 patient biopsied within 24 hours of injury had normal muscle; 2 patients biopsied 3 days after injury showed mild evidence of ACM; 2 patients biopsied on day 5 and 7, respectively, showed changes compatible with severe ACM. Patients in the control group were biopsied within 24 hours of injury ($n = 2$) and on day 5 ($n = 1$). Muscle biopsies and EMG activity were normal in all 3 control patients. Acknowledging the natural history of ACM improvement within 6 to 8 months from time of onset, the authors speculated that some of the motor improvement observed in the NASCIS II and III studies may have been due to resolution of an iatrogenic myopathy.

From 1998 through 2002, Tsutsumi et al²⁵ identified 278 consecutive admissions to their institution for acute mid to lower cervical SCI. From this group, 70 patients admitted within 7 days of injury and with 6 months of follow up were discovered. Thirty-seven received MP at NASCIS II doses within 8 hours of injury, while 33 received no drug, according to the preference of the treating physician at the time of injury. Neurological function was assessed through ASIA motor scores. Sensory function was not tested.

The study group was further subdivided into complete (ASIA A) and incomplete (ASIA B, C, D) patients. No difference in motor improvement was seen in MP patients ($n = 18$) compared to controls ($n = 25$) in those with complete injuries ($P = 0.48$). Incomplete patients treated with MP ($n = 19$) improved on average 18 more motor points than those who did not receive MP ($n = 8$) ($P = .005$). However, 84% ($n = 16$) of the 19 MP patients were ASIA grade C or D on admission compared to 75% ($n = 6$) of the 8 control group patients. Mean admission and follow-up ASIA motor scores were not published, making it impossible to further discern within this small retrospective group how much selection bias towards less severe injuries (and hence recovery) favored those who received steroids.

Lee et al²⁶ retrospectively analyzed 111 patients with SCI admitted to a single institution over the 2-year period spanning from January 2002 until December 2003 with respect to MP administration, surgical intervention, and complication rates. Neurological outcome was assessed according to the Frankel grading system, where improvement was defined as a change in 1 or more Frankel grades. Fifty-eight patients (52%) received MP according to either NASCIS-II or NASCIS-III dosing protocols, while, for reasons not specified, 53 patients did not. Potential neuroprotective effects of MP were not reported. Instead, the analysis compared patients who had both MP and surgery to those who did not have either. "Significant" changes in Frankel score were observed in 11 of 16 complete SCI patients treated with MP and surgery, compared to zero of 7 patients treated with surgery alone. Twenty-one of 31 incomplete SCI patients who underwent surgery and MP administration also showed "significant" Frankel grade improvement compared to 4 of 8 patients

treated with surgery alone. Unfortunately, neither statistical methodology nor P -values were reported. If one calculates Fisher exact test for 2-tailed significance on 2 independent samples, the significance of improvement seen in the complete group who received MP was $P = .005$, whereas in the incomplete group receiving MP it was $P = .42$. In the subanalysis it remains unclear why 47 MP patients were treated surgically (81% of the entire cohort of MP patients) compared to only 15 patients (28%) in the non-MP group, perhaps suggesting the latter to be a more severely or chronically injured patient group (Figure 4).

Complications ascribed to MP administration were observed in 24 of 58 patients treated with MP (41%), including peptic ulcer, upper GI hemorrhage, perforated peptic ulcer, and urinary tract infection. One patient with a complete SCI died as a result of sepsis from GI perforation. The incidence of complications was proportional to the completeness of the SCI. It is not specified whether there were any non-MP patients who suffered similar morbidity.

Leypold and colleagues reported a radiographic study comparing cord edema and hemorrhage in 82 patients with ASIA A (complete) cervical SCI.²⁷ Thirty-four of the patients were treated prior to 1994 and did not receive MP as part of their treatment. Forty-eight patients were treated after 1997 and received MP according to NASCIS II protocol. An unspecified number of patients treated in the 4 years spanning 1994 to 1997 were excluded to “avoid the possibility of assignment to the wrong group.” Magnetic resonance sequences (T1 and T2, dual echo SE, or gradient echo) were acquired in a 1.5T magnetic resonance unit within 3 days of injury. No images were available prior to

administration of MP in those patients treated with steroids. Neurological outcomes were not reported.

The mean age of the MP group was 16 years older than that of the historical controls (47 years vs 31 years; statistically significant P -value not provided). The incidence of spinal cord hemorrhage was higher in historical controls compared to MP-treated patients, but the difference was not statistically significant (91% vs 67%; $P = .162$). There was no difference in rostro-caudal length of edema within the spinal cord (4.0 vs 3.3 spinal segments; $P = .9$). However, length of hemorrhage was greater in controls compared to MP patients (1.5 vs 0.8 spinal segments; $P = .04$). Potential differences in mechanism of injury (eg, between a 50-year-old MP patient with central cord syndrome and a 30-year-old non-MP patient with fracture dislocation) were not explored. Of equal or more important concern, however, is the lack of a baseline (pre-MP) magnetic resonance imaging and the concurrent assumption that the extent of SCI hemorrhage within 3 days of injury was independent of the initial SCI. There have been no previous studies defining the temporal sequence of acute hematoma evolution in the spinal cord as a result of SCI.

In 2008, Suberviola et al²⁸ published a review of all adult patients admitted to their institutional ICU with acute SCI over a 12-year period. A total of 82 patients were identified, of which 59 received MP (NASCIS II protocol) and 23 did not. Patient demographics including admission Frankel grade did not differ between the groups except that the non-MP patients had a higher injury severity score compared to those who received steroids (31 vs 22; $P = .006$). Accordingly, the length of ICU stay was also longer for the non-MP patients (20 days vs 12 days; $P = .031$).

At time of ICU discharge, approximately 31% of patients in both groups improved by 1 or more Frankel grades. There was no difference in ICU mortality rate attributable to steroid administration or lack thereof. Similarly, wound infections, septicemia, and urinary tract infections were comparable between groups. However, MP patients suffered a higher rate of respiratory infections ($P = .02$), total infections ($P = .004$), and early hyperglycemia requiring insulin drip for up to 4 days ($P < .01$).

Ito et al²⁹ compared a consecutive series of acute SCI patients who received MP against a subsequent consecutive series of SCI patients who were not given steroids. The study was performed in a prospective nonrandomized manner over a 4-year period: from August 2003 through July 2005, 38 patients were given MP according to the NASCIS II protocol, while from August 2005 through July 2007 41 were treated for acute SCI without MP. Patients were excluded from the study if they presented more than 8 hours after injury. Neurological assessments were made on admission and 3 months later. Adverse events were recorded during the hospital stay.

An improvement by 1 or more ASIA grades was observed in 45% of those who received MP compared to 63% of those who did not ($P > .05$). On average, ASIA motor scores improved by 12 points in the MP group and 14 points in control group patients ($P > .05$). Similarly, there was no therapeutic benefit to MP if

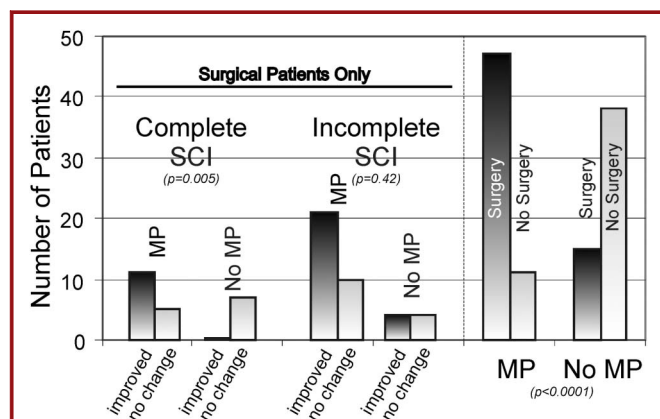


FIGURE 4. Left, graphical representation of MP effect reported by Lee et al⁶ in their retrospective review of 111 patients with acute SCI. A steroid benefit was reported only in patients who also underwent surgical intervention. Of those who had surgery and harbored neurologically complete injuries, improvement in Frankel grade was observed more frequently in the 16 patients who received MP compared to the 7 that did not ($P = .005$, Fisher exact test). This difference was not significant in 31 MP and 8 non-MP patients with incomplete injuries. Right, however, data from the entire cohort demonstrates that 81% of the MP-treated patients received surgery compared to only 28% of the non-MP patients ($P < .0001$) suggesting the latter to have more severe or more chronic injuries, presumably more resistant to treatment.

patients were compared on the basis of motor complete and motor incomplete injuries. ASIA sensory scores were not reported. Infections (pneumonia, urinary tract infection, wound infection) were observed in 68% of the MP group but in only 44% of control group patients ($P = .028$). Sixteen percent of MP-treated patients suffered GI hemorrhage compared to 5% of controls, but the difference was not statistically significant.

A rare complication of corticosteroid-induced acute tumor lysis syndrome was detailed in a case report published by Tsao et al³⁰ in 2009. A 37-year-old woman was treated with MP (NASCIS-II protocol) for an acute incomplete cervical SCI. She received MP treatment within 8 hours of injury but with concurrent (undiagnosed) intravascular diffuse large B-cell lymphoma. Sixteen hours after infusion, the patient developed ventricular fibrillation and acute renal failure. Resuscitation was successful and the patient responded to hemodialysis, but succumbed to her disease 8 months later.

Based on data from a small number of randomized head injury trials and the success reported in NASCIS II and III, a prospective randomized placebo-controlled trial investigating the effect of MP on head injury was undertaken in 239 hospitals across 49 countries.³⁰ Over a 5-year period, patients were enrolled into the Corticosteroid Randomization After Significant Head injury (CRASH) study, receiving either a 48-hour MP infusion according to NASCIS III dosing or a 48-hour placebo infusion of normal saline. The research hypothesis was constructed to evaluate the neuroprotective efficacy of high-dose steroids in cranial trauma. Primary outcome measures were: (1) death from any cause at 2 weeks, and (2) death or disability at 6 months. Sample-size calculations suggested that 20 000 patients were required to detect a 2% difference in the study groups.

Patients were eligible for enrollment if they were 16 years of age or older, were within 8 hours of injury, and had a Glasgow Coma Score ≤ 14 . Interim data of in-hospital mortality, complications, and 6-month outcome were supplied by each institution on an annual basis to an independent data monitoring and ethics committee. The committee was responsible for unmasking the results if the randomized comparisons provided proof beyond reasonable doubt of a difference in outcome between the study and control groups AND evidence that would be expected to substantially alter the choice of treatment for patients.

In May 1994, the trial was terminated prematurely as a result of interim analyses by the data monitoring and ethics committee. A total of 10 008 patients had been enrolled, just over 5000 patients in each treatment arm. Within the MP group, 1052 (21.1%) deaths were observed within the first 2 weeks of injury compared to 893 (17.9%) in control patients representing a relative risk for death of 1.18 (95% confidence interval [CI] 1.09-1.27; $P = .0001$). There was no difference in the severity of head injury between the 2 groups ($P = .22$). Six-month data were published a year later by the same group.³¹ The risk of death remained higher in the MP group (1248 deaths; 25.7%) compared to placebo (1075 deaths; 22.3%) ($P = .0001$). In other words, for every 29 patients treated with MP, 1 died from drug-associated morbidity.

The second outcome measure of death and disability at 6 months was also higher in the MP group (relative risk 1.05; 95% CI 0.99-1.10; $P = .079$). The authors concluded that corticosteroids should not be used routinely in the treatment of head injury.

SUMMARY

Methylprednisolone

Despite 4 prospective blinded randomized controlled trials investigating the effect of MP in acute SCI, there exists no Class I medical evidence of any beneficial effect.^{2,4,8,20} Two prospective Class II trials also failed to demonstrate the therapeutic efficacy of MP in SCI.^{14,29} In total, over 980 patients have received steroids for SCI and over 280 have participated as control subjects within the protocol of a prospective clinical trial—in which, universally, all primary comparisons to establish efficacy have been negative.

A variety of Class III medical evidence has been published supporting the neuroprotective effect of MP in SCI.^{6,7,13,14,22,23,25,26} In general, these studies suffer from 1 of 2 significant limitations: limited sample size derived retrospectively from much larger study populations^{6,7,14,22,23,25,26} and/or incomplete data reporting in which omitted data are likely to have negated the proposed beneficial effect.^{6,7,13,14,22,23,25,26} Additionally, the beneficial effects claimed related to MP administration in the setting of acute SCI have been inconsistent. Patients are reported to have demonstrated improvement in sensory but not motor function,^{14,22} motor but not sensory function,^{6,7,25} or some other (undefined) type of neurological recovery.^{13,23} It is important to note that none of these retrospective data analyses have claimed neurological improvement of a meaningful functional or behavioral nature. In light of both significant methodological errors and inconsistent neurological outcomes, the beneficial effects of MP can as easily be ascribed to random chance as to any true therapeutic effect.

Harmful side effects of MP administration in the setting of acute SCI have been reported as significant in 3 Class I studies,^{8,20,21} including wound infection, hyperglycemia requiring insulin administration, and GI hemorrhage. Although not statistically significant, similar trends were observed in Class I medical evidence from NASCIS II and III, including GI hemorrhage, sepsis, pneumonia, and death due to respiratory failure.^{2,4} In addition, Class II medical evidence shows a significantly higher risk of infection (respiratory, urinary, wound) and steroid-induced myopathy in patients treated with MP compared to controls.^{24,29} Several Class III medical evidence studies describe similar adverse events of statistical significance including pneumonia, respiratory failure, peptic ulcer disease, GI hemorrhage, and hyperglycemia requiring insulin administration.^{12,18,26,28} Most compelling is the Class I medical evidence from over 10 000 patients with head injury, indicating that high-dose MP administration leads to significantly higher mortality independent of injury severity.³¹

In summary, there is no consistent or compelling medical evidence of any class to justify the administration of MP for acute SCI. Both consistent and compelling Class I, II, and III medical evidence exists suggesting that high-dose MP administration is

TABLE 1. Evidentiary Table: Pharmacological Therapy: Methylprednisolone

Citation	Description of Study	Evidence Class	Conclusions
Ito, ²⁹ <i>Spine</i> , 2009	Prospective nonrandomized consecutive case series of 38 patients with SCI treated with MP (2003-2005) compared to a subsequent consecutive series of 41 who did not receive MP (2005-2007). Change in ASIA grade and motor scores determined by difference from admission to 3 months.	II	No difference in neurological improvement as defined by ASIA grade or ASIA motor score when total cohort of each group compared or when motor complete or motor incomplete injuries compared. Significantly higher incidence of infection (respiratory, urinary, and wound) in MP patients vs controls ($P = .028$).
Tsao, ³⁰ <i>Lancet</i> , 2009	Case report	III	Rare complication of corticosteroid-induced acute tumor lysis syndrome causing ventricular fibrillation and renal failure in a 37-year-old patient treated with MP for acute SCI.
Suberviola, ²⁸ <i>Injury, Int J Care Injured</i> , 2008	Retrospective review of ICU stay in 59 SCI patients who received MP (NASCIS II) and 23 who did not between 1994 and 2005.	III	No difference in neurological outcome based on Frankel grade at time of ICU discharge. MP patients had significantly higher rates of respiratory infection, total infections (all types) and early hyperglycemia requiring insulin drip.
Lee, ²⁶ <i>Surg Neurol</i> , 2007	Retrospective review of 111 patients with SCI, 58 treated with MP and 53 not. Recovery defined as improvement of 1 grade or more in Frankel classification. MP associated complications defined as peptic ulcer, upper GI hemorrhage, and urinary tract infection.	III	No neurological comparisons reported on primary cohort. Subanalysis of complete SCI patients who underwent surgery showed 11/16 treated with MP improved whereas none of the 7 non-MP patients improved. In the MP-treated group no one improved enough to ambulate independently. Incomplete patients undergoing surgery NS. In the entire cohort ($n = 111$) 41% of MP patients developed an MP-related complication.
Leybold, ²⁷ <i>Spine</i> , 2007	Retrospective review of magnetic resonance spinal cord signal changes in 48 MP-treated patients compared to 34 historical controls (all ASIA A).	III	MP group significantly older than historical controls (47 vs 31 yrs). No difference in incidence of spinal cord hemorrhage or rostro-caudal length of edema. Length of hemorrhage 0.8 spinal segments in MP patients compared to 1.5 in controls ($P = .04$). No accounting of mechanism. No baseline (pre-MP) magnetic resonance imaging.
Tsutsumi, ²⁵ <i>Spine</i> , 2006	Retrospective review of 70 cervical SCI patients treated over 5 years in which 37 received MP and 33 did not. Two hundred and eight patients excluded because of incomplete follow up, incomplete data, or steroids given outside of NASCIS II protocol.	III	ASIA sensory scores not assessed. No difference in ASIA motor recovery from MP in patients with complete SCI ($n = 43$). Recovery of 18 more ASIA motor points in MP patients ($n = 19$) compared to controls ($n = 8$) at 6 months ($P = .005$). Possibility of selection bias identified in MP administration for less severe SCI predisposing to greater recovery.

(Continues)

TABLE 1. Continued

Citation	Description of Study	Evidence Class	Conclusions
Aito, ²³ <i>Spinal Cord</i> , 2005	Retrospective review of 65 patients over 24 years with complete and incomplete injuries. Subanalysis of 30 patients treated from 1994 to 2002 with and without MP.	III	Presence of any neurological improvement more likely in 20 patients treated with MP compared to 10 who did not receive steroids ($P = .005$). Most improvement seen in 9 of 10 incomplete patients all of whom received MP.
Qian, ²⁴ <i>Spinal Cord</i> , 2005	Prospective case-control cohort of 5 patients with SCI treated with MP and 3 patients not eligible to receive MP looking for evidence of acute corticosteroid myopathy.	II	Muscle biopsy and EMG above the level of SCI used to confirm diagnosis. Time-dependent ACM demonstrated in patients who received MP. No similar changes observed in controls.
Pollard, ²² <i>Spine</i> , 2003	Retrospective review of 412 patients with incomplete SCI from 1982 to 2000. Data available in 104 patients who received MP and 200 who did not.	III	Final ASIA motor score and change in ASIA motor score from admission not improved by MP administration. No difference in final ASIA sensory score from MP. Eleven-point improvement in ASIA sensory score compared to admission in MP-treated patients ($P = .027$) but only 33 MP and 59 control patients available for analysis.
Matsumoto, ²¹ <i>Spine</i> , 2001	Prospective, randomized, double-blind study in 46 SCI patients for the purpose of comparing medical complications. Half were randomized to 24 MP and half to placebo.	I	Methylprednisolone patients had higher incidence of complications (56.5% vs 34.8%, NS). Respiratory complications ($P = .009$) and GI bleed ($P = .036$) were significantly higher in MP patients.
Pointillart, ²⁰ <i>Spinal Cord</i> , 2000	Multicenter, prospective, randomized clinical trial of 106 SCI patients treated with MP ($n = 27$), nimodipine ($n = 27$), MP + nimodipine ($n = 27$), or no pharmacological agent ($n = 25$).	I	No difference in neurological outcome between groups at 1 year (small sample size). Infection and GI bleed, and hyperglycemia higher in MP patients (NS, no power analysis). Hyperglycemia requiring insulin significantly higher in MP patients.
Bracken, ⁶ <i>J Neurosurg</i> , 1998	NASCIS III: One-year follow up	I* *(reported positive results III)	All primary (preplanned) comparisons negative. Post-hoc analyses showed improved ASIA motor scores of questionable significance in 48 MP patients compared to 24 MP ($P = .053$). 48 MP associated with higher rates of sepsis, pneumonia, and death (NS, no power analysis).
Gerndt, ¹⁸ <i>J Trauma Inj Inf Crit Care</i> , 1997	Retrospective review of 140 SCI patients. Comparison of medical complications among 93 who received NASCIS II MP compared to 47 historical controls who received no steroid.	III	MP treated patients had significant increases in pneumonia, acute pneumonia, ventilated days, and ICU stay. No adverse effects on long-term outcome.
Poynton, ¹⁹ <i>Injury</i> , 1997	Retrospective case control review of 71 consecutive SCI admissions. Thirty-eight patients treated with MP within 8 hours were compared to 25 referred more than 8 hours after injury who received no methylprednisolone.	III	No effect of MP or surgery on outcome after SCI.

(Continues)

TABLE 1. Continued

Citation	Description of Study	Evidence Class	Conclusions
Bracken, ⁴ <i>JAMA</i> , 1997	NASCIS III: Multicenter randomized, double-blind trial comparing 24-hour MP administration to 48-hour MP and 48-hour tirilazad mesylate administration in the treatment of 499 SCI patients.	I* *(reported positive results III)	No difference between groups in all primary (preplanned) comparisons. Post-hoc analyses showed improved ASIA motor scores at 6 weeks and 6 months in 48 MP patients compared to 24 MP.
Gerhart, ¹⁶ <i>Paraplegia</i> , 1995	Retrospective concurrent cohort comparison of 363 SCI patients managed in 1990 to 91 and 1993. 188 patients received NASCIS II MP dosing compared to 90 patients without MP.	III	No difference in neurological outcome between groups based on Frankel classification.
George, ¹⁷ <i>Amer Surg</i> , 1995	Retrospective review of 145 SCI patients, 80 treated with MP, and 65 who did not receive MP.	III	No difference in mortality or neurological outcome between groups despite younger age and less severe injury in MP patients.
Otani, ¹⁴ <i>Sekitsui Sekizui</i> , 1994	Prospective randomized (nonblinded) multicenter study evaluating NASCIS II MP dose given to 82 patients within 8 hours compared to 76 observational controls enrolled between January 1992 and March 1993.	II* *(reported positive results III)	Only 70 MP patients and 47 controls analyzed. No difference in motor or sensory function between groups. Post-hoc analysis suggested some degree of sensory recovery to occur more frequently in MP patients, possibly cancelled out by greater degree of improvement in controls.
Prendergast, ¹⁵ <i>J Trauma Inj Inf Crit Care</i> , 1994	Retrospective review of 29 acute SCI patients treated with NASCIS II MP dosing after 1990 compared to 25 patients treated without MP before 1990. Thirty-one patients suffered penetrating SCI.	III	No difference in neurological recovery between MP or control groups. Patients with penetrating SCI who received MP showed deterioration in motor and sensory scores compared to improvement observed in controls.
Kiwerski, ¹³ <i>Injury</i> , 1993	Retrospective review of 620 SCI patients from 1976 to 1991. Discretionary MP administration and discretionary dose based on physician assessment.	III	Some degree of recovery reported more frequently in MP patients. Mortality rates 2X higher in patients who did not receive MP, suggesting more severe and life-threatening injuries.
Galandiuk, ¹² <i>Ann Surg</i> , 1993	Prospective assessment of 15 patients from 1990 to 1993 and retrospective review of 17 patients from 1987 to 1990. Fourteen patients given MP within 8 hours of SCI compared to 18 patients not treated with MP.	III	No difference in neurological outcome. MP patients had immune response alterations, higher rate of pneumonia and longer hospital stay compared to control patients (NS).
Bracken, ⁷ <i>J Neurosurg</i> , 1992	NASCIS II: One-year follow-up.	I* *(reported positive results III)	All primary (preplanned) comparisons negative. Post-hoc analyses showed improvement in motor but not sensory scores at 1 year in patients given MP within 8 hours of injury ($P = .030$). Wound infections, GI hemorrhage, and pulmonary embolus more common in MP vs placebo (NS, no power analysis).
Bracken, ² <i>NEJM</i> , 1990	NASCIS II: Multicenter randomized, double blind, placebo-controlled trial comparing MP to naloxone and placebo in 487 patients with acute SCI.	I* *(reported positive results III)	No difference between groups in all primary (preplanned) comparisons. Post-hoc analyses showed improvement in motor and sensory scores at 6 months in patients given MP within 8 hours of SCI.

(Continues)

TABLE 1. Continued

Citation	Description of Study	Evidence Class	Conclusions
Bracken, ⁹ <i>J Neurosurg</i> 1985	NASCIS I: One-year follow up.	I	No significant difference in neurological recovery of motor or sensory function 1-year post-injury.
Bracken, ⁸ <i>JAMA</i> , 1984	NASCIS I: Multicenter, double-blind randomized trial comparing MP(1000 mg/d vs 100 mg/d for 11 days) in treatment of 330 patients with acute SCI.	I	No treatment effect at 6 weeks and 6 months post injury. No control group. Wound infections significantly higher in high-dose group ($P = .01$). Death in first 14 days 3X more common in high-dose group (NS, no power analysis).

ASIA, American Spinal Injury Association; ICU, intensive care unit; MP, methylprednisolone; NASCIS, National Acute Spinal Cord Injury Study; NS, not statistically significant; SCI, spinal cord injury.

associated with a variety of complications including infection, respiratory compromise, GI hemorrhage, and death. MP should not be routinely used in the treatment of patients with acute SCI.

GM-1 Ganglioside (Sygen)

Found indigenously in cell membranes of mammalian central nervous system tissue, GM-1 ganglioside is a compound thought to have antiexcitotoxic activity, promote neuritic sprouting, potentiate the effects of nerve growth factor, and prevent apoptosis. In 1991, Geisler et al³² reported promising results of a pilot study investigating its use in acute SCI. All patients received a 250 mg bolus of MP followed by 125 mg every 6 hours for 72 hours. GM-1 patients were administered 100 mg of GM-1 per day for 18 to 32 days, with the first dose provided within 72 hours of injury. Neurological assessment was accomplished with ASIA motor score assessments and the Frankel scale.

Of 37 patients entered into the study, 34 were available for 1-year follow up (16 GM-1 patients, 18 placebo). GM-1

ganglioside-treated patients showed significant improvement in Frankel grade from baseline to 1-year follow up ($P = .034$) and significantly greater improvement in ASIA motor scores compared to placebo-treated patients ($P = .047$). The recovery of motor function in GM-1 ganglioside-treated patients was felt to be due to recovery of strength in paralyzed muscles rather than strengthening of paretic muscles. There were no adverse effects attributed to the administration of the study drug. The authors concluded that GM-1 ganglioside enhanced neurological recovery in human patients following SCI and deserved further study.

The subsequent multicenter study involved 28 neurotrauma institutions and randomized 797 patients within 72 hours of injury to receive either GM-1 ganglioside (100 or 200 mg i.v./day) or placebo for a total of 56 days³³. All patients received NASCIS II doses of MP within 8 hours of injury. The duration of follow up was 1 year. Although patients with ASIA grade C and D SCI treated with Sygen demonstrated statistically significant improvement in modified Benzel grade compared to placebo-treated

TABLE 2. Evidentiary Table: Pharmacological Therapy: GM-1 Ganglioside

Citation	Description of Study	Evidence Class	Conclusions
Geisler et al, ³³ <i>Spine</i> , 2001	Prospective randomized, double blind, stratified multicenter trial of GM-1 ganglioside in 760 acute SCI patients. All received MP per NASCIS II protocol. (Placebo group)	I	No significant differences in neurological recovery identified between GM-1 treated patients and MP treated patients at 26-week follow up. Trend for earlier recovery in GM-1 treated patients. No true placebo group.
Geisler et al, ³² <i>NEJM</i> , 1991	Prospective, randomized, double blind trial of GM-1 ganglioside in 37 human SCI patients. All received 250 mg MP bolus followed by 125 mg/Q6H x72 hours before randomization (placebo group).	I	GM-1 ganglioside enhances recovery of neurological function, significant difference in recovery compared to MP group ($P = .047$). Insufficient numbers of patients to draw meaningful conclusions. No true placebo group.

NS, not statistically significant

patients at 4 and 8 weeks after injury, the advantage was lost at subsequent follow up visits. No difference between actively treated and placebo-treated patients was noted in any of the outcome measures at 1 year. There have been no further studies to confirm or refute these results in the last decade. Consequently, GM-1 ganglioside is not recommended for use in the routine management of patients with acute SCI at this time.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Occipital Condyle Fractures

Nicholas Theodore, MD*

Bizhan Aarabi, MD, FRCSC‡

Sanjay S. Dhall, MD§

Daniel E. Gelb, MD¶

R. John Hurlbert, MD, PhD,
FRCSC||

Curtis J. Rozzelle, MD#

Timothy C. Ryken, MD, MS**

Beverly C. Walters, MD, MSc,
FRCSC‡‡§§

Mark N. Hadley, MD§§

*Division of Neurological Surgery, Barrow
Neurological Institute, Phoenix, Arizona;

‡Department of Neurosurgery, and
¶Department of Orthopaedics, University

of Maryland, Baltimore, Maryland;
§Department of Neurosurgery, Emory
University, Atlanta, Georgia; ||Department
of Clinical Neurosciences, University of
Calgary Spine Program, Faculty of Medi-
cine, University of Calgary, Calgary, Alber-
ta, Canada; #Division of Neurological
Surgery, and §§Division of Neurological
Surgery, Children's Hospital of Alabama,
University of Alabama at Birmingham,
Birmingham, Alabama; **Iowa Spine &
Brain Institute, University of Iowa, Water-
loo/Iowa City, Iowa; ‡‡Department of
Neurosciences, Inova Health System, Falls
Church, Virginia

Correspondence:

Mark N. Hadley, MD, FACS, UAB
Division of Neurological Surgery,
510 – 20th Street South, FOT 1030,
Birmingham, AL 35294-3410.
E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS

Diagnostic:

Level II:

- Computed tomographic (CT) imaging is recommended to establish the diagnosis of occipital condyle fractures (OCFs).

Level III:

- Magnetic resonance imaging (MRI) is recommended to assess the integrity of the cranio-cervical ligaments.

Treatment:

Level III:

- External cervical immobilization is recommended for all types of OCFs. More rigid external immobilization in a halo vest device should be considered for bilateral OCF.
- Halo vest immobilization or occipitocervical stabilization and fusion are recommended for injuries with associated atlanto occipital ligamentous injury or evidence of instability.

RATIONALE

Acute traumatic OCF was first described by Bell in 1817. More frequent observations of this injury have been reported during the past 2 decades. Improvements in CT imaging technology and the use of CT imaging of head-injury patients that includes visualization of the craniovertebral junction have resulted in more frequent recognition of this injury. Despite this, acute traumatic OCF remains an infrequent occurrence.

An analysis of all of the reported cases of OCF in the scientific literature may facilitate development of diagnostic and treatment recommendations for

this disorder and is undertaken in this review. Specific questions that were evaluated include: accuracy of plain radiographs and CT imaging in the diagnosis of OCF, and the safety and efficacy of various treatment strategies for OCF including no treatment, traction, external immobilization, and surgical decompression with internal fixation and fusion.

The guidelines author group of the Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons (AANS) and Congress of Neurological Surgeons (CNS) produced a medical evidence-based guideline on this topic in 2002.¹ The purpose of the current review is to update the medical evidence on the diagnosis and treatment of OCF since that early publication.

SEARCH CRITERIA

A National Library of Medicine (Pubmed) computerized literature search of publications from 1966 to 2011 was performed using the following headings: occipital bone and fracture (spinal, skull, or fracture alone), and led to 2105 and 71 182 citations, respectively. A subset of 235 citations contained both headings. The bibliographies of the identified articles were scanned to identify additional citations. The articles were reviewed using the following criteria for potential inclusion in diagnosis: human subjects, type of fracture, and tomographic or plain radiographic findings. The articles were separately considered for inclusion in treatment within the following parameters: human subjects, type of fracture, management, and outcome. The observations from all of the citations were combined because the usual methods for analysis were precluded by the infrequent occurrence of this injury type. Fifty-one articles met the selection criteria. All but 2 articles contained Class III medical evidence of either single case

studies or case series. The 2 exceptions were prospective studies to evaluate the use of clinical criteria in blunt trauma patients to prompt CT imaging of the skull base.^{2,3} The duration of follow-up in the clinical articles ranged from not reported to 5 years. The data provided by these reports were compiled and make up the basis for this guideline. Summaries of the articles are provided in Evidentiary Table format (Table).

SCIENTIFIC FOUNDATION

OCFs have been classified by Anderson and Montesano⁴ into 3 types: Type I (comminuted), Type II (extension of a linear basilar skull fracture), and Type III (avulsion of a fragment). The current literature review identified 415 patients reported to have OCF. Clinical series and case reports provided data on 84 Type I, 125 Type II, 207 Type III unilateral OC fractures, 37 bilateral OCFs, and 2 old fractures.

OCFs are relatively uncommon injuries. Various reports have estimated a 1% to 3% frequency of OCF in patients sustaining blunt craniocervical trauma.^{5,6} Link et al described the results of craniocervical CT imaging on 202 consecutive acute blunt patients with a Glasgow Coma Score between 3 and 6.³ OCF was identified in 9 of the 202 impaired patients they imaged (4.4%). In 1997, Bloom et al performed a prospective study, with 1 year follow-up to identify the frequency of OCF in patients meeting certain clinical criteria.² Fifty-five consecutive patients with high-energy blunt craniocervical trauma underwent thin-section craniocervical junction CT imaging. Supplemental criteria included reduced Glasgow Coma Scale (GCS) on admission, occipitocervical tenderness, reduced craniocervical motion, lower cranial nerve abnormality, and retropharyngeal soft tissue swelling (STS). Nine (16.4%) of 55 patients meeting their criteria following trauma were identified with OCF. In 2009, Malhan et al, determined that the incidence of OCF was 1.7/1000 trauma patients per year.

Diagnosis

Plain radiographs of the cervical spine were reported to have been performed in 359 patients culled from the literature review. These radiographs were reported as “normal” in 42 patients. Twenty-four patients had prevertebral STS.⁷⁻¹⁰ Forty-eight OCF injury patients were reported to have sustained multiple cervical fractures. Associated fractures reported with OCF included fractures of the: atlas ($n = 22$); Type II odontoid ($n = 7$); axis ($n = 14$); isolated subaxial fractures ($n = 13$); and an unspecified cervical fracture ($n = 1$). Seven patients had atlantoaxial widening and 1 had a C5-6 subluxation without fracture.

Only 3 patients with OCF had their injury directly identified on plain radiographs of the skull or of the cervical spine.^{11,12} The results of plain radiographs were not reported in 141 patients with OCF. The calculated sensitivity of plain radiographs from these reports aiding in the diagnosis of OCF is 1.4% (3 of 218). Since the data were obtained from case reports and case series of patients known to have OCF, comparison with the findings of plain radiographs in patients without OCF could not be accomplished. As a result,

calculations of specificity, positive predictive value, and negative predictive value of plain x-rays for OCF could not be performed.

Three hundred sixty-three of the reported patients with OCF underwent CT imaging. Two patients had OCF diagnosed from retrospective review of CT images that were initially interpreted as normal. The diagnosis of OCF could be made in every patient with OCF on whom a CT scan was performed. The collective evidence (including several recent comparative studies) derived from the 363 cases identified in the literature review suggests that the sensitivity for CT imaging to depict OCF is 100%, and provides Class II medical evidence on this issue.

Only 59 patients with OCF have been reported to have been studied with MRI. Cervicomedullary hemorrhages were identified in 13 patients, 12 had a retrodental hemorrhage, 1 had a torn tectorial membrane, 4 identified the fracture (3 displaced), 24 had prevertebral or nuchal ligament edema and hemorrhage, and 5 patients had normal imaging. Acute MRI has been infrequently reported after OCF (11 described in various reports); therefore, no inferences about the role of early MRI in this setting can be offered. In 1997, Tuli et al proposed a new classification scheme using MRI to differentiate stable from unstable OCF (41). However, the case example they cited had concurrent atlantoaxial instability (rather than isolated atlanto-occipital instability).

Clinical clues suggesting OCF are variable and have not been consistently documented in the literature. Of the 415 patients with OCF described in the literature, there is detailed clinical information provided on only 119 patients. Loss of consciousness (poor GCS) was reported in 36 patients (30%). Thirty-five patients were reportedly normal (30%). Forty-eight had neurological deficits (40%), including acute or delayed cranial nerve deficits alone, cranial nerve deficits with limb weakness, mild to severe limb weakness without cranial nerve deficits, vertigo, hyperreflexia, and diplopia. Neck pain was reported as a consistent feature of OCF in responsive patients. Only 4 patients were described who did not complain of occipitocervical pain in the absence of significantly impaired consciousness.^{8,10,13} Of these 4 patients, 1 was intoxicated, 1 had severe extremity injury pain, and the other 2 had severe facial trauma.

In summary, the diagnosis of OCF is rarely made on plain radiographs. Evaluation of the craniocervical junction utilizing multiplanar CT with reconstruction images is recommended to evaluate for the presence of OCF. Blunt trauma patients sustaining high-energy craniocervical injuries are more likely to sustain OCF. Consequently, cranial imaging of these patients should include CT imaging of the craniocervical junction. Clinical criteria including altered consciousness, occipital pain or tenderness, impaired craniocervical motion, lower cranial nerve paresis, and neurological deficits potentially referable to the proximal spinal cord should prompt CT imaging of the craniocervical junction to exclude OCF.

Treatment

Of the 415 patients with OCF reported in the literature, treatment information is offered on 259 patients. Follow-up of these patients ranged from not reported to 5 years duration. Forty-three OCF patients (2 Type I; 14 Type II; 5 Type III; and 22

unknown type) did not receive treatment. Nine of these patients (1 Type I; 4 Type II; and 4 Type III) on whom clinical follow-up was described developed cranial nerve deficits within days to weeks after injury.^{6,14-21} One hypoglossal nerve palsy resolved, 2 hypoglossal nerve deficits improved, 3 other cranial nerve deficits persisted (2 hypoglossal, 1 glossopharyngeal and 1 vagal), and 3 outcomes were not reported. Six additional patients were identified in the literature with untreated OCF who developed delayed deficits or symptoms. Two of these initially untreated patients (1 Type II and 1 Type III) developed multiple lower cranial nerve deficits that reportedly improved with 6 weeks of cervical immobilization.²² Another initially untreated patient (Type III) developed vertigo 3 months after injury that resolved after 8 weeks of collar immobilization.²³ One patient (Type III) developed nystagmus and a lateral rectus palsy after precautionary collar immobilization was discontinued. The deficit resolved after resuming cervical immobilization.²⁴ One patient (Type III) developed double vision during cervical traction, which resolved with surgical decompression.²¹ Finally, 1 patient (Type III) developed delayed vagal, spinal accessory and hypoglossal nerve palsies during cervical immobilization in a cervical collar.²⁵ The cranial nerve X and XI palsies improved. However, the hypoglossal palsy persisted at 1 year.

One hundred ninety patients with OCF, including several patients with bilateral OCF injuries, were initially treated with cervical collar immobilization. Outcome following treatment was inconsistently reported. Sixty-eight with OCF treated with a collar on whom follow-up information was provided had complete recovery at last follow-up. Another patient had modest reduction of neck rotation after treatment. One patient had a hypoglossal nerve deficit at 50 months follow-up.²⁶ Two patients were described who had persistent mild dysphonia.²⁷ Three had persistent neck pain. Two of the 3 were unable return to work; however, 1 was reportedly without disability.²⁸

Thirty-two patients with OCF were treated with halo/Minerva immobilization devices. One of those patients had slight improvement of Collet-Sicard syndrome at last follow-up.²⁶ Another was reported with persistent trapezius weakness.²⁷ Two other patients were reported to have chronic neck pain. Two patients were reported to have had a complete recovery at last follow-up.²⁸

Of 37 patients with bilateral OCF reported in the literature, there is some treatment data on 29 patients. In the single largest series of these patients, Hanson et al described 22 patients with bilateral occipito-atlanto-axial injuries in a series of 95 OCF patients. Four of these patients died, 8 underwent occipitocervical fusion, and 4 were treated with halo immobilization. OCF patients in Hanson et al's series included patients with atlanto-occipital dislocation, precluding the ability to identify a treatment distinction between these 2 diagnoses.²⁹ In the remaining 7 bilateral OCF cases, there was 1 report of halo immobilization and 6 cases of conservative management, which was defined as either a rigid cervical orthosis or, "no specific treatment".^{27,30} The patient who was treated with halo immobilization had a good outcome. In the conservatively treated group, there was 1 case of dysphonia at 2-year follow-up.

Seventeen patients with OCF were treated with surgery. Fourteen of them were treated with occipitocervical internal fixation and fusion (1 unknown type, 2 Type II and 11 type III OCF injuries). Three of these patients underwent surgery for decompression of the brainstem (1 type II and 2 type III injuries), in addition to internal fixation and fusion. Surgery was offered in the setting of craniocervical misalignment in 2 cases, associated C1 and C2 fracture in 1 case,³⁰ displaced fractures with ligamentous instability in another 3 cases,^{10,31} and in 8 patients with bilateral or occipitoatlantal/atlandoaxial joint space widening in association with OCF.²⁹

One patient with delayed diplopia had symptom resolution after removal of the fracture fragment,²¹ while 1 patient with lower cranial nerve deficits³² and 1 with diplopia and hemiparesis²³ remained unchanged several days after surgery. One patient who was neurologically intact remained so following occipitocervical fusion.³¹ There is no reported follow-up for the remainder of the OCF patients treated surgically.

In summary, 12 of 15 patients who developed delayed symptoms or deficits were not initially treated. Only 3 of these 12 patients were subsequently treated with cervical immobilization. All 3 improved. In comparison, only 3 of 6 patients demonstrated improvement in deficits without treatment. Only 1 patient (OCF Type III) developed a deficit during treatment that persisted (hypoglossal nerve palsy) despite collar use. Only 3 patients underwent surgery for decompression of the brainstem, 1 of whom had immediate and lasting improvement in symptoms post-operatively. Nonoperative treatment with external cervical immobilization is almost always sufficient to promote bony union/healing and recovery or cranial nerve deficit improvement in all types of OCF. Isolated bilateral OCF should prompt consideration of more rigid external immobilization. Patients shown to have unilateral or bilateral OCF associated with occipitoatlantal injury may require surgical stabilization (occipitocervical internal fixation and fusion), or halo-vest immobilization, depending upon the extent of the injury. It is important to note that the presence of OCF should raise the suspicion for the potential of associated atlanto-occipital dislocation; however, either of these 2 traumatic injuries may be present independently.

SUMMARY

OCF is an uncommon injury and requires CT imaging to establish the diagnosis. Patients sustaining high-energy blunt craniocervical trauma, particularly in the setting of loss of consciousness, impaired consciousness, occipitocervical pain or motion impairment, and lower cranial nerve deficits, should undergo CT imaging of the craniocervical junction. Untreated patients with OCF can develop lower cranial nerve deficits that usually recover or improve with external immobilization. Nonsurgical treatment with external cervical immobilization is sufficient in nearly all types of OCF. Bilateral OCF injuries should prompt consideration for more rigid external immobilization in a halo vest device. Surgical treatment (cranio-cervical internal fixation and fusion) may be indicated in patients with OCF who have overt instability, neural compression from displaced fracture fragments, or who have associated occipital-atlantal or atlanto-axial injuries.

TABLE. Evidentiary Table: Occipital Condyle Fractures

Citation	Evidence Class	Age	Sex	Type	Loc	Pain	Plain	CT	MR	Exam	Treatment	Outcome
Aulino et al, ³³ <i>Emergency Radiology</i> , 2005	III	Avg. 30 y	53 M	I-21	Unrep	Unrep	Unrep	Unrep	Unrep	12%—CN palsies	Unrep	Unrep
			23 F	II-28								
				III-37								
Capuano et al, ²⁷ <i>Acta Neurochir</i> , 2004	III	29 y	M	II	Unrep	Unrep	Unrep	B, +	Unrep	CN IX	8 wk collar	2 yr dysphonia
		39 y	M	III	Unrep	Unrep	Unrep	L, +	SAH	CN X-XII	12 wk collar	2 y normal
		17 y	M	III	Unrep	Unrep	Unrep	L, +	Brain injury	CN X-XII	12 wk collar	2 y normal
		14 y	M	III	Unrep	Unrep	Unrep	L, +	Extradural blood	CN X-XII	12 wk halo	18 mo CN XI
		73 y	F	II	Unrep	Unrep	Unrep	R, +	Unrep	CN IX, X	8 wk collar	2 y normal
		26 y	M	II	Unrep	Unrep	Unrep	R, +	Unrep	Unrep	8 wk collar	18 mo normal
		46 y	M	III	Unrep	Unrep	Unrep	L, +	Unrep	CN X-XII	12 wk collar	18 mo normal
		58 y	F	II	Unrep	Unrep	Unrep	R, +	Unrep	Unrep	8 wk collar	18 mo dysphonia
		32 y	M	I	Unrep	Unrep	Unrep	R, +	Unrep	CN IX, X	12 wk halo	18 mo normal
		35 y	F	III	Unrep	Unrep	Unrep	R, +	Unrep	Unrep	12 wk collar	18 mo normal
Hanson et al, ²⁷ <i>AJR</i> , 2002	III	Mean: 33 y	64 M	I-3	Unrep	Unrep	Unrep	Unrep	Nuchal lig edema—73%.	Unrep	I : 2—Fusion/Halo	1 month after injury:
		31 y	F	II-23					Extradura/subdural blood—30%.		II : 2—Fusion/Halo	I: 66% normal
				III-69					Cord edema/hemorrhage—24%.		3-skull base decomp	II: 52% normal
											III : 18-Fusion/Halo	III: 59% normal
Legroset al, ²² <i>J Trauma</i> , 2000	III	71 y	F	III	-	Unrep	Unrep	L, +	Epidural blood	Del CN VI, VII, X	6 wk collar	18 mo CN X
		44 y	M	II	-	Unrep	Unrep	R, +	Normal	Del CN VI, IX-XII	6 wk collar	3 mo CN X
Ideet al, ³⁴ <i>J Neurosurg</i> , 1998	III	25 y	M	III	+	+	STS, C1fx	R, +	Tectorial membrane tear	Normal	10 wk collar	10 wk Normal
Demisch S et al, ¹⁷ <i>Clin Neurol Neurosurg</i> , 1998	III	45 y	F	II	Unrep	Unrep	Unrep	R, +	Fx	Del CN XII	None	1 y imp CN XII
Bloomet al, ² <i>Clin Radiol</i> , 1997	II	21 y	M	III	Unrep	Unrep	STS, C6, C7 Fx	R, +	Unrep	Normal	>8 wk collar	Normal
		36 y	F	III	Unrep	Unrep	Unrep	L, +	Unrep	Normal	>8 wk collar	Pain
		15 y	F	I/I	Unrep	Unrep	Unrep	B, +	Unrep	Q-paresis	>8 wk collar	Imp Q-paresis

(Continues)

TABLE. Continued

Citation	Evidence Class	Age	Sex	Type	Loc	Pain	Plain	CT	MR	Exam	Treatment	Outcome
		45 y	F	III/I	Unrep	Unrep	Unrep	B, +	Unrep	CN XII	>8 wk collar	Pain,CN XII
		22 y	F	II	Unrep	Unrep	Unrep	R, +	Unrep	Normal	>8 wk collar	Unrep
		21 y	M	I	Unrep	Unrep	STS,C1, C2, C5 Fx	R, +	Unrep	Normal	>8 wk collar	Unrep
		41 y	M	I	Unrep	Unrep	Unrep	R, +	Unrep	Normal	>8 wk collar	Normal
		6 y	F	II	Unrep	Unrep	Unrep	L, +	Unrep	Normal	>8 wk collar	Normal
		25 y	F	I	Unrep	Unrep	STS,C2 Fx	L, +	Unrep	Normal	>8 wk collar	Unrep
		20 y	M	I	Unrep	Unrep	Unrep	R, +	Unrep	P-plegia	>8 wk collar	Unrep
Tuliet al, ¹⁰ <i>Neurosurgery</i> , 1997	III	64 y	F	III	Unrep	+	STS	R, +	None	Normal	12 wk collar	3 mo Normal
		69 y	F	III	Unrep	-	AAWide	L, +	Fx	M-paresis, CN VII	OC Fusion	Improved
		27 y	M	Old	Unrep	-	Normal	L, +	None	Normal	None	3 y Normal
Cottalorda et al, ³⁵ <i>J Pediatr Orthop</i> , 1996	III	15 y	F	I	Unrep	+	Normal	R, +	None	Normal	7 wk Minerva, Traction, collar	4 mo Normal
Lam and Stratford, ³⁶ <i>Can J Neurol Sci</i> , 1996	III	20 y	F	III	Unrep	Unrep	Normal	R, +	Contusion	Hpa, CN XII	3 mo Halo	5 y imp CN XII
Urculo et al, ²⁰ <i>J Neurosurg</i> , 1996	III	62 y	M	III	Unrep	Unrep	Normal	R, +	Fx	Del CN I	None	6 mo same
Noble and Smoker, ⁶ <i>Am J Neuroradiol</i> , 1996	III	33 y	M	I	Unrep	Unrep	Unrep	?, +	None	Del CN XII	None	Unrep
		26 y	M	I	Unrep	Unrep	Unrep	?, +	None	GCS 15	None	Unrep
		16 y	M	II	Unrep	Unrep	Unrep	?, +	None	GCS 13	None	Unrep
		32 y	M	II	Unrep	Unrep	C2Fx	?, +	None	CN VII,XII	None	Unrep
		53 y	F	II	Unrep	Unrep	Unrep	?, +	None	GCS 8	None	Unrep
		47 y	F	II	Unrep	Unrep	Unrep	?, +	None	GCS 15	None	Unrep
		37 y	M	II	Unrep	Unrep	Unrep	?, +	None	GCS 8	None	Unrep
		11 y	M	II	Unrep	Unrep	Unrep	?, +	None	GCS 13	None	Unrep
		33 y	M	II	Unrep	Unrep	Unrep	?, +	None	GCS 15	None	Unrep
		23 y	M	II	Unrep	Unrep	Unrep	?, +	None	Unrep	Unrep	Unrep
		39 y	M	III	Unrep	Unrep	IIOfx	?, +	None	CN VII	Halo	Unrep
		88 y	M	III	Unrep	Unrep	C1,II Fx	?, +	None	GCS15	Halo	Unrep
		29 y	M	III	Unrep	Unrep	Unrep	?, +	None	Unrep	Unrep	Unrep
		14 y	F	III	Unrep	Unrep	Unrep	?, +	None	GCS 11	Collar	Unrep
		17 y	F	III	Unrep	Unrep	Unrep	?, +	None	GCS 7	None	Unrep
Castling and Hicks, ¹⁵ <i>Br J Oral Maxillofac Surg</i> , 1995	III	21 y	M	II	+	+	Normal	R, +	None	Del CN XII	None	2 y Normal
Emery et al, ³⁷ <i>Eur Spine J</i> , 1995	III	26 y	M	III	Unrep	+	Normal	L, +	Fx	Hyperreflexic	Collar	4 mo Normal
Paley and Wood, ¹⁹ <i>Br J Oral Maxillofac Surg</i> , 1995	III	21 y	M	III	Unrep	+	Normal	L, +	Normal	Del CN XII	None	6 mo imp CN XII
Stroobants et al, ³⁸ <i>J Neurosurg</i> , 1994	III	27 y	M	III	-	+	Normal	R, +	None	Normal	10 wk collar	21 mo Normal
		12 y	F	III	-	+	C1 Fx	L, +	None	Normal	4 wk Minerva	Normal
Wasserbergand Bartlett, ²¹ <i>Neuroradiol</i> , 1994	III	39 y	M	III	+	Unrep	Normal	L, +	None	Del CN XII	None	CN XII

(Continues)

TABLE. Continued

Citation	Evidence Class	Age	Sex	Type	Loc	Pain	Plain	CT	MR	Exam	Treatment	Outcome
Young et al, ³⁹ <i>Neurosurgery</i> , 1994	III	24 y	M	III	+	+	Normal	L, +	None	Del Diplopia	Traction, Decomp	Normal
		16 y	M	III	+	Unrep	Normal	R, +	None	Brain injury	Traction, collar	3 mo CN XII
		34 y	M	III	Unrep	Unrep	Normal	R, +	None	Unrep	Traction, halo	Unrep
		26 y	F	III	+	Unrep	Normal	L, +	None	Hpa, CN IX-XII	12 wk halo	14 mo imp IX-XII
Mann and Cohen, ⁴⁰ <i>Am J Radiol</i> , 1994	III	20 y	M	III	+	Unrep	Normal	R, +	None	GCS7	Collar	1 yr Hpa
		23 y	M	III	-	+	Normal	R, +	None	Normal	6 wk collar	Normal
Olsson and Kunz, ¹³ <i>Acta Radiologica</i> , 1994	III	43 y	M	III	Unrep	-	Normal	L, +	None	Normal	Collar	Normal
Sharma et al, ³² <i>Clin Neurol and Neurosurg</i> , 1993	III	35 y	M	II	Unrep	Unrep	Normal	L, +	None	CN IX,X	Decompression	3 mo imp IX, X
Massaro and Lanotte, ⁴¹ <i>Injury</i> , 1993	III	21 y	M	III	Unrep	Unrep	Normal	L, +	None	H-sensory, CN XII	8 wk Minerva	2 yr CN XII
Raila et al, ⁴² <i>Skeletal Radiol</i> , 1993	III	25 y	M	III	+	+	Normal	L, +	None	Normal	6 wk collar	Normal
Bettini et al, ⁴³ <i>Skeletal Radiol</i> , 1993	III	67 y	M	III	-	+	C1abnormal	L, +	None	Normal	collar	Normal
		39 y	F	I	Unrep	+	C3 Fx	L, +	None	Normal	Unrep	Unrep
Leventhal et al, ⁴⁴ <i>Orthopaedics</i> , 1993	III	24 y	M	II	+	Unrep	Normal	R, +	None	Coma	Unrep	Unrep
		21 y	F	III	+	Unrep	Unrep	?, +	Coma	Coma	Unrep	Unrep
		21 y	M	III/III	Unrep	+	Normal	B, +	None	Normal	Unrep	Unrep
		42 y	F	II	+	Unrep	Normal	L, +	None	CN VI,VII	3 mo collar	Unrep
Mody and Morris, ⁹ <i>Injury</i> , 1992	III	19 y	F	III	+	+	Normal	L, +	None	Normal	Collar	Unknown
		43 y	M	III	Unrep	+	C5 Fx	R, +	None	Normal	3 mo collar	Normal
		17 y	F	II	+	Unrep	L1 Fx	R, +	None	GCS 10	3 mo collar	Normal
		36 y	M	I	+	GCS 8	T1 Fx	R, +	None	GCS 8	3 mo halo	Normal
		17 y	M	I	+	GCS 4	Normal	R, +	None	GCS 4	3 mo collar	Normal
		21 y	M	III	+	Unrep	STS	L, +	None	Unrep	Traction, 6 wk collar	18 mo Normal
Bozboga et al, ²³ <i>Spine</i> , 1992	III	34 y	F	III	+	+	Normal	L, +	None	L hpa, diplopia	Late decomp.	4 y Normal
Bridgman and McNab, ²⁵ <i>Surg Neurol</i> , 1992	III	37 y	M	III	+	Unrep	Unrep	L, +	None	Del vertigo	8 wk collar	3 y Normal
		32 y	M	III	+	+	Normal	L, +	None	Del CN X-XII	Collar	1 y imp X-XII
Wani et al, ¹² <i>J Trauma</i> , 1991	III	67 y	M	II	+	Unrep	+ cond Fx	L, None	None	CN IX-XII	None	CN IX-XII
Wessels, ⁴⁵ <i>S Afr J Surg</i> , 1990	III	26 y	M	III	+	+	Unrep	R, +	None	CN VII	Collar	6 wk imp
		7 mo	M	II	+	Unrep	Unrep	L, +	None	V,VII	Collar	4 mo VII-XII
Mariani, ⁸ <i>Ann Emerg Med</i> , 1990	III	27 y	M	II	+	Unrep	Unrep	R, +	None	VII	Collar	6 wk imp
		30 y	M	III	+	-	STS	R, -	None	Normal	8 wk collar	Normal
Jones et al, ¹¹ <i>Am J Neuroradiol</i> , 1990	III	43 y	M	III/III	+	Unrep	+ con Fx	B, +	Contusion	Q-plegia	OCF	4 wk Q-plegia
Desai et al, ²⁴ <i>J Trauma</i> , 1990	III	33 y	M	III	-	+	Normal	L, +	None	6	Collar	4 mo normal

(Continues)

TABLE. Continued

Citation	Evidence Class	Age	Sex	Type	Loc	Pain	Plain	CT	MR	Exam	Treatment	Outcome
Valaskatzis and Hammer, ⁴⁶ <i>S African Med J</i> , 1990	III	19 y	M	III	+	+	Normal	R, +	None	Normal	6 wk collar	Normal
Orbay et al, ¹⁸ <i>Surg Neurol</i> , 1989	III	37 y	M	III	Unrep	+	Normal	L, + (tomo -)	None	Del CN XII	None	15 mo, CN XII
Savolaine et al, ⁴⁷ <i>J Orthop Trauma</i> , 1989	III	71 y	F	III	+	+	Normal	R, +	None	Hplegia, CN VI	Traction, Halo	LM paresis
Anderson and Montessano, ⁴ <i>Spine</i> , 1988	III	3 y	M	I	+	Unrep	Normal	R, +	None	Uncon	Soft	24 mo normal
		18 y	F	III	+	Unrep	Normal	?, +	None	Unrep	Minerva	36 mo
		22 y	M	III	+	Unrep	Normal	R,Tomo	None	Uncon	Halo	12 mo normal
		23 y	M	III	+	Unrep	Normal	L, +	None	Uncon	Collar	Death
		25 y	M	III	+	Unrep	Normal	? Tomo	None	Unrep	Minerva	17 mo
		37 y	M	II	+	Unrep	Normal	L, +	None	Uncon	Collar	12 mo normal
Curri et al, ⁴⁸ <i>J Neurosurg Sci</i> , 1988	III	16 y	F	III'	+	Unrep	Normal	R, +	None	Decerebrate	Collar	6 mo Unrep
Hashimoto et al, ⁴⁹ <i>Neurosurgery</i> , 1988	III	71 y	M	II	-	Unrep	Normal	L, +	None	CN IX,X,XI,XII	None	6 mo CN IX,X, XI,XII
Deeb et al, ¹⁶ <i>J Computed Tomography</i> , 1988	III	25 y	F	II	Unrep	Unrep	Normal	Del L,+	None	12	None	Unrep
		66 y	F	Old	Unrep	+	None	Del L,+	Fx	Normal	None	Unrep
Spencer et al, ⁵⁰ <i>Neurosurgery</i> , 1984	III	19 y	M	I	+	GCS8	Normal	L, +	None	GCS 8	Collar, Halo	BCN IX,X
Goldstein et al, ⁵¹ <i>Surg Neurol</i> , 1982	III	24 y	F	III	Unrep	+	C5-6 sublux	L,Tomo	None	Normal	2 mo collar	Normal
Harding-Smith et al, ⁷ <i>J Bone Joint Surg</i> , 1981	III	18 y	M	III	+	Unrep	STS	R,Tomo	None	Uncon	Collar	16 mo Normal
Bolender et al, ¹⁴ <i>Am J Radiol</i> , 1978	III	23 y	M	III	Unrep	Unrep	Normal	R,Tomo	None	CN IX,X	None	Unrep
		22 y	M	II	Unrep	Unrep	Normal	R,Tomo	None	Del VI,IX,X	None	Unrep

CT, computed tomography; MRI, magnetic resonance imaging; Unrep, unreported; Del, delayed; + done or positive; -, not done or negative; Fx, fracture; Imp, improvement; STS, soft tissue swelling; C, cervical; AA, atlantoaxial; Q quadric; P, para; M, mono-; OC, occipital condyle; CN, cranial nerve; GSC, Glasgow Coma Scale; Od, odontoid; L, left; R, right; B, bilateral; tomo, tomography; Tr, traction; Uncon, unconfirmed; Hpa, hemiparesis; Cond, condylar; slx, subluxation.

KEY ISSUES FOR FUTURE INVESTIGATION

CT imaging with 3-dimensional reconstruction is essential for the diagnosis of OCF. MRI is useful for the diagnosis of ligamentous and other soft tissue injuries, including injuries of the spinal cord. Because OCF injuries remain relatively infrequent, cooperative retrospective collection of CT, MRI, and treatment and outcome data in patients with OCF is recommended.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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The Diagnosis and Management of Traumatic Atlanto-occipital Dislocation Injuries

Nicholas Theodore, MD*

Bizhan Aarabi, MD, FRCSC‡

Sanjay S. Dhall, MD§

Daniel E. Gelb, MD¶

R. John Hurlbert, MD, PhD,
FRCSC||

Curtis J. Rozzelle, MD#

Timothy C. Ryken, MD, MS**

Beverly C. Walters, MD, MSc,
FRCSC‡‡§§

Mark N. Hadley, MD§§

*Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona;

‡Department of Neurosurgery, and
¶Department of Orthopaedics, University of Maryland, Baltimore, Maryland;

§Department of Neurosurgery, Emory University, Atlanta, Georgia; ||Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada; #Division of Neurological Surgery, Children's Hospital of Alabama, University of Alabama at Birmingham, Birmingham, Alabama; **Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa; ‡‡Department of Neurosciences, Inova Health System, Falls Church, Virginia

Correspondence:

Mark N. Hadley, MD, FACS, UAB
Division of Neurological Surgery,
510 – 20th Street South, FOT 1030,
Birmingham, AL 35294-3410.
E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS

Diagnostic Level I

- Computed tomography (CT) imaging to determine the CCI (condyle-C1 interval) in pediatric patients with potential atlanto-occipital dislocation (AOD) is recommended.

Level III

- If there is clinical or radiographic suspicion of AOD, CT of the craniocervical junction is recommended. The CCI determined on CT has the highest diagnostic sensitivity and specificity for AOD among all radiodiagnostic indicators in pediatric patients. The utility of CCI in adult patients has not been reported.
- A lateral cervical radiograph is recommended for the diagnosis of AOD. If a radiological method for measurement is used to determine AOD on the lateral radiograph, the basion-axial interval-basion dental interval (BAI-BDI) method is recommended. The presence of upper cervical prevertebral soft tissue swelling (STS) on an otherwise non-diagnostic plain cervical radiograph should prompt CT imaging to rule out AOD.

Treatment Level III

- Treatment with internal fixation and fusion using one of a variety of methods is recommended.
- Traction is not recommended in the management of patients with AOD, and is associated with a 10% risk of neurological deterioration.

RATIONALE

Although traumatic atlanto-occipital dislocation (AOD) was perceived to be an uncommon injury resulting in frequent death, improvements in the emergency management of the patient in the field, rapid transport, and better recognition have resulted in more survivors of AOD in the past 2 decades. Infrequent observation of patients with AOD and missed diagnoses may impair outcomes of patients with this unusual injury.¹ An assimilation of the reported experiences of clinicians evaluating and managing AOD in our scientific literature may facilitate development of diagnostic and treatment options for this traumatic disorder. The guidelines author group of the Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons (AANS) and Congress of Neurological Surgeons (CNS) produced a medical evidence-based guideline on this topic in 2002.² The purpose of the current review is to update the medical evidence on the diagnosis and treatment of AOD since that early publication. Specific questions that were investigated include the sensitivity of plain radiographs, CT, and MRI in the diagnosis of AOD, as well as the safety and efficacy of various treatment modalities for AOD, including no treatment, traction, external immobilization, and internal fixation with fusion.

ABBREVIATIONS: AOD, atlanto-occipital dislocation; BAI-BDI, basion-axial interval-basion dental interval; CCI, condyle-C1 interval; STS, soft tissue swelling; TBI, traumatic brain injury

SEARCH CRITERIA

A National Library of Medicine computerized literature search of publications from 1966 to 2011 was performed using the following headings: “atlanto-occipital joint” and “dislocation.” The search was limited to the English language and human studies. An exploded search of these headings led to 522 and 11 257 citations, respectively. A subset of 178 citations contained both headings. The references of the identified articles were reviewed to identify additional case reports. The articles were reviewed using the following criteria for inclusion in diagnosis: human survivors, type of traumatic atlanto-occipital dislocation, and plain radiographic findings. The articles were also reviewed using the following criteria for inclusion in treatment: human survivors, type of traumatic AOD, management, and outcome. The observations from the published reports were combined because the usual methods for analysis were precluded by the infrequent observation of this injury. The type of dislocation was classified according to Traynelis et al³ into Type I (anterior), Type II (longitudinal), and Type III (posterior) dislocations. Lateral, rotational, and multi-directional dislocations that could not be classified into 1 of these 3 types were considered separately and are notated as “other Type.” The duration of follow-up ranged from none reported to 4 years. Of the articles meeting the diagnostic selection criteria reported, 68 articles with 105 patients provided data on 38 Type I, 45 Type II, 4 Type III, and 18 other Types of AOD. Two of these articles^{1,4} included 1 patient each from 2 previously published individual case reports.^{5,6} Of the articles meeting the treatment selection criteria, 56 articles with 84 patients provided data on 31 Type I, 33 Type II, 4 Type III, and 16 other types of AOD. Two of these articles^{1,4} included 1 patient each from 2 previously published individual case reports.^{5,6} The information provided by these reports was compiled and scrutinized and make up the basis for this guideline. Summaries of these reports are provided in Evidentiary Table format (Tables 1-2).

SCIENTIFIC FOUNDATION

Diagnosis

A variety of radiographic and descriptive features have been proposed for the diagnosis of AOD (Table 1). Initially, the descriptive measurements were all based on lateral cervical radiographs.^{7-12,70} A displacement of more than 10 mm between the basion and dens is considered abnormal by Wholey et al.⁷ A ratio of the basion-posterior atlas arch distance divided by the opisthion-anterior atlas arch distance greater than one is considered abnormal by Powers et al.⁸ A distance of more than 13 mm between the posterior mandible and anterior atlas, or 20 mm between the posterior mandible and dens are considered abnormal by Dublin et al.⁹ Failure of a line from the basion to the axis spinolaminar junction to intersect C2, or a line from the opisthion to the posterior inferior corner of the body of the axis to intersect C1, are considered abnormal by Lee et al.¹⁰ Finally, a displacement of more than 12 mm, or less than minus 4 mm

between the basion and posterior C2 line, or a displacement of more than 12 mm from the basion to the dens (2 mm more than the Wholey recommendation) is considered abnormal by Harris et al.^{11,12} A comparative study by Lee calculated the sensitivity for the Wholey method of 50%, a 33% sensitivity for the Power's ratio, and a 25% sensitivity for the Dublin method. The authors determined that their X-line method had a sensitivity of 75%,¹⁰ although neither the Power's ratio nor X-line method could be applied in nearly half their patients. A comparative study reported by Harris et al found that the Power's ratio had a sensitivity of 60%, the Lee method a sensitivity of 20%, and the BAI-BDI method a sensitivity of 100% among those patients with AOD on whom the required landmarks could be identified on lateral cervical spine films.¹² Przybylski et al¹ reported failure to diagnose AOD in 2 of 5 patients with the Power's ratio, in 1 of 5 patients with the X-line method, and in 2 of 5 with the BAI-BDI method. No radiographic method reviewed has complete sensitivity. The BAI-BDI method proposed by Harris et al (which incorporates the basion-dens distance described by Wholey) is at present the most reliable means to diagnose AOD on a lateral cervical spine radiograph.⁷

Pang et al proposed the CCI as a sensitive diagnostic measurement of atlantooccipital dislocation as determined on CT imaging. They analyzed and compared CCI from sagittal and coronal reformatted CT images of the craniovertebral junction of 89 children without AOD and 16 children with AOD. They found the CCI to have sensitivity and specificity of 100% compared to “standard” tests on plain films that had sensitivity between 25% and 50% and specificity between 10% and 60%. They concluded that the CCI criterion has the highest diagnostic sensitivity and specificity for AOD among all radiographic methods. Their work provided Class I medical evidence for the diagnosis of AOD among pediatric patients.^{13,14}

Horn et al attempted to determine whether magnetic resonance imaging (MRI) findings on short TI inversion recovery (STIR) sequences following acute trauma are predictive of cervical spinal instability. Abnormal soft-tissue (pre-vertebral or para-spinal) findings on MRI were correlated with those identified on CT and plain and dynamic cervical spine x-rays in an attempt to determine cervical stability in 314 trauma patients. They found that MRI is sensitive to soft-tissue injuries of the cervical spine. However, they concluded that when CT and cervical radiographs, including dynamic X-rays, detect no fractures or signs of instability, MRI does not assist in determining cervical stability. In this circumstance they reported that MRI findings may lead to unnecessary testing when not otherwise indicated.¹⁵

Many of the case reports and case series in the literature do not describe the radiographic/imaging method(s) used to diagnose AOD. Since the most sensitive method to identify AOD on a lateral cervical spine radiograph (the BAI-BDI) was proposed by Harris et al in 1994,¹² this method was not likely used for many of the determinations. When the BAI-BDI was applied retrospectively, a diagnosis was possible on the first lateral radiograph in 53 of 105 patients, (sensitivity = 0.505). Of the 53 patients with AOD in

whom the diagnosis was made on the first lateral radiograph, 4 were not stratified by type. Of the 49 remaining patients, there were 24 Type I, 23 Type II and 2 Type III dislocations. A second, late and consecutive lateral radiograph (11 cases), tomography (1 case), fluoroscopy (2 cases), CT (11 cases), CT in addition to lateral radiographs (3 cases), and MRI (6 cases) were required to establish the diagnosis of AOD in 34 of the 105 patients. Since these data were obtained from case reports and small case series, a determination of the accuracy of plain radiographs to identify AOD compared to patients without AOD could not be performed. As a result, specificity, positive/negative predictive values, and likelihood ratios cannot be discerned from the available literature.

Of the 15 patients in whom the diagnosis was missed on the initial plain radiographs, the initial neurological condition of 3 patients was not described.¹⁶ Of the remaining 12 patients, 4 were neurologically normal (1 Type I, 1 Type III, 2 other type).^{17,18} Two of those 4 patients originally reported as normal developed a monoparesis (1 Type I, 1 other type).^{19,20} Neither recovered completely. Eight of the remaining 12 patients had neurologic abnormalities from the outset, 5 of whom worsened. Four of the 5 transiently worsened, including 1 Type I injury patient with quadriplegia and Cranial Nerve IX, X, and XII palsies²¹ who improved but was spastic at last follow-up. One patient with a Type I injury developed a hemiparesis that recovered.²² One Type I injury patient who developed quadriplegia was hemiparetic at follow-up.²³ One lateral AOD patient with paraparesis and toricollis reportedly recovered at last follow-up.²⁴ One patient (Type I) with a monoparesis initially experienced permanent worsening and was quadriplegic at follow-up.²⁵

The presence or absence of soft tissue swelling was described in half of the patients in whom plain spine films were obtained. The sensitivity of the presence of STS when AOD was confirmed by other radiographic means was determined to be 0.69 or 69% (43 of 62 cases). Although plain radiographs do not consistently and reliably identify AOD, the index of suspicion for the potential of AOD may be increased with the identification of prevertebral STS.

Acute craniocervical CT imaging was performed in 62 of the 105 patients with AOD. However, for 23 of the 62 patients studied by CT, the authors did not report whether AOD was diagnosed using this modality. The diagnosis of AOD was reportedly made by CT in 39 of 62 patients (sensitivity = 0.63). No CT abnormalities were reported in 15 of 62 patients. Twenty-eight patients with AOD studied with CT had hemorrhages (21 had craniocervical junction subarachnoid hemorrhage, 2 had paravertebral hemorrhage, 1 had a subdural hemorrhage, 2 had intraparenchymal cord hemorrhages, and 2 had spinal cord contusions). Craniocervical MRI was performed in 34 of 105 patients with AOD. The MRI findings were not reported for 4 of the 34 patients studied. The diagnosis of AOD could be made in 21 of 30 cases studied with MRI (sensitivity = 0.7, or 70%).

In summary, the diagnosis of AOD is often missed on spine plain radiographs, (sensitivity = 0.505), particularly in the circumstance of non-longitudinal AOD (non-Type II). Additional imaging of the craniovertebral junction with either CT or MRI is recommended in patients suspected of having AOD. Other imaging

methods such as fluoroscopy, tomography, and myelography have been reported to confirm the diagnosis of AOD, particularly in the older literature, but accuracy data is not available nor can it be calculated. Neurological abnormalities including lower cranial nerve paresis (particularly cranial nerves VI, X, and XII), monoparesis, hemiparesis, quadriplegia, respiratory dysfunction including apnea, and complete high cervical cord motor deficits in the setting of normal plain spinal radiographs should prompt additional imaging with CT or MRI. The presence of prevertebral STS on plain radiographs and subarachnoid hemorrhage on CT at the craniovertebral junction should prompt consideration of the diagnosis of AOD. The CCI determined from CT images has the highest diagnostic specificity and sensitivity among imaging diagnostic criteria for AOD and should be employed when attempting to make a diagnosis of AOD.

Treatment

Various treatment including rigid immobilization and internal surgical fixation and fusion have been described in the treatment of AOD (Table 2). Of 84 patients in whom treatment data are reported, 13 did not receive initial treatment for AOD.^{4,19,20,23-30,80} Six of 13 had Type I, 2 had Type II injuries and 5 had other type injuries. At last follow-up in this group of untreated patients, 2 died, 2 improved neurologically, 4 had unchanged deficits from presentation, and 5 worsened neurologically.^{4,19,20,25,26,31} There were 3 untreated AOD patients who presented with quadriplegia.^{26,31} One improved to quadriplegia at last follow-up; the 2 other remained quadriplegic. In summary, failure to treat AOD resulted in worsening in 7 of 13 patients (54%).

Of 21 patients with AOD initially treated with traction, 2 worsened transiently and developed worsening quadriplegia and CN VI deficits. Both had resolution of their CN VI deficits but had persistent quadriplegia at last follow-up. One patient had a Type II injury³² and 1 patient had a rotational other type dislocation.⁴ Four patients were initially normal and remained normal at follow-up.³³⁻³⁶ The remaining 15 patients with AOD treated initially with traction experienced improved neurological function compared to their initial findings at last follow-up. The improvement in neurological function in these patients could not be attributed to the initial period of traction. Ten had Type I injuries, 5 had Type II injuries, 2 had Type III injuries, and 2 had other type dislocations. In total, 1 of 6 patients with Type II injuries and 1 of 3 patients with other type, translational injuries experienced neurological worsening with the use of craniocervical traction. Because the frequency of neurological deterioration with traction in the treatment of AOD is approximately 10%, 10 times higher than that for subaxial injuries, the use of traction is not recommended in patients with AOD.

Of 29 patients initially treated with external immobilization excluding traction, 17 were immobilized in anticipation of internal fixation and fusion and none worsened during the pre-surgical interval (5 Type I, 9 Type II, 3 other type).^{1,4,36-48} Of the remaining 12 patients treated with external immobilization alone excluding

TABLE 1. Evidentiary Table: Imaging Diagnosis of Atlanto-Occipital Dislocation

Citation	Evidence Class	AOD Type	Diagnosis Made By	X-ray Findings	CT Findings	MRI Findings
Sweet et al, ⁵¹ <i>JNS: Spine</i> , 2010	III	II	CT	No mention STS	Basion and dens separation of 21 mm, +Dx	Ligament injury, Dx
Kleweno et al, ⁴³ <i>Spine</i> , 2008	III	II	Plain X-ray, CT	BDI, +Dx	SAH, + Dx	SC contusion. + Dx.
Gautschi et al, ³⁹ <i>Spinal Cord</i> , 2007	III	I	Plain X-ray	2 cm disarticulation, +Dx	Diagnosis	Complete transection of lower medulla, Dx
Bloom et al, ²⁶ <i>Emerg Med Australia</i> , 2007	III	I	Plain X-ray	STS, Powers, +Dx	Anterior paravertebral hematoma	SC transection
Vera et al, ⁵² <i>Childs Nerv Syst</i> , 2007	III	II	CT	No mention STS	O-C1 asymmetry, + Dx	None performed
Pang et al, ¹⁴ <i>Neurosurgery</i> , 2007	I (for pediatric patients)	Not specified	CT	"standard" tests 25%-50% sensitivity, 10%-60% specificity	CCI 100% sensitivity, 100% specificity, +Dx	Multiple "clues" to injury on MRI, but no comparison to other modalities
McKenna et al, ⁵³ <i>CJEM</i> , 2006	III	II	Plain X-ray	STS, BDI, +Dx	Unreported	None performed
Saveika et al, ⁵⁴ <i>Am J Phys Med Rehabil</i> , 2006	III	I/II	CT	No mention STS	+Dx	None performed
Hamai et al, ⁴¹ <i>Spine</i> , 2006	III	I	Plain X-ray	STS, Powers, +Dx	BDI. + Dx	Ligamentous injury. Dx.
Feiz-Erfan et al, ⁵⁵ <i>JNS: Spine</i> , 2005	III	I/II	CT	STS	+Dx	+Dx
Seibert et al, ⁴⁷ <i>Acta Neurochir</i> , 2005	III	I/II	CT	STS	Distraction, +Dx	Dx
		I/II	Plain X-ray	superior subluxation, +Dx	+Dx	+Dx
Gregg et al, ⁴⁰ <i>J Trauma</i> , 2005	III	I	CT	No mention STS	Anterior translation, +Dx	None performed
van de Pol et al, ⁴⁸ <i>Spine</i> , 2005	III	I	Plain X-ray, CT	BDI, Powers+, +Dx	Posterior fossa hematoma, +Dx	Brainstem contusion. Ligamentous injury, +Dx
Payer et al, ⁴⁵ <i>Neurosurg</i> , 2005	III	II	CT	No mention STS	CCI, + Dx	No SCI
Salinsky et al, ⁴⁶ <i>Pediatr Neurosurg</i> , 2005	III	II	Plain X-ray, CT	BDI, +Dx	+Dx	Near total SC transection, +Dx
Gonzalez et al, ⁵⁶ <i>JNS: Spine</i> , 2004	III	II	CT	STS	Widening space, + Dx	None performed
Labler et al, ²⁹ <i>Eur Spine J</i> , 2004	III	II	CT	No mention STS	Widening space. + Dx	Ligament injury, Dx
		I	Plain X-ray	Powers, +Dx		Epidural
		II	MRI			Traumatic lesions
Brinkman et al, ⁵⁷ <i>Am J Roentgenol</i> , 2003	III	II	Plain X-ray	BDI, +Dx	Unreported	None performed
Rose et al, ⁵⁸ <i>Am J Surg</i> , 2003	III	II	Plain X-ray	BDI, +Dx	Hematoma	None performed
Bani et al, ³⁷ <i>Spine</i> , 2003	III	I	Plain X-ray	Powers, +Dx	Normal	Normal
		II	Plain X-ray	Powers, +Dx	SAH	Medullary contusion, +Dx
Tomasini et al, ⁵⁹ <i>Am J Emerg Med</i> , 2002	III	II	Clinical	Powers normal	Normal	Ischemia
		I	Plain X-ray	Downward displacement, +Dx	+Dx	None performed
Grabb et al, ⁶⁰ <i>Pediatr Radiol</i> , 1999	III	I	Plain X-ray	STS, Powers, +Dx	Unreported	Part tear tectorial
		II	Plain X-ray	STS, Powers, +Dx	None performed	Tear Post. AOL
		II	MRI	STS, Powers	None performed	Part tear tectorial, +Dx
Naso et al, ⁶¹ <i>Neurosurg</i> , 1997	III	I/II	Plain X-ray	No mention STS, +Dx	Unreported	Delayed study

(Continues)

TABLE 1. Continued

Citation	Evidence Class	AOD Type	Diagnosis Made By	X-ray Findings	CT Findings	MRI Findings
Sponseller et al, ²⁰ <i>Spine</i> , 1997	III	I	Plain X-ray (missed)	No mention STS	None performed	None performed
		II	Plain X-ray	No mention STS, +Dx	Unreported	Brainstem contusion
Przybylski et al, ¹ <i>Spine</i> , 1996	III	I	MRI	Powers/BDI/Xline	SAH, -Dx	BS contusion, +Dx
Pang et al, ⁵ <i>Neurosurg</i> , 1980	III	II	Plain X-ray (missed)	Power/BDI/Xline	SAH, +Dx	BS contusion, +Dx
		II	2nd plain X-ray	Power/BDI-Xline, +Dx	SAH, +Dx	None performed
		I/Lateral	Plain X-ray (missed)	Power/BDI/Xline	Normal, Head only	None performed
		I/Lateral	Plain X-ray (missed)	Power/BDI/Xline	SAH, +Dx	None performed
Yamaguchi et al, ⁶² <i>Neurol Med Chir (Tokyo)</i> , 1996	III	I	Plain X-ray	No mention STS, +Dx	SAH, + tomo	BS Contusion, +Dx
Guigui et al, ⁶³ <i>Eur Spine J</i> , 1995	III	I	Plain X-ray	STS, +Dx	+Dx	None performed
Ahuja et al, ¹⁶ <i>Surg Neurol</i> , 1994	III	I	Fluoroscopy	STS,Powers	SAH, unknown	None performed
		II	5 Plain X-ray (3 missed)	STS,Powers, +Dx	None performed	None performed
		II		STS,Powers	SAH, +Dx	None performed
		II		STS,Powers	SAH, unknown	None performed
		I/II		STS,Powers	None performed	None performed
		I/II		STS,Powers	SAH, +Dx	None performed
Donahue et al, ³⁸ <i>Pediatr Neurosurg</i> , 1994	III	I	Plain X-ray	STS, +Dx	None performed	None performed
		II	Plain X-ray	STS, 5 mm distract, +Dx	None performed	None performed
		II	Plain X-ray	STS, +Dx	None performed	None performed
		II	Plain X-ray	6 mm distract, +Dx	Intracerebral bleed	None performed
Palmer et al, ³² <i>J Trauma</i> , 1994	III	II	CT	No mention STS	Unreported, +Dx	CordContusion, +Dx
Dickman et al, ⁴ <i>J Spinal Disord</i> , 1993	III	II	Plain X-ray	15 mm distraction, +Dx	None performed	None performed
Papadopoulos et al, ⁶ <i>Neurosurg</i> , 1991	III	Rotatory	CT	STS	+ Dx	None performed
		Rotatory	MRI	STS	No blood, -Dx	Epidural, +Dx
		II/Rotatory	2nd Plain X-ray	STS, +Dx	+Dx	Epidural, +Dx
Harmanli et al, ⁶⁴ <i>Surg Neurol</i> , 1993	III	II	Plain X-ray	No mention STS, +Dx	None performed	-Dx
Hosono et al, ²² <i>Spine</i> , 1993	III	I	Plain X-ray (missed)	STS	Edema, head only	Delayed study
Matava et al, ⁶⁵ <i>Spine</i> , 1993	III	II	Plain X-ray	STS, +Dx	Delayed study	None performed
		II	Plain X-ray	No mention STS, +Dx	None, +DX	None performed
		II	Plain X-ray	No mention STS, +Dx	SAH, +DX	BS Contusion
Nischal et al, ⁴⁴ <i>Br J Neurosurg</i> , 1993	III	II	Plain X-ray	STS, +Dx	BS contusion, +Dx	None performed
		II	Plain X-ray	STS, +Dx	-Dx	None performed
Bundschuh et al, ⁶⁶ <i>Spine</i> , 1992	III	I	Plain X-ray	STS, +Dx	SAH, +Dx	SAH, + Dx
		I	Plain X-ray	STS, Power/Xline, +Dx	SAH	-Dx

(Continues)

TABLE 1. Continued

Citation	Evidence Class	AOD Type	Diagnosis Made By	X-ray Findings	CT Findings	MRI Findings
Farley et al, ⁶⁷ <i>Spine</i> , 1992	III	I	Plain X-ray	STS, Powers, +Dx	None performed	Cord contusion
Belzberg et al, ⁶⁸ <i>J Neurosurg</i> , 1991	III	II	2nd Plain X-ray	STS, +Dx	SAH, +Dx	None performed
Hladky et al, ⁶⁹ <i>Neurochirurgie</i> , 1991	III	II	MRI	No mention STS	Contusion, head only	+ Dx
		II	MRI	No STS	Normal, Head only	+ Dx
Lee et al, ³⁶ <i>J Trauma</i> , 1991	III	II	Plain X-ray	STS, +Dx	SAH, +Dx	None performed
		I/Rotatory	Plain X-ray	STS, +Dx	+ Dx	None performed
Maves et al, ⁷⁰ <i>Pediatr Radiol</i> , 1991	III	II	Plain X-ray	No mention STS, +Dx	None performed	None performed
		II	Plain X-ray	No mention STS	None performed	None performed
		III	Plain X-ray	No mention STS, +Dx	None performed	None performed
Montane et al, ⁷¹ <i>Spine</i> , 1991	III	I	Plain X-ray	STS, +Dx	None performed	None performed
		II	2nd Plain X-ray	STS, +Dx	None performed	None performed
		II	2nd Plain X-ray	No STS, +Dx	None performed	None performed
DiBenedetto et al, ²¹ <i>Spine</i> , 1990	III	I	Plain X-ray (missed)	STS	ICH, +DX	None performed
Jones et al, ⁷² <i>Am J Neuroradiol</i> , 1990	III	I	Plain X-ray	No mention STS, +Dx	+DX	Premedullary edema
Colnet et al, ²⁷ <i>Neurochirurgie</i> , 1989	III	Lat/rotatory	Tomography	Late study	SAH, +Dx	Delayed study
Jevtich, ¹⁸ <i>Spine</i> , 1989	III	Lateral	Plain X-ray (missed)	No mention STS	Delayed study	None performed
Hummel et al, ⁷³ <i>Unfallchirurgie</i> , 1988	III	I	2nd Plain X-ray	No mention STS, +Dx	Subdural, Head only	None performed
Zampella et al, ³¹ <i>Neurosurg</i> , 1988	III	II	Plain X-ray	No mention STS, +Dx	SAH, Head only	Delayed study
Georgopoulos et al, ²⁸ <i>J Bone Joint Surg Am</i> , 1987	III	I	Cineradiography	No mention STS	Delayed study	None performed
Bools et al, ³⁴ <i>Am J Neuroradiol</i> , 1986	III	I	Plain X-ray	STS, +Dx	SAH, +DX	None performed
		III	2nd Plain X-ray	No mention STS, +Dx	None performed	None performed
Collalto et al, ¹⁹ <i>J Bone Joint Surg Am</i> , 1986	III	I/lateral	Plain X-ray (missed)	No STS	SAH, Head only	Delayed study
Putnam et al, ⁷⁴ <i>J Am Osteopath Assoc</i> , 1986	III	I	Plain X-ray	STS, Powers, +Dx	SAH, +Dx	None performed
Ramsay et al, ²³ <i>Injury</i> , 1986	III	I	Plain X-ray (missed)	No mention STS	None performed	None performed
Roy-Camille et al, ³⁰ <i>Rev Chir Orthop Reparatrice Appar Mot</i> , 1986	III	I	Late Plain X-ray	No mention STS, +Dx	Delayed study	None performed
		I	Plain X-ray	STS, +Dx	None performed	None performed
Zigler et al, ⁷⁵ <i>Spine</i> , 1986	III	I	Plain X-ray	No mention STS, +Dx	None performed	None performed
Watridge et al, ²⁴ <i>Neurosurg</i> , 1985	III	Lateral	Plain X-ray (missed)	No STS	Delayed study	None performed

(Continues)

TABLE 1. Continued

Citation	Evidence Class	AOD Type	Diagnosis Made By	X-ray Findings	CT Findings	MRI Findings
Banna et al, ³³ <i>J Bone Joint Surg Am</i> , 1983	III	Rotatory	Plain X-ray	No mention STS, +Dx	+ Dx	None performed
Kaufman et al, ⁴² <i>Am J Neuroradiol</i> , 1982	III	II	Plain X-ray	STS, +Dx	None performed	None performed
		II	Plain X-ray	STS, +Dx	None performed	None performed
Woodring et al, ²⁵ <i>Am J Roentgenol</i> , 1981	III	I	Plain X-ray	No mention STS, +Dx	None performed	None performed
		I	Plain X-ray (missed)	STS	None performed	None performed
Powers et al, ⁸ <i>Neurosurg</i> , 1979	III	I	Plain X-ray	Late study, +Dx	None performed	None performed
		II	2nd Plain X-ray	No mention STS, +Dx	None performed	None performed
Rockswold et al, ⁷⁶ <i>Minn Med</i> , 1979	III	II	Plain X-ray	No mention STS, +Dx	None performed	None performed
Eismont et al, ¹⁷ <i>J Bone Joint Surg Am</i> , 1978	III	III	Plain X-ray (missed)	No mention STS	None performed	None performed
Fruin et al, ⁷⁷ <i>J Neurosurg</i> , 1977	III	I	Plain X-ray	No mention STS, +Dx	None performed	None performed
Page et al, ⁷⁸ <i>J Neurosurg</i> , 1973	III	I	Plain X-ray	STS, +Dx	None performed	None performed
Evarts, ⁷⁹ <i>J Bone Joint Surg Am</i> , 1970	III	I	Plain X-ray	No mention STS, +Dx	None performed	None performed
Gabrielsen et al, ⁸⁰ <i>Am J Roentgenol Radium Ther Nucl Med</i> , 1966	III	I	2nd Plain X-ray	STS, +Dx	None performed	None performed
Farthing, ³⁵ <i>NC Med J</i> , 1948	III	III	Plain X-ray	No mention STS, +Dx	None performed	None performed

One patient was eliminated because the plain radiograph interpretation was not reported. Ferrara (1).

Two articles (11 patients) were eliminated because the type of dislocation was not reported. Cohen (1), Georgopolous (2/3), Hladky (1/3), Naso (1/2), Sun (6/6).

One article (5 patients) was eliminated because individual patient data was not reported. Bulas (5/5).

AOD, atlanto-occipital dislocation; MRI, magnetic resonance imaging; CT, computed tomography; STS, soft tissue swelling; BDI, basion-dental interval; SAH, subarachnoid hemorrhage; Dx, diagnosis; BS, brainstem; ICH, intracerebral hemorrhage; AOL, atlanto-occipital ligament.

TABLE 2. Evidentiary Table: Treatment of Atlanto-Occipital Dislocation

Citation	Evidence Class	AOD Type	Initial Exam	Treatment	Outcome
Sweet et al, ⁵¹ <i>JNS: Spine</i> , 2010	III	II	Quadriparesis, CN6	Fusion	Quadriparesis
Kleweno et al, ⁴³ <i>Spine</i> , 2008	III	II	ASIA A	Halo, fusion	ASIA A
Bloom et al, ²⁶ <i>Emerg Med Australia</i> , 2007	III	I	Quadriplegia	None	Quadriplegia
Gautschi et al, ³⁹ <i>Spinal Cord</i> , 2007	III	I	Quadriplegia	Collar + fusion	Quadriplegia
Pang et al, ¹⁴ <i>Neurosurgery</i> , 2007	III	Not specified	12/15 ASIA A-C quad, 3/15 ASIA D	Halo, Fusion	10/15 ASIA D & E, 2/15 ASIA C, 3/15 ASIA A (2 late death), 15/15 radiographic fusion
Saveika et al, ⁵⁴ <i>Am J Phys Med Rehabil</i> , 2006	III	I/II	Unreported	Fusion	Tetraplegia
McKenna et al, ⁵³ <i>CJEM</i> , 2006	III	II	Unreported	Fusion	Gradual improvement
Hamai et al, ⁴¹ <i>Spine</i> , 2006	III	II	Quadriparesis	Halo, Fusion	Quadriparesis
Salinsky et al, ⁴⁶ <i>Pediatr Neurosurg</i> , 2005	III	II	Quadriplegia	Halo, Fusion	Quadriplegia
van de Pol et al, ⁴⁸ <i>Spine</i> , 2005	III	I	Unreported	Halo, Fusion	Wheelchair. Legs spasticity
Payer et al, ⁴⁵ <i>Neurosurg</i> , 2005	III	II	Quadriparesis	Brace + Fusion	Full recovery 12 mos
Feiz-Erfan et al, ⁵⁵ <i>JNS: Spine</i> , 2005	III	I/II	Normal	Fusion	Normal
Seibert et al, ⁴⁷ <i>Acta Neurochir</i> , 2005	III	I/II	Normal	Fusion + collar	Normal
Gregg et al, ⁴⁰ <i>J Trauma</i> , 2005	III	I	Quadriplegia	Fusion + halo	Quadriplegia
Gonzalez et al, ⁵⁶ <i>JNS: Spine</i> , 2004	III	II	Unreported	Fusion	Normal
Labler et al, <i>Eur Spine J</i> , 2004 ²⁹	III	I	Normal	Fusion	Normal
		II	tetraparesis	Supportive	Death
		II	tetraparesis	Fusion	Normal
Bani et al, ³⁷ <i>Spine</i> , 2003	III	I	Unreported	Halo + Fusion	Wheelchair dependant
Govender et al, ⁴⁹ <i>J Bone Joint Surg Br</i> , 2003	III	III	Hemiparesis	Fusion	Normal
		I	CN VI/IX/X/XII	Fusion	Normal
		II	Quadriparesis, CN6	Fusion	Spasticity of lower limbs
		Other	Normal	Halo body jacket	Normal
Naso et al, ⁶¹ <i>Neurosurg</i> , 1997	III	Mixed I/II	Quadriplegia	Supportive	Death 5 weeks
Sponseller et al, ²⁰ <i>Spine</i> , 1997	III	I	Normal	None (neuro worse), Traction, Fusion + Brace	Spastic, CN X
		II	Normal	Brace failed (6 weeks), Fusion	Normal
Przybylsk et al, ¹ <i>Spine</i> , 1996	III	I	Quadriplegia	Collar + Fusion	Quadriplegia
Pang et al, ⁵ <i>Neurosurg</i> , 1980	III	II	Quadriplegia	Halo failed (22 weeks), Fusion	Quadriplegia
		II	Normal	Fusion + Collar	CN X
		Mixed I/ Lateral	Hemiplegia	Collar + Fusion	Monoparesis
		Mixed I/ Lateral	Quadriparesis, CN VI/VII/XII	Fusion + Collar	CN XII
Yamaguchi et al, ⁶² <i>Neurol Med Chir (Tokyo)</i> , 1996	III	I	Quadriplegia, CN X/XI/XII	Brace failed (10 weeks), Fusion	Quadriplegia, CN X/XI/XII
Guigui et al, ⁶³ <i>Eur Spine J</i> , 1995	III	I	Normal	Fusion + Brace	Normal

(Continues)

TABLE 2. Continued

Citation	Evidence Class	AOD Type	Initial Exam	Treatment	Outcome
Donahue et al, ³⁸ <i>Pediatr Neurosurg</i> , 1994	III	I	Hemiparesis	Halo distracted (temporary neurological worsening), Fusion	Hyperreflexic
		II	CNVI	Halo + Fusion	Normal
		II	Quadriplegia, CNVII/X	Collar/Traction + Fusion	Quadriplegia, CNVII/X
		II	Quadriplegia, CN III/VII	Fusion	Quadriplegia
Palmer et al, ³² <i>J Trauma</i> , 1994	III	II	Quadriplegia, CNVI	Traction (neurologically worse), Brace + Fusion	Quadriplegia
Dickman et al, ⁴ <i>J Spinal Disord</i> , 1993	III	II	Quadriplegia, CN IX/X	Brace	Unchanged (sepsis death at 3 months)
Papadopoulos et al, ⁶ <i>Neurosurg</i> , 1991	III	Rotatory	Quadriplegia, CNVI	Traction (neurologically worse), Fusion + Halo	Quadriplegia
		Rotatory	CNVI	None (neurologically worse), Fusion + Halo	Hemiparesis
		Mixed II/ Rotatory	Hemiparesis, CNIII III/VI	Halo + Fusion	Normal
Harmanli et al, ⁶⁴ <i>Surg Neurol</i> , 1993	III	II	Hemiparesis, CNIII	Fusion + Brace	Normal
Hosono et al, ²² <i>Spine</i> , 1993	III	I	Hemiparesis	Brace(neurologically worse), Fusion + Brace	Normal
Matava et al, ⁶⁵ <i>Spine</i> , 1993	III	II	Hemiplegia, CNVI.XII	Fusion + Brace	Spastic, CN VI
		II	Hemiparesis, CN VI	Fusion + Brace	Normal
		II	CN VI/IX/X	Fusion + Brace	Spastic
Nischal et al, ⁴⁴ <i>Br J Neurosurg</i> , 1993	III	II	Quadriplegia, CN III/VI/IX/X	Brace + Fusion	Hemiparesis, CN III/VI/IX/X
		II	Quadriplegia, CN IX, X	Brace + Fusion	Hemiparesis
Bundschuh et al, ⁶⁶ <i>Spine</i> , 1992	III	I	Quadriplegia CN VI/IX/X/XII	Traction + Fusion	CN VI/XII
Farley et al, ⁶⁷ <i>Spine</i> , 1992	III	I	Quadriplegia, CN X	Traction + Brace	Quadriplegia
Belzberg et al, ⁶⁸ <i>JNS</i> , 1991	III	II	Quadriplegia, CN VI/IX/X	Traction + Brace + Fusion	Monoparesis, CN VI
Lee et al, ³⁶ <i>J Trauma</i> , 1991	III	II	Normal	Traction + Fusion	Normal
		Mixed I/Rot	CN VI	Brace + Fusion	CN6
Montane et al, ⁷¹ <i>Spine</i> , 1991	III	I	Hemiparesis	Fusion + Brace	Spastic
		II	Quadriplegia	Traction, Fusion + Brace	Normal
		II	Quadriplegia	Fusion + Brace	Quadriplegia
DiBenedetto et al, ²¹ <i>Spine</i> , 1990	III	I	Quadriplegia, CN IX/X/XII	Collar (neurologically worse, 6 weeks), Fusion + Brace	Spasticity
Colnet et al, ²⁷ <i>Neurochirurgie</i> , 1989	III	Mixed lat/ rotatory	Hemiplegia, CN VI/IX/X	None (neurologically worse), Traction + Shunt + Decompression	Hemiparesis
Jevtich, ¹⁸ <i>Spine</i> , 1989	III	Lateral	Normal	Traction + Brace	Normal
Hummel et al, ⁷³ <i>Unfallchirurgie</i> , 1988	III	I	Hemiparesis	Fusion + Brace	Normal
Zampella et al, ³¹ <i>Neurosurg</i> , 1988	III	II	Quadriplegia, CN V-XII	None	Quadriplegia, CN VI
Georgopoulos et al, ²⁸ <i>J Bone Joint Surg Am</i> , 1987	III	I	Normal	None (neurologically worse), Fusion + Brace	Normal
Bools et al, ³⁴ <i>Am J Neuroradiol</i> , 1986	III	III	Normal	Traction, Fusion + Brace	Normal
Collalto et al, ¹⁹ <i>J Bone Joint Surg Am</i> , 1986	III	Mixed I/lateral	Normal	None (neurologically worse), Fusion + Brace	Monoparesis

(Continues)

TABLE 2. Continued

Citation	Evidence Class	AOD Type	Initial Exam	Treatment	Outcome
Putnam et al, ⁷⁴ <i>J Am Osteopath Assoc</i> , 1986	III	I	Quadriplegia, CN V	Brace	Death (sepsis 8 months)
Ramsay et al, ²³ <i>Injury</i> , 1986	III	I	Quadripareisis	None (neurologically worse), Traction + Brace	Hemiplegia
Roy-Camille et al, ³⁰ <i>Rev Chir Orthop Reparatrice Appar Mot</i> , 1986	III	I	CN VI, XI	None, Brace failed (3 months), Traction + Fusion	CN VI
Zigler et al, ⁷⁵ <i>Spine</i> , 1986	III	I	Quadriplegia, CN VI/IX-XII	Traction + Fusion	Quadriplegia
Watridge et al, ²⁴ <i>Neurosurg</i> , 1985	III	Lateral	Quadriplegia, CN XI	Traction + Brace + Fusion	Quadriplegia
			Paraparesis	None (neurologically worse), Traction + Fusion + Decompress + Brace	Normal
Banna et al, ³³ <i>J Bone Joint Surg Am</i> , 1983	III	Rotatory	Normal	Traction (2 weeks)	Normal
Kaufman et al, ⁴² <i>Am J Neuroradiol</i> , 1982	III	II	Quadriplegia	Brace + Fusion	Quadripareisis, CN IX/X
		II	Monoparesis	Brace	Normal
Woodring et al, ²⁵ <i>Am J Roentgenol</i> , 1981	III	I	Hemiparesis, CN VI	Traction	CN6
		I	Monoparesis	None (neurologically worse), Traction + Fusion	Quadriplegia
Powers et al, ⁸ <i>Neurosurg</i> , 1979	III	I	Hemiparesis, CN VI	Traction + Brace	Hemiparesis
		II	Hemiparesis, CN VII	Traction + Brace	Normal
Rockswold et al, ⁷⁶ <i>Minn Med</i> , 1979	III	II	Hemiparesis, CN VI	Traction, Brace + Fusion	Ambulates
Eismont et al, ¹⁷ <i>J Bone Joint Surg Am</i> , 1978	III	III	Normal	Collar (neuro worse) Fusion + Brace	Normal
Fruin et al, ⁷⁷ <i>Neurosurg</i> , 1977	III	I	Hemiparesis, CN VI/IX-XII	Traction + Fusion	CN VI/XI
Page et al, ⁷⁸ <i>JNS</i> , 1973	III	I	Quadriplegia, CN X/XII	Traction, Brace failed + (5 mo), Fusion	Quadripareisis, CN X
Evarts, ⁷⁹ <i>J Bone Joint Surg Am</i> , 1970	III	I	Hemiparesis, CN VI/IX/X/XII	Traction, Brace + Fusion	CN VI
Gabrielsen et al, ⁸⁰ <i>Am J Roentgenol Radium Ther Neucl Med</i> , 1966	III	I	Hyperreflexia, CN VI	Traction, Brace failed (3 mo), Fusion	Numb scalp
Farthing et al, ³⁵ <i>NC Med J</i> , 1948	III	III	Normal	Traction + Brace	Normal

Three articles (15 patients) were eliminated because the type of dislocation was not reported. Cohen (1), Georgopolous (2/3), Bulas (5/5), Naso (1/2), Sun (6/6).

Two articles (8 patients) were eliminated because the initial exam was not reported. Grabb (3), Ahuja (5).

Two articles (6 patients) were eliminated because the treatment was not reported. Maves (3), Hladky (3).

One article (2 patients) was eliminated because the outcome was not reported. Jones (1), Bools (1/2).

CN, cranial nerve.

traction, 4 worsened transiently (3 Type I, 1 Type II).^{17,21,22,38,49} All 4 of these patients subsequently underwent craniocervical fixation and fusion. Of the remaining 8 patients managed with external immobilization alone, 3 were unstable after 6 to 22 weeks of immobilization (1 Type I, 2 Type II). Of these 3 patients with persistent instability despite external immobilization, 2 presented with quadriplegia and 1 was neurologically normal. All 3 underwent internal fixation and fusion without change in their neurological condition at last follow-up. Only 5 patients with AOD described in the literature were successfully treated with external immobilization alone (1 Type I, 2 Type II, 2 other type dislocations). Since 7 of 12 (58%) patients managed with external immobilization either deteriorated neurologically or failed to achieve craniocervical stability without surgical internal fixation and fusion, treatment of AOD with external immobilization alone should be considered with caution.

There is only initial neurological examination data reported on 79 of 83 patients in the surgical treatment group. Of those 79 patients in whom the neurological exam at admission could be discerned, 16 (20.3%) were reportedly normal (4 Type I, 3 Type II, 3 Type III, 6 other type), 6 (7.6%) had cranial nerves deficits only, 14 (17.7%) had a hemiparesis, 2 had a monoparesis (2.5%), 1 (1.25%) had paraparesis, 16 were reported as quadriparetic (20.2%), 3 (3.8%) had hemiplegia, 1 (1.25%) had hyperreflexia but no motor deficit, and 20 were quadriplegic (25.3%). Seventeen patients with an initial paresis were reported to have completely recovered at last follow-up. Six patients with plegia improved to paresis. Eight patients with paresis and 13 patients with plegia had stable neurologic examinations at the last reported follow-up (no worse and no better).

Cranial nerve deficits appear to be common with AOD. Thirty-eight patients (48.1%) were reported to have CN deficits at presentation, including CN III (3 patients), CN V (1 patient), CN VI (26 patients), CN VII (5 patients), CN IX (12 patients), CN X (15 patients), CN XI (6 patients), and CN XII (11 patients). Twenty-four patients in whom follow-up was reported had complete resolution of their CN deficits, 9 had partial resolution, 5 had no change in their CN deficits, and 3 patients developed new CN deficits at last follow-up.

Finally, 29 patients described in the literature were treated with planned early craniocervical fusion with internal fixation. Only 1 patient worsened neurologically following surgery. This patient with a Type II injury was normal initially and developed a CN X deficit which persisted at follow-up.¹ All but 3 of the remaining 28 patients were reported to improve neurologically at last follow-up. Six had Type I, 17 had type II, 2 had Type III, and 4 had other type AOD injuries. None of the patients treated with craniocervical fusion and internal fixation were reported to have experienced late instability requiring reoperation or further treatment.

Recently, larger case series focusing on the diagnosis and treatment of AOD have been reported in the literature. Horn et al analyzed clinical and radiological factors that predict outcome and management in 33 patients treated at a single institution. Special attention was given to neurological injury at presentation and imaging factors that dictated/determined treatment. Screening cervical spine radiographs were initially obtained and thin-cut (2.5 mm) CT images were acquired thereafter. In addition, most patients

underwent MRI imaging. Five patients with severe traumatic brain injury (TBI) received no treatment and died early in their hospital course. Of the remaining 28 patients, 23 underwent craniocervical fixation with fusion and 5 were treated nonoperatively with an external orthosis. Five other severely injured patients died, all of whom were treated surgically. Two died due to TBI, 3 others due to other multiple organ system injuries and medical co-morbidities. The 5 patients treated nonoperatively were managed in this fashion because they had no abnormalities identified on cervical CT images based on established criteria (Power's ratio, BDI, BAI-BDI, X-line methods), despite the presence of abnormal findings in the occipitoatlantal joints, tectorial membrane, alar ligaments, or cruciate ligaments on MRI. TBI at presentation correlated with a high mortality rate (7 of 33 patients). Five patients died from TBI without treatment. Two additional patients treated surgically died as a result of TBI. The authors concluded that the craniocervical junction in patients with CT-documented AOD is unstable and requires surgical fixation if they survive their initial injuries (particularly traumatic brain injuries) and resuscitation.⁵⁰

Hosalkar et al described 16 pediatric patients with traumatic AOD. Eight of these 16 patients died on admission. Of the remaining 8, all were initially treated with halo immobilization. Three of the remaining 8 died due to severe TBI. Of the 5 surviving patients, 4 underwent craniocervical fixation with fusion and 1 was treated in a Minerva cast orthosis. At last follow-up, 1 patient was neurologically intact, 3 had mild hemi-paresis but were functional, and 1 patient was a ventilator-dependent quadriplegic. The authors concluded that early diagnosis, prompt intubation, and early immobilization of the neck and head with respect to the torso appeared to improve survival in young patients who survived their associated brain injuries.

Bellabarba et al analyzed potentially correctable causes of delayed diagnosis of AOD and treatment options in a retrospective evaluation of 17 consecutive AOD patients who survived their injuries. In 13 of their 17 patients, (76%), the diagnosis of AOD was delayed by a mean of 2 days (range 1-15 days). Five (38%) of these 13 patients suffered profound neurological deterioration before AOD was clinically recognized. Surgical stabilization was undertaken in all 17 patients. Only 1 patient deteriorated following surgery. The authors concluded that a delay in the diagnosis of AOD was associated with an increased likelihood of neurological deterioration. Craniocervical instability due to AOD was frequently missed/misdiagnosed with the use of standard lateral radiographs.

SUMMARY

AOD is an uncommon traumatic injury that can be difficult to diagnose and is frequently missed on initial lateral cervical spinal radiographs. AOD is often associated with severe traumatic brain injuries. Patients who survive AOD injuries often have neurological impairment including lower cranial nerve deficits, unilateral or bilateral weakness, or quadriplegia. Nearly 20% of patients with acute traumatic AOD will have a normal neurological examination on presentation. The lack of localizing physical/neurological

examination findings and/or global neurological deficits from severe brain injury may impede/hinder the diagnosis of AOD in patients with normal-appearing initial cervical radiographs. A high index of suspicion must be maintained in order to diagnose AOD. Prevertebral soft tissue swelling on a lateral cervical radiograph or craniocervical subarachnoid hemorrhage on axial CT images have been associated with AOD and should prompt consideration of the diagnosis. Additional imaging including CT and MRI may be required to confirm the diagnosis of AOD if plain radiographs are inadequate. The Condyle-C1 interval as determined on CT imaging has the highest diagnostic sensitivity and sensitivity for AOD among all other radiodiagnostic indicators.

All patients with AOD should be treated. Without treatment, nearly all patients developed neurological worsening, many of whom never fully recover. Treatment of AOD with traction is not recommended. Treatment with external immobilization has been used successfully in selected patients but has a high failure rate. Craniocervical fixation and fusion is recommended for the treatment of patients with acute traumatic AOD.

KEY ISSUES FOR FUTURE INVESTIGATION

Although the use of external immobilization for AOD was often associated with late instability, several patients achieved stability without operative management. The complimentary usage of CT imaging (with 3-dimensional reconstruction images for more precise measurement of the magnitude of displacement) and MRI (for differentiation of partial and complete ligament tears from stretch injuries) may be useful in identifying a subgroup of patients in whom craniocervical stability might be achieved with external immobilization alone. Long-term follow-up of both surgically and non-surgically treated patients with AOD will aid our understanding of the ideal treatment strategy for this unusual and potentially lethal injury.

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Management of Isolated Fractures of the Atlas in Adults

Timothy C. Ryken, MD, MS*

Bizhan Aarabi, MD, FRCSC‡

Sanjay S. Dhall, MDS

Daniel E. Gelb, MD¶

R. John Hurlbert, MD, PhD,
FRCSC||

Curtis J. Rozzelle, MD#

Nicholas Theodore, MD**

Beverly C. Walters, MD, MSc,
FRCSC‡‡§§

Mark N. Hadley, MD‡‡

*Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa; ‡Department of Neurosurgery and ¶Department of Orthopaedics, University of Maryland, Baltimore, Maryland; §Department of Neurosurgery, Emory University, Atlanta, Georgia; ||Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada; #Division of Neurological Surgery, Children's Hospital of Alabama, and ‡‡Division of Neurological Surgery, University of Alabama at Birmingham, Birmingham, Alabama; **Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona; §§Department of Neurosciences, Inova Health System, Falls Church, Virginia

Correspondence:

Mark N. Hadley, MD, FACS,
UAB Division of Neurological Surgery,
510 – 20th St S, FOT 1030,
Birmingham, AL 35294-3410.
E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS

Level III:

- Treatment of isolated fractures of the atlas based on the specific atlas fracture type and the integrity of the transverse atlantal ligament is recommended.
- For an isolated fracture of the atlas with an intact transverse atlantal ligament, cervical immobilization is recommended.
- For isolated fractures of the atlas with disruption of the transverse atlantal ligament, either cervical immobilization alone or surgical fixation and fusion is recommended.

RATIONALE

The isolated fracture of the atlas, or “Jefferson” fracture, has been an injury of historic interest and remains clinically germane. These injuries are rarely associated with neurological sequelae and are typically managed successfully with minimal intervention. Recommendations for their initial management have generally been conservative in the absence of gross spinal instability. Medical evidence-based recommendations for the management of isolated atlas fractures have been previously offered by the guidelines author group of the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons in 2002.¹ Class III medical evidence supports a recommendation that the treatment of isolated C1 fractures be based on the integrity of the transverse atlantal ligament. The guidelines

author group concluded, “Isolated fractures of the atlas with an intact transverse atlantal ligament may be treated with cervical immobilization alone.” In patients in whom the transverse atlantal ligament was disrupted, the authors concluded that “[these fractures] may be treated with either cervical immobilization or surgical fixation and fusion.” The purpose of this updated review is to identify additional medical evidence on this important topic since the initial 2002 guideline publication.

SEARCH CRITERIA

A National Library of Medicine (PubMed) computerized literature search from 1966 to 2011 was undertaken using Medical Subject Headings in combination with “vertebral fracture”: atlas and human. This strategy yielded 582 references. The abstracts were reviewed, and articles addressing clinical management and follow-up of atlas fractures were selected for inclusion. The relative infrequency of these fractures, the small number of case series, and the numerous case reports with pertinent information required rather broad inclusion and exclusion criteria. The bibliographies of the selected articles were reviewed to provide additional references and to assess completeness of the literature review.

These efforts resulted in 5 contemporary articles describing acute traumatic atlas fractures not included in the previous version of this guideline. One of these reports provided no new data and was excluded. Although case reports were included in the previous guideline because of the paucity of clinical material on this subject, no new case reports were identified that would affect the previous recommendations. Fourteen contemporary Class III medical evidence case series are summarized in Evidentiary Table

ABBREVIATION: LMD, lateral mass displacement

format and are described in the text. Selected supporting articles are included in the bibliography and contribute to the scientific foundation.

SCIENTIFIC FOUNDATION

Acute fractures of the atlas (C1) represent 1% to 2% of spinal column fractures and account for 2% to 13% of all acute cervical spine fractures.²⁻⁴ First reported by Cooper in 1822, the subsequent historical publication of Jefferson⁵ in 1920, and later reports by Segal et al⁶ and Sherk and Nicholson⁴ have resulted in the use of the term Jefferson fracture to indicate a burst fracture injury of the atlas ring.

A central issue in the management of atlas fractures has been the importance placed on the integrity of the transverse atlantal ligament. The widely quoted rule of Spence (ie, > 6.9-mm lateral mass displacement of C1 over C2 on the open-mouth radiograph suggests transverse atlantal ligament disruption) was based on only 2 combined biomechanical and clinical studies of relatively low quality.^{7,8} It was postulated to describe the severity of the atlas burst injury and to predict transverse ligament disruption. Historically, it has been used to determine/define the stability of burst fractures of the ring of the atlas. Heller et al⁹ in 1993 proposed that this number be adjusted to 8.1 mm as a result of radiographic magnification factors, but the approximate number of 7 mm is generally still cited in the literature.

In 1996, Dickman and colleagues¹⁰⁻¹² reported that magnetic resonance imaging was a more sensitive indicator of transverse atlantal ligament integrity/disruption than the rule of Spence because of the ability to visualize the ligament with magnetic resonance imaging (MRI). They described 39 patients with C1 ring fractures with abnormal signal in the transverse atlantal ligament, including 60% that would not have been defined as unstable with standard radiographs and the rule of Spence. Although of potential significance, the data they provided are Class III medical evidence for a diagnostic test (see Table 1) because of the lack of a true gold standard and their failure to

include the necessary data required for a formal bayesian analysis (eg, a false-positive rate could not be determined from the data provided).¹¹ The authors recommended treatment of atlas fractures based on the MRI findings. Fractures in which the substance of the ligament was injured without associated fracture of the atlas (type I injury) would be considered for early surgical fixation because of inherent instability. External immobilization was recommended for the finding of an avulsion fracture of the atlas at the insertion of the transverse atlantal ligament (type II injury).¹⁰ As with prior reports, the number of patients treated surgically for instability for whom there was outcome data available was limited. Their report provides Class III medical evidence for treatment.

The previous guideline on this topic summarized a number of case series in formulating treatment recommendations, all of which provided Class III medical evidence.³ In 1988, Hadley et al⁴ described a treatment algorithm based on 32 patients with isolated fractures of the atlas. There were no neurological injuries in their group of patients, and all were managed nonsurgically. This pre-MRI study reported that isolated fractures of the atlas could be managed with external immobilization alone (median, 12 weeks), with the type of immobilization determined by the combined lateral mass displacement (LMD) of C1 over C2. Atlas fractures with an LMD < 6.9 mm (12 patients) were successfully treated with a cervical collar. Twenty patients with an atlas fracture with an LMD > 6.9 mm were effectively treated with more rigid immobilization using the halo orthosis or a suboccipital mandibular immobilizer brace. Fowler et al¹³ described 48 patients with acute traumatic atlas fractures. They treated atlas fracture with an LMD < 7 mm with a cervical collar and those with an LMD > 7 mm with traction followed by immobilization in a cervical collar. None of their patients required surgical stabilization. Additional reports of patients with traumatic atlas fractures favored nonoperative management and are summarized in Table 2. Lee et al¹⁴ and Kesterson et al¹⁵ reported a total of 25 patients considered stable with an LMD < 7 mm; all were treated successfully with a cervical collar. All 34 patients with isolated C1 ring fractures in the Levine and Edwards³ retrospective review all healed successfully without surgery. Levine and Edwards treated fractures with an LMD < 7 mm with a cervical collar and those with an LMD > 7 mm with a halo orthosis or traction until healed. Although infrequent, late instability of isolated C1 fractures can occur; therefore, clinical follow-up during and after immobilization is recommended.¹⁶

The 1998 report of Lee et al¹⁴ attempted to characterize atlas fractures into 3 types: anterior or posterior arch fractures (Landell type I), burst fractures (Landell type II), and lateral mass fractures (Landell type III). In general, types I and III were considered stable. Treatment with rigid collar immobilization was recommended. Type II fractures were judged to be either stable or unstable on the basis of an LMD > 7 mm or documented disruption of the transverse atlantal ligament on MRI. A treatment algorithm resulting in cervical immobilization for stable atlas fractures and surgical stabilization for unstable atlas

TABLE 1. Treatment of Atlas Fractures^a

Atlas Fracture Type	Treatment Options
Anterior or posterior arch fractures (type I)	Collar
Anterior and posterior arch (type II, burst)	
Stable (transverse atlantal ligament intact)	Collar, halo
Unstable (transverse atlantal ligament disrupted)	Halo, C1-2 stabilization, and fusion
Lateral mass fractures (type III)	
Comminuted fracture	Collar, halo
Transverse process fractures	Collar

^aLMD, lateral mass displacement.

TABLE 2. Evidentiary Table: Management of Atlas Fractures

Citation	Description of Study	Evidence Class	Conclusions
Kontautas et al, ²² <i>Journal of Spinal Disorders and Techniques</i> , 2005	Retrospective review of 29 patients with atlas fractures including 17 isolated atlas fractures	III	Fusion rate was 96.4%.
	Atlas classification as by Landells and Van Peteghem et al ¹⁷		Isolated nondisplaced atlas fractures can be treated effectively with a rigid cervical collar alone. Unstable fractures if treated with a halo orthosis heal without surgical intervention in > 96% of cases.
Dvorak et al, ²³ <i>Journal of Neurosurgery: Spine</i> , 2005	Retrospective review, radiographic analysis, and cross-sectional outcome assessment performed in patients with isolated atlas fractures	III	Unstable atlas fractures appear to have a poorer outcome than previously believed. No standardized outcome assessments have been published for this population.
			Limitations of this review include low (60%) response rate and the lack of a comparison group.
Hein et al, ²⁴ <i>Acta Neurochirurgica (Wien)</i> , 2002	Retrospective review of 8 patients with "unstable" Jefferson fractures	III	Halo immobilization is uncomfortable, associated with failure in unstable fractures, and leads to complications in the elderly.
Horn et al, ²¹ <i>Journal of Neurosurgery: Spine</i> , 2006	Retrospective review of 53 patients treated with halo fixation either after trauma or after surgery	III	External halo fixation can be used safely to treat cervical instability in elderly patients.
			The high complication rate in this population may reflect the significant incidence of underlying associated disease processes in the elderly.
Lee et al, ¹⁴ <i>Spine</i> , 1998	Retrospective review including 12 cases of isolated fracture of the atlas	III	Nonoperative management successful.
McGuire and Harkey, ⁵ <i>Journal of Spinal Disorders</i> , 1995	Two cases of unstable atlas burst fractures treated with posterior transarticular screw fixation and fusion	III	Surgical management can be considered for unstable fractures defined as a predental space > 5 mm and/or LMD > 9 mm.
Levine and Edwards, ³ <i>Journal of Bone and Joint Surgery: American Volume</i> , 1991	Retrospective review of 34 patients with atlas fractures	III	If LMD < 7 mm, collar; if LMD > 7 mm, either halo alone or reduced in traction and maintained until healed (6 wk in traction and 6 wk in halo).
Kesterson et al, ¹⁵ <i>Journal of Neurosurgery</i> , 1991	Retrospective review of 13 patients with isolated atlas burst (Jefferson) fractures	III	Nonoperative management successful.
Fowler et al, ¹³ <i>Journal of Spinal Disorders</i> , 1990	Retrospective review of 48 consecutive atlas fractures divided into burst (30), posterior arch (17), and anterior arch fractures (1)	III	Reduction in traction if LMD > 7.0 mm followed by treatment in collar was successful.
Hadley et al, ¹ <i>Neurosurgery</i> , 1988	Retrospective review of 32 isolated fractures of the atlas	III	Isolated C1 fractures can be managed without early surgical fixation. If the LMD is > 6.9 mm, then Halo immobilization is indicated.
Landells and Van Peteghem, ¹⁶ <i>Spine</i> , 1988	Retrospective review of 35 patients with fractures of the atlas	III	Classification scheme is described based on fracture pattern. Nonoperative management successful in the majority of cases.
Segal et al, ⁶ <i>Journal of Bone and Joint Surgery: American Volume</i> , 1987	Retrospective review including 8 isolated atlas fractures; median follow-up 46 mo	III	Nonoperative management successful.
Kornberg, ¹⁷ <i>Orthopaedic Review</i> , 1986	Case report of unstable atlas burst fracture	III	Fusion appropriate for unstable burst fractures of the atlas (LMD > 6.9 mm).
Schlicke and Callahan, ¹⁹ <i>Clinical Orthopaedics</i> , 1981	Case report of unstable atlas burst fracture	III	Fusion appropriate for unstable burst fractures of the atlas (LMD > 6.9 mm).

fractures was described; however, the series did not include any unstable isolated atlas fractures. Surgical fixation, primarily C1-2 stabilization with fusion, has been reported as treatment for isolated atlas fractures using LMD criteria > 7 mm¹⁶⁻¹⁹ or a prelaminar interval on lateral x-ray of > 5 mm.¹⁸

This updated medical evidence review identified 4 more recent clinically relevant studies addressing the management of isolated atlas fractures in adults.²⁰⁻²⁴ These 4 publications include patient data and new information. A review by Kakarla et al²⁰ was identified but appeared to essentially summarize the previous guideline published on this topic and provided no new information.

Kontautas et al²² reviewed a series of 29 patients with upper cervical spine injuries. Although the authors described a prospective review, the study appears to be retrospective and is considered Class III medical evidence. There were no comparison groups or control subjects. The authors reported 17 patients with isolated atlas fractures. Thirteen were considered stable and were treated with a cervical collar. All achieved successful union. Four were considered unstable by Spence criteria and were managed with halo immobilization. Seventy-five percent ($n = 3$) healed. The authors concluded that nondisplaced atlas fractures could be treated with a cervical collar alone. They noted that even with halo immobilization, some unstable atlas fractures will require surgical stabilization. This citation supports the previous guideline recommendations, adds support to the collar-only treatment arm for nondisplaced fractures, but does not provide sufficient medical evidence to change the existing recommendations for unstable atlas fractures.

Dvorak et al²³ in 2005 published the first study attempting to address quality-of-life issues in patients with isolated atlas fractures. They surveyed a series of patients treated for atlas fractures using the Short Form-36 and the American Academy of Orthopaedic Surgeons/North American Spine Society pain value scales. They asked patients to compare their postinjury state with their preinjury status. The study included long-term follow-up (mean, 75 months; range, 19-198 months) but had a relatively low response rate (60%). The authors reported that patients who replied to the survey did not perceive themselves to return to their preinjury status after sustaining a traumatic atlas fracture. The presence of an unstable atlas fracture was associated with a worse outcome compared with those who sustained a stable atlas fracture.

Horn et al²¹ specifically reviewed the complications of halo fixation in the elderly population. Although this study did not specifically focus on atlas fractures alone, it is included in this review as an important consideration of treatment-related complications. Patients were included in their review if they were ≥ 70 years of age and were treated with a halo device either as treatment after injury or postoperatively. A total of 53 patients were included, 41 posttrauma and 12 postoperative patients. The analysis of complications of halo immobilization was based on a total of 42 patients on whom follow-up data were available. The perioperative mortality rate in this group from all causes was

$> 20\%$. Two of the deaths were felt to be unrelated to treatment, resulting in the reported 14% perioperative rate. Halo ring and vest complications included respiratory distress ($n = 4$, 9.5%), dysphagia ($n = 6$, 14.3%), and pin-related complications ($n = 10$, 23.8%). The authors concluded that halo immobilization can be accomplished safely in the elderly; however, the high complication rate associated with halo immobilization must be considered. The high perioperative morbidity rate in this report raises concern for surgical fixation of the cervical spine in this age group as well, highlighting the challenges of treating the elderly injured population in general.

Hein et al²⁴ described their clinical experience with 8 patients with unstable atlas burst fractures and provided their working definition of “unstable” atlas fractures: “The unstable atlas burst fracture, Jefferson fracture, is a fracture of the anterior and posterior atlantal arch with rupture of the transverse atlantal ligament and an incongruence of the atlanto-occipital and the atlanto-axial joint facets.” Their experience spanned a 10-year period, emphasizing the relative infrequency of this isolated fracture pattern. Five of their patients were initially treated with immobilization but required late transarticular screw fixation (62.5%). Eventually, all 8 patients they managed required surgical stabilization, all of whom reportedly achieved bony fusion. The authors concluded that although halo immobilization can be considered for the initial management of unstable atlas fractures, the discomfort of prolonged immobilization and the poor healing/union rate associated with immobilization alone should prompt clinicians to offer early surgical stabilization of unstable atlas fractures. This latter opinion is not supported by the data presented. Their retrospective case series without a control group (and no assurance that the entire cohort of treated patients was included) provides, at best, Class III medical evidence that surgical fixation is an option in selected patients with unstable C1 fractures. Their report does not alter the previously published recommendations on this topic.

These more recent clinical articles provide supportive Class III medical evidence on the treatment of patients with isolated atlas fractures. The issue of quality of life is new information and suggests that there may be more long-term morbidity associated with an atlas fracture than previously believed. The complications associated with halo immobilization of atlas/cervical fractures, particularly in the elderly, are highlighted in this review. The definition of the unstable atlas fracture provided by Hein et al may prove useful for future comparative studies.

SUMMARY

No Class I or Class II medical evidence addressing the management of patients with isolated atlas fractures was identified. Class III medical evidence on this topic from case series and case reports supports several treatment strategies for patients with acute isolated fractures of the atlas. One study addressing quality-of-life issues has been published.

Nondisplaced isolated anterior or posterior atlas arch fractures and fractures of the atlas lateral mass (types I and III) have been effectively treated with external cervical immobilization devices. Rigid collars, suboccipital mandibular immobilizer braces, and halo ring-vest orthoses used for 8 to 12 weeks have been described with successful union/healing rates > 96%. There is no medical evidence suggesting the superiority of 1 form of external immobilization over another.

Combined anterior and posterior arch fractures of the atlas (type II or burst fractures) with an intact transverse atlantal ligament (stable) have been effectively managed with use of a rigid collar, a suboccipital mandibular immobilizer brace, or a halo orthosis for a duration of 10 to 12 weeks.

Combined anterior and posterior arch fractures of the atlas (type II or burst fractures) with evidence of transverse atlantal ligament disruption (unstable) have been effectively treated with either rigid immobilization alone (halo orthosis) for a period of 12 weeks or surgical stabilization and fusion. Consideration of the potential complications of halo immobilization, particularly in the elderly, is suggested and must be balanced against the potential morbidity/mortality associated with surgical treatment for these fracture injuries.

Criteria proposed to determine transverse atlantal ligament injury with associated C1-C2 instability include the sum of the displacement of the lateral masses of C1 on C2 of > 6 to 9 mm on a plain open-mouth x-ray (or 8.1 mm, the rule of Spence corrected for magnification), a predental space of > 5 mm in adults, and evidence of transverse atlantal ligament disruption or avulsion on MRI.

KEY ISSUES FOR FUTURE INVESTIGATION

The main issue in the management of patients with isolated fractures of the atlas remains being able to predict which patients with an unstable atlas fracture will fail to respond to immobilization alone and require surgical stabilization and fusion. Because of the relative infrequency of these fractures, registry data with a retrospective analysis using case-control study design appear to be the most feasible means to study this issue and provide Class II medical evidence.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Management of Isolated Fractures of the Axis in Adults

Timothy C. Ryken, MD, MS*

Mark N. Hadley, MD‡

Bizhan Aarabi, MD, FRCSCS

Sanjay S. Dhall, MD¶

Daniel E. Gelb, MD||

R. John Hurlbert, MD, PhD,
FRCSC#

Curtis J. Rozzelle, MD**

Nicholas Theodore, MD‡‡

Beverly C. Walters, MD, MSc,
FRCSC‡§§

*Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa; ‡Division of Neurological Surgery and **Division of Neurological Surgery, Children's Hospital of Alabama, University of Alabama at Birmingham, Birmingham, Alabama; §Department of Neurosurgery and ||Department of Orthopaedics, University of Maryland, Baltimore, Maryland; ¶Department of Neurosurgery, Emory University, Atlanta, Georgia; #Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada; ‡‡Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona; §§Department of Neurosciences, Inova Health System, Falls Church, Virginia

Correspondence:

Mark N. Hadley, MD, FACS,
UAB Division of Neurological Surgery,
510 – 20th St S, FOT 1030,
Birmingham, AL 35294-3410.
E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS

Fractures of the Odontoid

Level II:

- Consideration of surgical stabilization and fusion for type II odontoid fractures in patients ≥ 50 years of age is recommended.

Level III:

- Initial management of nondisplaced type I, type II, and type III odontoid fractures with external cervical immobilization is recommended, recognizing that a decreased rate of union (healing) has been reported with type II odontoid fractures compared with type I or type III odontoid fractures.
- Surgical stabilization and fusion of type II and type III odontoid fractures with dens displacement ≥ 5 mm, comminution of the odontoid fracture, and/or inability to achieve or maintain fracture alignment with external immobilization are recommended.
- If surgical stabilization is elected, either anterior or posterior techniques are recommended.

Traumatic Spondylolisthesis of the Axis (Hangman Fracture)

Level III:

- External immobilization as the initial management of traumatic spondylolisthesis of the axis is recommended.
- Surgical stabilization and fusion for the treatment of Hangman fractures in cases of severe angulation of C2 on C3, disruption of the C2-3 disk space, and/or inability to achieve or maintain fracture alignment with external immobilization are recommended.

Fractures of the Axis Body (Miscellaneous Fractures)

Level III:

- External immobilization for the treatment of isolated fractures of the axis body is recommended. Consideration of surgical stabilization and fusion in unusual situations of severe ligamentous disruption and/or inability to achieve or maintain fracture alignment with external immobilization are recommended.
- In the presence of comminuted fracture of the axis body, evaluation for vertebral artery injury is recommended.

RATIONALE

The unique anatomy of the axis vertebra results in a variety of fracture patterns in the setting of significant cervical trauma. Fractures of the axis are often associated with other cervical fracture or ligamentous injuries. In 2002, the guidelines author group of the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons published a medical evidence-based guideline on this important topic¹ and subdivided axis fractures into 3 general subtypes: fractures of the odontoid process, traumatic spondylolisthesis of the axis (Hangman fractures), and miscellaneous nonodontoid non-Hangman fractures of the C2 vertebra. The previous guideline recommended that surgical stabilization of type II odontoid fractures in patients ≥ 50 years of age be considered on the basis of Class II medical evidence. All other recommendations for the treatment of all other isolated fractures of the axis were made at a lower level of medical evidence (Class III) and included both cervical

immobilization and surgical fixation with fusion, depending on the fracture type and its radiographic features. It was recommended that type I, II, and III odontoid fractures be managed by immobilization alone. Surgical fixation and fusion were recommended for those cases with a dens displacement of ≥ 5 mm, comminution of the odontoid fracture (type IIA fractures), and/or the inability to maintain fracture alignment. It was recommended that traumatic spondylolisthesis of the axis be managed initially with external immobilization. However, consideration of surgical stabilization and fusion for Hangman fractures was recommended in cases of severe angulation of C2 on C3 (Francis grade II and IV, Effendi type II), disruption of the C2-3 disk space (Francis grade V, Effendi type III), or the inability to maintain alignment with external immobilization. Finally, it was recommended that fractures involving the axis body be treated with cervical immobilization. The purpose of this review is to update the medical evidence on the treatment of isolated axis fractures since the 2002 guidelines publication.¹

SEARCH CRITERIA

A National Library of Medicine (PubMed) computerized literature search from 1966 to 2011 was undertaken using Medical Subject Headings in combination with “spinal cord injury”: “axis,” “vertebrae,” “fracture,” and “human.” A total of 1181 articles were identified. Those articles focusing on the clinical management of acute traumatic axis fractures were selected for review. The bibliographies of these articles were scanned for additional references to confirm completeness of the literature review. Relevant articles addressing the mechanism of injury or the biomechanics and radiology of the C2 vertebra were considered for inclusion in the scientific foundation of this document.

Forty-six articles not previously included in the original guidelines document were identified, reviewed, and classified using established methodology. Thirty-one articles described the management of odontoid fractures; 10 articles were focused on traumatic spondylolisthesis of the axis; and 5 articles described the treatment of patients with miscellaneous axis fractures and are summarized in Evidentiary Table format.

SCIENTIFIC FOUNDATION

Odontoid Fractures

Classification of Odontoid Fractures

The classification of odontoid fractures into 3 types, as described by Anderson and D’Alonzo² in 1974, remains an accepted classification scheme for odontoid fracture injuries. The authors defined 3 odontoid fracture types based on their series of 49 patients. Type I fractures were described as oblique fractures through the upper portion of the odontoid process. Type II fractures were described as fractures across the base of the odontoid process near the junction with the axis body. Type III fractures were fractures that include the odontoid and extend into the body of the axis. This historic series includes 2 type I fractures

(4%), 32 type II fractures (65%), and 15 type III fractures (31%). Hadley et al³ modified this classification scheme in 1988, defining the type IIA odontoid fracture as a comminuted fracture of the base of the odontoid with associated free fracture fragments. This unique fracture was associated with severe instability in their series and represented 3 of the 62 type II odontoid fractures they treated. Further odontoid fracture classification modification was proposed by Grauer et al,⁴ who described 3 subtypes of type II fractures. Type IIA was defined as a minimally or nondisplaced fracture with no comminution treated with external immobilization. Type IIB was defined as a displaced odontoid fracture that extends from anterior-superior to posterior-inferior, or a transverse fracture, amenable to anterior screw fixation if reducible, assuming adequate bone quality. Type IIC was defined as a fracture extending from anterior-inferior to posterior-superior or a fracture with significant comminution likely to be considered for posterior internal fixation and fusion. These modifications were introduced to specifically address the issue that the original Anderson-D’Alonzo scheme did not take into account the direction of the fracture across the dens, the presence of comminuted fragments, or the degree of displacement or angulation of the fractured odontoid process. In addition, the authors noted the difficulty in differentiating a low type II fracture from a high type III fracture. They applied their revised scheme to a series of 52 patients with odontoid fractures. Seven raters were asked to characterize the odontoid fracture injuries. There was agreement in 70% of the cases by at least 5 of 7 raters. The overall κ value for the modified system was 0.48, indicating moderate to good agreement. Other than this single study, none of these classification schemes (Table 1) have been subjected to rigorous validity and reliability evaluation.

Treatment

Numerous therapeutic strategies for odontoid fracture management have been described on the basis of a variety of factors, including the fracture type, degree of dens displacement, angulation of the dens with respect to the body of C2, interval between the fracture and treatment, and patient age. The medical evidence supporting the nonoperative management of odontoid fractures with external immobilization, including traction, a cervical collar, or the halo orthosis (including custom devices such as the suboccipital mandibular device and Minerva devices), and the surgical management of these fracture injuries, including posterior cervical fusion with or without supplemental screw fixation or anterior odontoid screw fixation, is the subject of this updated review.

Nonoperative Treatment

In 1985, the Cervical Spine Research Society published a multicenter review addressing the management of odontoid fractures. Their report included 18 patients with type II odontoid fractures and 3 patients with type III odontoid fractures who received no treatment. None of these patients achieved bony healing or fracture union. The authors concluded that no treatment was not a good option for patients with odontoid fractures.⁵

Traction. Evidence-based reviews by Traynelis⁶ in 1997 and Julien et al⁷ in 2000 include evidentiary tables that contain Class III medical evidence addressing the use of traction and subsequent immobilization in a cervical collar for patients with odontoid fractures. The combined radiographic union rates from these reports were as follows: type I, 100% (3 of 3); type II, 43% (42 of 97); and type III, 87% (55 of 63).

Cervical Collar. As described in the previous guideline publication, the treatment of the infrequent type I odontoid fracture with cervical collar immobilization has been reported to be successful in nearly 100% of cases (Class III medical evidence).^{2,5,8} No new data of higher quality was identified in this review. Previous Class III medical evidence reports describing the outcome of type II fractures treated with a cervical collar alone resulted in union rates ranging from 53% to 57%.^{9,10} The management of type III odontoid fractures with cervical collars results in union rates ranging from 50% to 65%, also based on Class III medical evidence.^{5,10}

Halo Immobilization. In the largest reported series of axis fractures published in 1997, Greene et al¹¹ described the management of 199 patients with odontoid fractures: type I, n = 2; type II, n = 116; type IIA, n = 4; and type III, n = 77. Union rates for those treated with a halo orthosis were reported to be the following: for type I, 100% (2 of 2); for type II, 72% (68 of 95); and for type III, 99% (68 of 69). Analysis of the type II fractures with nonunion indicated that a dens displacement of ≥ 6 mm was associated with an increased rate of nonunion regardless of patient age, direction of displacement, or neurological deficit. The negative impact of dens displacement ranging from 2 to 6 mm on successful healing/union was confirmed in other reports.^{5,12-14}

The evidenced-based review by Julien et al⁷ included a total of 269 patients with odontoid fractures treated with rigid external fixation (halo orthosis or Minerva vest) for 8 to 12 weeks. Reported union rates were as follows: for type I, 100% (3 of 3); for type II, 65% (110 of 168); and for type III, 84% (67 of 80). The Class III medical evidence provided in these reports was the foundation for the option level/Level III recommendations for treatment of odontoid fractures published in the previous guideline.

Shears and Armitstead¹⁵ in 2008 published a Cochrane Review of odontoid fracture management and concluded that no randomized medical evidence existed on this topic.

In 2007, Platzer and colleagues¹⁶ reported their series of 90 patients with type II odontoid fractures. The authors prospectively studied the success of halo immobilization with union as the outcome of interest. The mean patient age in their series was 69 years. The reported union rate was 84% (76 of 90). Eighty-three percent of these patients (75 of 90) returned to their preinjury status. The authors identified the following risk factors for failure of halo immobilization ($P < .05$): older patients (cases, 77.2 years vs controls, 60.8 years; $P < .05$) and displaced fractures > 2 mm (cases, 11 of 14 [79%] vs controls, 16 of 76 [21%]). Two other factors had a significant effect on the multivariate regression analysis they performed: secondary loss of reduction and delay of

treatment ($P < .05$). If 2 of these covariate risk factors were present, there was a 57% risk of nonunion. The likelihood of nonunion increased to 70% with 3 covariate risk factors and was 87% when all 4 risk factors were present. The authors concluded that halo immobilization provided satisfactory outcome with an 84% union rate. This publication supports the previous case-control study published by Lennarson et al¹⁷ in which patient age was identified as a risk factor for nonunion, along with the degree of dens displacement, secondary loss of reduction, and delay of treatment. Although the authors described their analysis as a case-control study, with respect to treatment, it is a prospective cohort study. Because all of the patients were treated the same, there is no comparison group. Their study offers Class III medical evidence on this topic.

Kim et al¹⁸ present a prospective cohort study of 20 patients with type II odontoid fractures to evaluate radiographic indicators for predicting failure of treatment with halo immobilization. Of 14 patients in a halo group, 4 patients developed nonunion. All 4 patients had a $> 5^\circ$ change of angulation in the dens fracture between supine and upright films at the 2-week time point. None of the patients in the successful union group demonstrated this radiographic finding.

In 2005, Kontautas et al¹⁹ reported their prospective non-randomized cohort study of 37 patients with type II odontoid fractures treated initially with traction to determine reducibility. Two groups were identified: group 1 with dens displacement ≤ 5 mm and group 2 with dens displacement > 5 mm. The groups were equivalent by age, sex, neurological condition, and associated spinal fractures ($P > .05$). Eleven group 1 injuries (64%) and 13 Group 2 fractures were able to be reduced and treated in a halo device. The nonunion rate at 8 weeks for group 1 injuries was 0%. Fracture injuries had a 16.7% nonunion rate. Patients with fractures that could not be reduced and those who failed halo treatment were treated with posterior internal fixation and fusion. The authors concluded that when closed reduction of an odontoid fracture can be achieved, external immobilization with a halo-vest device will likely be effective.

Nourbakhsh et al²⁰ published a meta-analysis using a random-effects model to assess the effectiveness of nonoperative management of type II odontoid fractures. The authors identified a union rate $> 80\%$ for all patients < 55 years of age regardless of the mode of treatment. External immobilization (halo vest or collar) was equally effective with anterior displacement of the dens fracture and younger patients (< 55 years of age).

Müller et al²¹ in 2003 reported a retrospective analysis of 26 "stable" type II and III fracture patients managed with collar immobilization. A stable fracture met the following criteria: fracture gap of < 2 mm, displacement of < 5 mm, and angulation of $< 11^\circ$. Reported union fusion rates were 73.7% for type II fractures and 85.7% for type III fractures. In 4 patients (15%), a fibrous union was documented. Three of these patients were > 65 years of age. No correlation between clinical outcome and the radiological finding of a fibrous union was identified. Patients with a stable fibrous union were as pleased with their

outcome as those patients with documented bony fusion. The authors concluded that stable type II and III fractures of the odontoid can be treated successfully with collar immobilization.

In 2010, Butler et al²² reported their series of 66 patients with type II odontoid fractures treated with halo immobilization. The nonunion rate was 21% in patients > 65 years of age (compared with 2% for patients < 65 years of age). Age was associated with poorer functional outcomes. Similarly, Komadina et al²³ described a high rate of union for type II and III odontoid fractures managed in a halo immobilization device (86%). Sixty-five percent of their patients had complete symptom resolution at the 1-year follow-up.

Operative Treatment

Posterior Cervical Fixation. The previous guideline publication summarized the outcome of 177 patients with odontoid fractures treated with posterior cervical fixation and fusion. Fusion success after operative treatment was as follows: type I, 100% (1 of 1); type II, 87% (128 of 147); and type III, 100% (29 of 29). Of note, Maiman and Larson²⁴ reported a union rate at the fracture site of only 35% but a fusion rate of 100% at the posterior operative site. These patients were treated with an instrumented (wire or cable) posterior C1-2 arthrodesis followed by immobilization in a rigid orthosis. At the time of the previous guideline publication, transarticular screw fixation and fusion of C1-2 had been described,²⁵ particularly in patients with fracture nonunion after initial management, but the experience was limited.

Anterior Cervical Fixation. Screw fixation of odontoid fractures from an anterior approach, although technically challenging, has the potential to maintain rotational motion at the atlantoaxial joint, which is lost with posterior C1-2 fusion techniques. Anterior odontoid screw fixation is best suited for fractures that are either horizontal or oblique and posterior with an intact transverse atlantal ligament.²⁶⁻²⁹ The previous guideline identified Class III medical evidence addressing the role of anterior odontoid screw fixation. Julien et al⁷ described fusion rates of 89% (112 of 126) for type II fractures and 100% (20 of 20) for type III fractures. Subach et al³⁰ reported 1 failure resulting from inadequate reduction in their series of 26 type II fractures treated with anterior odontoid fixation (fusion rate, 96%). The success of anterior odontoid fixation has been reported to be similar with 1 vs 2 screws (81% vs 85%)³¹ and greater when it is performed within 6 months of injury compared with 18 months after injury (88% vs 25%).³²

Smith et al³³ examined a 20-year period to identify trends in the role of surgery for type II odontoid fractures. They found that the rate of surgical intervention for these injuries increased during the study period. A thorough report on the role of surgery for odontoid fractures was published recently by Nourbakhsh et al.²⁰ Their meta-analysis offers Class III medical evidence on this issue. The authors concluded that operative treatment of acute type II fractures (posterior C1-2 fixation or anterior screw fixation) increases the union/fusion success rate compared with external immobilization and is recommended for older patients,

patients with posterior displacement of the dens fracture, and in cases with dens displacement > 4 to 6 mm.

A large number of case series without comparison groups (Class III medical evidence) have been published and support the safety and efficacy of anterior odontoid screw fixation in the treatment of type II and III odontoid fractures. Moon et al³⁴ treated 32 patients with type II or III odontoid fractures with anterior odontoid screw fixation followed by halo vest immobilization and reported a 100% fusion rate at 9 weeks. Fountas et al³⁵ in 2005 reported their results with anterior odontoid screw fixation in 31 patients with type II and “shallow” type III odontoid fractures. They identified an 87% fusion rate at long-term follow-up (mean, 58.4 months). Lee et al³⁶ described 48 patients with type II and III odontoid fractures treated with single anterior odontoid screw fixation. They reported a fusion rate of 96% and a failure rate of 10% (1 nonunion and 1 malposition). Bhanot et al³⁷ reviewed their experience with 17 type II odontoid fractures managed with ventral screw fixation. They reported fusion in 94% of patients (16 of 17) with 1 nonunion and 1 case of screw back-out. Chi et al³⁸ described 10 patients with type II and III odontoid fractures managed with a percutaneous anterior odontoid screw technique. They described fusion success in 9 of 10 patients. Song et al³⁹ described 16 patients with type II and III odontoid fractures treated with single anterior odontoid screw fixation. They found a 94% fusion rate. One patient required a subsequent posterior procedure. Cervical spine range of motion after treatment was reported as full in 12 patients and limited in 4 patients.

Odontoid Fracture Management in the Elderly Patient

The management of odontoid fractures in the elderly is controversial. The previous guideline publication identified 1 Class II medical evidence article favoring surgical fixation of type II odontoid fractures in patients > 50 years of age. Multiple Class III medical evidence articles offer conflicting evidence on this issue, although the majority of the case series previously reviewed support a role for surgery in elderly patients with type II odontoid fractures.

The case-control study by Lennarson et al¹⁷ provides Class II medical evidence on the topic. The authors examined 33 patients with isolated type II odontoid fractures treated with halo vest immobilization. Patients were divided by age and outcome and by union or nonunion of their odontoid fracture. Patients ≥ 50 years of age had a risk of nonunion 21 times greater than patients < 50 years of age when treated with halo immobilization. Medical conditions, sex of the patient, degree of fracture displacement, direction of fracture displacement, length of hospital stay, and length of follow-up were not found to have a significant effect on outcome.

The ability of elderly patients to tolerate halo fixation immobilization has been questioned.⁴⁰ Mortality rates as high as 26% with the use of the halo device have been reported.⁴¹ Reported union rates for odontoid fractures in elderly patients treated with halo immobilization vary between 20% and 100% in the literature.^{2,41,42} Fusion rates reported for elderly patients treated with surgery are generally higher.^{2,43,44} The majority of

published papers on this topic favor consideration of surgery in the elderly patient with an odontoid fracture.^{25,45-47} Multiple Class III medical evidence articles and the single Class II medical evidence citation formed the basis for the previous guideline recommendations on the management of odontoid fractures. The current review identified 12 citations on the management of elderly patients with odontoid fractures published since 2002. All provide Class III medical evidence.

Börm et al⁴⁸ reported their study of the effect of age on outcome in 27 patients with type II odontoid fractures treated with anterior odontoid screw fixation. The patients were evaluated in 2 groups. Group 1 contained patients ≥ 70 years of age, and group 2 contained patients < 70 years of age. The groups were equivalent in terms of demographics. There was no significant difference between the 2 groups with respect to fusion success rate (73% vs 75%), the need for subsequent posterior operative procedures (13% vs 17%), or the incidence of complications (20% vs 8%). This article provides Class III medical evidence that age alone does not have a negative impact on outcome after anterior odontoid screw fixation.

Dailey et al⁴⁹ retrospectively reviewed 57 type II odontoid patients > 70 years of age whom they treated with anterior odontoid screw fixation. Postoperative stability was reported in 81% of the patients. In patients treated with 2 screws, stability was 96% compared with 56% for 1-screw fixation. They reported a 25% incidence of significant dysphagia and a 19% rate of aspiration pneumonia in their series.

Platzter et al⁵⁰ in 2007 published their series of patients with type II odontoid fractures ($n = 110$) managed with anterior screw fixation. They examined the effect of age on nonunion. The overall fusion rate was 93%. They identified an increased rate of nonunion in older patients (12% vs 4%; $P < 0.05$). The authors concluded that anterior screw fixation was a safe and effective option for the treatment of type II odontoid fractures in patients of all ages.

Smith et al⁵¹ published a retrospective cohort analysis of older patients with type II odontoid fractures (≥ 80 years of age) and compared operative ($n = 32$) and nonoperative ($n = 20$) treatment strategies. The length of acute hospital stay was longer in the operative treatment patients (mean, 22.8 vs 11.2 days; $P < .05$). Significant complications were greater in the operative group compared with the nonoperative group (62% vs 35%; $P < .05$). The mortality rate was similar in the 2 groups (12.5% vs 15%; $P > .05$). The authors concluded that type II odontoid fractures in the octogenarian population are associated with significant morbidity and mortality regardless of management. They found that nonoperative management was associated with fewer complications and outcomes similar to those from operative management. This retrospective comparative cohort study offers Class III medical evidence on this topic.

White et al⁵² published a systematic review of the literature from 1990 through 2010 on the role of surgery for odontoid fractures in the elderly. Fourteen articles met their criteria for analysis. They identified a postoperative mortality rate of 10.1% (in-hospital, 6.2%; after discharge, 8.8%). There was no

difference in postoperative mortality on the basis of operative approach, anterior vs posterior. The incidence of postoperative complications in this patient group was airway compromise (17%), pneumonia (9.9%), respiratory failure (7.7%), cardiac failure (6.8%), deep vein thrombosis (3.2%), stroke (3.2%), liver failure (6.7%), and severe infection (3.2%).

Koech et al⁵³ evaluated the effectiveness of nonoperative management of type II odontoid fractures in 42 elderly patients treated with either collar ($n = 10$) or halo ($n = 32$) immobilization. They found bony fusion rates of 50% and 37.5%, respectively. They described radiographic stability rates of 90% and 100%, respectively. They found no difference in clinical outcome between bony fusion, fibrous union, and radiographic stability. The authors suggested that fibrous union with radiographic stability may be a suitable outcome in elderly patients.

Majercik et al⁵⁴ compared patient age and outcome with treatment in a halo immobilization device (not specifically odontoid fracture patients) and found a mortality rate of 21% in patients ≥ 66 years of age compared with 5% in patients < 66 years of age ($P < .05$). These authors strongly recommended against halo vest immobilization in the treatment of cervical fracture injuries in elderly patients if other treatment alternatives were available.

Similarly, Tashjian et al⁵⁵ reported the morbidity and mortality of halo immobilization compared with collar and/or operative treatment in a cohort of 78 patients with type II, type III, and combination atlas-axis fractures in patients with a mean age of 81 years. All patients were > 65 years of age. There were 24 deaths during the initial hospitalization (31%). Of those treated in a halo device, 42% died. Major complications were twice as likely with a halo device, 66% vs 36% ($P = .003$). The authors concluded that odontoid fractures are associated with significant morbidity and mortality in the elderly. Both appear to increase significantly when treated in a halo immobilization device.

In 2010, Fagin et al⁵⁶ published a retrospective review of 108 patients with odontoid fractures whom they managed. Sixty-nine patients were managed nonoperatively; 17 were treated with an immediate operation; and 23 were treated with a delayed operation. The mean age of the nonoperative group was older, 82.4 years, compared with 77.4 and 76.4 years, respectively ($P = .006$). The mortality rate was not significantly different between the 3 groups (17.6%, 11.7%, and 8.7%, respectively; $P > .05$). The need for tracheostomy or gastrostomy and the development of urinary tract infection or pneumonia were equivalent in all groups. The incidence of deep vein thrombosis was lower in the nonoperative group compared with the early surgery group (3% compared to 18%; $P = .02$). The length of stay was less for nonoperative patients compared with operated patients (8.5 compared to 13.9 days; $P < .001$). The authors recommended that nonoperative treatment be strongly considered for elderly patients with odontoid fractures.

In 2009, Omeis et al⁵⁷ described 24 elderly patients with type II odontoid fractures treated surgically. They found a 7% incidence of central cord syndrome at presentation. Perioperative

TABLE 1. Initial Management of Isolated Axis Fracture in the Adult

Fracture Type	Treatment Options
Odontoid fracture	
Type I	Collar immobilization
Type II	Consider for early surgery, age \geq 50 y; Halo immobilization, age \leq 50 y
Type IIA (Hadley), type IIC (Gauer)	Consider for early surgery
Type III	Collar or Halo immobilization, surgical fusion
Traumatic spondylolisthesis of the axis (Hangman fracture)	
Stable (Effendi type I; Francis type I, II)	Halo immobilization, collar
Unstable (Effendi type II, III; Francis type III, IV, V)	Halo immobilization, consider surgical stabilization and fusion
Miscellaneous axis fractures	External immobilization in a collar or halo device

complications were identified in 10.3% of patients, including 1 perioperative death caused by a myocardial infarction. Sixteen patients underwent anterior odontoid screw fixation, and 13 underwent posterior fixation and fusion. Ultimately, 86.2% of patients treated surgically returned to their previous level of activity. The authors concluded that the elderly patient with a type II odontoid fracture can be treated with surgical fixation and fusion with acceptable morbidity and a relatively high expectation of returning to their preinjury status.

Frangen et al⁵⁸ published a retrospective review of elderly patients (median age, 85.5 years) with type II odontoid fractures treated with posterior C1-2 fusion. Their 2010 publication described a 22% perioperative mortality rate. Survivors in their series had a 95% rate of fusion with minimal operative complications. The authors concluded that compared with historical control subjects described in the literature, their fusion rate was high. They concluded that posterior surgery is recommended for the treatment of type II odontoid fractures in the elderly, but they recognized the relatively high mortality rate in this age group.

Traumatic Spondylolisthesis of the Axis (Hangman Fracture)

Classification of Hangman Fractures

Historically, the classification schemes for traumatic spondylolisthesis of the axis proposed by Effendi et al⁵⁹ and Francis et al⁶⁰ (with modification by Levine and Edwards⁶¹) have been the most widely used. The Francis classification⁶⁰ recognizes 5 injury grades of increasing severity based on displacement and angulation of C2 on C3:

- Grade I: fractures with 0- to 3.5-mm displacement and/or C2-3 angulation up to 11°
- Grade II: fractures with displacement < 3.5 mm and angulation > 11°
- Grade III: fractures with displacement > 3.5 mm but less than half of C3 vertebral width < 0.5 and angulation < 11°
- Grade IV: fractures with displacement > 3.5 mm but less than half of C3 vertebral width with > 11° angulation
- Grade V: fractures with complete C2-3 disk disruption.

The classification scheme proposed by Effendi et al⁵⁹ defines 3 types of fractures of the ring of the axis based on the mechanism of injury:

- Type I: isolated hairline fracture of the ring of the axis with minimal displacement of the body of C2 associated with axial loading and hyperextension
- Type II: fractures of the ring of the axis with displacement of the anterior fragment with disruption of the disk space below the axis associated with hyperextension and rebound flexion
- Type III: fractures of the ring of the axis with displacement of the body of the axis in a flexed forward position (angulation), in conjunction with C2-3 facet dislocation associated with primary flexion and rebound extension.

The incidence of type I, II, and III fracture injuries in the Effendi et al⁵⁹ original series of 131 patients was 65%, 28%, and 7%, respectively.

The modification of the Effendi classification scheme proposed by Levine and Edwards⁶¹ added flexion-distraction as a mechanism of injury (type IIA), with 4 injury types:

- Type I: nondisplaced fractures and all fractures with < 3-mm displacement of C2 on C3 associated with hyperextension and axial loading.
- Type II: fractures with significant displacement (> 3 mm) and angulation > 11° defined as displacement of the anterior fragment with disruption of the C2-3 disk space associated with hyperextension and secondary flexion-compression.
- Type IIA: fractures with a minimum degree of C2-3 displacement but severe angulation associated with flexion-distraction
- Type III: fractures with unilateral or bilateral C2-3 facet dislocation in addition to fracture of the posterior elements associated with flexion-compression.

Greene et al¹¹ applied the Francis and Effendi classification schemes to 74 patients with Hangman fractures. They noted a strong correlation between Francis grade I and Effendi type I injuries and between Francis grade IV and Effendi type III injuries. The most common fracture types in their series were Effendi type I (72%) and Francis grade I (65%). Burke and Harris⁶² applied the Effendi classification scheme to their series of 65 patients with Hangman fractures; 11% of the fracture injuries in their series were not accurately described by the Effendi scheme.

TABLE 2. Evidentiary Table: Axis Fractures: Odontoid Fracture

Reference	Description of Study	Evidence Class	Conclusions
Butler et al, ²² <i>European Spine Journal</i> , 2010	Retrospective review of 66 type II odontoid fractures treated with external immobilization	III	Nonoperative treatment was successful.
Dailey et al, ⁴⁹ <i>Journal of Neurosurgery: Spine</i> , 2010	Retrospective review of 57 patients with type II odontoid fractures > 70 y of age treated with anterior odontoid screws	III	Advancing age associated with significantly poorer long-term functional outcomes. Higher stabilization rates with 2 screws.
Fagin et al, ⁵⁶ <i>Journal of Trauma</i> , 2010	Retrospective review of 108 odontoid fractures evaluating operative vs nonoperative management by age; age \geq 60 y compared with < 60 y	III	Anterior approach associated with dysphagia. Nonoperative management should be strongly considered in the elderly population.
White et al, ⁵² <i>Spine</i> , 2010	Systematic review addressing role of 14 articles discussing the role of surgery for odontoid fracture in the elderly	III	Morbidity is increased but acceptable in the elderly.
Nourbakhsh et al, ²⁰ <i>Journal of Neurosurgery: Spine</i> , 2009	Meta-analysis of the role of surgery in type II odontoid fractures	III	Operative treatment increases fusion rate and is recommended in older patients, posterior displacement, and displacement > 4 mm.
Omeis et al, ⁵⁷ <i>Journal of Spinal Disorders and Techniques</i> , 2009	Retrospective review of 24 type II odontoid fractures treated surgically	III	Nonoperative management equally effective with anterior displacement of the fracture and younger patients. Odontoid fractures in the elderly can be treated surgically with acceptable morbidity and mortality.
Collins and Min, ⁸² <i>Journal of Trauma</i> , 2008	Retrospective review of 15 elderly patients with type IIB (Grauer) odontoid fractures	III	The majority return to their preinjury levels of activity. Fusion rate was 77%.
Kim et al, ¹⁸ <i>Spine Journal</i> , 2008	Prospective cohort study of 20 patients with type II odontoid fractures to identify radiographic indicators of potential failure of immobilization	III	The results of anterior odontoid screw fixation in the elderly are satisfactory. Fracture angulation between supine and upright lateral x-ray films \geq 5° associated with failure of external immobilization.
Koech et al, ⁵³ <i>Spine</i> , 2008	Retrospective review of 42 elderly patients with type II odontoid fracture managed nonoperatively	III	Class III because there are no comparative treatment groups. No difference in outcome between fusion and stable fibrous union.
Shears and Armitstead, ¹⁵ <i>Cochrane Database System Review</i> , 2008	Cochrane Review of odontoid fracture management; no studies fitting criteria identified	III	Fibrous union may be an adequate outcome in the elderly. Appropriately designed clinical trials are recommended.
Smith et al, ³³ <i>Orthopedics</i> , 2008	Retrospective review of type II odontoid fracture management trends over a 20-y period	III	The rate of surgical intervention increased during the study period.
Chi et al, ³⁸ <i>European Spine Journal</i> , 2007	Retrospective review of 10 patients treated with percutaneous anterior odontoid screw fixation	III	Fusion rate 90%. Percutaneous screw fixation for odontoid fracture is effective.

(Continues)

TABLE 2. Continued

Reference	Description of Study	Evidence Class	Conclusions
Frangen et al, ⁵⁸ <i>Journal of Trauma</i> , 2007	Retrospective review of 27 patients with isolated unstable type II odontoid fractures	III	Posterior surgical stabilization and fusion was superior to halo-vest immobilization.
Platzer et al, ¹⁶ <i>Neurosurgery</i> , 2007	Retrospective comparative study of risk factors in 90 patients with type II odontoid fractures treated nonoperatively	III	Risk factors for failure of external immobilization include age and displacement > 2 mm, loss of reduction, and delay in treatment. Nonoperative management was successful. Class III because there is no comparative treatment group.
Platzer et al, ⁵⁰ <i>Spine</i> , 2007	Retrospective review of 110 patients with Type II odontoid fractures treated with anterior screw fixation.	III	Fusion rate 93%. Anterior screw fixation is successful. Younger patients have higher fusion rates.
Song et al, ³⁹ <i>Journal of Clinical Neuroscience</i> , 2007	Retrospective review of 16 patients with odontoid fractures using single anterior screw fixation	III	Fusion rate was 94%. No major complications. Single screw fixation was successful.
Bhanot et al, ³⁷ <i>Journal of Surgical Orthopaedic Advances</i> , 2006	Retrospective review of 17 patients with type II odontoid fractures treated with anterior screw fixation	III	Fusion rate was 94%. Anterior odontoid screw fixation is safe and effective and maintains motion.
Moon et al, ³⁴ <i>Bulletin of the Hospital for Joint Diseases Orthopaedic Institute</i> , 2006	Retrospective review of 32 odontoid fractures treated with anterior screw fixation	III	Fusion rate was 100%. No complications. No difference between 1 and 2 screws. Anterior odontoid screw fixation is safe and effective and maintains motion.
Tashjian et al, ⁵⁵ <i>Journal of Trauma</i> , 2006	Retrospective review of type II (n = 50) or III odontoid fractures (n = 17) or combined (C1/C2) (n = 11)	III	Odontoid fractures are associated with significant morbidity and mortality in the elderly and appear worse with the use of a halo device.
Fountas et al, ³⁵ <i>Spine</i> , 2005	Retrospective review of 32 patients with type II and "shallow" type III odontoid fractures with anterior screw fixation	III	Anterior odontoid screw fixation safe with high stability and low mechanical failure rates after long-term follow-up.
Grauer et al, ⁴ <i>Spine Journal</i> , 2005	Proposal of a modified classification system for odontoid fractures	III	κ Value was 0.48. Downgraded to Class III because no validation group.
Kontautas et al, ¹⁹ <i>Medicina</i> , 2005	Prospective comparative study of outcomes with different amounts of displacement of 37 patients with type II odontoid fractures treated with traction followed by halo	III	Displacement of > 5.0 mm is associated with an increased rate of failure with external immobilization. Class II because it does not have a comparative treatment group.
Majercik et al, ⁵⁴ <i>Journal of Trauma</i> , 2005	Retrospective review of nonoperative management in odontoid fracture with respect to age	III	Age > 65 y is associated with a significant increase in failure rate of external immobilization.

(Continues)

TABLE 2. Continued

Reference	Description of Study	Evidence Class	Conclusions
Lee et al, ³⁶ <i>Journal of Clinical Neuroscience</i> , 2004	Retrospective review of 48 patients with type II and III odontoid fractures treated with single odontoid screw fixation	III	Fusion rate was 96%. Complication rate of 10% (malposition rate, 6%; nonunion rate, 4%). Sagittally oblique type II fractures had an increased rate of fusion failure.
Börm et al, ⁴⁸ <i>Neurosurgery</i> , 2003	Retrospective review of 27 patients with type II odontoid fractures treated with anterior odontoid double-screw fixation with respect to age	III	Outcome after anterior odontoid screw fixation is not affected by patient age. The authors describe this as a case-control trial. Classified as Class III for treatment because there is no comparative treatment group.
Komadina et al, ²³ <i>Archives of Orthopaedic and Trauma Surgery</i> , 2003	Retrospective review of 14 type II and III odontoid fractures treated with halo immobilization	III	Radiographic fusion rate was 85.7%.
Müller et al, ²¹ <i>European Spine Journal</i> , 2003	Retrospective review of 26 type II and III minimally displaced odontoid fractures treated with nonrigid immobilization	III	External immobilization was successful. Minimally displaced type II and III fractures of the odontoid can be successfully treated with nonrigid immobilization.
Andersson et al, ²⁶ <i>European Spine Journal</i> , 2000	Retrospective review of 29 patients with odontoid fractures > 65 y of age managed with posterior fusion, anterior odontoid fixation, or immobilization	III	Posterior fusion was most successful.
Apfelbaum et al, ³² <i>Journal of Neurosurgery</i> , 2000	Retrospective review of 147 odontoid fractures; 2-institution experience with anterior odontoid screw fixation	III	Fusion rate up to 88%. Fractures oriented in the horizontal or posterior oblique planes had best fusion rates.
Dai et al, ²⁸ <i>European Spine Journal</i> , 2000	Retrospective review of 57 cases of failed management for odontoid fracture	III	Both occipitocervical fusion and atlantoaxial fusion used with success.
Lennarson et al, ¹⁷ <i>Spine</i> , 2000	Case-control study of 33 patients with isolated type II odontoid fracture treated with halo vest immobilization; cases defined as nonunions in halo and controls defined as unions	II	Patients \geq 50 y of age had a risk for failure 21 times higher than for those < 50 y of age.
Julien et al, ⁷ <i>Neurosurgery Focus</i> , 2000	Systematic review of odontoid fracture management	III	Type I and III odontoid fractures can be managed initially with external immobilization. Type II fractures can be managed initially with external immobilization or surgery.
Müller et al, ⁸³ <i>European Spine Journal</i> , 2000	Retrospective review of 28 cases of anterior screw fixation for odontoid fracture	III	Procedure is technically demanding.
Campanelli et al, ²⁵ <i>Surgical Neurology</i> , 2000	Retrospective review of 7 patients with displaced type II odontoid treated with posterior transarticular screw fixation	III	Fusion rate 86%.
Müller et al, ⁴⁵ <i>European Spine Journal</i> , 1999	Retrospective review of 23 patients > 70 y of age with odontoid fractures	III	One vertebral artery injury. Elderly patients are at high risk for morbidity and mortality.

(Continues)

TABLE 2. Continued

Reference	Description of Study	Evidence Class	Conclusions
Morandi et al, ²⁹ <i>Surgical Neurology</i> , 1999	Retrospective review of 17 cases of anterior odontoid screw fixation	III	Fusion rate was 94%. Anterior fixation based on the orientation of the fracture line.
Subach et al, ³⁰ <i>Neurosurgery</i> , 1999	Retrospective review of 26 patients (mean age, 35 y) with type II fractures treated with anterior odontoid screw fixation (single screw)	III	Fusion rate was 96%.
Seybold and Bayley, ⁴⁷ <i>Spine</i> , 1998	Retrospective review of 37 type II and 20 type III odontoid fractures divided into age groups: < 60 and > 60 y	III	Fusion rates did not differ significantly between the 2 groups.
Müller et al, ⁸⁴ <i>Unfallchirurgie</i> , 1998	Retrospective review of 10 cases of nonunion pseudoarthrosis after immobilization for type II odontoid fractures	III	Elderly patients had a decreased tolerance for halo immobilization. The authors favor surgical fixation.
Jenkins et al, ³¹ <i>Journal of Neurosurgery</i> , 1998	Retrospective review of 42 patients with type II odontoid fractures treated with anterior screw fixation comparing 1 and 2 screws	III	No difference in fusion rate with 1 vs 2 screws.
Berlemann and Schwarzenbach, ⁴⁴ <i>Acta Orthopaedica Scandinavica</i> , 1997	Retrospective review of 19 patients with type II odontoid fractures > 65 y of age treated with anterior odontoid screw fixation	III	Fusion rate was 84%.
Traynelis, ⁶ <i>Clinical Neurosurgery</i> , 1997	Systematic review of type II odontoid fractures	III	Anterior fixation was successful. First evidence-based report on odontoid fracture management. Four treatment options for type II odontoid fractures: traction followed by immobilization, immobilization with halo or Minerva, posterior cervical fusion, or anterior screw fixation. Higher fusion rate reported with anterior screw fixation might be offset by its higher complication rate and learning curve.
Greene et al, ¹¹ <i>Spine</i> , 1997	Retrospective review of 340 cases of axis fractures, including 199 odontoid fractures	III	The highest nonunion rate was observed in type II odontoid displaced ≥ 6 mm. Surgery recommended for instability despite external immobilization, transverse ligament disruption, or type II odontoid fracture with > 6-mm displacement.
Polin et al, ⁹ <i>Neurosurgery</i> , 1996	Retrospective review of 36 type II fractures treated with halo or collar	III	Lower rate of fusion with collar.
Chiba et al, ⁸ <i>Journal of Spinal Disorders</i> , 1996	Retrospective review of 104 patients with odontoid fractures:	III	Type I fractures can generally be managed nonoperatively.
	Type I, 2 patients		Anterior screw fixation recommended for most type II and unstable type III fractures. Type III fractures can be treated with halo immobilization or anterior screw fixation.
	Type II, 62 patients		Established nonunions and irreducible fractures should be treated with posterior fusion.
	Type III, 32 patients		
Bednar et al, ⁴³ <i>Journal of Spinal Disorders</i> , 1995	Prospective cohort study of 11 geriatric patients with odontoid fractures treated with surgical stabilization	III	Mortality can be reduced by surgical intervention and avoiding the use of halo immobilization.

(Continues)

TABLE 2. Continued

Reference	Description of Study	Evidence Class	Conclusions
Dickman et al, ⁸⁵ <i>Journal of Neurosurgery</i> , 1995	Retrospective review of 16 cases of atlantoaxial instability undergoing salvage surgical management including 2 type II odontoid fractures	III	Class III because there is no comparative group. Failed fusion can be successfully salvaged with a secondary procedure.
Hanigan et al, ⁴¹ <i>Journal of Neurosurgery</i> , 1993	Retrospective review of 19 patients > 80 y of age with odontoid fractures	III	Displacement > 5 mm required posterior surgical fixation with good results. The mortality rate in the conservative treatment group was 27%.
Ryan and Taylor, ⁴² <i>Journal of Spinal Disorders</i> , 1993	Retrospective review of 30 patients with type II fractures > 60 y of age	III	Patients treated with surgery had a higher fusion rate.
Hadley et al, ³ <i>Neurosurgery</i> , 1988	Retrospective review of 62 patients with type II odontoid fractures, including 3 with comminution at the base	III	Type IIA odontoid fracture defined as a type II with comminution at the base of the dens with a high risk of nonunion with external immobilization.
Govender and Charles, ⁶⁴ <i>Injury</i> , 1988	Retrospective review of 41 patients with type II and III odontoid fractures treated with a rigid collar or halo	III	Fusion rate for type II was 73% and for type III was 100%.
Fujii et al, ⁸⁶ <i>Spine</i> , 1987	Retrospective review of 52 patients with odontoid fractures treated with immobilization or surgery	III	External immobilization was successful. Both immobilization and surgery were successful, although the fusion rate was lowest for type II fractures treated with immobilization.
Lind et al, ¹⁴ <i>Spine</i> , 1987	Retrospective review of 14 patients with odontoid fractures treated with halo immobilization	III	Fusion rate was 91%.
Dunn and Seljeskog, ¹² <i>Neurosurgery</i> , 1986	Retrospective review of 74 patients with odontoid fractures treated primarily with rigid bracing	III	External immobilization was successful. Fusion rate was 68%.
Clark and White, ⁵ <i>Journal of Bone and Joint Surgery: American Volume</i> , 1985	Retrospective review of multicenter data including 144 patients managed by 27 different surgeons	III	Immobilization in a cervical collar resulted in a reasonable rate of fusion. Surgical management, either anterior or posterior, had the highest rate of fusion, approaching 100%.
Pepin et al, ⁴⁰ <i>Clinical Orthopaedics and Related Research</i> , 1985	Retrospective review of 41 patients with odontoid fractures including 26 treated conservatively with tongs, 4-poster brace, collars, and/or halo vests	III	Fusion rate with halo for type II fractures was 46%.
Wang et al, ¹⁰ <i>Spine</i> , 1984	Retrospective review of 25 patients with odontoid fractures treated with a variety of cervical immobilization techniques	III	Fusion rate with surgery was 100%. Immobilization was poorly tolerated in patients > 75 y of age. Fusion rate for type II fractures treated with a collar only was 57% and 80% with a halo.
Böhler, ⁸⁷ <i>Surgery Annual</i> , 1982	Retrospective review of 15 patients with odontoid fractures treated with anterior screw fixation	III	Fusion rate was 100%.
Maiman and Larson, ²⁴ <i>Neurosurgery</i> , 1982	Retrospective review of 49 cases of odontoid fracture, including 34 type II fractures treated with posterior wire/graft stabilization	III	Anterior surgery was successful. Fusion rate of 35% is lowest reported.

(Continues)

TABLE 2. Continued

Reference	Description of Study	Evidence Class	Conclusions
Ryan and Taylor, ⁹⁶ <i>J Bone Joint Surg Br</i> , 1982	Retrospective review of 23 patients with odontoid fractures treated nonoperatively	III	Fusion rate for type I and III was 100% and for type II was 60%. External immobilization was successful.
Ekong et al, ¹³ <i>Neurosurgery</i> , 1981	Retrospective review of 22 cases of odontoid fracture treated nonoperatively	III	Fusion rate for type II was 50% and for type III was 80%. External immobilization was successful.
Marar and Tay, ⁸⁸ <i>Australian and New Zealand Journal of Surgery</i> , 1976	Retrospective review of 26 cases of odontoid fractures treated with traction	III	Fusion rate for type II 37.5% and for type III was 100%.
Anderson and D'Alonzo, ² <i>Journal of Bone and Joint Surgery: American Volume</i> , 1974	Retrospective review of 49 patients with odontoid fractures managed nonoperatively and operatively	III	Fusion rates were higher in the operative patients.

Treatment

The initial management of Hangman fractures has typically been nonsurgical, and high success rates have been reported. Early surgical stabilization and fusion of Hangman fractures have been reserved for situations of severe C2-C3 instability. The series described by Effendi et al,⁵⁹ Francis et al,⁶⁰ and Greene et al¹¹ reported that the majority of patients with Hangman fractures were effectively treated with external immobilization. These authors recommended that surgical internal fixation and fusion be reserved for Effendi type III fractures and for nonunion of other Hangman fractures after 3 months of halo immobilization.

In the Levine and Edwards⁶¹ series of 52 patients with Hangman fractures, all isolated Effendi type I, II, and IIa injuries were successfully managed nonoperatively (n = 47 combined). Three of the 5 type III injury patients (60%) required surgical stabilization for failure to obtain or to maintain fracture reduction with a halo orthosis.

The Francis et al⁶⁰ series of 123 patients with Hangman fractures, from which their classification scheme was developed, reported that nonoperative management (traction followed by conversion to halo fixation) was successful in 95% of patients (116 of 123). Three of 9 grade II injury patients (33%) and 2 of 7 grade V injury patients (28%) developed nonunion despite halo management and required subsequent surgical treatment. Greene et al¹¹ successfully treated 65 of 74 patients (87%) with Hangman fractures nonoperatively with external immobilization for a median of 12 weeks. Of patients with either Effendi type II or III injuries, 7 (33%) required early surgical treatment because of failure of external immobilization. The authors concurred with Effendi et al and Francis et al that conservative management (external immobilization) should be the initial treatment in virtually every patient with a Hangman fracture. They concluded that early surgical management of Hangman fractures should be reserved for unstable injuries ineffectively immobilized in a halo device. Reports of smaller

case series have described 100% successful fracture union with halo immobilization (42 patients)⁶³ or cervical collar immobilization alone (39 and 8 patients^{64,65a}) regardless of C2-3 displacement or angulation. Class III medical evidence describing the nonoperative management for Hangman fractures is found in Table 3.

The current updated literature search on the management of Hangman fractures identified additional Class III medical evidence in support of initial nonoperative management for these injuries. To be fair, halo immobilization does not always achieve or maintain fracture reduction, as evidenced by the occasional need for surgical fixation in the larger series reported previously.^{11,59,60} Halo immobilization is associated with a number of known complications, including but not limited to pin loosening, infection, cranial fracture, pressure sores, poor patient compliance, pulmonary issues, pneumonia, and restricted patient mobility.⁵⁴ Although treatment over and above fracture immobilization may not be necessary, there may be significant management advantages in avoiding the potential complications associated with halo vest use by performing early surgery to stabilize and fuse the C2-C3 vertebral segments.

In their review of axis fractures, Suchomel and Hradil^{65b} presented their argument in favor of early surgical fixation: "A fracture-dislocation of the C3/4 level in an otherwise healthy person would be treated by anterior surgery and fusion today. It becomes very hard to find a reasonable argument against the use of the same principle for C2/3 intervertebral space."

Li et al^{65a} in 2006 performed a systematic review to address the issue of the operative vs the nonoperative management of Hangman fractures. The authors indicated that the classification scheme by Effendi et al as modified by Levine and Edwards was preferred. Thirty-one of the 32 articles they included in their review (97%) advocated nonsurgical management for Hangman fractures. The authors summarized the literature and made the following recommendations for the treatment of Hangman fractures:

TABLE 3. Evidentiary Table: Axis Fractures: Traumatic Spondylolisthesis of the Axis (Hangman Fracture)

Reference	Description of Study	Evidence Class	Conclusions
ElMiligui et al, ⁷³ <i>European Spine Journal</i> , 2010	Prospective multicenter study (n = 15) of consecutive patients with displaced type II (Effendi) traumatic spondylolisthesis of the axis treated with direct transpedicular screw fixation	III	Fusion rate was 100% with no limitation in range of motion.
			Transpedicular screw fixation through the C2 pedicles is safe and effective.
			Class III because there is no comparative group.
Xu et al, ⁷¹ <i>International Orthopaedics</i> , 2010	Retrospective review of 28 patients with Hangman fracture treated with anterior discectomy and fusion	III	Fusion rate 100%.
			No complications.
			Anterior discectomy can be used successfully in the treatment of unstable Hangman fracture.
Dalbayrak et al, ⁷⁴ <i>Turkish Neurosurgery</i> , 2009	Retrospective review of 4 patients with Hangman fracture type II (Levine Edwards) treated with direct C2 pars fixation	III	Successful fusion 100%.
			Screw fixation through the pars is safe and effective.
Ying et al, ⁷² <i>Spine</i> , 2008	Retrospective review of 30 patients with Hangman fractures treated with anterior cervical discectomy and fusion	III	Fusion rate was 100%.
			Anterior cervical discectomy at C2-C3 can be used successfully for unstable Hangman fracture.
Li et al, ^{65a} <i>European Spine Journal</i> , 2006	Systematic review to address operative vs nonoperative management of Hangman fracture	III	The classification system proposed by Effendi et al and modified by Levine and Edwards provided a clinically reasonable guideline for successful management of Hangman fractures.
	32 relevant articles included.		Class III because all included studies were Class III.
Watanabe et al, ⁶⁶ <i>Journal of Spinal Disorders and Techniques</i> , 2005	Retrospective review of 9 patients with Hangman fracture treated nonoperatively	III	Angulation was associated with poorer healing.
Boullousa et al, ⁷⁵ <i>Arquivos de Neuro-Psiquiatria</i> , 2004	Retrospective review of 10 patients with Hangman fracture not candidates for halo placement treated with transpedicular C2 fixation	III	Fusion rate was 100%.
			Transpedicular C2 fixation can be used successfully in cases when halo placement is not an option.
Vaccaro et al, ⁶⁸ <i>Spine</i> , 2002	Retrospective review of 31 patients with Hangman fracture treated with traction reduction and early halo immobilization	III	Traction reduction and early halo immobilization are an effective treatment for Hangman fractures.
			Angulation of 12° appears to have a higher risk of failure.
Moon et al, ³⁴ <i>Bulletin of the Hospital for Joint Diseases Orthopaedic Institute</i> , 2001	Retrospective review of 42 patients with Hangman fracture	III	Fusion 100%.

(Continues)

TABLE 3. Continued

Reference	Description of Study	Evidence Class	Conclusions
	Stable fractures were treated nonoperatively (n = 20), unstable fractures were treated surgically (n = 22)		No reported complications.
			Stable Hangman fracture can be successfully treated with reduction and external immobilization.
			Unstable Hangman fracture can be successfully treated with surgical stabilization.
Barros et al, ⁸⁹ <i>Spinal Cord</i> , 1999	Case report of surgical fixation in Hangman fracture	III	Surgical treatment for Hangman fracture is an option.
Verheggen and Jansen, ⁹⁰ <i>Surgical Neurology</i> , 1998	Retrospective study of 16 patients treated with early posterior screw fixation of the neural arch following Hangman fracture	III	Posterior stabilization and fusion is effective for Edwards and Levine (Effendi) type II and III fractures.
Greene et al, ¹¹ <i>Spine</i> , 1997	Retrospective review of 72 patients with traumatic spondylolisthesis of the axis	III	Immobilization is generally sufficient treatment.
			Surgery may be considered for severe Francis- or Effendi-type Hangman fractures.
Corric, ⁹⁷ <i>Journal of Neurosurgery</i> , 1996	Retrospective review of 39 patients with nondisplaced Hangman fracture including nondisplaced treated with nonrigid immobilization	III	Fusion rate 100%.
			Nonrigid immobilization successful.
Starr, ⁹⁸ <i>Spine</i> , 1993	Retrospective review of 19 cases of axis fracture including 6 cases of a pattern occurring through the posterior aspect of the vertebral body continuity of the posterior cortex with subluxation	III	Neurological deficit is uncommon and occurs primarily with subluxation.
Tan, ⁹⁹ <i>Paraplegia</i> , 1992	Retrospective review of 33 patients with Hangman fracture	III	Normal neurologic examination at admission in 77%.
			Complete recovery in 85% at 1 year. Neurologic deficit is uncommon and long-term outcome is good.
Torreman, ¹⁰⁰ <i>Nederlands Tijdschrift Voor Geneeskunde</i> , 1990	Retrospective review of 23 patients with Hangman fractures treated with immobilization with long term follow-up	III	Fusion rate was 100%.
			Nonoperative management was successful.
Govendor, ¹⁰¹ <i>Injury</i> , 1987	Prospective study of 39 patients with Hangman fracture	III	Nonoperative management was successful.
Grady, ¹⁰² <i>Neurosurgery</i> , 1986	Retrospective review of 27 patients including 16 managed with halo, 8 with a collar, and 3 with bed rest	III	Nonoperative management was successful.
Levine and Edwards, ⁶¹ <i>Journal of Bone and Joint Surgery: American Volume</i> , 1985	Retrospective review of 52 patients with traumatic spondylolisthesis of the axis; this study updates the Effendi classification by adding the type IIA fracture	III	Nonoperative management was successful for nondisplaced fractures.
			Surgery was successful for Effendi type II, and III fractures and for Levine and Edwards type IIA fractures.
Borne et al, ⁷⁰ <i>Journal of Neurosurgery</i> , 1984	Retrospective review of 18 cases of "pedicle" fracture of the axis treated with direct internal fixation	III	Aggressive surgical approach for fixation of pedicle-isthmus fractures of the axis resulted in 100% fusion rate.

(Continues)

TABLE 3. Continued

Reference	Description of Study	Evidence Class	Conclusions
Francis et al, ⁶⁰ <i>Journal of Bone and Joint Surgery: British Volume</i> , 1981	Retrospective review of 123 Hangman fractures	III	A classification is described based on the amount of C2-3 displacement and angulation.
Pepin and Hawkins, ⁶³ <i>Clinical Orthopaedics and Related Research</i> , 1981	Retrospective review of 42 Hangman fractures	III	Defines a classification scheme for Hangman fracture based on displacement of posterior elements.
Effendi et al, ⁵⁹ <i>Journal of Bone and Joint Surgery: British Volume</i> , 1981	Retrospective review of 131 Hangman fractures	III	Defines the most popular classification system based on mechanism of injury, displacement, and stability.
			Nonoperative management is successful in the majority of cases.
Brashear, ¹⁰³ <i>Journal of Bone and Joint Surgery: American Volume</i> , 1975	Retrospective review of 29 Hangman fractures	III	No case of neurologic deficit.
			Nonoperative management was successful.

- Levine-Edwards type I and II injuries: nonrigid external fixation was sufficient.
- Effendi type I and II and Levine-Edwards type II fractures: traction followed by external immobilization.
- Levine-Edwards type IIa and III and Effendi type III fractures (significant dislocation): rigid immobilization; consider surgical fixation and fusion.

Watanabe et al⁶⁶ reported 9 patients with Hangman fractures treated with halo immobilization. They observed that those patients with angulation and C2-3 translation caused by fracture of the inferior C2 facet joint had a worse outcome and should be considered for surgical fixation and fusion rather than halo immobilization.

In 2001, Moon et al⁶⁷ described a series of 42 patients with Hangman fractures. Patients without displacement or angulation were considered stable ($n = 20$) and were treated with traction followed by a cervical orthosis with 100% fusion success. Patients with C2-3 angulation or displacement with ligamentous disruption were considered unstable and were treated with anterior C2-3 interbody fusion. They described a 100% fusion rate and reported no complications.

Vaccaro et al⁶⁸ described their experience with early halo immobilization in a series of 31 patients with Hangman fractures (type II, $n = 27$; type IIA, $n = 4$). All the type IIA patients achieved bony union and 21 of 27 of the patients with type II injuries (78%) achieved successful union. Six patients with type II injuries (22%) failed initial attempts at closed reduction/immobilization and had to be replaced in traction, which was followed by surgical fixation and fusion. All 6 patients (100%) had an initial fracture angulation of 12° or greater.

A number of investigators have advocated early surgical intervention for patients with more severe Hangman fracture injuries, particularly those patients with significant displacement

and angulation at the C2-C3 level. The reported advantages of surgical treatment include improved fracture alignment, reduction in hospitalization and treatment times, faster patient mobilization, and potentially an improved quality of life. Surgical options for unstable Hangman fracture injuries, particularly those that fail to heal despite external immobilization, include anterior C2-3 interbody fusion,⁵⁹ dorsal C1-C3 fusion procedures,⁶⁹ direct pars fixation,⁷⁰ or combinations of these approaches. Class III medical evidence addressing surgery for Hangman fractures is found in Table 3.

Anterior surgical approaches to C2-C3 have the advantage of being safe and familiar to surgeons. Xu et al⁷¹ retrospectively reviewed their series of 28 patients with Effendi type II and III Hangman fractures treated with C2-3 anterior discectomy and fusion. Fusion was obtained in 100% of cases, and complete recovery was reported. Ying et al⁷² reported 30 patients with Effendi type II and III Hangman fractures treated with anterior cervical discectomy and fusion. They described 100% fusion success at 6 months with 1 transient complication (dysphagia).

Posterior surgical approaches have the advantage of allowing direct access to the C2-3 facets for reduction (Effendi type III). The additional muscle dissection required with this approach may be a disadvantage for patients with less severe Hangman injuries. A posterior approach for reduction and stabilization coupled with anterior C2-3 fusion has been reported for severe C2-3 instability. Direct pars fixation has been described as an alternative for Hangman fractures with limited disk and ligamentous injury but may be the most technically challenging procedure. As with any posterior C2 screw fixation technique, there is concern for vertebral artery injury. ElMiligui et al⁷³ described their operative experience with 15 type II Hangman fractures treated with transpedicular screw fixation. They reported a fusion rate of 100% with minimal complications

TABLE 4. Evidentiary Table: Axis Fractures: Fractures of the Axis Body (Miscellaneous Fractures)

Reference	Description of Study	Evidence Class	Conclusions
Ding et al, ⁷⁷ <i>Spine</i> , 2010	Retrospective review of C2 fractures (n = 100), 18 (17.8%) with vertebral artery injury	III	No correlation between C2 fracture type and vertebral artery injury.
Aydin and Cokluk, <i>Turkish Neurosurgery</i> , ⁷⁸ 2007	Case report of C2 unilateral pars interarticularis fracture treated with cervical collar	III	Vertebral artery injury correlated with comminution fracture ($P = .03$) fragment(s) in foramen transversarium ($P = .008$). Nonoperative treatment was successful.
German et al, ⁷⁹ <i>Neurosurgery</i> , 2005	Retrospective review of 21 vertical axis fractures	III	Nonoperative treatment was successful.
Korres et al, ⁸⁰ <i>Spine</i> , 2005	Retrospective review of 674 cervical fractures	III	Incidence of horizontal (Chance-type) fractures of the axis, 2/674 (0.05%). Nonoperative treatment was successful.
Korres et al, ⁸¹ <i>Orthopedics</i> , 2004 ⁷⁷	Retrospective review of 674 cervical fractures	III	Incidence of multiple fractures involving the axis was 9/674 (1%). Nonoperative treatment was successful.
Greene et al, ¹¹ <i>Spine</i> , 1997	Retrospective review of 61 miscellaneous C2 fractures	III	Nonoperative treatment was successful in 98%.
Fujimura et al, ⁹¹ <i>Journal of Orthopaedic Trauma</i> , 1996	Retrospective report of 31 C2 fractures categorized with radiographic imaging	III	4 Types: avulsion (9/9 fused with immobilization), transverse (2/2 healed with immobilization), burst (2/3 treated with C2-3 fusion), and sagittal fractures (15/17 healed with immobilization).
Benzel et al, ⁷⁶ <i>Journal of Neurosurgery</i> , 1994	Retrospective report of 15 patients described with fractures of the axis body	III	Classified into type 1, (coronal) most common; type 2 (sagittal); type 3 (oblique); and type 3, equivalent to the type III odontoid fracture.
Korres et al, ⁹² <i>European Spine Journal</i> , 1994	Retrospective review of 14 cases of avulsion fracture of the anterior inferior portion of the axis	III	Nonoperative treatment was successful.
Bohay et al, ⁹³ <i>Journal of Orthopaedic Trauma</i> , 1992	Retrospective review of 3 cases of vertical fractures of the axis	III	Nonoperative treatment was successful.
Craig and Hodgson, ⁹⁴ <i>Spine</i> , 1991	Retrospective review of 9 cases of superior facet fracture of the axis vertebra	III	Nonoperative treatment was successful in 5 patients but 3 patients required open reduction and posterior fusion.
Burke and Harris, ⁶² <i>Skeletal Radiology</i> , 1989	Retrospective review 31 miscellaneous C2 body fractures	III	Nonoperative treatment was successful.
Jakim and Sweet, ⁹⁵ <i>Journal of Bone and Joint Surgery: British Volume</i> , 1988	Case report of a transverse fracture of the axis	III	Nonoperative treatment was successful.

and preservation of postoperative range of motion. In 2009, Dalbayrak et al⁷⁴ described 4 patients with Levine-Edwards type II Hangman fractures treated with C2 pars fixation. All 4 patients had successful union. Boullosa et al⁷⁵ reported 10 Hangman fracture patients successfully treated with transpedicular C2 fixation in whom external immobilization had failed or a halo device was contraindicated. They described a 100% fusion success rate. Ninety percent of their patients experienced complete resolution of symptoms.

Fractures of the Axis Body

The treatment of miscellaneous fractures of the axis body remains challenging because of their diversity and relative infrequency. The

majority of clinical reports cited in the literature describe successful fracture union with nonoperative techniques. The most comprehensive attempt at classifying these fractures remains the report of Benzel et al.⁷⁶ They characterized C2 body fractures into 3 anatomical subtypes: type I, coronal; type II, sagittal; and type III, transverse. The Greene et al¹¹ series included 61 patients with miscellaneous axis fractures. Ninety-nine percent were treated successfully with nonoperative techniques. Only 1 patient with a miscellaneous axis fracture required surgical intervention for delayed nonunion. Class III medical evidence studies on the treatment of miscellaneous fractures of the axis described in the previous guideline on this subject are compiled in Table 4. Of the 119 patients included in these reports, 117 were successfully

treated nonoperatively (99%). The present updated review of this topic identified 5 additional citations. All provide Class III medical evidence and are summarized in Table 4.

In 2010, Ding et al⁷⁷ published a retrospective review of 102 patients with axis fractures of all types and found that comminuted fractures of any type with fragments of bone within the foramen transversarium were associated with an increased risk of vertebral artery injury. Many miscellaneous axis fractures involve the transverse foramen; therefore, a high level of suspicion for potential vertebral artery injury should be maintained when these patients are evaluated. Aydin and Cokluk⁷⁸ described an axis pars interarticularis fracture that they successfully treated with a cervical collar. German et al⁷⁹ described their series of 21 patients with vertical C2 body fractures. Sixteen were coronally oriented type I vertical C2 body fractures, and 5 were sagittally oriented type II C2 body fractures. Three patients died of associated injuries. All 18 surviving patients (100%) were successfully treated nonoperatively. Korres et al⁸⁰ reported 2 separate observations after review of their database of 674 cervical fractures. The first⁸⁰ described the incidence of horizontal (Chance-type) fractures of the atlas, identified in 2 of 674 injuries that they managed (0.05%). Both were treated nonsurgically with success at the long-term follow-up. The second observation⁸¹ described the occurrence of multiple fractures of the atlas, an injury that occurred in 9 of their 674 patients (1%). The most common multiple fracture patterns were a teardrop fracture of the axis body associated with a traumatic spondylolisthesis or the combination of a traumatic spondylolisthesis of the axis with an odontoid fracture. The authors recommended computed tomography as the imaging modality of choice for patients with C2 fractures.

SUMMARY

A summary of the recommendations for the acute management of axis fractures is provided in Table 1 and the data supporting the recommendations in this section are provided in Table 2.

Fractures of the Odontoid

There is no Class I medical evidence on the management of patients with acute traumatic odontoid fractures. Class II medical evidence exists indicating that the risk of nonunion of a type II odontoid fracture in patients ≥ 50 years of age is 21 times greater than the incidence of nonunion for younger patients with a similar type II odontoid fracture. Therefore, consideration of surgical stabilization and fusion for type II odontoid fractures in patients ≥ 50 years of age is recommended. Type I, II, and III odontoid fractures are often effectively managed with external cervical immobilization, with the understanding that the failure of external immobilization is significantly higher for type II odontoid fractures. Treatment of type II odontoid fractures with a cervical collar alone or traction followed by cervical collar immobilization may be undertaken but is associated with lower fracture union rates. Class III medical evidence indicates that factors associated with nonunion of type II fractures include age, fracture

displacement, secondary loss of reduction, and delays in treatment. Similarly, Class III medical evidence suggests that a change in angulation of the type II odontoid fracture of $\geq 5^\circ$ on lateral radiography taken at 2 weeks after immobilization in a halo device is associated with failure of fusion. Closed reduction of displaced type II odontoid fractures is associated with successful treatment with halo immobilization. Type II and III odontoid fractures should be considered for surgical fixation in patients with dens displacement of ≥ 5 mm, comminution of the odontoid fracture (type IIA), and/or inability to achieve or maintain fracture alignment with external immobilization. The treatment of isolated type I odontoid fractures with cervical immobilization is recommended, resulting in fusion rates approaching 100%. Anterior and posterior surgical fixation and fusion of type II and III odontoid fractures have been reported with fusion rates exceeding 90% with low morbidity. The management of odontoid fractures in elderly patients is associated with increased failure rates, and higher rates of morbidity and mortality irrespective of the treatment offered.

Traumatic Spondylolisthesis of the Axis

There is no Class I or Class II medical evidence in the literature addressing the management of traumatic spondylolisthesis of the axis. Class III medical evidence supports a variety of treatments for these injuries. The majority of Hangman fractures heal with 12 weeks of cervical immobilization with either a rigid cervical collar or a halo immobilization device. Surgical stabilization is an option in the treatment of Hangman fractures and is typically reserved for cases of severe angulation, disruption of the C2-3 disk space, or inability to establish or maintain fracture alignment with external immobilization.

Fractures of the Axis Body (Miscellaneous Axis Fractures)

There is no Class I or Class II medical evidence in the literature addressing the management of traumatic fractures of the axis body. Class III medical evidence supports the use of external immobilization as the initial treatment strategy for the variety of traumatic fractures of the C2 body.

KEY ISSUES FOR FUTURE INVESTIGATION

More data are necessary to determine the definitive management of odontoid fractures. For type I and III fractures, a well-designed multicenter case-control study could provide Class II medical evidence to define their appropriate management in the early postinjury period. For type II fractures, the literature suggests that both operative management and nonoperative management remain treatment options. A randomized analysis or a case-control study would be of benefit in establishing definitive treatment recommendations for this fracture type.

Traumatic spondylolisthesis of the axis and miscellaneous axis fractures are treated successfully with external immobilization in the majority of cases. A multicenter case-control study of patients

with these injury types would help to define optimal treatments for each specific fracture subtype.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Management of Acute Combination Fractures of the Atlas and Axis in Adults

Timothy C. Ryken, MD, MS*

Mark N. Hadley, MD‡

Bizhan Aarabi, MD, FRCSCS

Sanjay S. Dhall, MD¶

Daniel E. Gelb, MD||

R. John Hurlbert, MD, PhD,
FRCSC#

Curtis J. Rozzelle, MD**

Nicholas Theodore, MD‡‡

Beverly C. Walters, MD, MSc,
FRCSC‡§§

*Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa; ‡Division of Neurological Surgery and **Division of Neurological Surgery, Children's Hospital of Alabama, University of Alabama at Birmingham, Birmingham, Alabama; §Department of Neurosurgery and; ||Department of Orthopaedics, University of Maryland, Baltimore, Maryland; ¶Department of Neurosurgery, Emory University, Atlanta, Georgia; #Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada; ‡‡Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona; §§Department of Neurosciences, Inova Health System, Falls Church, Virginia

Correspondence:

Mark N. Hadley, MD, FACS,
UAB Division of Neurological Surgery,
510 – 20th St S, FOT 1030,
Birmingham, AL 35294-3410.
E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS

Level III:

The treatment of combination atlas-axis fractures based primarily on the specific characteristics of the axis fracture is recommended.

- External immobilization of most C1-C2 combination fractures is recommended.
- C1-type II odontoid combination fractures with an atlanto-dental ratio of ≥ 5 mm and C1-Hangman combination fractures with C2-C3 angulation of ≥ 11 should be considered for surgical stabilization and fusion.

RATIONALE

The unique anatomy and relationship of the atlas and axis vertebra result in a variety of fracture patterns in the setting of significant cervical trauma. Although each of these vertebral bodies is subjected to isolated fractures, combination fractures occur with sufficient frequency to warrant special consideration. Recommendations for the management of acute combination fractures of the atlas and axis were published by the guidelines author group of the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons in 2002.¹ The previous guideline was based on Class III medical evidence and recommended that management decisions for combination C1-C2 fractures be based on the fracture characteristics of the axis fracture. The purpose of the current review is to update the medical evidence on the management of acute combination fractures of the atlas and axis in adults.

SEARCH CRITERIA

A National Library of Medicine (PubMed) computerized literature search from 1966 to 2011

was undertaken using Medical Subject Headings in combination with “vertebral fracture”: “atlas,” “axis,” and “human.” This strategy yielded 202 references. The abstracts were reviewed, and articles focusing on clinical management and follow-up of combination fractures of the atlas and axis were selected for inclusion. The relative infrequency of these fractures, the small number of case series, and the numerous case reports with pertinent information required rather broad inclusion criteria. The bibliographies of the selected papers were reviewed to provide additional references.

These efforts resulted in 47 manuscripts describing the clinical features and the management of acute traumatic atlas and axis combination fractures and are summarized in Evidentiary Table format. All provide Class III medical evidence.

SCIENTIFIC FOUNDATION

The historic series of 46 atlas fractures described by Sir Geoffrey Jefferson² contained 19 fractures that were actually combination fractures of the atlas and the axis (Table 1). The incidence of concurrent atlas and odontoid fracture ranges from 5% to 53% in the literature, and the incidence of combination atlas and Hangman fractures ranges from 6% to 26%.

Gleizes et al³ compiled incidence data over a 14-year period on combination fracture injuries in the upper cervical spine. The authors concluded that combination fractures are relatively common and require a high level of surveillance to detect. They identified 784 cervical spine injuries, including 116 upper cervical spine injuries. Of these, 31 were combined C1-C2 fractures, representing 4% of the total. The most frequent C1-C2 fracture combinations included combined bipedicular fracture of the axis and

odontoid fracture, combined fracture of the posterior arch of C1 and odontoid fracture, combined Jefferson fracture with odontoid fracture, and C2 articular pillar fracture with odontoid fracture. The authors observed that 70% of atlas fractures, 30% of odontoid fractures, and 30% of C2 traumatic spondylolistheses (Hangman fractures) were involved in a combination fracture injury. It has been suggested that the likelihood of a neurological deficit is greater with combination fractures than with either atlas or axis fractures alone.⁴⁻⁶ Historically, combination fractures of C1 and C2 have been managed sequentially, as proposed by Levine and Edwards,⁷ allowing 1 fracture to heal (usually the atlas) before attempting definitive management of the axis injury.

In 1989, Dickman et al⁸ reported their experience with 25 cases of acute atlas-axis combination fractures from an overall series of 860 patients with acute cervical spinal fracture injuries (3%). They identified an incidence of neurological deficit of 12%. Four combination atlas-axis fracture types were identified: C1-type II odontoid (10 cases, 40%), C1-miscellaneous axis fracture (7 cases, 28%), C1-type III odontoid (5 cases, 20%) and C1-Hangman fracture (3 cases, 12%). Rigid immobilization was the initial management strategy in 20 of 25 of patients (84%) for a median duration of 12 weeks (range, 10-22 weeks). The reported fusion rate of was 95% (19 of 20). Five patients were treated surgically, and all achieved fusion (100%). Four were treated with early surgery based on an atlantoaxial interval of ≥ 6 mm, and 1 patient with an initial atlantoaxial interval of 5 mm failed halo treatment requiring posterior C1-C2 fusion. The authors recommend computed tomography in all patients with either a C1 or a C2 fracture to evaluate for a combination injury. They recommend that atlas fractures in combination with type II or III odontoid fractures with an atlantoaxial interval of ≥ 5 mm be considered for early surgical management.

Guiot and Fessler⁹ in 1999 described a series of 10 patients with combination atlas-axis fractures ultimately treated with surgical stabilization with anterior odontoid fixation. Five had failed a previous attempt at halo immobilization. There were 9 C1-type II odontoid fractures and 1 C1-type III odontoid combination fracture injury. There was 1 death unrelated to surgery. All surviving patients achieved fusion. The authors recommended that surgery be considered in patients with fractures that were irreducible or could not be maintained with external immobilization and for unstable fractures with a high likelihood of nonunion.

Treatment of Combination C1-Type II Odontoid Fractures

The treatment of specific C1-C2 fracture combinations has been the subject of numerous reports. Similar to the literature on isolated type II odontoid fracture management (see Management of Isolated Axis Fractures in Adults), the C1-type II odontoid fracture combination fracture injury has generated the most controversy. Options for management of C1-type II odontoid combination fractures include traction followed by immobiliza-

tion, semirigid immobilization (collar), rigid immobilization (halo, Minerva, sterno-occipital mandibular immobilizer), posterior C1-C2 fusion with and without instrumentation, and anterior odontoid screw fixation.

Several authors have described traction followed by semirigid immobilization as treatment for acute combination C1-C2 fractures.^{10,11} Esses et al¹² described the successful treatment of a C1-type II odontoid combination fracture managed in a cervical collar. The decreased union rate reported for type II odontoid fractures managed with nonrigid immobilization must be considered. The majority of reports of combination C1-C2 fractures have described treatment with rigid external immobilization, including the halo, sterno-occipital mandibular immobilizer, and Minerva devices.^{8,13-15,47,49} Dickman et al⁸ treated 6 patients with < 6 -mm atlanto-dens interval with halo immobilization and reported an 83% success rate (5 of 6). The single treatment failure had an atlantoaxial interval of 5 mm and underwent posterior C1-C2 fusion at 12 weeks after injury. Segal et al,¹⁴ Andersson et al,¹³ and Seybold and Bayley¹⁵ described a total of 7 additional cases of C1-type II odontoid combination fractures successfully treated with halo immobilization.

Three contemporary case series presenting conflicting arguments on the role of halo immobilization in the treatment of cervical spinal fracture injuries are summarized in Table 2.¹⁶⁻¹⁸ None of these citations contain exclusively C1-C2 combination fractures, thus limiting their use for specific recommendations. They are included to provide perspective on the role of halo immobilization in upper cervical spine fracture management. Longo et al¹⁷ conducted an extensive systematic review on halo vest management of cervical spine injuries. They identified 47 reports describing a total of 1078 patients with cervical spine fractures, including 50 patients with combination C1-C2 fracture injuries (4.6%). Although the specifics of outcome with this subgroup were not presented, the authors concluded after review that the management of upper cervical spine injuries, including combination fracture injuries, with halo immobilization is a safe and effective treatment option. Daentzer and Flörkemeier¹⁶ retrospectively reviewed 29 patients with upper cervical spine injuries treated in a halo vest. They divided the patients into 2 groups: patients < 65 years of age ($n = 18$) and patients ≥ 65 years of age ($n = 11$). The fracture subtypes were as follows: type II odontoid fracture (6 patients), type III odontoid fracture (6 patients), combination C1-C2 fractures (6 patients), and other subaxial cervical fractures (11 patients). The outcomes of interest were the clinical and radiological results, treatment complications, and rate of nonunion requiring surgery. Only 2 patients required surgery: 1 patient with an isolated type II odontoid fracture and 1 patient with a type II odontoid fracture in combination with a C1 arch fracture. Both were > 65 years of age. The clinical and radiological results were not statistically significantly different between the 2 patient groups. The incidence of complications and the time interval for fracture healing were greater in the older patient group but were not statistically significant.

TABLE 1. Initial Management of Combination Fractures of the Atlas and Axis in the Adult

Combination Fracture Type	Treatment Options
C1-type II odontoid fractures	
Stable	Collar, halo, surgical fixation/fusion
Unstable (atlanto-dental ratio ≥ 5 mm)	Halo, surgical fixation/fusion
C1-type III odontoid fractures	Collar, halo, surgical fixation/fusion
C1-Hangman fractures	
Stable	Collar, halo
Unstable (C2-C3 angulation $\geq 11^\circ$)	Halo, Surgical fixation/fusion
C1-miscellaneous C2 body fractures	Collar, halo

In a more focused study, Tashjian et al¹⁸ reviewed 78 patients > 65 years of with odontoid fractures: isolated type II (n = 50) or isolated type III odontoid fractures (n = 17) and combination C1-C2 odontoid fractures (n = 11) treated with halo immobilization. Treatment included collar (n = 27), halo (n = 34), and operative (n = 17) (4 operation plus halo). Combination fracture outcomes were not specifically described. There were 24 deaths (31%) during the initial hospitalization. Of those patients treated with a halo vest, 42% died compared with a 20% mortality rate among patients not treated in a halo device ($P = .03$). The incidence of major complications in the halo-treated group was 66% compared with 36% in the nonhalo group ($P = .003$). The authors concluded that odontoid fractures in the elderly are associated with significant morbidity and mortality and appear to be magnified with the use of a halo immobilization device.

C1-type II odontoid combination fractures considered to be unstable have been successfully managed with surgical stabilization and fusion. Techniques have included posterior C1-C2 fixation (with or without transarticular screws), anterior odontoid screw fixation, and occipitocervical fusion. Dickman et al,⁸ Andersson et al,¹³ Coyne et al,¹⁹ and Lee et al²⁰ treated a total of 8 patients with C1-type II odontoid combination fractures with early surgical fusion based on an atlantoaxial interval of ≥ 6 mm. Six patients had posterior C1-C2 fusion, and 1 patient underwent occipital-cervical fusion for multiple fractures of the posterior atlantal arch. Occipitocervical fixation has been used to treat C1-C2 combination fractures by other authors in cases of C1 posterior arch incompetence or gross C1-C2 instability.^{8,13} Guiot and Fessler⁹ described 2 patients with this combination injury pattern treated posteriorly with C1-C2 transarticular screw fixation and fusion. Multiple authors have reported anterior odontoid fixation with fusion rates exceeding 90%. Montesano et al,²¹ Berlemann and Schwabenbach,⁵⁵ Guiot and Fessler,⁹ Henry et al,²² and Apostolides et al²³ have reported a combined total of 25 patients with C1-C2 combination fractures treated successfully with anterior odontoid fixation. Cases reported by Guiot and Fessler⁹ and Apostolides

et al²³ describe the use of anterior transarticular fixation for combination C1-C2 fracture injuries.

More recently, Ben Aïicha et al²⁴ described the surgical management of 4 patients with combination fractures of the type II odontoid and C1 arch. Two patients were treated with posterior transarticular C1-2 fusion, 1 patient with occipitocervical fusion, and 1 patient with anterior odontoid screw fixation. The authors recommended that the management of patients with C1-C2 combination fracture injuries be based on the type of odontoid fracture and the presence of neurological injury.

Agrillo and Mastronardi²⁵ reported the successful use of triple anterior screws (odontoid and bilateral transarticular C1-C2) in the management of a combination C1 arch-type II odontoid fracture in a 92-year-old man. The authors concluded that in presence of a potentially unstable type II odontoid fracture with a fractured posterior atlas arch, triple anterior screw fixation is an option, even in the elderly.

Omeis et al²⁶ described their surgical series of 29 elderly patients with odontoid fractures (type II alone, n = 24; type II in combination with C1 fractures, n = 5) with a mean follow-up of 18 months postoperatively. Twenty-seven patients (93%) were neurologically intact, and 2 patients (7%) presented with a central cord syndrome. Anterior odontoid screw fixation was the treatment offered to 16 patients (55%). Fusion occurred in 6 patients (37.5%); stability occurred in 9 patients (56.2%); and 1 patient (6.3%) required subsequent posterior stabilization and fusion. Posterior fixation and fusion were the initial treatment in 13 patients (45%). Fusion occurred in 4 patients (30.7%), and stability was achieved in 9 patients (69%). The authors reported 1 death and 3 other perioperative complications (10%). Twenty-five of 29 patients (86%) reportedly returned to their previous level of activity. The authors concluded that odontoid fractures in the elderly can be treated surgically with acceptable morbidity and mortality and that the majority of patients can return to their previous level of independence.

In summary, treatment options for C1-type II odontoid combination fractures include external orthoses (both nonrigid and rigid) and surgical fixation with fusion. C1-C2 instability defined by an atlantal-dens interval of ≥ 5 mm or the failure of external immobilization warrants consideration for surgical treatment by one of several acceptable means.

Treatment of Combination C1-Type III Odontoid Fractures

Dickman et al⁸ described 5 patients with C1-type III odontoid combination fractures. All were successfully treated with halo immobilization for an average of 12 weeks. Ekong et al²⁷ identified 2 similar cases. One was managed successfully in a halo device; the second failed halo immobilization and required a delayed posterior C1-C2 fusion. Omeis et al²⁶ reported a patient with a C1-type III odontoid-Hangman combination fracture that they successfully treated with ventral odontoid screw fixation followed by posterior pedicle screw fixation and fusion. It appears that external immobilization is effective in the management of these injuries in the majority of patients.

TABLE 2. Evidentiary Table: Combination Atlas Axis Fractures

Reference	Description of Study	Evidence Class	Conclusions
Longo et al, ¹⁷ <i>Injury</i> , 2010	Systematic review of halo management including 50 patients with a combination C1-C2 fracture	III	Available evidence suggests that management of upper cervical spine fracture with halo fixation is safe and effective.
Ben Acha, ²⁴ <i>Orthopaedics and Traumatology, Surgery and Research</i> , 2009	Individual outcomes of the combination fracture patients are not reported Retrospective review of 4 patients with a combination fracture of C1 and odontoid	III	Management is recommended based on the type of odontoid fracture and the presence of neurological involvement. Posterior wiring is not indicated with C1 posterior arch fracture.
Daentzer and Flörkemeier, ¹⁶ <i>Journal of Neurosurgery: Spine</i> , 2009	Retrospective review of 6 combination C1-odontoid fractures examining effect of age on management	III	If the conditions for conservative treatment of upper cervical spine injuries with halo fixation are favorable, the clinical and radiological results are similar in patients regardless of their age. There is a tendency for more complications in older patients.
Omeis et al, ²⁶ <i>Journal of Spinal Disorders and Techniques</i> , 2009	Retrospective review of 5 elderly patients with combination C1-odontoid fractures	III	Elderly patients with combination C1-odontoid fractures can be treated surgically with acceptable morbidity and mortality rates. The majority of these patients can be mobilized early and return to their previous levels of independence.
Agrillo and Mastronardi, ²⁵ <i>Surgical Neurology</i> , 2006	Case report of a 92-year-old patients with a C1-type II odontoid fracture treated with a combination of odontoid and bilateral transarticular C1-C2 anterior screw fixation	III	Triple anterior screw fixation of C1-type II odontoid fracture is an option, even in the elderly.
Tashjian et al, ¹⁸ <i>Journal of Trauma</i> , 2006	Retrospective review of 11 elderly patients with combination C1-C2 fractures managed with cervical immobilization	III	Odontoid fractures are associated with significant morbidity and mortality in the elderly and appear worse with the use of a halo device.
Andersson et al, ¹³ <i>European Spine Journal</i> , 2000	Retrospective review of 3 elderly patients with combination C1-type II odontoid fractures	III	Either halo or posterior fusion was successful.
Gleizes et al, ³ <i>European Spine Journal</i> , 2000	Retrospective review of 784 cervical spine injuries including 31 C1-C2 combination fractures	III	C1 posterior arch-odontoid fractures were a common pattern. 70% of C1 fractures and 30% of odontoid fractures were associated with a second upper cervical fracture.
Müller et al, ³⁶ <i>European Spine Journal</i> , 2000	Retrospective review of combination C1- Hangman fractures	III	Nonoperative management was successful.
Guiot and Fessler, ⁹ <i>Journal of Neurosurgery</i> , 1999	Retrospective review of 10 patients undergoing surgical fixation for combination C1-C2 fractures	III	Surgical fusion with either anterior odontoid screw or posterior transarticular screw fixation was successful.
Henry et al, ²² <i>Journal of Bone and Joint Surgery: British Volume</i> , 1999	Retrospective review of 10 patients with C1-type II odontoid treated with anterior screw fixation	III	The presence of the C1 fracture did not reduce the success rate of anterior odontoid screw fixation.
Morandi et al, ³⁷ <i>Surgical Neurology</i> , 1999	Retrospective review of 2 cases of C1-posterior arch with a posterior displaced type II odontoid fractures treated with anterior screw fixation	III	Anterior fixation was successful.
Lee et al, ²⁰ <i>Spine</i> , 1998	Retrospective review of patients with combination C1-C2 fractures managed with either a halo or a cervical collar	III	Management of the combination fracture should be based on the C2 fracture, and halo immobilization is not always required.

(Continues)

TABLE 2. Continued

Reference	Description of Study	Evidence Class	Conclusions
Apostolides et al, ²³ <i>Journal of Neurosurgery</i> , 1997	Case report of C1-type II odontoid combination fractures failing halo immobilization	III	Anterior C1-C2 transarticular fixation with an odontoid screw was successful.
Berlemann and Schwabenbach, ⁵⁵ <i>Acta Orthopaedica Scandinavica</i> , 1997	Retrospective review of 4 patients > 65 y of age with C1-type II odontoid fractures	III	Anterior odontoid screw fixation was successful.
Greene et al, ³⁸ <i>Spine</i> , 1997	Retrospective review of 48 patients with C1-C2 combination fractures	III	Management should be based on the C2 fracture.
Weller et al, ³⁹ <i>Surgical Neurology</i> , 1997	Retrospective review of 5 patients > 70 y of age with combination C1-C2 fractures	III	Halo immobilization and posterior fusion both resulted in high rates of fusion, but halo is poorly tolerated in the elderly. Nonrigid immobilization resulted in lower fusion rates.
Coric et al, ²⁸ <i>Journal of Neurosurgery</i> , 1996	Retrospective review of 7 patients with a combination of C1-Hangman fractures	III	Nonoperative management was successful. If C2-C3 displacement was > 6 mm, posterior fusion was successful.
Fujimura et al, ⁵⁶ <i>Paraplegia</i> , 1996	Retrospective review of 3 patients of C1-miscellaneous axis body fractures	III	Nonoperative management was successful.
Polin et al, ³³ <i>Neurosurgery</i> , 1996	Retrospective review of 5 patients with C1-C2 fractures	III	Nonoperative management was successful.
Coyne et al, ¹⁹ <i>Spine</i> , 1995	Retrospective review of 1 patient with a combination C1-C2 fracture	III	Posterior stabilization was successful.
Fujimura et al, ⁶ <i>Paraplegia</i> , 1995	Retrospective review of 247 admissions with upper cervical spine fractures including 82 patients with neurological deficit	III	In patients with combined injury of C1-C2, neurological deficit occurred in patients with posterior arch fracture, burst fracture of the atlas, or body fracture of the axis associated with either an odontoid fracture or a Hangman fracture.
Pedersen and Kostuik, ⁴⁰ <i>Journal of Spinal Disorders</i> , 1994	Case report of a 70-year-old man with fracture dislocation of C1-C2 with 20-mm atlantoaxial displacement	III	Successfully treated with O-C4 decompression, internal fixation, and posterior fusion with complete recovery.
Hanigan et al, ⁴¹ <i>Journal of Neurosurgery</i> , 1993	Retrospective review of 2 patients > 80 y of age with C1-odontoid fractures	III	Nonoperative management was successful if patients survived the initial postinjury period.
Bohay et al, ³⁵ <i>Journal of Orthopaedic Trauma</i> , 1992	Retrospective review of a patient with C1 burst and vertical C2 body fracture treated with a cervical collar	III	Nonoperative management was successful.
Hays and Alker, ⁴² <i>Spine</i> , 1992	Retrospective review of 2 patients with C1 arch and type II odontoid fractures	III	Nonoperative management was successful in 1 case. O-C2 fusion was performed in the other.
Jeanneret and Magerl, ⁴³ <i>Journal of Spinal Disorders</i> , 1992	Retrospective review of 2 patients with combination C1-type II or III odontoid fractures	III	The integrity of the posterior arch of C1 should be considered in planning surgical treatment.
Ryan and Henderson, ⁴⁴ <i>Injury</i> , 1992	Epidemiological report of 717 cervical spine fractures	III	Atlas fractures occurred with odontoid fractures (53%) and with Hangman fractures (24%). Odontoid fractures occurred with atlas fractures (15%). Hangman's fracture occurred with atlas fracture (9%).
Kesterson et al, ⁴⁵ <i>Journal of Neurosurgery</i> , 1991	Retrospective review of 4 patients with C1-type II odontoid fractures treated surgically	III	Surgery should be considered if combination fracture considered unstable as defined by an atlantoaxial interval of > 5 mm or lateral mass displacement > 7 mm.
Levine and Edwards, ⁴⁶ <i>Journal of Bone and Joint Surgery: American Volume</i> , 1991	Retrospective review of 15 patients with combination C1-2 fractures	III	The integrity of the posterior arch of C1 should be considered in planning surgical treatment.
Montesano et al, ²¹ <i>Spine</i> , 1991	Retrospective review of 7 patients with combination C1-type II odontoid fractures treated with anterior odontoid screw fixation	III	Management should be based on the C2 fracture.

(Continues)

TABLE 2. Continued

Reference	Description of Study	Evidence Class	Conclusions
Zavanone et al, ⁴ <i>Journal of Neurosurgical Sciences</i> , 1991	Case series of 23 C1-C2 fractures	III	Included 2 combination fractures (9%): C1-type II odontoid: patient died; C1-Hangman: patient treated successfully with traction reduction and Minerva.
Fowler et al, ⁵ <i>Journal of Spinal Disorders</i> , 1990	Retrospective review of 18 patients with combination C1-C2 fractures	III	Data suggest increased mortality associated with combination C1-C2 fractures. Six of the 7 early deaths (86%) had a C1 fracture associated with either a type II or III odontoid fracture.
Dickman et al, ⁸ <i>Journal of Neurosurgery</i> , 1989	Retrospective review of 25 patients with a combination fracture of both C1 and C2	III	Management should be determined based on the type of C2 fracture. Surgery with either anterior or posterior approaches can be considered if failure of nonoperative therapy or displacement of the odontoid fracture of > 6 mm.
Fielding et al, ³² <i>Clinical Orthopaedics and Related Research</i> , 1989	Retrospective review of 15 patients with a combination C1-Hangman fractures	III	Management should be based on the C2 fracture. Anterior C2-3 fusion should be considered for those patients with C2-3 angulation > 11° because this group has an 85% nonunion rate with cervical immobilization.
Govender and Charles, ⁴⁷ <i>Injury</i> , 1987	Retrospective review of 2 patients with combination C1-odontoid fractures	III	Nonoperative therapy successful.
Hanssen and Cabanela, ⁴⁸ <i>J Trauma</i> , 1987	Retrospective review of 7 patients with combination C1-odontoid fractures	III	Nonoperative therapy successful.
Lind et al, ⁴⁹ <i>Spine</i> , 1987	Retrospective review of 1 patient with C1-type II odontoid fractures managed in a halo orthoses	III	Nonoperative therapy successful.
Segal et al, ¹⁴ <i>Journal of Bone and Joint Surgery: American Volume</i> , 1987	Retrospective review of 6 cases with combination C1-2 fractures managed with immobilization	III	Nonoperative therapy was successful.
Levine and Edwards, ⁷ <i>Orthopedic Clinics of North America</i> , 1986	Review article on management of C1-C2 traumatic fractures	III	Comments on combined injuries: 1. The presence of 3 injuries to the C1-C2 complex associated with a high likelihood of neurological injury. 2. If find 1 injury or fracture, look carefully for another. 3. Mechanism of injury usually consistent with the injury observed. 4. Each injury needs to be evaluated individually; eg, the presence of 2 fractures does not always indicate instability (posterior arch of C1 plus a nondisplaced Hangman fracture). 5. Staging of treatment may be required (as described by Lipson ⁵³ below) with allowing 1 fracture to heal before treating definitively.
Levine and Edwards, ⁵⁰ <i>Journal of Bone and Joint Surgery: American Volume</i> , 1985	Retrospective review of 9 patients with combination C1-odontoid and C1-Hangman fracture	III	Nonoperative therapy successful in most cases. If fracture grossly unstable, posterior fusion can be successful.
Pepin et al, ⁵¹ <i>Clinical Orthopaedics</i> , 1985	Retrospective review of 9 patients with combination C1-odontoid fractures	III	Nonoperative therapy successful.
Effendi et al, ⁵² <i>Journal of Bone and Joint Surgery: British Volume</i> , 1981	Retrospective review of 2 patients of C1 arch or odontoid fracture with Hangman fracture	III	Management based on the odontoid fracture was successful.

(Continues)

TABLE 2. Continued

Reference	Description of Study	Evidence Class	Conclusions
Ekong et al, ²⁷ <i>Neurosurgery</i> , 1981	Retrospective review of 3 patients with C1-odontoid fractures	III	Nonoperative therapy successful.
Lipson, ⁵³ <i>Journal of Bone and Joint Surgery: American Volume</i> , 1977	Case series of 3 cases of C1-type II odontoid fractures	III	A staged strategy of halo immobilization until the posterior arch of the atlas fracture has healed followed by atlantoaxial fusion to definitively manage the odontoid fracture was successful.
Brashear et al, ²⁹ <i>Journal of Bone and Joint Surgery: American Volume</i> , 1975	Retrospective review of 2 patients of C1- Hangman fracture	III	Nonoperative therapy was successful.
Anderson and D'Alonzo, ⁵⁴ <i>Journal of Bone and Joint Surgery: American Volume</i> , 1974	Retrospective review including 1 patient with C1-type II odontoid fractures	III	O-C2 fusion was successful.

Treatment of Combination C1-Hangman Fractures

The combination of C1-Hangman fractures has been successfully treated with external immobilization in the majority of reported cases. Successful treatment with immobilization has been reported with a cervical collar,²⁸ the halo device, and the sterno-occipital mandibular immobilizer-type orthosis.^{4,8,29-31} The report by Fielding et al³² included 15 patients with combination C1-Hangman fractures. They reported that when the combination Hangman fracture was associated with C2-3 angulation $> 11^\circ$, they considered these C1-C2 combination injuries unstable. Surgical stabilization and fusion were recommended.

Treatment of Combination C1-Miscellaneous C2 Body Fractures

The recommended initial treatment of C1-C2 body fractures as reported in the literature is nonoperative. Both rigid immobilization and nonrigid immobilization have been described with nearly universal success.^{6,20,33-35} The Dickman et al⁸ series, which included 7 patients with combination C1-C2 body fractures were all successfully treated with either halo or sterno-occipital mandibular immobilizer immobilization.

SUMMARY

Combination fractures of the atlas and axis occur relatively frequently and are associated with an increased incidence of neurological deficit compared with either isolated C1 or isolated C2 fractures. C1-type II odontoid combination fractures are the most common C1-C2 combination fracture injury pattern, followed by C1-miscellaneous axis body fractures, C1-type III odontoid fractures, and C1-Hangman combination fractures. Class III medical evidence addressing the management of patients with acute traumatic combination atlas and axis fractures describes a variety of treatment strategies for these unique fracture injuries based primarily on the specific characteristics of the axis fracture injury subtype.

The type of axis fracture present generally dictates the management strategy for the C1-C2 combination fracture injury. Rigid external immobilization is typically recommended as the initial management for the majority of patients with these injuries. Combination atlas-axis fractures with an atlantoaxial interval of ≥ 5 mm or angulation of C2 on C3 of $\geq 11^\circ$ have been considered for and successfully treated with surgical stabilization and fusion. Surgical options in the treatment of combination C1-C2 fractures include posterior C1-2 internal fixation and fusion or combination anterior odontoid and C1-2 transarticular screw fixation with fusion. Fractures of the posterior ring of the atlas can complicate the surgical treatment of unstable C1-C2 combination fracture injuries. If the posterior arch of C1 is incompetent and a dorsal operative procedure is indicated, occipitocervical internal fixation and fusion, posterior C1-C2 transarticular screw fixation and fusion, and C1 lateral mass-C2 pars/pedicle screw fixation and fusion techniques have been reported to be successful.

KEY ISSUES FOR FUTURE INVESTIGATION

Review of the available literature highlights the lack of prospective data and comparison studies to help guide appropriate treatment of combination atlas-axis fractures. Although immobilization has been recommended as the initial management of choice, the increased morbidity and mortality of halo use in the elderly, the increased rate of nonunion of type II odontoid fractures, and patient preferences all raise the question of the benefit of early surgical fixation and fusion for these injuries. Prospective data derived from appropriately designed comparative studies would assist in determining the most favorable outcome strategies and would provide Class II medical evidence on this topic.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Os Odontoideum

Curtis J. Rozzelle, MD*

Bizhan Aarabi, MD, FRCSC‡

Sanjay S. Dhall, MD§

Daniel E. Gelb, MD¶

R. John Hurlbert, MD, PhD,
FRCSC||

Timothy C. Ryken, MD, MS#

Nicholas Theodore, MD**

Beverly C. Walters, MD, MSc,
FRCSC‡‡§§

Mark N. Hadley, MD||‡

*Division of Neurological Surgery, Children's Hospital of Alabama, University of Alabama at Birmingham, Birmingham, Alabama; ‡Department of Neurosurgery, University of Maryland, Baltimore, Maryland; §Department of Neurosurgery, Emory University, Atlanta, Georgia; ¶Department of Orthopaedics, University of Maryland, Baltimore, Maryland; ||Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada; #Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa; **Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona; ‡‡Division of Neurological Surgery, University of Alabama at Birmingham, Birmingham, Alabama; §§Department of Neurosciences, Inova Health System, Falls Church, Virginia

Correspondence:

Mark N. Hadley, MD, FACS,
UAB Division of Neurological Surgery,
510 – 20th St S, FOT 1030,
Birmingham, AL 35294-3410.
E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS

Diagnosis:

Level III:

Plain radiographs of the cervical spine (anterior-posterior, open mouth-odontoid, and lateral) and plain dynamic lateral radiographs performed in flexion and extension are recommended to diagnose and evaluate os odontoideum, with or without tomography (computerized or plain) and/or magnetic resonance imaging of the craniocervical junction.

Management:

Level III:

- Clinical and radiographic surveillance or posterior C1-C2 internal fixation and fusion are recommended for patients with os odontoideum without symptoms or neurological signs.
- Posterior C1-C2 internal fixation and fusion are recommended for patients with os odontoideum with neurological symptoms, signs, or C1-C2 instability.
- Postoperative halo immobilization is recommended as an adjunct to posterior internal fixation and fusion unless rigid C1-C2 internal fixation is accomplished.
- Occipital-cervical internal fixation and fusion with or without C1 laminectomy is recommended in patients with os odontoideum who have irreducible dorsal cervicomedullary compression and/or evidence of associated occipital-atlantal instability.
- Ventral decompression should be considered in patients with os odontoideum who have irreducible ventral cervicomedullary compression.

RATIONALE

The definition of an os odontoideum is uniform throughout the literature: an ossicle with smooth

circumferential cortical margins representing the odontoid process that has no osseous continuity with the body of C2.¹ The origin of os odontoideum remains debated in the literature with evidence for both acquired and congenital causes.²⁻⁴ The etiology of os odontoideum, however, is not relevant to its diagnosis or subsequent management.

Diagnosis

Os odontoideum can present with a wide range of clinical symptoms and signs or as an incidental finding on imaging. The literature has focused on 3 groups of patients with os odontoideum: those with occipital-cervical pain alone, those with myelopathy, and those with intracranial symptoms or signs from vertebrobasilar ischemia.⁵ Patients with os odontoideum and myelopathy have been subcategorized further into those with transient myelopathy (commonly after trauma), those with static myelopathy, and those with progressive myelopathy.⁶ Because patients with occipital-cervical pain, myelopathy, or vertebrobasilar ischemia likely will have etiologies other than os odontoideum, the diagnosis of os odontoideum is not usually considered until imaging is obtained. The presence of an os odontoideum is usually first suggested after plain cervical spine radiographs are obtained. Most often, plain cervical spine radiographs are sufficient to obtain a diagnosis.⁷

Os odontoideum has been classified into 2 anatomic types: orthotopic and dystopic. Orthotopic defines an ossicle that moves with the anterior arch of C1, and dystopic defines an ossicle that is functionally fused to the basion. The dystopic os odontoideum may sublux anterior to the arch of C1.⁶ Tomograms and computerized tomography (CT) have been used to better define the bony anatomy of the os odontoideum and the odontoid process. Plain dynamic radiographs in flexion and extension have been used to depict the degree of abnormal motion between C1 and C2. Most often, there is anterior instability, with the os

odontoideum translating forward in relation to the body of C2. However, at times, one will see either no discernible instability or “posterior instability” with the os odontoideum moving posteriorly into the spinal canal during neck extension.^{6,8}

With respect to diagnosis, there are 2 issues regarding the imaging of os odontoideum. First, although plain radiographs are often diagnostic for os odontoideum, the sensitivity and specificity of plain cervical radiographs for os odontoideum remain unreported. The utility of confirmatory studies such as CT and magnetic resonance imaging (MRI) has not been well defined. Second, after the diagnosis of os odontoideum on plain cervical x-rays, instability and osseous anomalies associated with os odontoideum can influence clinical management. The best methods of further evaluating or excluding these complicating factors deserve definition.

Management

The natural history of untreated os odontoideum covers a wide spectrum. The literature provides many examples of both asymptomatic and symptomatic patients with known os odontoideum who have never been treated and who have had no reported new problems in follow-up over many years.¹ Conversely, examples of sudden spinal cord injury in association with os odontoideum after minor trauma have also been reported.^{9,10} The natural history of os odontoideum is variable, and predictive factors for deterioration, particularly in the asymptomatic patient, have not been identified. Indications for surgical stabilization include simply the existence of an os odontoideum, os odontoideum in association with occipital cervical pain alone, and/or os odontoideum in association with neurological symptoms and signs.^{1,6,10-12} Other factors that may assist in determining the need for stabilization and/or decompression include C1-C2 instability, associated deformities, and spinal cord compression. A variety of techniques have been used to stabilize C1 and C2 in patients with os odontoideum.^{1,6,8,13-26} Fusion success rates and complication rates for these various procedures may provide evidence as to whether a preferred method of C1-C2 arthrodesis is supported by the literature.

Finally, neural compression is an important consideration in patients with os odontoideum. Neural compression may be anterior from a combination of bone and soft tissue or posterior from the dorsal arch of C1. Surgical techniques to stabilize and fuse across the craniocervical junction with or without C1 laminectomy and techniques that provide ventral decompression have been reported in the treatment of os odontoideum with irreducible neural compression.^{18,21,27}

The guidelines author group of the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons previously produced a medical evidence-based guideline on this topic.²⁸ The present review is undertaken to update the medical evidence on the diagnosis and management of patients with os odontoideum since that 2002 publication.

SEARCH CRITERIA

A National Library of Medicine (PubMed) computerized literature search from 1966 to 2011 was performed through MEDLINE using the key phrase “os odontoideum.” The search identified 224 articles. Articles written in English were reviewed. Thirty-eight articles that described the clinical aspects and management of patients with os odontoideum were identified and used to generate these guidelines. None of the articles meeting selection criteria provided Class I or Class II medical evidence. All 38 citations offered Class III medical evidence on the diagnosis and/or management of os odontoideum. These 38 articles represent the basis for this review and are summarized in Evidentiary Table format (Table).

SCIENTIFIC FOUNDATION

Diagnostic Evaluation

There is no literature that describes the sensitivity and specificity of imaging studies for os odontoideum. Dai et al¹⁸ in their review of 44 patients with os odontoideum used tomography, CT, and MRI, in addition to “routine” plain cervical radiographs (anterior-posterior, lateral, open mouth, flexion and extension x-rays), in 39, 27, and 22 patients, respectively. Matsui et al²⁹ described only the plain radiographs of 12 patients with os odontoideum. They excluded patients with Down syndrome and Klippel-Feil anomalies. The authors made no mention of any other studies to obtain or confirm the diagnosis in these 12 patients. Likewise, Watanabe et al²⁰ and Spierings and Braakman¹ described the plain radiographs of 34 and 37 patients, respectively, with os odontoideum, without reference to other imaging studies. Fielding et al⁶ described 35 patients with os odontoideum: “Each patient had extensive roentgenographic investigation, including multiple roentgenograms of the cervical spine and *often* flexion-extension lateral roentgenograms and flexion-extension laminagrams.” No mention was made as to whether additional studies beyond static plain c-spine x-rays were necessary to confirm the diagnosis of os odontoideum in their series of patients.

The literature supports the ability of plain cervical spine radiographs to establish the diagnosis of os odontoideum. There is no compelling medical evidence in the literature that supports the need for additional studies to confirm the diagnosis of os odontoideum.

Specific characteristics or associated abnormalities of os odontoideum, including C1-C2 instability, soft-tissue masses, spinal canal diameter, associated osseous anomalies, spinal cord appearance, and vertebral artery compromise, have been investigated with a variety of imaging studies. The imaging of abnormal motion and spinal cord compression in association with os odontoideum has received the most attention in the literature.

Instability of C1-C2 in association with os odontoideum has been investigated with multiple imaging modalities. Using flexion and extension lateral cervical spine x-ray studies in 33 patients,

Fielding et al⁶ reported 22 patients (67%) with anterior instability who had a mean atlanto-dens interval of 10.3 mm, 5 patients (15%) with posterior instability (mean posterior translation of the os odontoideum during extension of 8.4 mm), 3 patients (9%) with < 3.0 mm of C1-C2 motion, and 3 patients (9%) with no detectable C1-C2 motion. Eight patients (23%) had both anterior and posterior instability. The authors noted that cineradiography was helpful in examining the range of motion at C1-C2 in these patients, but it was not of benefit in the measurement of the degree of instability. Of note is that almost one fifth of the patients in their series manifested no radiographic evidence of C1-C2 instability.

Klimo et al¹⁰ retrospectively reviewed flexion/extension lateral cervical spine radiographic findings in 60 patients with os odontoideum as part of their surgical case series. Defining C1-C2 instability as “a change in C-1 translation from the neutral position” either anteriorly or posteriorly, they found only 4 patients (7%) who demonstrated no radiographic evidence of instability. Anterior instability was observed in 42 patients (70%), ranging from 3 to 17 mm (mean, 8.8 mm); posterior instability ranging from 4 to 13 mm (mean, 7.7 mm) was demonstrated in 6 patients (10%); and 8 patients (13%) had both anterior and posterior instability. Only 1 of their 14 “asymptomatic” patients was found to have no radiographic evidence of instability.

Spierings and Braakman¹ studied 21 of their 37 patients with os odontoideum with flexion and extension cervical spine radiographs or tomograms. They measured the maximal distance the os odontoideum moved in the sagittal plane, the inner diameter of the atlas, and the minimal spinal canal diameter (the distance between the posterior aspect of the C2 body and the dorsal arch of C1 during flexion). They compared these measurements in 2 groups: those with and those without myelopathy. The degree of C1-C2 instability did not correlate with neurological status, but the measured minimal spinal canal diameter was significantly smaller ($P < .05$) in the group with myelopathy. They identified 13 mm as the critical anterior-posterior spinal diameter. Watanabe et al²⁰ made similar measurements in 34 patients using plain lateral cervical radiographs in flexion and extension. Like Spierings and Braakman, the degree of instability in their patients did not correlate with the presence of myelopathy. Shirasaki et al⁸ described radiographic findings on lateral flexion and extension radiographs in 9 patients with os odontoideum. They reported that a distance of ≤ 13 mm between the os odontoideum and the dorsal arch of C1 “specifically defined severe cervical myelopathy” in their patients. They also found that the degree of C1-C2 instability did not correlate with the presence of myelopathy. Yamashita et al³⁰ studied atlantoaxial subluxation with plain radiography and MRI and correlated the imaging studies with the degree of myelopathy in 29 patients (4 with os odontoideum). They found that the degree of myelopathy did not correlate with the distance of subluxation of C1 on C2 on plain radiographs. The degree of cord compression on MRI correlated well with the degree of

myelopathy determined clinically. Matsui et al²⁹ classified os odontoideum into 3 types according to the morphology of the os odontoideum on plain radiographs: round, cone, and blunt tooth. They compared these 3 os odontoideum types to the degree of clinical myelopathy and found the degree of myelopathy correlated most closely with the “round” os odontoideum type. Kuhns et al³¹ described the MRI appearance of os odontoideum in 4 children and identified signal changes within the posterior ligaments consistent with trauma. They could not discern whether these changes represented a primary or secondary phenomenon with respect to atlantoaxial instability.

These studies provide 2 consistent conclusions: The degree of C1-C2 instability does not appear to correlate with neurological status in patients with os odontoideum, and sagittal spinal canal diameter on plain radiographs of ≤ 13 mm is strongly associated with clinical symptoms and signs of myelopathy.

Beyond plain spine radiographs and flexion-extension x-rays, imaging to assist with operative planning of unstable os odontoideum receives brief mention in several reports.^{9,14,19,27,32} Important factors to consider before proceeding with surgical intervention for this disorder are the ability to reduce C1-C2, spinal cord compression, an assimilated atlas, an incomplete C1 ring, the course of the vertebral arteries at C1 and C2, and the presence of an associated congenital fusion of the cervical spine (eg, Klippel-Feil). Plain radiographs, tomography, and CT scans provide information regarding the ability to achieve anatomic alignment of C1 on C2 and the presence or absence of a congenital fusion. CT can provide important information about the bony anatomy at the craniocervical junction, including the completeness of the atlas ring and the position of the transverse foramina at C1 and C2.³³ Hosono et al³⁴ made interesting observations on the different motions of the posterior arch of C1 in relation to C2 in patients with os odontoideum. They observed 2 patterns of motion: linear and sigmoid. They felt that in those patients with a sigmoid-shaped motion pattern, posterior wiring and fusion techniques may not provide adequate stability. MRI is the best modality for viewing cord compression even after apparent C1-C2 realignment.³⁰ The selection of and necessity for additional imaging in the evaluation of patients with os odontoideum appear to be made on a patient-by-patient basis. The literature provides no convincing evidence as to which patients should undergo supplemental imaging (CT or MRI) after the diagnosis of os odontoideum has been made.

Management

The universal theme of the various management strategies offered in the treatment of patients with os odontoideum has been either confirming or securing cervical spinal stability at the C1-C2 levels. The earliest reports of os odontoideum describe small pediatric case series treated surgically. In 1978, Griswold et al³⁵ described 4 children with os odontoideum who underwent posterior C1-C2 wiring and autologous iliac fusion. Three children had successful arthrodesis. The fourth child did not achieve fusion/stability despite 3 attempts. In the same year,

Brooks and Jenkins¹⁶ described their technique of C1-C2 wiring and fusion and reported 3 children with os odontoideum who were immobilized postoperatively in Minerva jackets. All 3 patients achieved successful fusion. In summary, 6 of the 7 children with os odontoideum described in these 2 early reports were successfully treated.

Two larger series, reported in the early 1980s, included adults and children with os odontoideum and described both operative and nonoperative management strategies for these patients. Fielding et al⁶ described 35 patients with os odontoideum, of whom 27 had radiographic evidence of instability. Twenty-six of these 27 patients underwent successful posterior C1-C2 internal fixation and fusion (Gallie type). Fusions were noted to be “solid” after 2 months of immobilization in children and after 3 months in adults. One patient with instability refused surgery and remained well at the 2-year follow-up. The 8 remaining patients with no evidence of C1-C2 instability managed nonoperatively remained well at last follow-up of 1 to 3 years. Spierings and Braakman¹ described 37 patients with os odontoideum whom they managed. Seventeen were treated surgically. They provide 20 patients for analysis of the natural history of os odontoideum. Information about radiographic stability was provided for only 21 of the 37 patients they reported. Sixteen patients in their series presented with neck pain only or had an incidentally discovered os odontoideum. Nine of these 16 patients had flexion and extension radiographs. Of these 9 patients, 7 had abnormal motion of ≥ 8.0 mm. With a median follow-up of 7 years, none of these 16 patients developed a neurological deficit. Four additional patients who presented with myelopathy were treated nonoperatively with follow-up from 6 months to 14 years. Three of these 4 patients presented with transient myelopathy and had no recurrence at last follow-up despite abnormal motion of C1 on C2 of 8 to 16 mm. The fourth patient had a stable monoparesis at last follow-up. Of the 17 patients who underwent surgery, 1 patient had neurological worsening and 2 died. Eight of the 17 patients treated surgically underwent posterior C1-C2 internal fixation and fusion. Nine patients underwent occipital-cervical internal fixation and fusion with C1 laminectomy. The authors did not report a single failed fusion. They had a combined surgical morbidity and mortality of 18% (3 of 17 patients). The authors concluded that patients with os odontoideum without C1-C2 instability can be managed without surgical stabilization and fusion with good result. Although they did not provide operative treatment to every os odontoideum patient with C1-C2 instability, those with myelopathy and greater amounts of instability were more likely to be operated on.

More recently, Zhang et al¹² reviewed 10 cases of os odontoideum diagnosed following acute spinal cord injury. All were treated with posterior internal fixation and fusion (8 C1-C2, 2 O-C2). No complications were reported, and all patients' American Spinal Injury Association scores improved. If these 3 series are considered representative of patients with os odontoideum, the implication is that minimally symptomatic or asymptomatic patients with os odontoideum without C1-C2 instability can be managed non-

operatively with little or no morbidity over time. Although patients with os odontoideum and myelopathy or C1-C2 instability have been managed conservatively, most patients with myelopathy and/or instability are treated surgically.

Clements et al⁵ in 1995 reported a patient who had a documented os odontoideum without instability who at 5 years of follow-up developed symptomatic frank C1-C2 instability that required surgical stabilization and fusion. It appears that a lack of C1-C2 instability at initial diagnosis does not guarantee that instability will not develop in these patients. In the largest published os odontoideum case series to date, Klimo et al¹⁰ described 3 individuals who sustained neurological deterioration after a known os odontoideum was left untreated. Therefore, it is recommended that patients diagnosed with os odontoideum be counseled regarding the risk of delayed instability/late neurological deterioration and that clinical and radiographic follow-up be provided to patients with untreated os odontoideum.

The literature reviewed on the surgical treatment of os odontoideum for the original “Guidelines for the Management of Acute Cervical Spine and Spinal Cord Injury” described posterior C1-C2 fusion procedures using sublaminar cables with or without transarticular screw fixation.²⁸ All reports provided Class III medical evidence. The conclusions drawn were that posterior C1-C2 fusion is a treatment option for os odontoideum and that postoperative halo immobilization should be used unless successful transarticular screw fixation was accomplished. Since the publication of the original guidelines, the reported transarticular screw fixation experience has grown, and several new techniques for atlantoaxial internal fixation have been described for patients with os odontoideum. Gluf et al¹³ reported 191 C1-C2 transarticular screw fixation and fusion procedures in patients > 16 years of age. Although only 4 patients had os odontoideum as the cause of their instability, the overall radiographic fusion rate was 98%. Five vertebral artery injuries occurred in their series, including bilateral injuries in 1 patient resulting in death. Simultaneously, the same authors reported a series of C1-C2 transarticular screw fixation and fusion procedures in patients < 16 years of age. Os odontoideum was the surgical indication in 22 of 67 procedures they accomplished. Radiographic fusion was documented in all cases, and only 2 vertebral artery injuries were observed, both asymptomatic. The overall complication rate was 10.4%, predominantly wound infections.

More recently, Reilly and Choi¹¹ described their experience with transarticular screw fixation/posterior C1-C2 fusion for pediatric C1-C2 instability. Nine of the 12 cases reported were performed for os odontoideum-associated instability. All achieved radiographic fusion. There were no vertebral artery injuries or other major complications.

Klimo et al¹⁰ reviewed 78 patients with os odontoideum who were 1.5 to 73 years of age (mean, 20.5 years), all treated surgically. Posterior fusion with transarticular screw fixation was performed in 76 patients (C1-C2 in 74 and O-C2 in 2). One patient underwent odontoid screw fixation. One posterior C1-C2 fusion was supplemented with a C1 lateral mass/C2 pedicle screw construct.

All patients achieved radiographic fusion in 2 to 17 months (median, 4.8 months). Approximately 90% of patients had improvement or resolution of presenting symptoms. The only reported complication was a superficial wound infection that was treated successfully with antibiotics. The authors' high success rate and negligible complication rate and the 3 patients who experienced neurological deterioration following nonsurgical management led them to recommend consideration of C1-C2 posterior fusion with internal screw fixation for all patients diagnosed with os odontoideum.

Review of the recent literature identified 2 series of polyaxial screw/rod fixation and fusion of C1-C2, first described by Harms et al⁴¹ for instability caused by os odontoideum. Brecknell and Malham²⁵ reported successful C1-C2 internal fixation and fusion for 3 adult patients with os odontoideum using polyaxial C1 lateral mass and C2 pedicle screws placed with image guidance. No complications were reported. Haque et al²² subsequently reviewed 17 cases of screw fixation of the upper cervical spine in pediatric patients (3-17 years of age) without intraoperative image guidance. Five C1-C2 posterior fusions were performed in patients with os odontoideum, all with bilateral C1 lateral mass and C2 pars screws. Intentional bilateral C2 nerve root sacrifice was performed in 2 of the 5 cases to improve visualization of the C1 lateral mass. There were no unintended neurovascular injuries, wound infections, or hardware revisions, and all patients achieved radiographic stability. C2 nerve root sacrifice reportedly did not cause postoperative pain. Polyaxial screw/rod constructs appear to be comparable to transarticular screw fixation for the treatment of atlantoaxial instability.

Other alternative posterior fusion techniques have been reported recently. Visocchi et al²³ reported 7 children with unstable os odontoideum associated with Down syndrome (n = 6) or Morquio syndrome (n = 1). All underwent posterior C1-C2 or O-C2 fusions with rod and sublaminar wire internal fixation constructs. All patients were immobilized postoperatively with halo or sterno-occipital mandibular immobilizer devices for a minimum of 4 months. Six patients had no complications and documented radiographic fusion after 6 months. The seventh patient required a revision fusion procedure following treatment of a wound infection and cerebrospinal fluid leak. Chamoun et al²⁴ described their experience using translaminar screw fixation and fusion followed by nonhalo immobilization for pediatric upper cervical spine instability. "Os odontoideum/terminale" was present in 2 of the 7 cases reviewed. All 7 accomplished subsequent fusion documented radiographically. The only reported complication was dysphagia resulting from a malpositioned C1 lateral mass screw. Ni et al¹⁴ used C1 laminar hooks and C2 pedicle screws for internal fixation in a series of 13 C1-C2 posterior internal fixation and fusion procedures. Os odontoideum was the cause of instability in 4 patients and chronic odontoid fracture was the pathology in another 4 patients. After 3 months in a Philadelphia collar, radiographic fusion was achieved in all 13 cases with no report of vertebral artery injury or new neurological deficits. These reports provide additional Class III medical evidence that

posterior fusion procedures are an effective treatment for C1-C2 instability, regardless of the internal fixation construct applied.

Apfelbaum et al³⁶ described their experience in treating recent and remote (≥ 18 months after injury) odontoid injuries with anterior screw fixation. They reported a fusion rate of 25% in 16 "remote" odontoid injuries. If an os odontoideum were considered anatomically similar to a remote odontoid fracture, then the rate of fusion for os odontoideum treated with an odontoid screw fixation would likewise be expected to be poor. Anterior C1-C2 transfacet fixation techniques may have merit in the surgical treatment of os odontoideum, but there are no descriptions in the literature of its application for os odontoideum.

The surgical treatment of patients with C1-C2 instability in association with os odontoideum has been demonstrated to be successful when combined fusion and internal fixation techniques are used, usually in conjunction with postoperative halo immobilization. Fusion success rates and reports of operative morbidity varied considerably among the clinical case series reported in the literature. Although the numbers are small, rigid C1-C2 internal fixation and fusion (whether transarticular screw, C1-C2 screw/rod, C1 hook/C2 screw, etc) have been associated with higher rates of fusion compared with posterior wiring and fusion techniques alone. Of note, patients treated with rigid C1-C2 screw fixation have been managed in hard collars postoperatively, obviating the need for halo immobilization devices. If a rigid internal fixation construct is not used in the treatment of unstable os odontoideum, postoperative halo immobilization as an adjunct to dorsal internal fixation and fusion is recommended.

Ventral or transoral decompression for irreducible ventral cervicomedullary compression in association with os odontoideum has been suggested.²⁷ Reports of the management of ventral compression and os odontoideum are scant. In a review of 36 patients with Down syndrome and craniovertebral junction abnormalities, 12 patients with os odontoideum were described. Eleven of the 36 patients were noted to have basilar invagination. Five of these 11 patients with basilar invagination had irreducible ventral spinal cord compression and were treated with transoral decompression. The authors reported stable to excellent outcomes without complications following transoral decompression in all 5 patients; however, the total number of patients who had basilar invagination resulting from os odontoideum was not given. The report implies, however, that selected patients with atlantoaxial instability and irreducible symptomatic ventral cervicomedullary compression may benefit from ventral decompression. Recently, Lü et al²¹ described endoscopically assisted anterior release and reduction of fixed atlantoaxial dislocations in 21 consecutive patients. Seven of their patients had os odontoideum and another 8 had "late odontoid fractures." Anatomic reduction was attained in all patients followed by successful posterior internal fixation and fusion. They reported no complications. On the other hand, Dai and colleagues¹⁸ reported the successful use of occipital cervical internal fixation and fusion, with or without C1 laminectomy, in cases of

TABLE. Evidentiary Table: Os Odontoideum

Reference	Description of Study	Evidence Class	Conclusions
Lü et al, ²¹ <i>Spine</i> , 2010	Retrospective series of 21 fixed atlantoaxial dislocation cases treated with endoscope-assisted anterior release and reduction followed by posterior fixation	III	Fixed atlantoaxial dislocation was due to os odontoideum in 7 cases, all of which achieved anatomic reduction with no complications reported.
Ni et al, ¹⁴ <i>European Spine Journal</i> , 2010	Retrospective case series of 13 posterior C1-C2 fusion procedures using bilateral C1 hook and C2 pedicle screw fixation	III	Os odontoideum was the indication in 4 cases and chronic odontoid fracture in another 4. Radiographic fusion was documented in all 13, and no new neurological deficits or vertebral artery injuries were observed.
Zhang et al, ¹² <i>Journal of Clinical Neuroscience</i> , 2010	Review of 10 patients 22-52 y of age treated with posterior fusion for os odontoideum; mean follow-up of 20.7 mo	III	All 10 patients presented with acute spinal cord injury following minor trauma and underwent posterior C1-C2 (n = 8) or O-C2 (n = 2) fusion. No complications were reported, and all patients' American Spinal Injury Association scores improved.
Haque et al, ²² <i>Journal of Neurosurgery: Pediatrics</i> , 2009	Retrospective case series of 17 patients 3-17 y of age treated surgically with posterior C1-C2 or O-C2 fusion using screw fixation	III	Lateral mass screws were placed in C1, whereas C2 fixation was with pars or laminar screws. Os odontoideum was the indication in 5 cases, radiographic stability was achieved in 100%, and there were no vertebral artery injuries or major complications.
Visocchi et al, ²³ <i>Acta Neurochirurgica</i> , 2009	Retrospective series of 7 children with os odontoideum (5 with Down syndrome, 1 with Morquio syndrome) treated with posterior sublamina wiring/fusion	III	Six patients achieved radiographic fusion within 6 mo; the seventh required repeat bone grafting to achieve fusion (after treatment of cerebrospinal leak and wound infection). No other complications and no new neurological deficits were reported.
Chamoun et al, ²⁴ <i>Neurosurgery</i> , 2008	Review of translaminar screw fixation for upper cervical spine instability in 7 pediatric (< 15 y of age) patients (follow-up, 4-21 mo)	III	Os odontoideum/terminale was the cause of instability in 2 patients; radiographic fusion was achieved in 100%; and 1 patient experienced prolonged dysphagia resulting from C1 lateral mass screw malposition.
Klimo et al, ¹⁰ <i>Journal of Neurosurgery: Spine</i> , 2008	Retrospective case series of 78 patients 1.5-73 y of age with os odontoideum; median follow-up of 14 mo	III	All were treated surgically (77 posterior rigid screw fixation/fusion and 1 odontoid screw; no mortality or major morbidity); 13 of 14 asymptomatic patients had C1-C2 instability on dynamic x-rays. Neurological deterioration following conservative management of os odontoideum was seen in 3 cases.
Brecknell and Malham, ²⁵ <i>Journal of Clinical Neuroscience</i> , 2008	Report of 3 cases of os odontoideum treated surgically with posterior C1-C2 fusion and polyaxial screw/rod fixation	III	C1 lateral mass and C2 pedicle screw fixation was achieved using image guidance. All 3 patients achieved radiographic fusion without complications.
Reilly and Choit, ¹¹ <i>Journal of Pediatric Orthopedics</i> , 2006	Retrospective case series of 12 patients 5-17 y of age treated surgically with posterior C1-C2 fusion and transarticular screw fixation; mean follow-up of 5.1 y	III	9 had os odontoideum as the cause of C1-C2 instability, radiographic fusion was achieved in 100%, and there were no vertebral artery injuries or other major complications.
Gluf and Brockmeyer, ¹³ <i>Journal of Neurosurgery: Spine</i> , 2005	Retrospective case series of 67 C1-C2 transarticular screw fixations in patients < 16 y of age	III	Os odontoideum was the indication in 22 cases; radiographic fusion was achieved in 100%; and 2 asymptomatic vertebral artery injuries were observed.

(Continues)

TABLE. Continued

Reference	Description of Study	Evidence Class	Conclusions
Gluf et al, ¹³ <i>Journal of Neurosurgery: Spine</i> , 2005	Retrospective case series of 191 C1-C2 transarticular screw fixations in patients >16 y of age	III	Os odontoideum was the indication in 4 cases; radiographic fusion was achieved in 98%; and 5 vertebral artery injuries occurred—bilateral in 1 case resulting in patient death.
Apfelbaum et al, ³⁶ <i>Journal of Neurosurgery</i> , 2000	18 patients with odontoid fractures incurred \geq 18 mo before treatment who were treated with anterior odontoid screw fixation	III	16 patients with follow-up. 25% fusion rate. 3 with screw fracture and 2 with screw pullout.
Brockmeyer et al, ¹⁵ <i>Journal of Neurosurgery</i> , 2000	Review of transarticular screw placement in 31 children, 12 children with os odontoideum (age, 4-16 y)	III	55 of 62 possible sites deemed suitable for transarticular screws. All children with os odontoideum were able to have 2 screws placed.
Dai et al, ¹⁸ <i>Surgical Neurology</i> , 2000	A review of 44 patients 7-56 y of age with os odontoideum; mean follow-up, 6.5 y	III	7 patients were asymptomatic. 5 of these 7 were treated with a cervical collar only and have remained stable. 39 underwent fusion successfully (9 atlantoaxial and 33 occipitocervical). Symptoms and signs disappeared in 26 and improved in 13.
Taggard et al, ²⁷ <i>Journal of Neurosurgery</i> , 2000	A review of craniovertebral junction abnormalities in 36 patients with Down syndrome; os odontoideum present in 12	III	Twenty-seven underwent surgical procedures. Of 11 with basilar invagination, it was irreducible in 5 and transoral decompression was performed.
Dickman and Sonntag, ¹⁶ <i>Neurosurgery</i> , 1998	Review of 121 patients treated with posterior C1-C2 transarticular screws and wired posterior bone struts; os odontoideum was present in 9; this group was compared with 74 patients treated with posterior wiring techniques alone	III	2 failures in the transarticular group. The cause of the C1-C2 instability was not stated for these 2 failures. 1 of 8 patients with os odontoideum in the posterior wiring group had a nonunion. Overall fusion rate for transarticular was 98% vs 86% for posterior wiring techniques.
Wang et al, ¹⁹ <i>Pediatric Neurosurgery</i> , 1999	16 children treated for atlantoaxial instability, 4 of whom had os odontoideum and were treated with C1-C2 transarticular screws and posterior wiring and fusion techniques	III	All fused. No halo immobilization. Transarticular screws were successfully used in children as young as 4 y of age.
Kuhns et al, ³¹ <i>Journal of Pediatric Orthopedics</i> , 1998	4 children with os odontoideum underwent magnetic resonance imaging examinations	III	All 4 children had changes in the nuchal cord consistent with injury.
Lowry et al, ⁷ <i>Journal of Neurosurgery</i> , 1997	A review of 25 children requiring upper cervical fusions; 11 children had os odontoideum	III	10 underwent a Brooks-type C1-C2 fusion. 2 of these children did not fuse. 1 underwent a Gallie-type fusion. This child remained unstable and was revised to a Brooks-type fusion, which was successful.
Matsui et al, ²⁹ <i>Spine</i> , 1997	Review of the plain radiographic morphology of C2 in 12 patients (15-71 y of age) with os odontoideum unrelated to any syndrome	III	3 configurations described from an anteroposterior view: round, cone, and blunt tooth. Myelopathy was more severe in the group with a round configuration.
Verska and Anderson, ⁴ <i>Spine</i> , 1997	Report of a pair of identical twins, 1 with and 1 without os odontoideum	III	History of trauma in the twin with an os odontoideum. Fell at 3 y of age and had torticollis and neck pain for several months.

(Continues)

TABLE. Continued

Reference	Description of Study	Evidence Class	Conclusions
Watanabe et al, ²⁰ <i>Spine</i> , 1996	Review of 34 patients with os odontoideum (5-76 y of age). Divided into groups by Rowland classification (1 = local symptoms, 2 = posttraumatic transient myelopathy, 3 and 4 = progressive myelopathy or intracranial symptoms); lateral neutral and dynamic radiographs obtained; sagittal-plane rotation angle, minimum distance, and instability index were measured	III	Low correlation between sagittal-plane rotation angle and instability index. Sagittal-plane rotation angle of > 20° or instability index of > 40% correlates with myelopathy.
Clements et al, ⁵ <i>Injury</i> , 1995	Report of nonoperative treatment of an incidentally discovered os odontoideum without C1-C2 instability at diagnosis	III	After 5 y, profound C1-C2 instability and symptoms had developed, necessitating posterior instrumentation and fusion.
Coyne et al, ¹⁷ <i>Neurosurgery</i> , 1995	Review of posterior C1-C2 fusion and instrumentation techniques; 5 of 32 patients had os odontoideum	III	3 of 5 with os odontoideum failed with posterior wiring techniques. All were immobilized in halos. 2 of 5 developed new neurological deficits as operative complications.
Stevens et al, ³ <i>Brain</i> , 1994	Review of abnormal odontoids and C1-C2 instability; 24 of 62 patients with os odontoideum: 9 children and 15 adults	III	Periodontoid soft-tissue thickening was present only in those with Morquio disease. Following fusion, the odontoid was noted to partially or completely regenerate in cases of Morquio disease.
Menezes and Ryken, ⁹ <i>Neurosurgery</i> , 1992	Review of 18 Down syndrome patients with symptomatic cervicomedullary compromise; 4 had os odontoideum	III	All 4 had gross instability on dynamic radiographs. Successful fusion with posterior wiring techniques and full-thickness rib grafts. Immobilized for a "minimum of 3 mo."
Dickman et al, ³⁸ <i>Journal of Neurosurgery</i> 1991	Review of 36 patients treated with C1-C2 posterior wiring and fusion for various reasons; 4 patients had os odontoideum (16, 25, 38, 43 y of age); all patients were maintained in a halo for 12 wk after surgery	III	Of the 4 with os odontoideum, 3 developed osseous unions and 1 had a stable fibrous union (follow-up, 15-44 months). No complications for these 4 patients.
Hosono et al, ³⁴ <i>Spine</i> , 1991	Cine-radiographic evaluation of 6 patients with os odontoideum	III	2 types of C1 posterior arch translation: straight (vertical; n = 4) and sigmoid (n = 2). Correlated abnormal motion with biomechanics of posterior wiring techniques.
Smith et al, ³⁹ <i>Spine</i> , 1991	Review of 17 children operated on for C1-C2 instability; 11 had os odontoideum; posterior wiring techniques, autologous bone, and halo used in all	III	2 of the 11 with os odontoideum had nonunions. 1 cord injury thought secondary to sublaminar wire passage.
Shirasaki et al, ⁸ <i>Spine</i> , 1991	9 patients with os odontoideum and posterior instability had 3 radiographic parameters measured: distance between the os odontoideum and C2 spinous process in extension, distance between the os odontoideum and posterior C1 arch, and "degree of instability"; these findings were compared with their neurological status	III	Those without history or evidence of myelopathy had a distance between the os odontoideum and C2 spinous process in extension of > 16 mm. It was ≤ 16 mm in those with myelopathy. The presence or absence of myelopathy was not related to the degree of instability. In those with myelopathy and a distance between the os odontoideum and posterior C1 arch > 13 mm, there was reversible cord compression in extension. In those with a distance between the os odontoideum and posterior C1 arch of ≤ 13 mm, the cord remained compressed in flexion and extension.
Morgan et al, ² <i>Journal of Neurosurgery</i> , 1989	Report of 3 family members with C2-3 Klippel-Feil abnormalities and os odontoideum	III	Ages: 16 y (index case), 39 y (father), and 64 y (paternal grandmother). None with neurological signs or symptoms.

(Continues)

TABLE. Continued

Reference	Description of Study	Evidence Class	Conclusions
Yamashita et al, ³⁰ <i>Acta Radiologica</i> , 1989	Correlation of clinical status, magnetic resonance imaging, and radiographs in 29 patients with C1-C2 instability; 4 had os odontoideum	III	The atlanto-dens interval did not correlate with the degree of myelopathy, but magnetic resonance imaging degree of cord compression correlated with degree of myelopathy.
French et al, ³² <i>Journal of Pediatric Orthopedics</i> , 1987	Review of dynamic cervical spine radiographs in 185 patients with Down syndrome	III	Six had abnormal odontoids consistent with os odontoideum for an incidence of 3%. 3 had prior radiographs showing no abnormality. 1 had an exaggerated atlanto-dens interval of 6 mm.
Spierings and Braakman, ¹ <i>Journal of Bone and Joint Surgery: British Volume</i> , 1982	37 patients with os odontoideum; 20 treated conservatively	III	Of 20 managed conservatively, 1 was lost to follow-up. 15 had no myelopathy (median follow-up, 5 y), and none developed myelopathy. Of 4 with myelopathy (follow-up, 0.5, 1, 7, and 14 y), 1 died of cancer, 1 has neck pain, 1 has neck pain and paresthesias, and 1 has headaches.
Fielding et al, ⁶ <i>Journal of Bone and Joint Surgery: American Volume</i> , 1980	35 patients (3-65 y of age) with os odontoideum; 25 patients were symptomatic	III	22 patients had anterior instability with a mean atlanto-dens interval of 10.3 mm. 5 had posterior instability. 3 had no detectable motion. 3 had $le < 3$ mm of C1-C2 motion. 26 underwent posterior fusion successfully. 5 were not operated, 3 were asymptomatic with no instability. They remained well with no instability at 1, 2, and 3 y, respectively. 1 patient with instability refused surgery but was well at 2 y of follow-up. 1 patient died of renal failure.
Brooks and Jenkins, ¹⁶ <i>Journal of Bone and Joint Surgery: American Volume</i> , 1978	3 children (8, 11, 12 y of age) with os odontoideum treated with sublaminar C1-C2 wires and autologous iliac crest graft; Minerva cast immobilization	III	All fused. Spontaneous extension of fusion to C3 in 1 child.
Dyck, ⁴⁰ <i>Neurosurgery</i> , 1978	Review of 8 children (7-17 y of age) with os odontoideum; 6 were treated with posterior wiring and fusion of C1-3; external immobilization for "usually" 3 to 4 mo	III	6 children underwent posterior fusion by the author. Two required reoperation.
Griswold et al, ³⁵ <i>Journal of Bone and Joint Surgery: American Volume</i> , 1978	4 patients with os odontoideum treated with sublaminar C1-C2 wires and autologous iliac crest	III	3 fused. 1 did not fuse after 3 attempts.

irreducible deformity with cervicomedullary neural compression in 33 patients with os odontoideum. They described improvement in all patients and no complications related to their dorsal only approach. Although it may seem intuitive to remove ventral neural compression in association with os odontoideum, the literature suggests that treatment with dorsal stabilization and fusion without ventral decompression is an effective management option.

SUMMARY

Plain cervical spine radiographs appear adequate to make a diagnosis of os odontoideum in the vast majority of patients

with this disorder. Lateral flexion and extension radiographs can provide useful information regarding C1-C2 instability. Tomography (CT or plain) may be helpful to define the osseous relationships at the skull base, C1, and C2 in patients in whom the craniovertebral junction is not well visualized on plain radiographs. The degree of C1-C2 instability identified on cervical x-rays does not correlate with the presence of myelopathy. A sagittal diameter of the spinal canal at the C1-C2 level of < 13 mm does correlate with myelopathy detected on clinical examination. MRI can depict spinal cord compression and signal changes within the cord that correlate with the presence of myelopathy.

Surgical treatment is not required for every patient in whom os odontoideum is identified. Patients who have no neurological deficit

and no instability at C1-C2 on flexion and extension studies can be managed without operative intervention. Even patients with documented C1-C2 instability and neurological deficits have been managed nonoperatively without clinical consequence during finite follow-up periods. Most investigators who study and treat this disorder favor operative stabilization and fusion of C1-C2 instability associated with os odontoideum. The concern exists that patients with os odontoideum with C1-C2 instability have an increased likelihood of future spinal cord injury. Although not supported by Class I or Class II medical evidence from the literature, multiple case series (Class III medical evidence) suggest that stabilization and fusion of C1-C2 is meritorious in this circumstance. Because a patient with an initially stable os odontoideum has been reported to develop delayed C1-C2 instability and because there are examples of patients with untreated stable os odontoideum who have developed neurological deficits following minor trauma, surgical consideration and longitudinal clinical and radiographic surveillance of patients with os odontoideum without instability are recommended.

Posterior C1-C2 internal fixation with arthrodesis in the treatment of os odontoideum provides effective stabilization of the atlantoaxial joint in the majority of patients. Posterior wiring and fusion techniques supplemented with postoperative halo immobilization provided successful fusion in 40% to 100% of cases reported. Rigid internal screw fixation and fusion appear to have merit in the treatment of C1-C2 instability in association with os odontoideum and appear to obviate the need for postoperative halo immobilization. Neural compression in association with os odontoideum has been treated with a reduction of deformity, dorsal decompression of irreducible deformity, and ventral decompression of irreducible deformity, each in conjunction with C1-C2 or occipital cervical fusion with internal fixation. Each of these combined approaches has provided satisfactory results. Odontoid screw fixation has no role in the treatment of this disorder.

KEY ISSUES FOR FUTURE INVESTIGATION

A cooperative, multi-institutional, natural history study of patients with os odontoideum without C1-C2 instability would provide demographic and clinical information that may provide predictive factors for the development of subsequent instability. In a related study, the prevalence of os odontoideum as an incidental finding should be established.

The literature supports essentially no treatment for os odontoideum, even with C1-C2 subluxation. Whether activity restriction is called for in these patients would be helpful and should be studied.

A cooperative, multi-institutional, prospective, randomized trial of posterior wiring and fusion techniques with and without C1-C2 rigid internal screw fixation for patients with os odontoideum and C1-C2 instability would help to definitively identify the risks and merits of each of the 2 procedures in this patient population.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Subaxial Cervical Spine Injury Classification Systems

Bizhan Aarabi, MD, FRCSC*

Beverly C. Walters, MD, MSc, FRCSC‡§

Sanjay S. Dhall, MD¶

Daniel E. Gelb, MD||

R. John Hurlbert, MD, PhD, FRCSC#

Curtis J. Rozzelle, MD**

Timothy C. Ryken, MD, MS‡‡

Nicholas Theodore, MD§§

Mark N. Hadley, MD‡

*Department of Neurosurgery, University of Maryland, Baltimore, Maryland; ‡Division of Neurological Surgery, University of Alabama at Birmingham, Birmingham, Alabama; §Department of Neurosciences, Inova Health System, Falls Church, Virginia; ¶Department of Neurosurgery, Emory University, Atlanta, Georgia; ||Department of Orthopaedics, University of Maryland, Baltimore, Maryland; #Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada; **Division of Neurological Surgery, Children's Hospital of Alabama, University of Alabama at Birmingham, Birmingham, Alabama; ‡‡Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa; §§Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona

Correspondence:

Mark N. Hadley, MD, FACS,
UAB Division of Neurological Surgery,
510 – 20th Street South, FOT 1030,
Birmingham, AL 35294-3410.
E-mail: mhadley@uabmc.edu,
205-934-3655 phone, 205-975-6081 fax

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RECOMMENDATIONS

Level I

- The Subaxial Injury Classification (SLIC) and severity scale is recommended as a classification system for spinal cord injury. This system includes morphological, ligamentous, and neurological information in its scoring, thus communicating a greater amount of information regarding the extent of the patient's injury. Its overall inter-rater reliability has an intraclass correlation coefficient of 0.71.
- The Cervical Spine Injury Severity Score (CSISS) is recommended as a classification system for graded instability and fracture patterns in patients with spinal cord injury. Although there is excellent reliability, (intra-observer and interobserver intraclass correlation coefficients for 15 reviewers were 0.977 and 0.883, respectively) the system is somewhat complicated, and its use may be limited to clinical trials rather than daily practice.

ABBREVIATIONS: **ALC**, anterior ligamentous complex; **ALL**, anterior longitudinal ligament; **ASIA**, American Spinal Injury Association; **AIS**, ASIA Impairment Scale; **CSISS**, Cervical Spine Injury Severity Score; **CE**, compressive extension; **CF**, compressive flexion; **DLC**, discoligamentous complex; **DE**, distractive extension; **DF**, distractive flexion; **LF**, lateral flexion; **MIV**, major injury vectors; **PLC**, posterior ligamentous complex; **PLL**, posterior longitudinal ligament; **STSG**, Spine Trauma Study Group; **SLIC**, Subaxial Injury Classification; **TRU**, Trauma Resuscitation Unit; **VC**, vertical compression

Level III

- The Harris classification of subaxial spinal injury is not recommended for describing the bony and soft tissue characteristics seen on imaging studies in spinal cord injury due to its low reliability (intraclass correlation coefficient of 0.42). It may be used in addition to more reliable measures for comparison to previous or other studies using this system.
- The Allen classification of subaxial spinal injury is not recommended for describing the mechanistic and imaging findings in cervical spine and spinal cord injury due to its low reliability (intraclass correlation coefficient of 0.53). Fortunately, this classification system is not in widespread use.

RATIONALE

Cervical spine fractures and fracture dislocations are heterogeneous in pattern and pathogenesis, and difficult to classify. Traditionally, based upon visual (imaging) appearance and a number of ambiguous and descriptive classifications,¹⁻⁵ spine surgeons have preferred using simple, nonspecific terms such as “locked facets,” “wedge” or “burst” fractures in order to infer the mechanics of cervical spine injury, segmental alignment, and instability. Using these classification schemes, algorithms for management in order to achieve spinal cord protection, prevention of deformity, long-term spinal stability and mitigation of pain have been recommended.^{1,2,6} Recent mechanistic classification strategies have taken advantage of radiographs,^{3,7} and in a few instances axial computed tomography (CT),^{1,2} in order to define major vector forces such as flexion, extension, and compression in order to further define injury severity and spinal instability. Many of these

classification schemes are descriptive and cannot be validated easily.^{1,3-5,8,9} With the advent of multi-dimensional reformatting static or dynamic CT and magnetic resonance imaging (MRI), an attempt has been made to introduce classifications with more reliability and validity.¹⁰⁻³⁴ An easy, reliable, and well-validated injury classification system for quantification of skeletal and ligamentous damage may help with communication, management, prognostication, and research in the field of subaxial cervical spine injuries.³⁵⁻³⁸

SEARCH CRITERIA

A computerized search of the National Library of Medicine (PubMed) database of English literature published from 1966 to 2011 was performed focusing on human studies and subaxial cervical spine injury classification systems using MEDLINE medical subject headings and keywords “cervical spine trauma,” “cervical spine injury,” “cervical spine injury classification,” and “subaxial cervical spine injury.” Approximately 28 500 citations were obtained. Additional search terms “Cervical Spine Injury Classification” resulted in 593 citations, “lower cervical spine injury classification” resulted in 87 citations, and “subaxial cervical spine injury classification” resulted in 25 citations. Titles and abstracts of these 112 manuscripts were reviewed. Additional publications were cross-referenced from the citation lists of these papers. Finally, the members of the author groups were asked to contribute articles known to them on the subject matter that were not found by other search means. Duplications, case reports, pharmacokinetic reports, general reviews, editorials, and critiques were excluded. Twenty-one manuscripts were fully reviewed and contributed to the topic of subaxial cervical spine injury classification systems; 4 of which contributed to the formulation of recommendations and are summarized in Evidentiary Table format at the end of this paper (Table 3).

SCIENTIFIC FOUNDATION

Anatomy

Each subaxial motion segment is made of 2 subjacent vertebrae connected together by the intervertebral disc, the posterior arch ligaments, and the facet joints. Facet joints in the subaxial spine are almost flat (~45 degrees with horizon) and the angle of inclination increases from C7 to C3.^{3,9} In their classification scheme, which applies best to the cervical spine, Holdsworth and Panjabi et al divided the cervical spine motion segments into 2 columns or elements: (1) Anterior: anterior longitudinal ligament (ALL), anterior annulus, vertebral bodies, transverse processes, posterior annulus, and the posterior longitudinal ligament (PLL); and (2) Posterior: ligamentum flavum, facet capsules, interspinous ligament, supraspinous ligament, pedicles, laminae, and the spinous processes^{3,9} (Figure 1).

CLASSIFICATION SYSTEMS

Holdsworth Classification

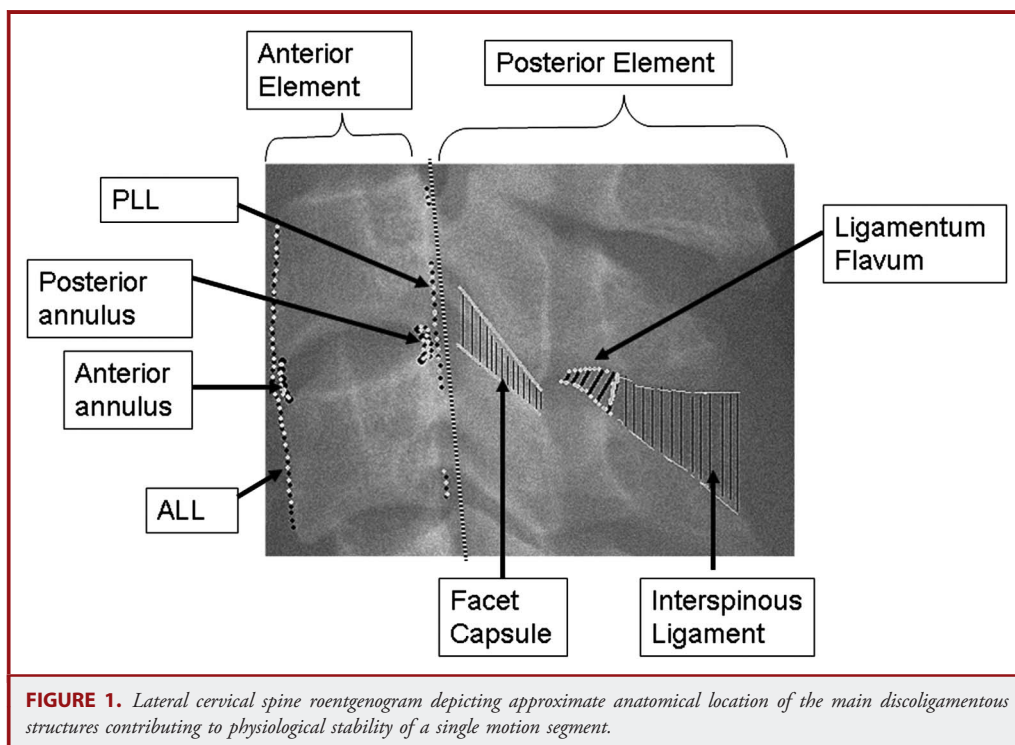
In 1949, Nicoll⁵ introduced the concept of stability and instability in the treatment of thoracolumbar injuries. In 1963, based on clinical, radiological, surgical, and postmortem observational studies of 1000 patients, Holdsworth^{3,39,40} proposed his 2-column concept of thoracolumbar and cervical spine stability/instability, emphasizing the importance of posterior ligamentous complex (PLC) and the morphology of facet joint sustaining violence. PLC was composed of interspinous, supraspinous, and capsular ligaments, and ligamentum flavum. Holdsworth's observational studies indicated the absolute necessity of flexion/rotation for disruption of PLC; pointing out that direct longitudinal pull along PLC fibers rarely, if ever, results in rupture, unless the intensity of trauma is extremely high. According to Holdsworth, 5 patterns of trauma can cause fractures or fracture dislocations of the spine: (1) Flexion, (2) Flexion/rotation, (3) Extension, (4) Compression, and (5) Shear (Figure 2). Flexion results in wedge fractures, which are usually stable, while flexion/rotation forces result in fractures or fracture/dislocations that are usually unstable. Extension will rupture the disc space; however, the PLC stays intact (stable in flexion). Compression will produce a burst, but because of the intactness of the PLC, these fractures are usually stable. Stability is lost in shearing injuries (Figure 2). Holdsworth's classification system establishes the importance of segmental ligaments and the influence of facet anatomy in determining stability. However, despite its apparent simplicity, it has not been widely put into practice and has never been validated.

Allen's Mechanistic Classification

As conceptualized by Allen and associates, translation of kinetic energy into fractures and dislocations is determined by 2 independent variables: injury vector and the posture of the cervical spine at the time of accident. Using these mechanistic analogies and the pattern of segmental failure on radiographs of the cervical spine from 165 patients, in 1982 Allen et al introduced their classification of the subaxial cervical spine fractures and dislocations. These investigators presumed that identical segmental failures could result from injury vectors of the same magnitude when applied to cervical spines set in similar postures.⁷ Based on the mechanism of injury, fractures and dislocations occur in families, or phylogenies, with specific anatomic derangements. These families of fractures and dislocations include: (1) Compressive Flexion, (2) Vertical Compression, (3) Distractive Flexion, (4) Compressive Extension, (5) Distractive Extension, and (6) Lateral Flexion (Figure 3). The nomenclature in each category describes the forces upon the cervical spine at the time of injury and the magnitude of the force vector. Within each category, a series of injuries were described from mild to severe stages (Figure 3).

Compressive Flexion (CF)

Up to 36 percent of the 165 patients described by Allen et al had evidence of compressive flexion injury of 5 degrees of severity. This

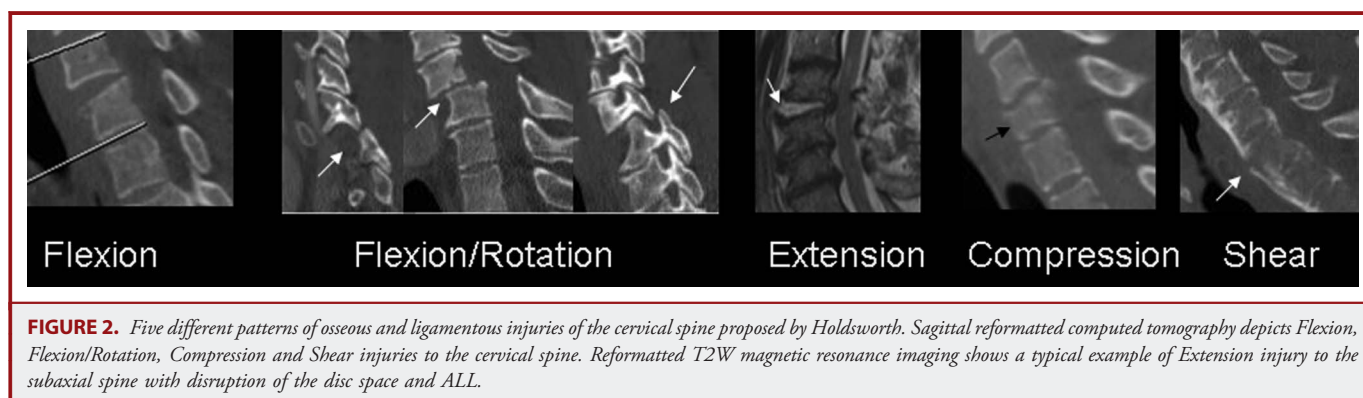


fracture most frequently occurred at C5/6 with the C5 body sustaining the CF injury.

- a. CF stage 1: Blunting of the anterior superior vertebral margin was seen in 36 patients, none of which had any evidence of neurological deficit and failure of posterior arch ligaments (Figure 4A).
- b. CF stage 2: A “Beak” vertebral body and loss of height is characteristic of CF stage 2. Seven of the 165 patients had this radiographic pattern of injury, 1 of whom had central cord syndrome (Figure 4B).
- c. CF stage 3: There is a fracture line through the “beak-form” vertebral body but there is no translation of the vertebral bodies. Two of the 4 patients in this category had a neurological

deficit; 1 had a central cord injury, and the other 1 had a complete spinal cord injury (Figure 4C).

- d. CF stage 4: Patients in CF stage 4 had less than 3 mm translation of the fractured bodies. Of 8 patients in this category, 2 had central cord syndrome, 1 had a partial lesion, and 3 had a complete spinal cord injury (Figure 4D).
- e. CF stage 5: There is more than 3 mm of translation of the vertebral bodies. One of 11 patients with CF stage 5 had a central cord injury and the remaining 10 had complete spinal cord injuries. In CF stage 5, the posterior aspect of the anterior element ligaments and the entire posterior arch ligaments are disrupted (Figure 4E).



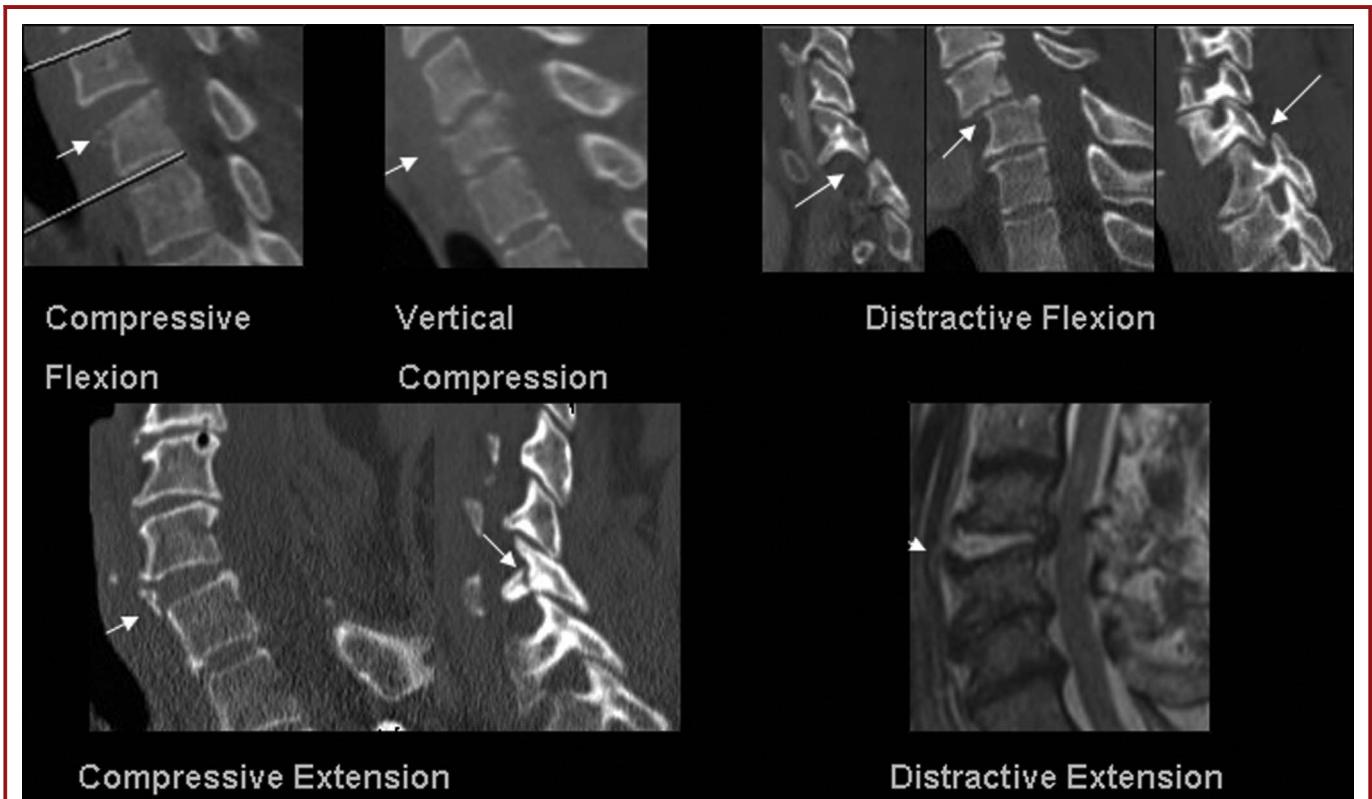


FIGURE 3. Reformatted computed tomography (Compressive Flexion, Vertical Compression, Distractive Flexion and Compressive Extension) and magnetic resonance (MR) views (Distractive Extension) of the Mechanistic Classification of Allen and associates. Each phylogeny can have several stages of injuries.

Vertical Compression (VC)

In vertical compression, the compressive force is transmitted to the cervical spine with the neck in a neutral position. In the series of 165 patients reported by Allen et al, 14 had vertical compression. Of the 14, 5 were in stage 1, 4 were in stage 2, and 5 were in stage 3.

- VC stage 1: There is a “cupping” deformity of either the superior or the inferior endplate, without evidence of ligamentous failure. One of 5 patients had central cord syndrome.
- VC stage 2: There is a “cupping” deformity of both endplates. None of the 4 patients in this series had a neurological deficit (Figure 5A).
- VC stage 3: There is extensive fragmentation and bursting of the vertebral body in this category. The posterior part of the body may be bulging into the canal and the ligamentous structures may or may not be disrupted. Three of 5 patients in this stage had complete cord injury (Figure 5B).

Distractive Flexion (DF)

In distractive flexion injury, vector force is transmitted to the occiput while the neck is in flexion. Sixty-one of the 165 patients in this series had DF injuries. In descending levels in the subaxial spine, there is an increase in stage and the degree of severity of neurological

deficit with the C6/7 interspace most commonly involved in DF stage 4 and with the greatest number of complete injuries. Fifty-seven percent of DF stage 4 occurred at C6/7. The DF category is a typical example of tension-shear of the posterior arch ligaments.

- DF stage 1: There is facet subluxation in flexion with divergence of the spinous processes. Twelve of 61 patients in the DF category had DF stage 1 injuries (Figure 6).
- DF stage 2: There is a unilateral facet dislocation (locked facet, interlocked facet) with varying degrees of posterior arch ligamentous failure. Rotary listhesis may be seen in the injured motion segment (Figure 7A).
- DF stage 3: In this stage there is a bilateral facet dislocation with a degree of listhesis of up to 50%. Seventeen of 61 patients in this series had DF stage 3 injuries (Figure 7B).
- DF stage 4: There is extreme translation of 1 vertebral body on the other 1, hence “floating vertebra,” and there are bilateral locked facets. There is significant failure of the posterior arch ligaments and there may be significant injury to the posterior arch (Figure 7C).

Compressive Extension (CE)

In CE, there is a blow to the forehead or face that forces the neck into extension and thrusts the head toward the torso. The major

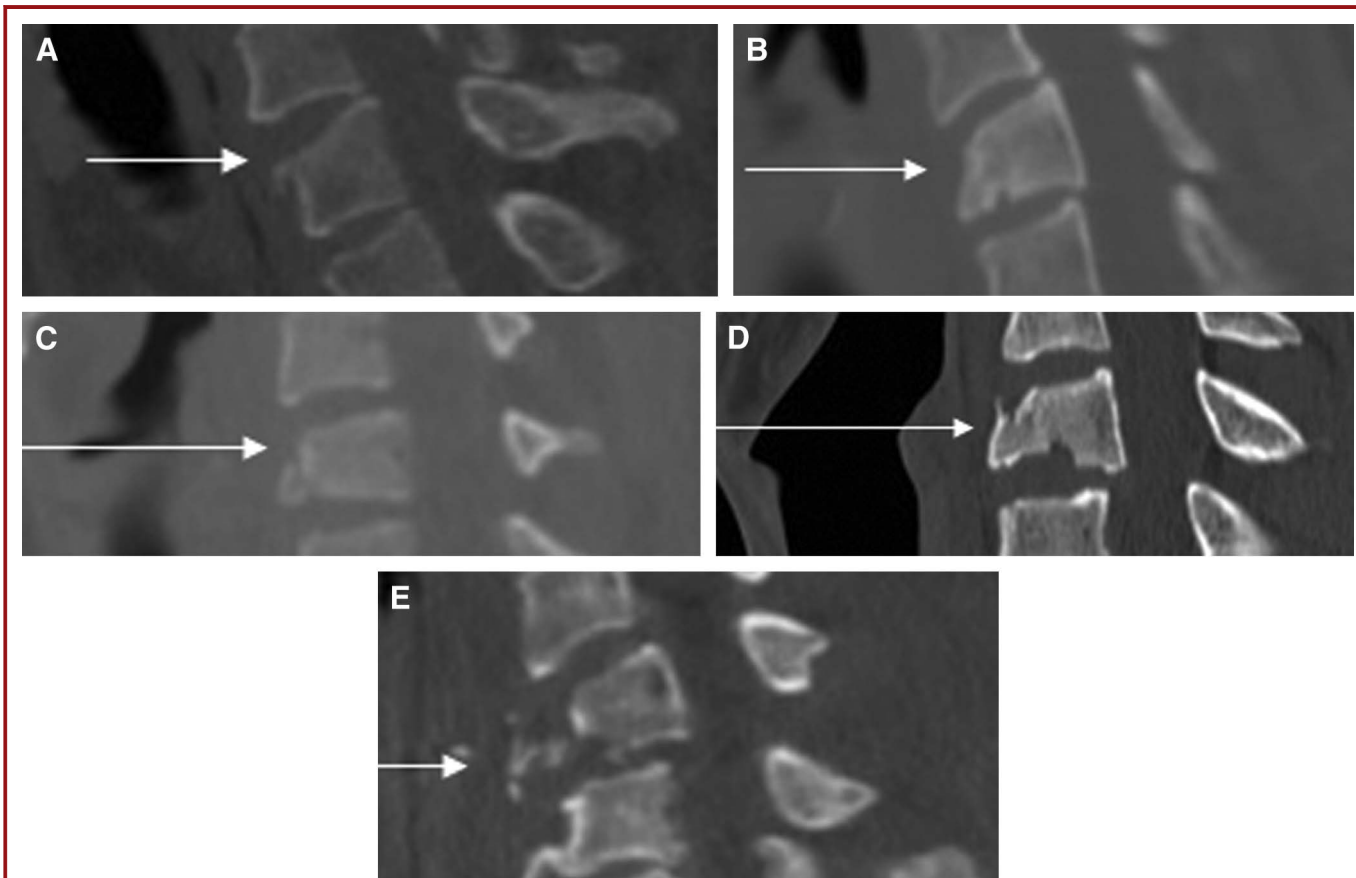


FIGURE 4. Reformatted sagittal computed tomographic views (A-E) of cervical spine indicating compressive flexion (CF) phylogeny stages 1 to 5 of Allen et al Classification. CF stage 1 (A) is associated with blunting of the antero-superior end plate of the vertebral body. In CF stage 2 (B) there is a “beak-shape” deformity of the vertebral body without translation. In CF stage 3 (C) there is a “broken beak” of the vertebral body without translation. CF stage 4 (D) indicates a broken beak with up to 3 mm translation and in CF stage 5 (E) we have a broken vertebral body with more than 3 mm translation. Stages 4 and 5 are very much reminiscent of “teardrop” fractures.

injury vector stresses posterior elements in compression. There is fracture or impaction of the posterior arch. Forty of the 165 cases in the Allen series suffered from CE with stage 1 as the most frequent (32 cases). Although theoretically sound, the authors did not present any CE stage 3 or CE stage 4 cases. The majority of CE stage 1 and CE stage 2 injuries were concentrated at the C6/C7 motion segment.

- a. CE stage 1: Unilateral fracture of an articulating process, combined unilateral pedicle and lamina fracture (floating lateral mass) or combined pedicle and articulating process fractures are grouped in CE stage 1. There may be slight rotary listhesis of subjacent bodies. The majority of patients with CE stage 1 injury had no deficit. However, 8 patients did suffer from radiculopathy, 4 from partial spinal cord injuries, and 1 from a complete spinal cord injury (Figure 8A).
- b. CE stage 2: Pathology in CE stage 2 is a bilaminar fracture of the posterior arch that could occur at multiple levels. Five of 40 cases in this report had a CE stage 2 injury.
- c. CE stages 3 and 4: There are bilateral vertebral arch fractures at the corners (eg, facets, pedicles or laminae). In CE stage 4, but

not in CE stage 3, there is partial vertebral body width displacement anteriorly. Allen et al did not encounter any patients in this category (Figure 8B).

- d. CE stage 5: Two motion segments are involved with bilateral posterior arch fractures and full anterior displacement of 1 vertebral body on the other. Three patients in this series had CE stage 5. Despite significant injury to 2 subjacent motion segments, none of the 3 patients in this series had a complete spinal cord injury (Figure 9).

Distractive Extension (DE)

In DE, the neck is extended and the vector force is applied over the anterior calvarium or face. This is typically seen in the elderly who fall on their faces from a sitting or standing position. There is widening of the disc space or a transverse non-deforming fracture of the vertebral body. Nine of 165 patients in this series had DE. The investigators believed the incidence of this entity is underreported (Figure 10).

- a. DE stage 1: In DE stage 1, there is widening of the interspace with possible chip fracture of the anterior lips of the

spinal cord injury. Seven of 9 patients had DE stage 2 and all except 1 had a neurological deficit (Figure 10).

Lateral Flexion (LF)

A major compressive injury vector (slow forced flexion of the head towards 1 shoulder) on 1 side causes vertebral arch fracture and a minor distractive injury vector on the opposite side produces asymmetric compression of 1 motion segment (LF stage 1). In LF stage 2, in addition to an ipsilateral compression fracture of the posterior arch, there is displacement of 1 body on the other. Five of 165 patients in this series were classified in this category, with 3 in stage 1 without deficit, and 2 in stage 2 with no deficit, 1 of whom had a complete spinal cord injury.

In summary, Allen's classification system for subaxial cervical spine fractures provides more mechanistic detail than that proposed by Holdsworth, but the utility of such detail remains unknown. Attempt at measurement of reliability has been undertaken and the intraclass correlation coefficient is only 0.53.³⁸ The additional intricacies make the system more complicated and likely explain why, despite having been published almost 30 years ago, this classification system is not widely used.

Harris Classification

Based on biomechanical, cadaveric, and pathological evidence that vector forces along the "central coordinating system" are fundamental determinants of cervical spine injuries, Harris and his colleagues introduced yet another mechanistic classification

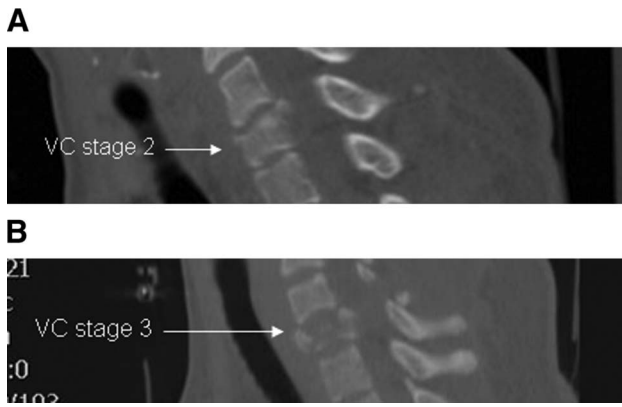


FIGURE 5. Reformatted sagittal computed tomography views of cervical spine indicating vertical compression (VC) fracture stages 2 and 3 of Allen et al Classification. In VC stage 2 (A) there is cupping of superior and inferior end plates of C6 vertebral body and in VC stage 3 (B) there is significant compression fracture of the vertebral body with protrusion of bone fragments into the spinal canal. The latter is an example of a burst fracture.

cephalad or caudad vertebrae. There were 2 patients in this series demonstrating this finding; neither had a neurological deficit.

- b. DE stage 2: In addition to a widened disc space, there is failure of the posterior arch ligaments, with an added opportunity for

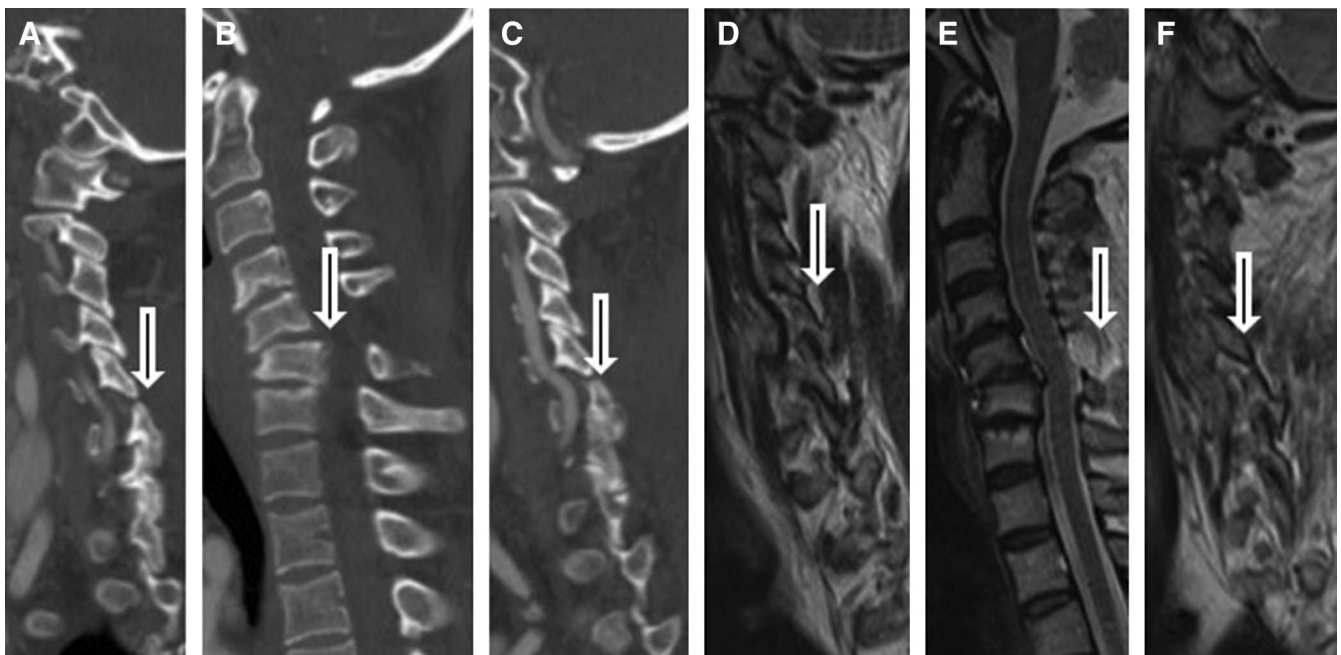
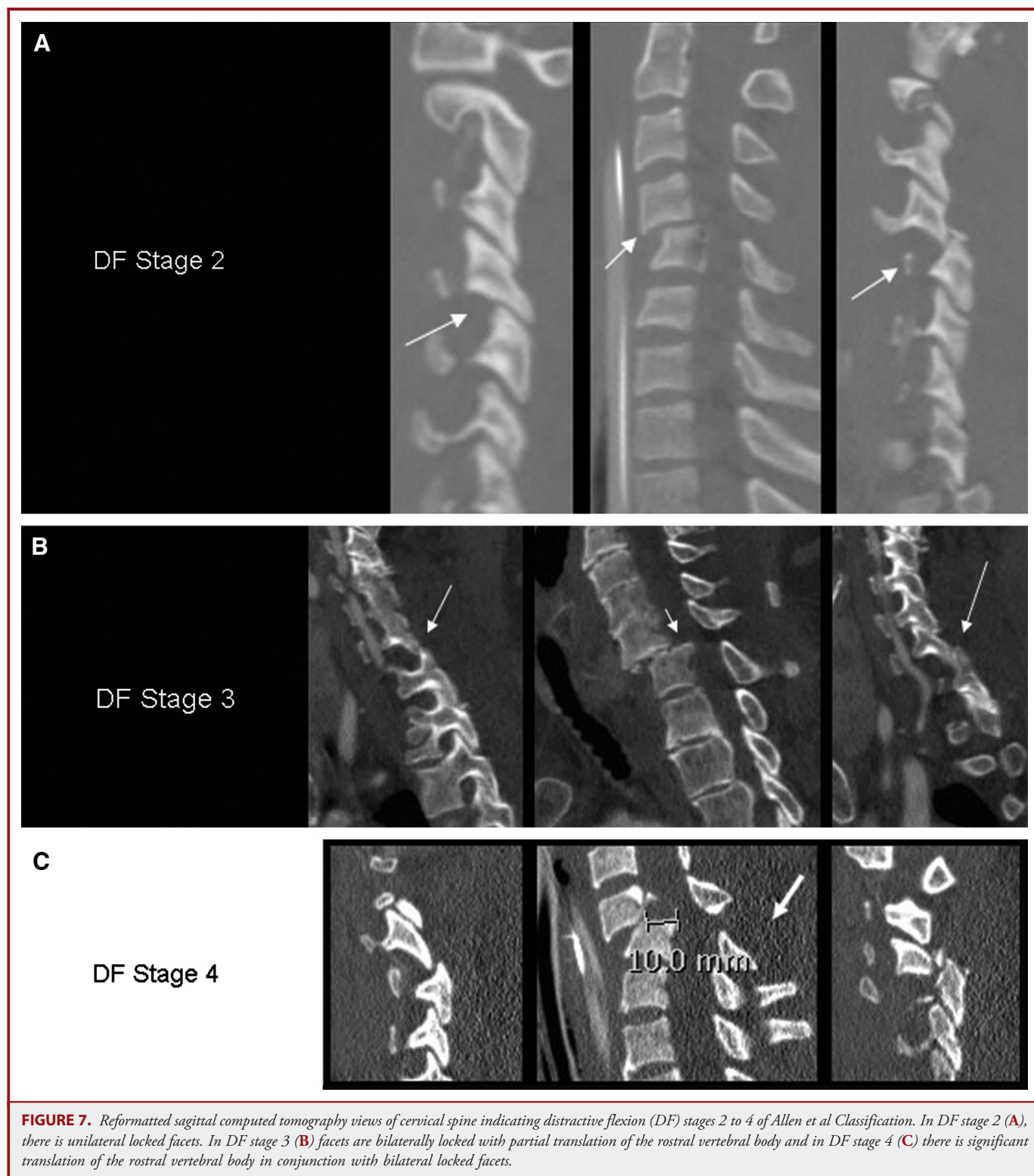


FIGURE 6. Sagittal reformatted views of cervical spine indicating distractive flexion stage 1 phylogeny of Allen et al Classification (A, B, C) associated with significant ligamentous injury (D, E, F).



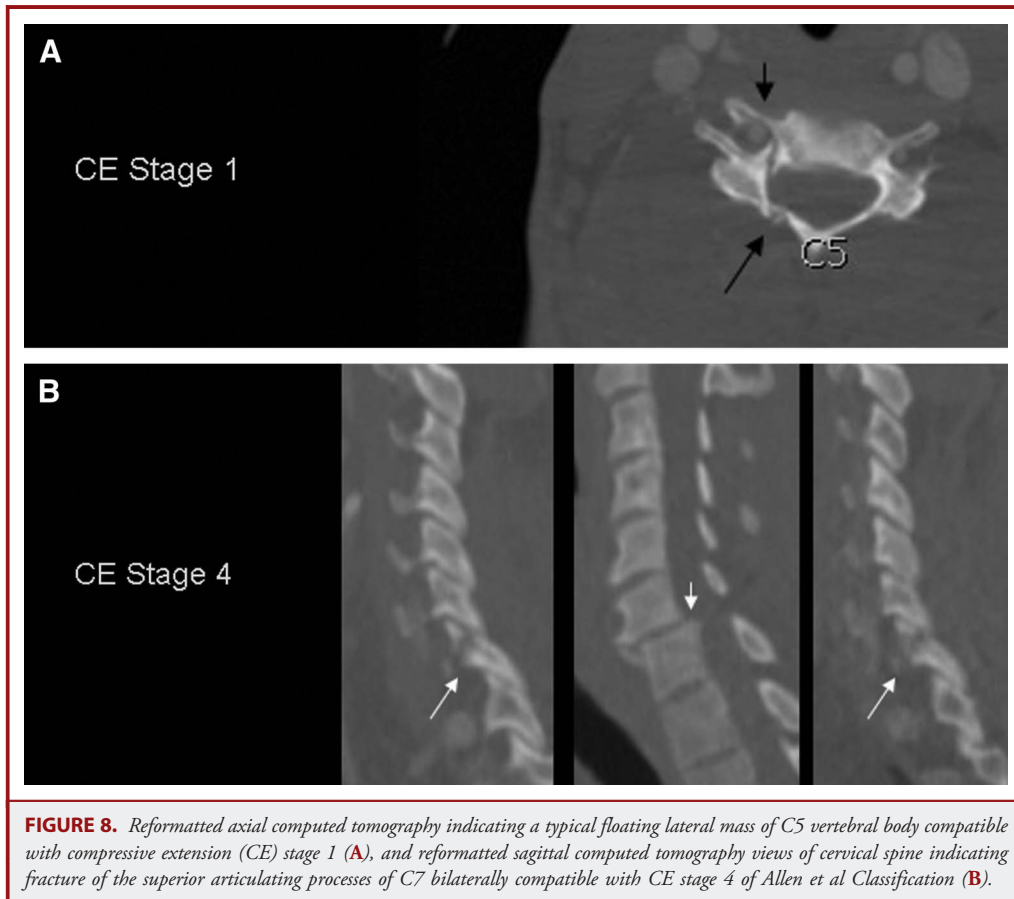


FIGURE 8. Reformatted axial computed tomography indicating a typical floating lateral mass of C5 vertebral body compatible with compressive extension (CE) stage 1 (A), and reformatted sagittal computed tomography views of cervical spine indicating fracture of the superior articulating processes of C7 bilaterally compatible with CE stage 4 of Allen et al Classification (B).

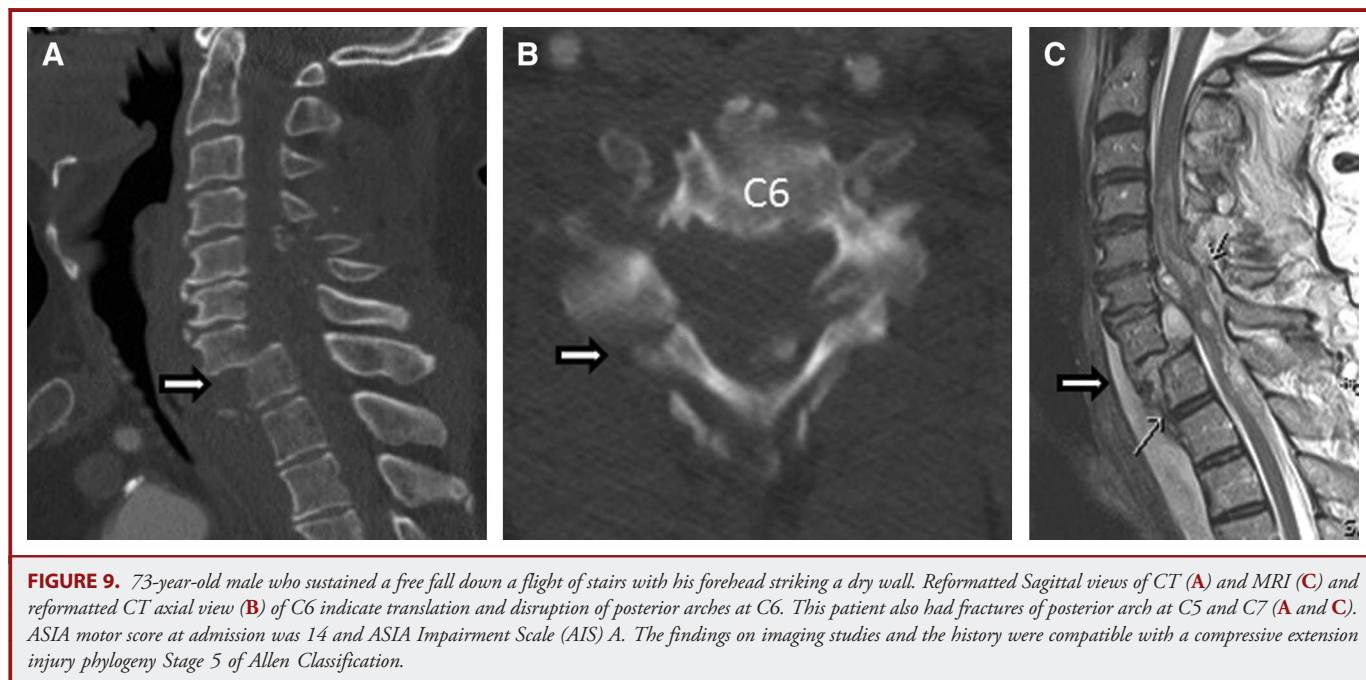
system for cervical spine fractures and dislocations in 1986.² This classification was also derived from data from the literature, and from clinical and radiographic observations. Major vector forces were flexion, extension, rotation, vertical compression, and lateral bending. A combination of vector forces such as flexion-rotation, extension-rotation, and lateral bending may produce added varieties of injuries. It was believed that specific vector forces and the magnitude of causative force determine groups of injuries that could be used in a new classification.

Flexion

- a. Anterior subluxation (hyperflexion sprain): Flexion vector forces along the Z-axis produce bilateral disruption of posterior ligamentous complex, including the joint capsules. On radiographs, there is widening of the interspinous ligament (Figure 11). There is a 30 to 50% chance of delayed dislocation if not managed properly. This category is identical with distractive flexion stage 1 described by Allen et al.
- b. Bilateral interfacetal dislocation: In this category, there is dislocation or locking of both facet joints. There may be evidence of translation of up to 50%. Anterior and posterior

ligamentous complexes are disrupted, producing complete instability of the involved motion segment. In the Allen et al classification, this pathology is referred to as distractive flexion injury stage 3 (Figure 7B).

- c. Simple wedge (compression) fracture: In this class of injuries, the body of the involved vertebra assumes a wedge deformation. PLC may or may not be disrupted. In the Allen et al classification, this category ranged from compressive flexion injury stages 1 to 3 as described above (Figure 4A-C).
- d. Clay-shoveler (coal-shoveler) fracture: a vertical fracture through the spinous processes of C6, C7 and T1 is the result of forced flexion of the neck with intense tightening of interspinous and supraspinous ligaments.
- e. Flexion teardrop fracture: The degree of flexion and anatomical injury in this category is quite substantial. There is a triangular fracture of the body with encroachment into the spinal canal (Figure 4D-E). Anterior ligamentous complex (ALC) and PLC are both disrupted and there is a flexion deformity of the cervical spine at that motion segment. Neurological injury is severe, and in the Allen et al classification, this category is designated as compressive flexion stages 4 and 5.



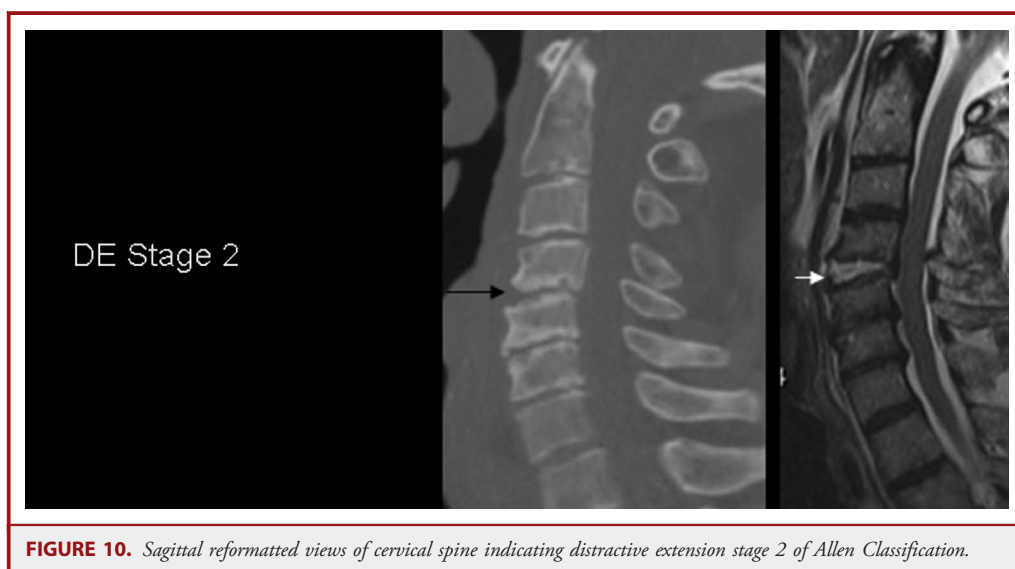
Flexion-Rotation

Unilateral interfacetal dislocation: A combination of major forces of flexion and rotation is the main pathogenetic mechanism in this category of cervical spine injury. This pattern of injury is also referred to as unilateral locked facet. There may be less than 50% translation of the bodies of the involved motion segment. The ligamentous complex is usually partially damaged. Allen et al designated this injury as distractive flexion stage 2 (DFS2, see

above). The locked superior and inferior articulating processes may have small splinter fractures at the tip (Figure 7A).

Extension-Rotation

Pillar fracture: Extension and impaction of the articulating processes in Z-axis results in fracture of the articulating processes. In the Allen Classification, this category is referred to as compressive extension stage 1 (see above). There is no translation





and the patient may have radicular symptoms because of impaction upon the neural foramen involved (Figure 8A).

Vertical Compression

- a. Jefferson fracture of the atlas: In this class of upper cervical spine injuries, vertical compression along the Y-axis will fracture the C1 arch and lateral dislocation of C1 lateral masses.
- b. Burst (bursting, dispersion, axial loading) fracture: Translation of vector forces along the Y-axis via the occipital condyles or sacrum when the cervical spine is in a neutral position will result in a burst fracture with possible retropulsion of fragmented bone into the spinal canal. There may be a bilaminar fracture of the posterior arch. In plain radiographs, a straight cervical spine will differentiate this injury from a tear drop fracture (CF stages 4 and 5), which is a flexion injury. In the Allen Classification, a burst fracture is under the vertical compression category and has a stage 3 character (VCS3, see above) (Figure 5B).

Hyperextension

- a. Hyperextension dislocation: Extreme vector forces in the Z-axis will disrupt the ALL and intervertebral disc and put tension on the PLL. There may be end plate avulsion fractures (in up to 60%) of the involved motion segment. Some translation of the vertebral bodies without fracture of the posterior arch is not unusual. Allen et al classified the injury as distractive extension stage 2 (DES2, see above) (Figure 10).
- b. Avulsion fracture of anterior arch of the atlas: Hyperextension vector force against the anterior tubercle of atlas via intact longus colli and the atlantoaxial ligament may cause a horizontal fracture of atlas.

- c. Extension teardrop fracture of the axis: Translation of hyperextension vector forces via an intact ALL can result in an avulsive triangular fracture of antero-inferior portion of C2. This phenomenon is especially prevalent in patients with cervical spondylosis and osteopenia.
- d. Fracture of the posterior arch of the atlas: Impaction of the posterior arch of the atlas between the occiput and the posterior arch of C2 during hyperextension is considered to be the pathogenic mechanism behind this fracture.
- e. Laminar fracture: Laminar fractures were considered as compressive extension injury stage 2 (CES2).
- f. Traumatic spondylolisthesis (hangman's fracture): This is the classic bilateral fracture of the pars interarticularis of C2 in extreme hyperextension.
- g. Hyperextension fracture-dislocation: Extreme hyperextension may cause fracture of the posterior arch through the lateral masses and facets, and in severe degrees, dislocation of 2 subjacent motion segments. This category of fractures corresponds to Allen et al's compressive extension stages 3, 4, and 5 (CES4-5, see above) (Figure 9).

Lateral Flexion

Uncinate process fracture: This fracture occurs along the X-coordinate by extreme lateral flexion of the cervical spine.

Diverse or Imprecisely Understood Mechanisms

- a. Atlanto-occipital dissociation: These are described in detail elsewhere in this publication. The exact pathogenic mechanisms of atlantooccipital and atlantoaxial dissociation injuries are unknown.
- b. Odontoid fractures: Horizontal transmission of vector forces, flexion, extension, and rotation, from the skull base into the

odontoid process may cause odontoid fractures. These are described in detail elsewhere in this publication.

In summary, Harris added to the classification systems already proposed by Holdsworth and Allen et al.^{2,3,7} However, much like the Allen classification system, this 1 is highly detailed with respect to presumed injury mechanism, yet has questionable utility in guiding treatment or predicting outcome. Similar to the Holdsworth and Allen systems, the Harris classification system, when subjected to a validation process by Vaccaro et al,³⁸ demonstrated an intraclass correlation coefficient of only 0.42. Nonetheless, the descriptive components of this system that describe the anatomic areas of failure (eg, bilateral facet dislocation) have been widely adopted and are commonly used as a means of describing subaxial cervical spine trauma.

White and Panjabi Clinical Checklist

In 1990, White and Panjabi described a formula for evaluating fracture stability. Under normal physiological conditions, cervical spine movements are smooth, effortless, pain-free, and do not produce neurological symptoms. Two fundamental structures of cervical motion segments facilitate abnormal kinematics: discoligamentous complex and the articulating facet joints.^{7,38,39,41,42} White and Panjabi's extensive biomechanical investigations reproduced the share of each motion segment in maintaining stability. Based on these cadaveric experiments, ALL and PLL best maintained the stability of the anterior element, and joint capsules and the anatomy of facets were most important in maintaining posterior stability (Figure 1).

The stability check list (Table 1) introduced by White and Panjabi was based on these studies.⁴³ One should consider the fact that White and Panjabi's checklist was based on radiographs, before the widespread use of CT and MRI. Similarly, some maneuvers, such as stretch testing or dynamic studies, may not be compatible with the present standards of cervical spine clearance in patients with traumatic brain or cervical spine injuries.^{11,22,28,29,32,44-52} Nonetheless, many of the principles for determining stability upon which the checklist is built remain widely utilized in clinical practice today, albeit in a less formal manner. The checklist has never been validated nor its reliability measured.

CSISS

In 2007, Anderson³⁵ and a working group of the Spine Trauma Study Group (STSG) surgeons introduced a new classification system, the CSISS, which considers the premise that instability is not a binary status and that grades of instability must be defined, scored, and considered in any new classification. In this classification, the degree of discoligamentous injury is scored by the degree of skeletal displacement or osseous displacement on computed tomography. A cervical spine motion segment is divided into 4 columns: vertebral body, including ALL, annulus and PLL; right facet joint and capsule; left facet joint and capsule; and laminae including the spinous processes, pedicles, interspinous and supraspinous ligaments (Figures 1 and 12). Depending on the extent of skeletal or fracture line separation (0-5 mm), each column was given a weighted score of 0 to 5, therefore, collective scores of 0 to 20. Scores were given to a young male driver with distractive flexion stage 5 of Allen et al and complete spinal cord injury (Figure 7C). Right and left pillars were each given a maximum score of 5. Anterior column and posterior columns were also given each a score of 5 because of spondyloptosis and widening of the spinous processes of cervical vertebrae 4 and 5, and rupture of ligamentum flavum on the MRI. The total score in this case was 20. The patient had circumferential fusion to ensure long-term stability. Anderson et al recommended surgical fixation for all patients having a score of 7 or more. Validity and reliability of this classification were calculated after 15 surgeons reviewed the clinical and imaging studies of 34 patients. The mean intraobserver and interobserver intraclass correlation coefficients for 15 reviewers were 0.977 and 0.883, respectively. In addition, internal consistency can be inferred from the fact that the higher the score, the worse the injury—every injury over a score of 10 includes significant bony injury and neurological compromise.

Anderson's system provides a detailed analysis of fracture pattern and stability, which may be of use in guiding management decisions. An attempt at establishing reliability and validity has been published. However, the system is complicated, which may interfere with incorporation into routine practice.

TABLE 1. Stability Checklist as Suggested by White and Panjabi^a

Diagnostic Checklist Elements	Point Value	Individual Clinical Value
Anterior elements destroyed or unable to function	2	
Posterior elements destroyed or unable to function	2	
Relative sagittal plane translation >3.5 mm ⁺	2	
Relative sagittal plane rotation >11 degrees	2	
Positive Stretch test	2	
Cord damage	2	
Root damage	1	
Abnormal disc narrowing	1	
Dangerous loading anticipated		

^aA total of 5 points or more = unstable + or a translation >20% of the anteroposterior diameter of the involved vertebrae.

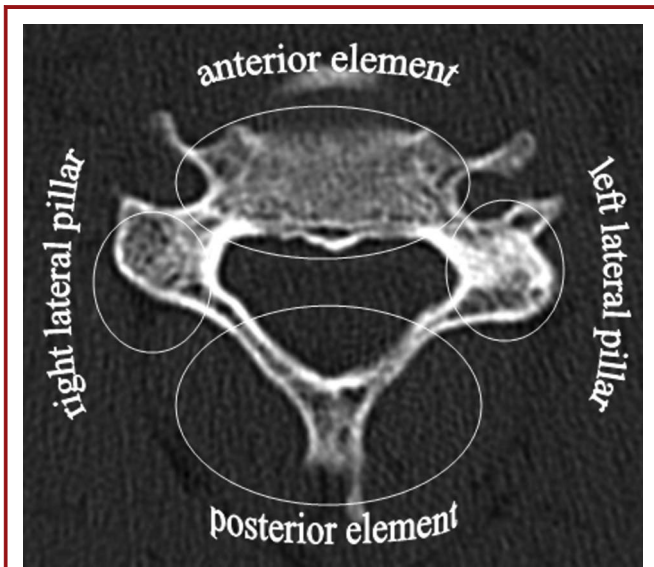


FIGURE 12. Axial reformatted CT scan of the cervical spine depicting the 4-anatomical pillar concept of Anderson Classification.

SLIC

SLIC was introduced in 2007 by Vaccaro and the STSG (Table 2).³⁶⁻³⁸ The objective behind this classification was to quantify stability. The scale was based on literature reviews, consensus agreements, and limited validity determinations. In order to standardize and quantify injury severity and concomitant disrupted stability of the anterior and posterior elements of a motion segment, a weighted score was given to 3 parameters of morphology, discoligamentous complex (DLC) and neurological examination.

Morphology of a fracture or fracture/dislocation was assessed by a reformatted CT scan of the cervical spine, and the ligamentous injury was graded by review of the MRI or indirectly by computed tomography. Criterion, or more specifically concurrent, validity was determined by seeking agreement between SLIC and the Allen et al.

Classification.⁷ Compressive flexion injuries (Stages 1-3) were named as “compression” and vertical compression as “burst.” Distractive flexion injuries (Stages 2, 3, and 4) were designated as “translation-rotation” and distractive flexion stage 1 as “distraction.” Compressive extension stages 1, 2, and 3 are considered as compression, and distractive extension stage 1 was assigned to “distraction,” as well. Compressive flexion stages 4 and 5, distractive extension stage 2, and compressive extension stages 4 and 5 were considered as translation-rotation. Reliability and validity of the SLIC and Severity Scale were calculated after 20 spine surgeons reviewed the clinical studies, including imaging, of 11 patients twice within 6 weeks. They graded the injury severity, instability, and recommendation for either surgical or non-surgical management. Inter-rater agreement as assessed by intraclass correlation coefficient of the morphology, DLC, and neurological status scores were 0.49, 0.57, and 0.87, respectively. Intra-rater agreement as assessed by intraclass correlation coefficient of the morphology, DLC, and neurological scores were 0.66, 0.75, and 0.90, respectively. There is somewhat of an implicit consistency in that the worse the injury, the more invasive the treatment, and the worse the patient’s condition. In addition, agreement upon treatment indicated using the scoring system has been reported at 74%.

SLIC and Severity Scale in Detail

Morphology (Figure 13)

Compression. All the compression fractures, regardless of the flexed or neutral position of the neck at the time of axial loading, are grouped here. This includes the compression and burst fracture of Denis¹ or wedge and burst fractures of Harris² and Holdsworth.³ Compressive flexion S1-3 and vertical compression fractures of Allen et al are grouped in this category.⁷ Typically, teardrop fractures and CFS 4-5 with translation are not in this category; however, facet fractures (compressive extension stages 1-3) are allowed (Figure 13A-B).

Distraction. Morphology in this category of injury is anatomic dissociation of the motion segment in the vertical axis with significant injury to discoligamentous complex. In Harris et al² classification,

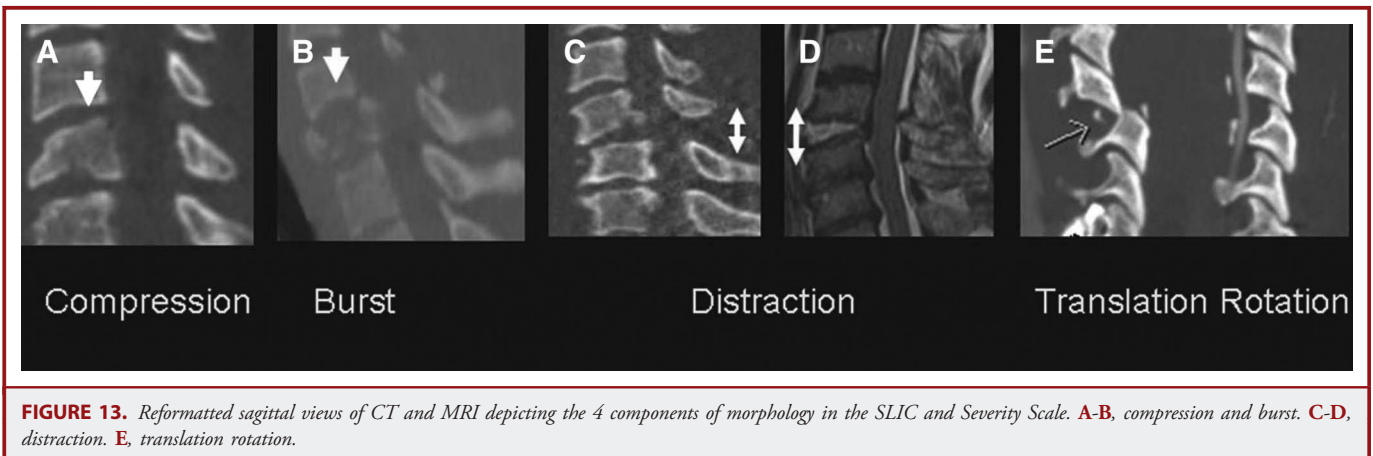


FIGURE 13. Reformatted sagittal views of CT and MRI depicting the 4 components of morphology in the SLIC and Severity Scale. A-B, compression and burst. C-D, distraction. E, translation rotation.

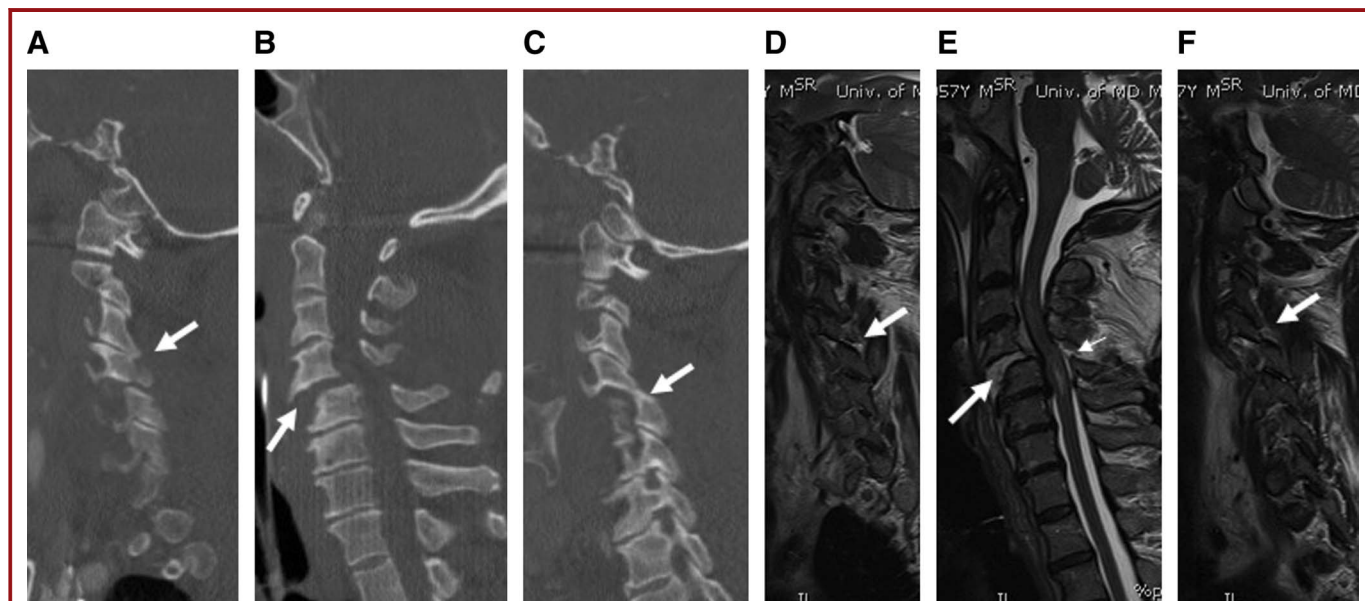


FIGURE 14. 57-y-o male with motor vehicle accident 8 hours prior to admission and manifesting incomplete spinal cord injury in form of acute traumatic central cord syndrome. The SLIC severity score was 10. Sagittal reformatted views of CT and MRI depicting unilateral facet subluxation on the right side (**A, D**), significant translation (**B, E**) and perched facet on left side (**C, F**). Magnetic resonance imaging showed complete disruption of ALL, annulus, PLL, ligamentum flavum, interspinous and supraspinous ligaments.

this form of injury is hyperflexion sprain or facet subluxation (Figure 13C-D), and in the Allen et al⁷ classification, the following injuries are included in this category: distractive flexion stage 1 (DFS1), vertical distraction, and distractive extension stage 1. Fractures of the posterior elements, such as facets and laminae or spinous processes, are not unusual in this category.

Translation Rotation. When evaluating the pattern of injury involving the vertebral bodies of a motion segment, a horizontal translation of more than 3.5 mm or a sagittal angulation of more than 11 degrees signifies major disruption of anterior or posterior ligamentous complex, hence, eligible for the highest¹³ weighted score in calculating the SLIC and severity scale. There may or may not be bony damage to the spinal columns (Figure 13E and Figure 14).

Bilateral interfacetal dislocation (bilateral locked facets), flexion teardrop fractures, unilateral interfacetal dislocation, and hyperextension fracture-dislocations of Harris et al²; and compressive flexion stage 5, distractive flexion stages 2, 3 and 4, compressive extensions stages 4 and 5, and distractive extension of stage 2 in Allen et al⁷ classification fall in this category of SLIC classification and severity scale (Figure 15).

Discoligamentous Complex

The integrity of discoligamentous complex is crucial for maintaining normal bony relationships and providing restraint for the cervical spine against deforming forces while allowing movement of the spine under normal physiological loads. ALL, anterior annulus, posterior annulus, PLL, ligamentum flavum, facet capsules, interspinous and supraspinous ligaments form major components of DLC (Figure 1).⁹

The most important structure resisting hyperextension is the ALL, while the joint capsules resist hyperextension.^{41,42} Roaf's study of the mechanics of spinal injuries indicated that it was impossible to produce DLC injury with extreme hyperflexion or hyperextension.^{53,54} Evaluation of the integrity of the DLC is either by inference, such as locked facets (Figures 11 and 14), or by MRI evidence (Figure 14D-F). Using computed tomography, articular apposition of $\leq 50\%$ (Figure 14C) or diastesis > 2 mm through the facet joint is considered absolute evidence of facet joint disruption. Using T2 weighted or STIR sequences of MRI, one can easily pinpoint disruption of ALL, anterior annulus, disc interspace, PLL, posterior annulus and ligamentum flavum (Figure 14D-F). In patients with cervical spine injury and near normal looking morphology, at times there is sometimes swelling of the paravertebral tissues without clear-cut disruption of the ligaments. These observations are best classified as evidence of indeterminate ligamentous injury until a better understanding of this imaging finding is achieved.

SLIC Score Determination

By adding the maximum score determined and taking into consideration morphology, DLC status and neurology, a SLIC score is determined. The ultimate objective of the SLIC score is to determine the threshold for surgical intervention. SLIC scores 1 to 3 fall under the category of non-surgical and a score of 5 and above falls under the umbrella of surgical fixation. If a patient's SLIC score is 4, the surgeon may decide on either a non-operative or operative approach.



FIGURE 15. 25-year-old male construction worker who sustained a fall from a 25 meter-height. Reformatted sagittal CT and MRI indicate bilateral locked facets (A, C, D, F), complete disruption of DLC (B, E) and compression of spinal cord which has central hematomyelia (see text).

Clinical Examples

A 25-year old male was admitted to the Trauma Resuscitation Unit (TRU) following a fall from a 25 m height. His American Spinal Injury Association (ASIA) motor score was 43 and ASIA Impairment Scale (AIS) A. Cervical spine computed tomography showed distractive flexion injury stage 3 of the Allen et al classification at the level of C7/T1 (Figure 15A-C arrows). MRI indicated complete disruption of discoligamentous complex

(Figure 15D-F arrows). There was persistent spinal cord compression (modifier score 1). The total score in this case was 9. The patient was treated with circumferential (anterior cervical discectomy and fusion and posterior spinal fusion) fusion of the cervical spine. Morphology in this case is eligible for a score of 4 (translation/rotation), DLC a score of 2 (complete disruption), and neurology a score of 2 for complete spinal cord injury.

TABLE 2. Subaxial Injury Classification and Severity Scale as Suggested by Vaccaro and Colleagues^{37,38}

Sub-Axial Injury Classification Scale	Points
Morphology	
No abnormality	0
Compression	1
Burst	+1 = 2
Distraction (facet perch, hyperextension)	3
Rotation/translation (facet dislocation, unstable teardrop or advanced stage flexion compression injury)	4
Disco-ligamentous Complex (DLC)	
Intact	0
Indeterminate (isolated interspinous widening, magnetic resonance imaging signal change only)	1
Disrupted (widening of disc space, facet perch or dislocation)	2
Neurological Status	
Intact	0
Root injury	1
Complete cord injury	2
Incomplete cord injury	3
Continuous cord compression in setting of neurological deficit (NeuroModifier)	+1 = 1

The SLIC scale represents the first classification scheme to combine fracture morphology, discoligamentous integrity, and neurological deficit in an attempt to quantify subaxial fracture stability and management. The scale is simple and shows promise for ease of daily use. Partial validation has been performed, but further prospective studies are necessary to confirm reliability amongst different

institutions and to establish validity in case management. Compared to the current gold standard, which is a simple descriptive expression of fracture/dislocations and management strategies that are impossible to validate, the SLIC system may be the first of many classifications aimed at scaling injury severity and therefore prescribing a graded system of surgical or conservative management.

TABLE 3. Evidentiary Table: Subaxial Injury Classification Systems

Citation	Description of Study	Evidence Class	Conclusions
Anderson, ³⁵ <i>J Bone and Joint Surgery Am</i> , 2007	Report of a new cervical spine injury classification system featuring degrees of instability defined by a scoring system utilizing injury to 4 "columns" of the spine: anterior, posterior, and right and left facets.	I	The CSISS, Cervical Spine Injury Severity Score was shown to be reliable (intraclass correlation coefficients of 0.883 and 0.977 for interobserver and intraobserver, respectively). Internal consistency indicated by worsening of score reflecting worse injury.
Vaccaro, ³⁸ <i>Spine</i> , 2007	Report of a novel Subaxial Spine Classification System that includes morphology of the anatomical injury, including the discoligamentous complex and neurological condition of the patient. In addition, this paper also assesses the reliability of earlier proposed systems, including the Allen and Harris scales.	I	This classification system (shown in Table 1) was shown to be reliable overall (overall intraclass correlation coefficient of 0.71). Internal consistency indicated by worsening of score reflecting worse injury. With respect to the Allen and Harris scales, the reliability was shown to be less than would be required to recommend use.
Harris, ² <i>OrthopClin North Am</i> , 1986	This report introduced another mechanistic classification of cervical spine fractures and dislocations based on biomechanical, cadaveric and pathological evidence that vector forces along the "central coordinating system" are fundamental determinants of cervical spine injuries.	III	No measurement of reliability or validity were undertaken. (See Vaccaro above.)
Allen, ⁷ <i>Spine</i> , 1982	This study, based on findings in 165 patients with acute spinal cord injury, created a classification scheme based on the belief that translation of kinetic energy into fractures and dislocations is determined by 2 independent variables: injury vector and the posture of the cervical spine at the time of accident.	III	No measurement of reliability or validity were undertaken. (See Vaccaro above.)

SUMMARY

The challenge confronting providers caring for patients with cervical spine traumatic injuries is how to quantify instability and create an algorithm of treatment in order to protect the spinal cord from further damage, prevent future spinal deformity and mitigate pain and discomfort.^{7,38-40,54-61} Biomechanical, cadaveric, and autopsy studies have confirmed the importance of ligamentous integrity of anterior and posterior cervical spine elements for smooth, effortless movements of cervical spine under physiological loads.^{9,39-42,54} Due to the lack of appropriate sectional imaging, previous investigators have resorted to major injury vectors (MIV) in order to construct descriptive mechanical classification of cervical spine injuries.^{1-4,7,8,10,12,13,16,17,21-23,25,27,29,54,62-65} However, these systems are complicated and difficult to use; their clinical relevance is not intuitive. In addition, their reliability is low, and they probably do not add value to clinical research on spinal cord injury. The only suggestion might be to use the Harris classification system in addition to a more reliable classification for comparison with previously reported studies using this older scheme.

Anatomical injury severity is one of the major independent variables that needs to be quantified for future therapeutic trials. Two partially validated classification systems, the SLIC and severity scale and the C-SISS, have tried to scale and score injury severity, taking advantage of sectional imaging.^{35,37,38,59,60}

Key Issues For Future Investigation

Novel and quantifiable cervical spine injury classification systems that are easy to remember and can be utilized by different providers are needed in order to design appropriate treatment algorithms and better understand treatment effects of therapeutic trials. The SLIC and severity scale and C-SISS classifications need further validation and reliability studies, with careful measurement of internal consistency.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Treatment of Subaxial Cervical Spinal Injuries

Daniel E. Gelb, MD*

Bizhan Aarabi, MD, FRCSC‡

Sanjay S. Dhall, MD§

R. John Hurlbert, MD, PhD,
FRCSC¶

Curtis J. Rozzelle, MD||

Timothy C. Ryken, MD, MS#

Nicholas Theodore, MD**

Beverly C. Walters, MD, MSc,
FRCSC‡‡§§

Mark N. Hadley, MD‡‡

*Department of Orthopaedics; and
‡Department of Neurosurgery, University
of Maryland, Baltimore, Maryland;
§Department of Neurosurgery, Emory
University, Atlanta, Georgia; ¶Department
of Clinical Neurosciences, University of
Calgary Spine Program, Faculty of Medi-
cine, University of Calgary, Calgary, Alberta,
Canada; ||Division of Neurological Surgery;
and ‡‡Division of Neurological Surgery,
Children's Hospital of Alabama, University
of Alabama at Birmingham, Birmingham,
Alabama; #Iowa Spine & Brain
Institute, University of Iowa, Waterloo/Iowa
City, Iowa; **Division of Neurological
Surgery, Barrow Neurological Institute,
Phoenix, Arizona; §§Department of Neuro-
sciences, Inova Health System, Falls
Church, Virginia

Correspondence:

Mark N. Hadley, MD, FACS,
UAB, Division of Neurological Surgery,
510 – 20th St S, FOT 1030,
Birmingham, AL 35294-3410.
E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS

Level III:

- Closed or open reduction of subaxial cervical fractures or dislocations is recommended. Decompression of the spinal cord/restoration of the spinal canal is the goal.
- Stable immobilization by either internal fixation or external immobilization to allow for early patient mobilization and rehabilitation is recommended. If surgical treatment is considered, either anterior or posterior fixation and fusion is acceptable in patients not requiring a particular surgical approach for decompression of the spinal cord.
- Treatment of subaxial cervical fractures and dislocations with prolonged bed rest in traction is recommended if more contemporary treatment options are not available.
- The routine use of computed tomography and magnetic resonance imaging of trauma victims with ankylosing spondylitis is recommended, even after minor trauma.
- For patients with ankylosing spondylitis who require surgical stabilization, posterior long-segment instrumentation and fusion or a combined dorsal and anterior procedure is recommended. Anterior standalone instrumentation and fusion procedures are associated with a failure rate of up to 50% in these patients.

RATIONALE

Acute subaxial cervical spine injuries following trauma remain a common problem. These injuries are often associated with neurological deficits on presentation. Refinements in spinal

instrumentation have led to an increased reliance on the operative treatment of subaxial cervical injuries. The guidelines author group of the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons have previously produced a medical evidence-based guideline on this topic and described nonsurgical and surgical treatment strategies for acute subaxial cervical spinal injuries.¹ Since the publication of that guideline in 2002, subsequent clinical data reported in the spinal literature have focused primarily on the use of internal fixation in the treatment of subaxial cervical fractures and dislocations. Case series describing both anterior- and posterior-based surgical techniques for patients with these injuries have been published. The purpose of this updated medical evidence-based review is to provide a contemporary analysis of anterior and posterior surgical techniques in the treatment of subaxial cervical spinal fractures and dislocation injuries.

SEARCH CRITERIA

A National Library of Medicine (PubMed) computerized literature search was performed in a fashion similar to the one that formed the basis of the previous guideline on this topic. The search consisted of publications from 1966 through 2011 using the following headings limited to the English language: “cervical vertebrae,” “spinal fractures,” and “dislocations,” leading to 8684, 5810, and 9450 citations, respectively. The first heading was combined with the second 2 headings, leading to a subset of 1118 and 466 citations, respectively. Another search of “therapeutics” or “treatment” limited to the English language led to 1 870 663 citations. This was combined with each of the 2 prior subsets, leading to 856 citations with abstracts. These abstracts were reviewed, and only

ABBREVIATION: AS, ankylosing spondylitis

those containing 10 or more cases of subaxial cervical injury after nonpenetrating cervical trauma were included. Twenty-eight articles met the selection criteria and provide the basis for this updated review. They are summarized in Evidentiary Table format (Tables 1-2).

SCIENTIFIC FOUNDATION

Individual subaxial cervical spine injuries represent a wide spectrum of damage to the anatomic structures of the neck, including fractures, ligamentous injury, and disk disruption, often with injury to the cervical spinal cord and nerve roots. Although each injury is unique in terms of the particular complex of bone and soft-tissue disruption, some type of classification is necessary as an intellectual framework to develop consistent treatment algorithms. Some variation of the Allen and Ferguson mechanistic classification system continues to be used as the basis for injury classification.² Unfortunately, the complexity of individual injuries, often comprising different types of injuries to multiple segments of the spine, frequently necessitates complex reconstructive strategies. Few clinical series describe a pure population of a single subaxial cervical spinal injury type treated completely uniformly.

Summary of Previous Findings

The previous medical evidence-based guideline on this topic focused on “the utility of closed reduction with or without external immobilization compared to arthrodesis with or without internal fixation.” Several generalizations can be distilled from that early medical evidence-based review. Treatment with external immobilization only (traction or orthosis) failed to maintain adequate spinal alignment in approximately 30% of injuries treated in that fashion. Approximately 9% of surgically treated patients had a similar fate. Vertebral compression of 40%, kyphosis of 15%, or vertebral subluxation > 20% were cited as risk factors for failure of external immobilization. A greater proportion of failed alignment patients had residual cervical pain compared with similarly treated patients in whom anatomic spinal alignment was achieved and maintained. Twenty-six percent of patients failed closed reduction of their cervical facet dislocation injuries, whereas 96% of patients treated surgically (open reduction) achieved successful reduction. Anterior plate fixation and posterior lateral mass plate/screw systems were both highly successful at maintaining spinal reduction and alignment postoperatively. Posterior fusion procedures were associated with a higher rate of complications (37%) than anterior fusion procedures (9%).¹

Nonsurgical Treatment

Four articles in the current literature review were identified that dealt with the nonsurgical management of subaxial fractures: 3 articles related to unilateral subaxial facet injuries and 1 article related to compressive flexion injuries.

Unilateral facet injuries represent a broad spectrum of potential degrees of mechanical instability. Although the injury to the facet complex itself is often obvious, it can be difficult to determine whether the amount of injury is sufficient to render the spine unstable to the point where external immobilization would likely be inadequate to maintain spinal alignment to facilitate healing. In 1997, Halliday et al³ studied 24 unilateral facet injuries and evaluated these injuries by magnetic resonance imaging (MRI). Injuries to the anterior longitudinal ligament, posterior longitudinal ligament, facet capsule, and interspinous ligament were studied. Patients were treated both surgically and nonsurgically in their retrospective series. Twelve patients were treated nonsurgically. Six of the 7 treatment failures in this group had 3 of 4 ligaments injured. Eight of 12 surgically treated patients also had at least 3 ligaments injured. Spector et al⁴ studied 24 unilateral facet fractures treated nonsurgically. Five of these injuries eventually required surgical stabilization either for loss of position or for the development of radiculopathy. In addition, 4 of 6 patients who presented with radicular complaints had no improvement of their symptoms by the end of the study period. These authors found that fractures involving $\geq 40\%$ of the absolute height of the intact lateral mass or an absolute height of 1 cm were at increased risk for failure of nonoperative treatment. Lee and Sung⁵ described 39 patients treated with single-level anterior interbody fusion for unilateral lateral mass fractures. In their cohort study, 15 patients were initially treated nonoperatively. Twelve of these 15 patients eventually required surgical treatment. The authors, however, did not detail the reasons for their nonoperative treatment failures.

In 2002, Fisher and associates⁶ reported a retrospective cohort study comparing halo vest immobilization with anterior cervical fusion for the treatment of subaxial cervical compression-flexion (teardrop) fractures. Four of 24 patients treated in a halo device eventually required surgical treatment. The average kyphosis in the halo treatment group was 11.4° compared with 3.5° in the group treated with instrumented anterior fusion (21 patients). However, functional outcome, as judged by Short Form-36 scores, was equivalent between the 2 groups. Although the patients were matched in many respects, because of the retrospective nature of the series and the manner in which treatment was determined (based on the preference of the attending surgeon), this study offers Class III medical evidence.

Anterior Arthrodesis

Proponents of anterior internal fixation and fusion for the treatment of acute subaxial cervical spinal fractures cite several potential advantages of this treatment approach. Patient positioning is safe and straightforward, obviating the need to turn the patient prone with the potential of an unstable injury. The surgical dissection is accomplished along defined tissue planes with little if any iatrogenic muscle injury. Ventral decompression of the spinal cord can be performed under direct visualization. However, anterior screw/plate instrumentation may be biomechanically

inadequate to control instability postoperatively. Several authors have investigated the utility of standalone anterior instrumentation and fusion in the treatment of subaxial cervical spinal injuries.

Woodworth et al⁷ performed a retrospective review of 19 patients with a mixture of injury types treated with anterior decompression and fusion. They reported an 88% fusion rate with only 1 instrumentation failure. There were no cases of neurological deterioration and no infections. Kasimatis et al⁸ described a series of 74 patients, also with a mixture of injury types. Ninety percent of the patients in their series achieved success fusion. Although they reported 11 postoperative infections (15%), only 3 patients required revision surgery. Reindl et al⁹ reported a retrospective series of 41 consecutive patients with “disruptions of both anterior and posterior structures and subluxation or dislocation of at least one facet” treated with anterior instrumented fusion. All patients went on to solid fusion with no loss of reduction or instrumentation failures. One patient experienced a transient neurological deterioration. Six of 19 patients with a spinal cord injury on admission improved at least 1 Frankel grade. Twenty percent of patients had transient dysphagia postoperatively, and 20% had persistent moderate to severe neck pain at last follow-up.

Other authors have reported on anterior internal fixation and fusion more specifically for facet and lateral mass injuries. Lee and Sung⁵ described 39 patients treated with a single-level anterior fusion for unilateral lateral mass fractures. Radiographic failure was observed in 8 patients (21%). Three cases had instability or malalignment at an adjacent segment; 5 cases had incomplete reduction of their subluxation injuries. Henriques and associates¹⁰ reported a series of 39 patients with ligamentous unilateral and bilateral facet dislocations treated with anterior instrumentation and fusion. Only 2 of 17 patients with unilateral injuries lost reduction postoperatively. Conversely, 7 of 13 patients with bilateral injuries demonstrated postoperative recurrent subluxation. Although no statistical analysis was performed on this small sample, the authors noted that 4 of 5 patients with complete neurological injuries and bilateral facet dislocations had radiographic failure. Johnson et al¹¹ published a retrospective series of 87 patients (of 107 total) with unilateral and bilateral facet injuries treated with anterior instrumentation and fusion. Thirteen percent of patients suffered radiographic failure; none had neurological deterioration. Analyzing the 11 patients who suffered a loss of reduction after surgery, the authors identified facet fracture (10 of 11), endplate fracture (9 of 11), and C6-7 injury level (8 of 11) as risk factors for radiographic failure in their experience.

Posterior Arthrodesis

Proponents of posterior fixation and fusion as treatment for subaxial cervical spinal fracture injuries cite superior biomechanics as the primary advantage of this internal fixation strategy. Furthermore, open reduction of facet dislocations is straightforward with the posterior approach and has been the traditional

surgical method used. Five contemporary articles reported clinical series of subaxial injuries treated with posterior fixation and fusion. Kotani et al,¹² Zhou et al,¹³ and Yukawa et al¹⁴ all reported retrospective series of patients treated with pedicle screw instrumentation for a variety of subaxial injuries. Overall, these series document a low rate of instrumentation-related and other complications and good neurological recovery with this demanding surgical technique. Lenoir and associates¹⁵ reported a series of 30 patients treated with posterior fixation and fusion for fractures around the cervicothoracic junction, an area where instrumentation failure has been felt to be common because of high biomechanical stress. Five patients with similar injuries were also treated with anterior decompression and fusion with internal fixation (dorsal-ventral combination procedure). The postoperative pulmonary infection rate (30%) and mortality rate (23%) were high in patients with these severe high-energy injuries, but the number of instrumentation failures (2) and wound infections (2) was low. Finally, Pateder and Carbone¹⁶ described a series of 29 patients with a mixed series of cervical spinal subaxial injuries treated with posterior lateral mass screw fixation and fusion. Of these 29 patients, only 1 experienced instrumentation failure and 1 suffered a root injury. There were 4 postoperative wound complications. On average, the authors noted a 2° loss of correction in sagittal angulation with posterior operative reduction and internal fixation techniques.

Anterior-Posterior Arthrodesis

Several authors have reported series of patients treated with a combination of anterior and posterior decompression, internal fixation, and fusion techniques. Harrington and Park¹⁷ treated unilateral and bilateral facet injuries with single-level arthrodesis in 22 patients. The authors did not differentiate outcomes between the anterior standalone and anterior and posterior techniques. They reported 68% correction of sagittal angulation and 70% correction of translational deformity for unilateral injuries compared with 51% and 65%, respectively, for bilateral injuries. They identified no nonunions or cases of neurological deterioration. Toh et al¹⁸ reported a retrospective study of 31 patients treated with a variety of surgical techniques (24 anterior, 7 posterior) for a mixture of subaxial cervical spinal injuries (11 burst fractures, 20 teardrop injuries). The group treated with posterior fixation and fusion had higher rates of postoperative spinal canal compromise and required more spinal levels to achieve effective fixation. Bone fragment removal and decompression of the spinal canal were better for patients treated anteriorly compared with those treated posteriorly. Nine of 24 patients treated with anterior surgery improved neurologically, but none of the patients treated posteriorly improved. No Frankel A patient recovered motor function regardless of treatment. Song and Lee¹⁹ compared anterior and combined anterior and posterior internal fixation and fusion techniques in a series of 50 patients with distractive subaxial cervical flexion injuries. They found no differences in the rate of union, complications, or

radiographic or neurologic outcomes. Lambiris et al²⁰ published a comparative cohort study of patients undergoing either anterior (74 patients) or posterior (23 patients) fixation and fusion for a variety of subaxial cervical spinal injuries. They reported no difference in the complication rates between the 2 techniques.

Brodke and colleagues²¹ randomized 52 consecutive patients with unstable subaxial cervical spine injuries to anterior or posterior stabilization and fusion. Injuries in all patients were reduced and decompressed preoperatively by closed reduction; therefore, the choice of surgical approach was not dictated by the need to decompress the spinal canal. The authors found no difference in the neurological outcome, final degree of kyphosis, fusion status, or rate of complications between the 2 surgical approaches. Because of the small number of patients included in this randomized comparative study (inadequate study power), this report provides Class III medical evidence.

Kwon et al²² performed a prospective randomized trial of unilateral facet injuries comparing anterior with posterior internal fixation and fusion techniques in 42 patients. All injuries were judged to require surgical stabilization by the treating surgeon. Patients with significant vertebral body fractures, disk herniations, or spinal cord injuries were excluded from the trial. The authors found no difference in the primary outcome: time to fulfill criteria for hospital discharge. They also found no difference in postoperative pain scores, 1-year self-reported outcomes measures, or fusion rates. More than 50% of the patients treated with anterior fusion procedures complained of dysphagia, all of which reportedly resolved by 3 months. Four of 22 patients treated with posterior internal fixation and fusion procedures suffered wound complications (1 deep, 3 superficial); none of the 20 patients treated anteriorly had wound complications. Patients treated with posterior procedures had statistically more kyphosis (1.6°) compared with those treated with anterior procedures (8.8° lordosis). Patients treated with plates posteriorly had more kyphosis than those treated with wires, although the plates used were not constrained. Because of the small number of study patients and because the primary study end point was only meeting criteria for hospital discharge, this study was considered to offer Class III medical evidence on this issue.

Ankylosing Spondylitis

In the previous version of the guideline on the treatment of subaxial cervical spinal injuries, the author group noted that comparatively few studies examined the specific difficulties associated with the management of patients with ankylosing spondylitis (AS) who sustain subaxial cervical spinal injuries.¹ Results of the treatment of these patients were rather dismal. In 4 articles reporting patients with this entity and subaxial injuries, 9 of 22 total patients died. Four patients managed nonoperatively died. Two of 9 survivors treated with external immobilization failed treatment. One worsened neurologically when placed in a halo and was subsequently treated successfully with laminectomy and posterior internal fixation and fusion. The other patient

had persistent cervical subaxial spinal instability but refused further therapy. In contrast, 5 of 9 AS patients with subaxial cervical fracture injuries treated primarily with surgery died. One patient was neurologically worse after surgery. Three patients healed successfully without instability.²³⁻²⁵

Four additional reports concerning the care of patients with AS and subaxial cervical spinal injuries were identified in the current literature search. Corneford et al²⁶ published a retrospective case series (Class III medical evidence) of 19 patients with AS and subaxial cervical spine fractures treated with posterior fixation and fusion. Four patients were also treated with anterior fusion procedures. Five patients died during the follow-up period, but no deaths were related to surgery. All patients sustained fractures after low-energy trauma. One patient deteriorated neurologically postoperatively. Two of 8 patients with neurological deficits improved postoperatively. There were no cases of instrumentation failure or loss of reduction. The authors concluded that long-segment rigid posterior fixation was an acceptable method for treating patients with AS who sustained subaxial cervical spine fractures.

Einsiedel and colleagues²⁷ described a retrospective review of 37 AS patients with subaxial fractures from 2 institutions over a 16-year period. All patients were treated surgically. Ten patients were treated with anterior standalone instrumentation and fusion. Twenty-four patients were treated with anterior and posterior instrumentation and fusion. Two cases were treated with posterior instrumentation and fusion alone, and 1 patient underwent laminectomy only without fusion. Patients were followed up only until hospital discharge. All patients improved neurologically. Despite the short-term follow-up, 50% of patients treated with anterior instrumentation suffered instrumentation failure. No patient treated with posterior instrumentation experienced instrumentation failure. Three patients died in the early postoperative period. The authors noted a high rate of fractures detected with only computed tomography or MRI in the thoracic and lumbar regions in association with the primary subaxial cervical fractures. From this class III medical evidence, the authors concluded that cervical spinal fractures in patients with AS should be treated with combined anterior and posterior instrumentation and fusion procedures.

In 2008, Kanter and colleagues²⁸ published a series of 13 patients with AS and subaxial cervical fractures. Twelve patients had either posterior standalone instrumentation and fusion or anterior and posterior surgery. Only 1 patient underwent anterior-only instrumentation and fusion. An average of 5.6 segments were instrumented. Five of 13 patients improved neurologically; 1 patient had neurological deterioration. Thirty-eight percent of the patients experienced complications, including instrumentation failure in 2 patients and death in 1 patient. All of the 10 patients available for radiographic follow-up went on to achieve fusion confirmed by computed tomography imaging. The authors offered a complex management algorithm and recommended surgical treatment for all patients with AS and cervical fractures. This study represents Class III medical evidence on this issue.

TABLE 1. Evidentiary Table: Treatment of Subaxial Injuries

Reference	Fracture Type	Description of study	Evidence Class	Conclusions
Zhou et al, ¹³ <i>Annals of the Royal College of Surgeons of England</i> , 2010	Mixed	Retrospective review of 48 patients treated with pedicle screw instrumentation	III	18 of 20 incomplete injuries improved. No neurological deterioration, no instrumentation failure, no pseudoarthrosis.
Kasimatis et al, ⁸ <i>Clinical Neurology and Neurosurgery</i> , 2009	Mixed	Cohort study of 74 patients treated with anterior surgery	III	90% fusion rate. 11 postoperative complications. 3 revision surgeries. 4 mortalities.
Lee and Sung, ⁵ <i>Journal of Trauma</i> , 2009	Lateral mass	Retrospective review of 39 patients treated with single-level anterior cervical discectomy and fusion	III	12 of 15 patients treated in an orthosis require late surgery. 6 cases of persistent radiculopathy.
Woodworth et al, ⁷ <i>Journal of Neurosurgery: Spine</i> , 2009	Mixed	Retrospective review of 19 patients treated with anterior cervical discectomy and fusion	III	88% fusion rate. 1 instrumentation failure. Average Neck Distensibility Index = 6.5 ± 2.9 . No neurological deterioration. 10 of 11 radiculopathies resolved. No wound infections.
Yukawa et al, ¹⁴ <i>European Spine Journal</i> , 2009	Mixed	Retrospective study of posterior fixation with pedicle screws	III	13% screw malposition. 1 radiculopathy. 1 vertebral artery injury. 5 loss of correction. 4 deep infections.
Lambiris et al, ²⁰ <i>Journal of Spinal Disorders and Techniques</i> , 2008	Mixed	Comparative cohort study of anterior and posterior fixation	III	No difference in complications between either group.
Song and Lee, ¹⁹ <i>Journal of Clinical Neuroscience</i> , 2008	Distractive flexion	Retrospective comparative study of anterior vs anterior-posterior fixation in 50 patients	III	No difference in union, radiographic or neurological outcome, or complications.
Harrington and Park, ¹⁷ <i>Journal of Spinal Disorders and Techniques</i> , 2007	Unilateral and bilateral fractures	Prospective cohort study of 22 patients treated with anterior or anterior-posterior instrumentation	III	No neurological worsening, 1 wound infection, no nonunions. 51% sagittal angulation, 65% translational correction for bilateral injuries. 68% sagittal angulation, 70% translational correction for unilateral fracture injuries.
Kwon et al, ²² <i>Journal of Neurosurgery: Spine</i> , 2007	Unilateral facet injuries	Prospective randomized trial of 42 patients with unilateral facet injuries without spinal cord injury, disk herniation, or vertebral body fracture judged unstable by treating surgeon	III	No difference in hospital stay, postoperative neck pain or 1-y self-reported health-related quality of life measures or fusion rate. 11 of 20 anterior patients had dysphagia (all resolved by 3 months). 4 of 22 posterior patients with wound complications vs 0 of 20 anterior patients. Lateral mass plates had more kyphosis. Insufficient study numbers.
Lenoir et al, ¹⁵ <i>Spine Journal</i> , 2006	Cervical-thoracic junction fractures	Retrospective review of 30 patients treated with posterior fixation	III	Mortality: 7 of 30. Neurological recovery: 9 of 30. Neurological deterioration: 1 of 30. Pulmonary infection: 30%. 2 instrumentation failures. 2 wound infections.
Pateder and Carbone, ¹⁶ <i>Spine Journal</i> , 2006	Mixed	Retrospective review of 29 patients treated with lateral mass screws	III	1 instrumentation failure. 1 root injury. 2° average loss of correction. 4 wound complications.
Reindl et al, ⁹ <i>Spine</i> 2006	Facet injuries	Retrospective review of 41 consecutive patients treated with anterior cervical discectomy and fusion	III	No instrumentation failure, loss of reduction or pseudoarthrosis. 1 neurological deterioration. 5 patients with persistent moderate to severe neck pain.

(Continues)

TABLE 1. Continued

Reference	Fracture Type	Description of study	Evidence Class	Conclusions
Spector et al, ⁴ <i>Spine</i> , 2006	Unilateral facet fractures	Retrospective study of 24 patients treated nonsurgically	III	5 patients required surgical stabilization, loss of position (4), progressive radiculopathy (1). 4 of 6 patients with radiculopathy had persistent symptoms at the end of treatment. Unilateral cervical facet fractures involving 40% of the absolute height of the intact lateral mass or an absolute height of 1 cm are at increased risk for failure of nonoperative treatment.
Toh et al, ¹⁸ <i>International Orthopaedics</i> , 2006	Compressive flexion	Retrospective study of burst and teardrop fractures treated either anteriorly or posteriorly	III	Patients treated with anterior surgery had better decompression and better neurological recovery than those who received posterior surgery alone.
Kotani et al, ¹² <i>European Spine Journal</i> , 2005	Lateral mass fractures	Retrospective review of 31 patients treated with pedicle screw fixation	III	6 of 31 residual malalignment, no pseudoarthrosis. 0% neurological deterioration. All myelopathy improved. 3 of 21 with residual radiculopathy. 1 deep infection, 1 instrumentation removal.
Henriques et al, ¹⁰ <i>Journal of Spinal Disorders and Techniques</i> , 2004	Distractive flexion	Retrospective review of 39 patients treated with anterior cervical discectomy and fusion	III	2 of 17 unilateral injuries with nonunion. 7 of 13 bilateral injuries lost reduction.
Johnson et al, ¹¹ <i>Spine</i> , 2004	Distractive flexion	Retrospective review of 87 (of 107) patients treated with anterior single-level fusion	III	13% failure rate (11 of 87): 8 of 11 at C6-7, 10 of 11 facet fracture, 9 of 11 endplate fracture. No neurologic deterioration
Brodke et al, ²¹ <i>Journal of Spinal Disorders and Techniques</i> , 2003	Mixed subaxial fractures	Randomized consecutive series of 52 patients with unstable injuries and spinal cord injury treated with either anterior or posterior surgery	III	No difference in neurological outcome, kyphosis, fusion status, or complications. Insufficient study numbers, inadequate power.
Fisher et al, ⁶ <i>Spine</i> , 2002	Subaxial cervical fractures (teardrop)	Retrospective cohort comparing anterior cervical fusion (21 patients) and Halo vest (24 patients).	III	4 of 24 Halo patients failed. Average final kyphosis: 11.4° in the halo group, 3.5° in the anterior cervical fusion group. No difference in Short Form-36 scores.
Halliday et al, ³ <i>Spine</i> , 1997	Unilateral facet fracture	Retrospective review of 24 unilateral facet fractures evaluated by magnetic resonance imaging	III	6 of 7 nonsurgical treatment failures had at least 3 of 4 ligaments injured. 8 of 12 patients managed surgically had at least 3 of 4 ligaments injured.

In 2010, Caron et al²⁹ published a retrospective review of their experience treating patients with AS or diffuse idiopathic skeletal hypertrophy syndrome who had sustained spinal fractures. One hundred twelve patients were identified in their database. Clinical and radiographic follow-up was available for 62 of 84 patients who survived the initial hospitalization with a mean follow-up of 6.5 months. Sixty-seven fractures (55%) were in the cervical spine. The authors did not quantify their results by spinal level. Neurological deterioration occurred in 81% of patients for whom there was a delay in diagnosis (19% of all patients). The reported overall mortality was 32%. Mortality was significantly higher ($P = .005$) in patients treated nonsurgically, but some of these patients were not treated surgically because of their severe medical comorbidities. Linear regression analysis revealed that age was the primary predictor of mortality in their review. The authors

concluded that patients with AS and those with diffuse idiopathic skeletal hypertrophy who sustained traumatic spinal fractures were sufficiently similar to be considered together in terms of treatment and prognosis. Extreme vigilance and the routine use of advanced imaging (computed tomography and MRI) were recommended because of the significant number of patients who presented with a delayed diagnosis and neurological deterioration.

SUMMARY

Subaxial cervical spine fractures and dislocations encompass a broad spectrum of acute traumatic injuries. Adequate decompression of the neural elements and the restoration of sufficient spinal stability to allow early mobilization and rehabilitation remain basic treatment tenets. Although nonsurgical treatment

TABLE 2. Evidentiary Table: Treatment of Subaxial Injuries Ankylosing Spondylosis

Reference	Description of study	Evidence Class	Conclusions
Caron et al, ²⁹ <i>Spine</i> , 2010	Retrospective cohort study of 62 (of 84) patients with spinal fractures and ankylosing disorders	III	8% noncontiguous fractures. 19% delay in diagnosis (81% of these with neurological deterioration). 32% overall mortality. Age best predictor of mortality.
Kanter et al, ²⁸ <i>Neurosurgical Focus</i> , 2008	Retrospective review of 13 ankylosing spondylitis patients treated surgically	III	1 of 13 neurological deterioration. 5 of 13 neurological improvement. 38% complications. 1 mortality.
Einsiedel et al, ²⁷ <i>Journal of Neurosurgery: Spine</i> , 2006	Retrospective study of 37 patients with ankylosing spondylitis treated surgically	III	16% multilevel injury. 35% delayed diagnosis. 50% failure rate in anterior only instrumentation. All patients improved neurologically.
Cornefjord et al, ²⁶ <i>European Spine Journal</i> , 2005	Retrospective review of Olerud pedicle screw-rod system. 19 ankylosing spondylitis patients	III	0% mortality. 0% instrumentation failure/loss of reduction. 1 deep wound infection.
Weinstein et al, ²³ <i>Journal of Neurosurgery</i> , 1982	Retrospective study. 13 ankylosing spondylitis: 7 traumatic cervical, 6 quadriplegic, 2 central cords without fracture	III	2 treated with traction died of pneumonia. 2 treated with traction/brace healed. 1 worse halo, treated surgically. 1 laminectomy/fusion worse. 1 laminectomy/fusion had pseudoarthrosis.
Bohlman, ²⁴ <i>Journal of Bone and Joint Surgery: American Volume</i> , 1979	Retrospective study; 300 cervical injuries; 8 ankylosing spondylitis patients	III	5 of 8 patients died. 2 healed after brace treatment and 1 after laminectomy.
Cheshire, ³⁰ <i>Paraplegia</i> , 1969	Retrospective study; 257 cervical injuries; 1 ankylosing spondylitis patient	III	1 C5-C6 extension injury healed with surgical fusion.
Grisolia et al, ²⁵ <i>Journal of Bone and Joint Surgery: American Volume</i> , 1967	Retrospective study of 6 ankylosing spondylitis patients	III	3 of 4 healed with brace ± traction. 2 with laminectomy and posterior cervical fusion died of pulmonary embolism.

can be employed successfully, surgical treatment of these injuries achieves these goals more consistently and more quickly, especially in higher grades of injury. Both anterior and posterior surgical approaches have been reported as effective. Neither approach is necessarily superior to the other as long as the goals of treatment can be accomplished. Treatment must be individualized on the basis of the specific characteristics of each particular injury. Factors to be considered include neurologic status, the degree and type of bony and/or ligamentous disruption, and the degree and cause of spinal cord compression. The treatment of patients with AS who sustain traumatic subaxial cervical spinal fractures is challenging and has a comparatively high associated morbidity and mortality, regardless of the treatment offered or the surgical approach used.

KEY ISSUES FOR FUTURE INVESTIGATION

Subaxial cervical spine injuries are common, can have devastating personal consequences, and represent a significant cost to individuals and society. Research continues to be hampered by lack of an accurate, reproducible, universally accepted classification system. Recent literature continues to suffer from poorly characterized patient populations, inconsistent treatment protocols, and variable outcome measures that make generalizations regarding treatment difficult. Only 2 prospective Class I trials in

investigation of these injury types were identified in the present literature review; unfortunately, both provided Class III medical evidence because of inadequate power and other study design or process factors. Future research needs to incorporate more precisely characterized patient groups, more rigorously defined treatment protocols, and generalizable outcome measures obtained by complete, comprehensive follow-up.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Management of Acute Traumatic Central Cord Syndrome (ATCCS)

Bizhan Aarabi, MD, FRCSC*

Mark N. Hadley, MD‡

Sanjay S. Dhall, MD§

Daniel E. Gelb, MD¶

R. John Hurlbert, MD, PhD, FRCSC||

Curtis J. Rozzelle, MD#

Timothy C. Ryken, MD, MS**

Nicholas Theodore, MD‡‡

Beverly C. Walters, MD, MSc, FRCSC‡§§

*Department of Neurosurgery, and

¶Department of Orthopaedics, University of Maryland, Baltimore, Maryland;

‡Division of Neurological Surgery, and

#Division of Neurological Surgery, Children's Hospital of Alabama, University of Alabama at Birmingham, Birmingham, Alabama;

§Department of Neurosurgery, Emory University, Atlanta, Georgia;

||Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada;

**Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa;

‡‡Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona;

§§Department of Neurosciences, Inova Health System, Falls Church, Virginia

Correspondence:

Mark N. Hadley, MD, FACS,
UAB Division of Neurological Surgery,
510 – 20th Street South, FOT 1030,
Birmingham, AL 35294-3410.

E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS

Level III

- Intensive care unit management of patients with acute traumatic central cord syndrome (ATCCS), particularly patients with severe neurological deficits, is recommended.
- Medical management, including cardiac, hemodynamic, and respiratory monitoring, and maintenance of mean arterial blood pressure at 85 to 90 mm Hg for the first week after injury to improve spinal cord perfusion is recommended.
- Early reduction of fracture-dislocation injuries is recommended.
- Surgical decompression of the compressed spinal cord, particularly if the compression is focal and anterior, is recommended.

RATIONALE

First introduced by Thorburn in 1887 and popularized by Schneider and Taylor, the concept of ATCCS has changed significantly during the past several decades.^{1–7} In its severe form, as it was proposed by Schneider,³ there is differential weakness of the upper and lower extremities and variable involvement of the sensory system and a variable impact on bladder function. In its most mild form it may result in symptoms only, including “burning hands,” as reported by Maroon et al,⁸ while the subject's neurological examination remains completely intact. Recent

studies indicate that in order to apply the diagnosis of ATCCS, the upper extremity American Spinal Injury Association (ASIA) motor score should be at least 10 points less than the lower extremities ASIA Motor Score.^{9,10} Based on 2 postmortem studies and considering the clinical thoughts of Foerster,³ Schneider¹¹ proposed central necrosis with hematomyelia involving the centrally located laminations of the corticospinal tract as the main pathological feature of ATCCS. Recent necropsy studies by Levi et al,¹² Quencer et al¹³ and Jimenez et al¹⁴ have confirmed that hematomyelia does not necessarily have to be present. To the contrary, the major share of the pathology in ATCCS is swelling and disruption of the axons in the posterolateral funiculus of the spinal cord with very little evidence of bleeding. Tracing studies of Pappas et al,¹⁵ anatomic transections of the corticospinal tract by Bucy et al,¹⁶ and Marchi degeneration studies of Coxe and Landau¹⁷ and Barnard and Woosley¹⁸ all indicate that the somatotopic segregation of the corticospinal tract is valid in the internal capsule up to the cerebral peduncles. However, beyond those structures and at the level of the pyramids and the lateral funiculus of the spinal cord, there is no lamination of the descending fibers; therefore, no somatotopic organization. A current proposal by Levi et al¹² is that in primates, the corticospinal tract is critical for hand function but not locomotion.

Pathologically, ATCCS is a heterogeneous phenomenon.^{19–21} Besides the classic hyperextension injuries superimposed on spinal stenosis, up to 60% of patients with ATCCS suffer from fracture subluxations, acute disc herniation, or, rarely, spinal cord injury without any radiographic abnormality.^{19,20,22–37} In Schneider's^{2,3,5} early series of 21 patients with ATCCS, there were 10 patients with cervical fracture injuries and

ABBREVIATIONS: ASIA, American Spinal Injury Association; ATCCS, acute traumatic central cord syndrome

11 patients with spinal stenosis without bony fracture injury. One of the fundamental characteristics of ATCCS is its potential for spontaneous recovery of function irrespective of the treatment provided. Surgical decompression for ATCCS has been advocated.^{3,22,24,32} Only 2 of the 21 patients in Schneider's series were treated with surgical decompression, and in contemporary practice, early decompression of the injured spinal cord in the setting of spinal stenosis without bony fracture remains controversial.^{2,3,5,19,22,24,31,32,34,37-41} In recent years, investigators have developed a better understanding of the pathophysiology of the secondary injury of spinal cord injury, emergency medical services and transport techniques have improved, imaging modalities and their availability and application have become first-rate, and the critical care management of acute spinal cord injury patients has evolved.⁴²⁻⁴⁴

In 2002, the guidelines author group of the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons (AANS) and the Congress of Neurological Surgeons (CNS) published a medical evidence-based Guideline on this important topic.⁴⁵ This present effort is to update the medical evidence on ATCCS focused on the specific issues of the natural history, medical management, and the potential surgical treatment of acute traumatic cervical central cord syndrome.

SEARCH CRITERIA

A computerized search of the National Library of Medicine (PubMed) database of the literature published from 1966 to 2011 was undertaken. The medical subject headings "central cord syndrome" yielded 1533 citations, "spinal cord injury combined with central cord syndrome" yielded 421 citations, and "traumatic central cord syndrome" yielded 74 citations. Non-English language citations were excluded.

These search parameters resulted in 29 articles specifically describing the management and outcome of patients with central cervical spinal cord injuries. The reference lists of these articles were searched for any additional articles germane to this topic. These 29 manuscripts make up the foundation for this updated review and are summarized in Evidentiary Table format. A comprehensive, contemporary bibliography is provided containing 101 citations.

SCIENTIFIC FOUNDATION

Diagnosis

Definition

ATCCS is an incomplete spinal cord injury in which the upper extremities are weaker, (at least 10 points in ASIA Motor Score) than the lower extremities with variable involvement of the sensory system and a variable effect on bladder function.^{2,3,5}

Biomechanics

The basic biomechanics of ATCCS result from translation of kinetic energy into major injury vectors that damage anterior and posterior spinal cord columns centrally in the spinal cord with or without disruption of the bony vertebrae, the disc space, or spinal ligaments.⁴⁶⁻⁵¹

Pathogenesis and Pathology

Regardless of the trajectory of the major injury vectors and moments, in nearly 70% of patients suffering from incomplete spinal cord injuries, the resulting deformation, stretch, and compression of the spinal cord will manifest as the clinical picture of central cord syndrome.^{24,51,52} A major proportion of the reported case series describing the management of patients with ATCCS, including those of Schneider et al, describe a heterogeneous group of patients suffering from herniated discs, fractures and/or subluxations, or spinal stenosis without bony fracture.^{2,3,5,20,21,23,27-29,53} Only a minority of the patients have been reported to have ATCCS due to hyperextension injuries without spinal stenosis or any other cervical spinal structural injury, bony or ligamentous.^{19,29,37}

In the Chen et al²⁷ series, 16 of the 28 surgical cases (57%) of ATCCS they treated had either disc herniation or fracture subluxations, and 12 suffered from spinal stenosis without bony fracture. On the other hand, in the Dvorak et al²⁸ report, 45 of 70 subjects sustained disc herniations or fracture subluxations (65%). The remaining 25 patients had spinal stenosis without bony fracture. Nearly 50% (26 of 50) of the reported cases with ATCCS in the Guest et al²⁹ series had either acute disc herniation or fracture dislocations. Twenty-four patients had spinal stenosis without bony injury. In a recent report by Aarabi et al¹⁹, describing 211 patients with ATCCS, 41 had herniated cervical discs (19.4%), 65 had fracture subluxations (30.8%), and 79 suffered from spinal stenosis without bony fracture (37.4%). In their review, 26 patients (12.3%) did not show any evidence of bony or ligamentous injury or spinal canal narrowing, although there was signal change on T2 weighted MR images of the spinal cord in these patients.

Kato et al⁵⁴ identified 127 trauma patients with cervical spinal cord injuries without bony injury on plain films or computed tomography. The incidence of ATCCS without bony injury was 32.2%. High-energy mechanisms of injury were significantly more common for younger patients. Older patients had a high incidence of injury sustained from a fall. Degenerative changes in the cervical spine and spinal stenosis were identified as risk factors for developing ATCCS without bony injury. The authors noted that ATCCS can occur in young adults during high energy injuries in the absence of pre-existing spinal disease.

In the original necropsy descriptions of Schneider et al,^{2,3,5} in 5 patients with ATCCS and spinal stenosis who died between four and 38 days following trauma, the dominant pathological finding was central necrosis of the spinal cord in association with degeneration of neurons and white matter fibers. Swelling, disruption, and necrosis of the axons in the posterolateral funiculus

of the spinal cord correlate with magnetic resonance imaging (MRI) studies of patients with ATCCS.^{12-14,55} MRI evidence of spinal cord injury following ATCCS has not been reported extensively.^{19,27,34,40} In a recent study by Miranda⁴⁰ describing 15 patients with ATCCS, 12 of 13 patients had MR studies depicting edema only. A single patient had MR findings consistent with hemorrhage. In the Aarabi et al¹⁹ investigation of 42 patients with ATCCS due to spinal stenosis without bony fracture, only one patient had evidence of hematomyelia on pre-operative MRI studies.

Imaging Criteria

ATCCS is a clinical entity and does not indicate the exact morphology of injury, the potential disruption of the disc or ligaments, the presence of bony injury, maximum spinal canal compromise, maximum spinal cord compression, and the degree of spinal cord injury.^{19,27,37,40,53,56-58} These associated features and confounding contributing variables have direct impact on the management of patients with ATCCS. They define the degree of instability,^{59,60} biomechanical failure,^{46-49,60,61} the urgency of spinal cord decompression,^{25,31,38,62} and the need for internal fixation of a potentially unstable cervical spine.^{19,63} These spinal structural/anatomic features of ATCCS are best defined by reformatting computed tomography and MRI of the cervical spine as early as possible after injury.⁶⁴⁻⁷⁸

Clinical Criteria

Though declared as an independent clinical spinal cord injury entity in which the upper extremities are weaker than the lower extremities, the differential weakness of the upper and lower extremities in ATCCS was not defined until recently. A systematic review of the medical literature by Pouw et al^{9,10} indicated that, in order for a patient to be eligible for the diagnosis of ATCCS, the ASIA Motor Score in the upper extremities should be 10 points less than the ASIA motor score in the lower extremities. In the study by Aarabi et al,¹⁹ of 42 patients with ATCCS due to spinal stenosis without bony injury, the mean upper extremity ASIA motor score was 25.8 and the mean lower extremity ASIA motor score was 39.8.

Treatment

The level of medical evidence on the treatment of patients with ATCCS is Class III derived from case reports and case series. The strength of recommendations for a specific treatment strategy, or a combination of treatment strategies, aimed at preventing further spinal cord injury, protecting the spinal cord against secondary injury after ATCCS, and providing decompression of the spinal cord with or without spinal stabilization and fusion is therefore Level III.^{2,5,19,22,23,26,28,29,31,34,37,62}

Schneider et al^{2,5} recommended conservative management of patients with ATCCS for maximal potential recovery. Between 1954 and 1958, Schneider et al described 26 cases of spinal cord injury with the clinical picture of ATCCS. Six of the 26 cases

were from the literature.^{1,79,80} Two of 26 had a clinical picture indicative of motor complete spinal cord injury. Nine of 24 patients had unequivocal fractures or fracture subluxations on plain x-rays of the cervical spine, leaving only 15 patients with ATCCS due to spinal stenosis without bony fracture. Only three of 15 patients were imaged with cervical myelography. Three patients were treated surgically, two via laminectomy with sectioning of the dentate ligament followed by attempted transdural decompression of the ventral cord. Postoperatively, one patient was rendered quadriplegic, the other patient was unchanged neurologically. The third patient with a unilateral facet dislocation improved dramatically following operative reduction, decompression, and fusion. Thirteen of 15 patients who were treated expectantly with immobilization and physical rehabilitation demonstrated improved motor function; however, the majority of patients had persistent, significant, and enduring weakness/dysfunction of the distal upper extremities and hands. Recovery of function typically started in the lower extremities, was followed by bladder function return and finally upper extremity recovery, if it were to occur. They concluded that medical management resulted in a variable recovery in most patients with ATCCS, and that surgery that could harm patients was contraindicated in the setting of ATCCS.^{2,3,5}

In contrast to Schneider et al's early recommendations about the role of surgery for ATCCS, other authors have described positive experiences with surgery in selected patients with ATCCS. In 1980, Brodkey et al²⁵ reported their experience with delayed decompression of the spinal cord in seven patients with ATCCS, all of whom had significant neurological deficits. All patients were imaged with myelography documenting compression of the spinal cord. Anterior cervical discectomy and fusion was performed in five patients, dorsal decompression in one and a combined anterior cervical discectomy and fusion and dorsal decompression in the seventh patient. Decompression of the spinal cord in these patients was performed from 18 to 45 days following trauma, at which time medical management was complete and the patients' neurological recovery and deficits had stabilized. All patients demonstrated accelerated neurological recovery after their surgical procedures.

In 1984, in a retrospective review, Bose et al²³ compared the ASIA motor score recovery at discharge of two groups of patients with ATCCS (14 in each group). One group was treated medically; most patients in this group had cervical spinal stenosis without bony fracture. The second group was treated medically but also underwent surgical decompression of the spinal cord followed by internal fixation and fusion; most patients in this group had cervical fracture/subluxation injuries. Surgery was performed 20 ± 4 days after admission. Although the two groups were not truly similar, the authors found that the group treated surgically did significantly better than those treated medically based on discharge ASIA motor scores ($P < 0.05$).

In 1997, Chen et al²⁷ reported their retrospective study of 114 patients with ATCCS who were either managed medically (86 patients) or medically with surgery (28 patients). Criteria

for surgical intervention were either spinal instability or lack of progress in neurological improvement (or neurological deterioration) in the setting of imaging evidence of spinal cord compression. Decompression was performed a mean of 10 days after admission. Twelve of 28 patients in the surgical group had spinal stenosis without bony fracture. The rest (16 patients) had either disc herniation or fracture dislocations as the cause of ATCCS. Their follow-up (mean 3.5 months) indicated that younger patients did better than older patients and that surgery was associated with a more rapid and complete return of neurological function, especially in the upper extremities, compared to nonoperative management.

In 1998, Chen et al⁸¹ published another retrospective review of 37 patients with ATCCS due to spinal stenosis without bony fracture who had spinal cord compression. Twenty-one patients were managed nonoperatively. Sixteen patients were treated surgically for focal cord compression identified on MRI. Surgery was performed a mean of nine days after admission. In their study, improvement in recovery of function after surgery was more immediate and impressive in patients in the surgical group (81%) than was recovery in the medical group (62%). However, functional recovery in the two groups was nearly equal at late follow-up (two years).

In 2000, Dai and Jia⁶² reported their retrospective investigation of the efficacy of surgical decompression of the spinal cord in a discrete group of patients with ATCCS due to focal cord compression/injury as determined by initial MRI. The researchers compared preoperative and postoperative ASIA motor scores in 24 patients with acute traumatic disc herniation (in seven patients, there was also a fracture dislocation). Although the overall motor recovery among the operated patients was impressive (average ASIA motor scores increased from 47.8 to 86.5), outcome was blunted in older patients and those with fracture dislocation injuries ($P < 0.01$). The degree of spinal cord compression was unrelated to the response to decompression ($P < 0.01$).

In a 2002 report by Guest et al,²⁹ the timing of decompression of the spinal cord and its efficacy on motor recovery was reported in 50 patients with ATCCS. Their cohort consisted of 24 patients with spinal stenosis without bony fracture, and 26 patients with disc herniation (16 patients) or fracture subluxations (10 patients). MRI of the cervical spine indicated evidence of contusion in 34 and no evidence of contusion in 16. Among the 24 patients with spinal stenosis without bony fracture, six underwent decompression within 24 hours of injury and 18 were decompressed after 24 hours. Ten of 26 patients with disc herniations or fracture dislocation injuries were treated early; 16 were treated late. The researchers evaluated the influence of early vs late decompression with the Post Spinal Injury Motor Function Scale. The timing of decompression did not affect the motor recovery in patients with spinal stenosis without bony fracture ($P = .51$). Older patients ($P = .03$) and those with early bladder dysfunction did poorly ($P = .02$). The response to early surgery was significantly better in patients with disc herniations or fracture dislocations as the cause of ATCCS ($P = .04$).

In 2005, Yamazaki et al³⁷ evaluated predictors of outcome in 47 patients with ATCCS due to spinal stenosis without bony fracture. Twenty-three patients were treated surgically and 24 were managed nonoperatively. Outcome was evaluated with the Japanese Orthopedic Association functional scale. Among 7 predictors, only sagittal diameter of the spinal canal and the time interval between injury and surgery influenced outcome. Patients with smaller sagittal diameters ($P = .04$) and those treated with surgical decompression later than two weeks after injury ($P < .001$) did significantly worse. The authors concluded that nonoperative management was inferior to surgery.

In a retrospective study reported in 2009, Chen et al²⁶ explored predictors of motor and functional outcome in 49 patients with ATCCS who had surgical decompression of the spinal cord. The pathology in this series was heterogeneous: spinal stenosis without bony fracture in 27 patients, disc herniation in 13, fractures in 8, and vertebral dislocation in 1 patient. Patients were followed for more than six months. The authors reported mean ASIA motor score improvement from 54.9 at admission to 89.6 at last follow-up ($P > .05$). Younger age at admission was a predictor of better outcome ($r = 0.55$, $P = .023$). Surgical decompression (less than 4 days from injury vs greater than 4 days) and the surgical approach utilized were not significant with respect to motor recovery or functional outcome. The Walking Index score (WISCI) was significantly lower among older patients. Almost one-third of the 49 patients expressed dissatisfaction with their outcomes when evaluated by the 36-Item Short Form Health Survey.

A 2010 systematic review³¹ combined with a retrospective analysis of the Spine Trauma Study Group observational database addressed the question: "Is there a role for urgent (within 24 hours from injury to surgery) surgical decompression in acute central cord syndrome due to spinal stenosis without bony fracture to enhance neurologic recovery?" A total of 73 ATCCS patients had either early ($n = 17$) or late ($n = 56$) decompression of the spinal cord. Data analysis was controlled for age, gender, mechanism of injury, and comorbidities. At 12-month follow up, surgery within 24 hours of injury resulted in a 6.31-point greater improvement in total ASIA motor scores ($P = .0358$), a higher chance of improvement in ASIA Grade (odds ratio of 2.81), and a 7.79-point greater improvement in the Functional Independence Measure (FIM) total score ($P = .0474$), compared to patients operated upon after 24 hours following injury.

In a retrospective study of 126 patients with ATCCS in 2010, Stevens et al³⁵ analyzed the response of the timing of surgical decompression at three separate time intervals: (1) Early—decompression within 24 hours of injury (16 patients), (2) Late—decompression after 24 hours and during the same hospital stay (34 patients; mean time to surgery 6.4 days), and (3) Delayed—decompression during a second hospital admission (17 patients; mean time interval of 137 days after trauma). Neurological outcome was assessed using the Frankel grading system. Comparing the Frankel outcome score of 67 patients treated with surgical decompression to 59 similar patients managed nonoperatively, the

investigators concluded that surgical decompression was safe, but that the timing of surgery did not affect outcome. Surgically treated patients fared better with respect to outcome, length of stay, and the incidence of complications compared to patients who were not treated surgically.

In 2011, predictors of outcome were evaluated by Aarabi et al¹⁹ in 42 patients with ATCCS due to spinal stenosis without bony fracture (although 15 patients also had disc or ligamentous injuries on MRI). All patients were operated on and followed for at least 1 year. Outcome was evaluated using the ASIA motor score, FIM, manual dexterity tests, and an assessment of neuropathic pain, the Visual Analog Scale. The ASIA motor score at admission, midsagittal diameter of the spine, maximum spinal cord compression (MSCC) on MRI, maximum canal compromise (MCC) on MRI, length of signal change on T2 weighted MRI, number of skeletal segments involved in stenosis, timing of decompression (within 48 hours or after 48 hours), age, and surgical approach were considered factors that could influence outcome. Different domains of outcome were determined by different variables. At the time of admission, the average ASIA motor score was 63.8 (upper extremities score, 25.8 and lower extremities score, 39.8). The ASIA motor score at one year follow up (94.1) was significantly correlated to the admission ASIA motor score ($P = .003$), the midsagittal diameter ($P = .02$) and MCC ($P = .02$). FIM at 1 year follow up (111.1) was significantly influenced by the admission ASIA motor score ($P = .03$), MCC ($P = .02$), and age ($P = .02$). Manual dexterity at one year follow up (64.4%) significantly correlated with the admission ASIA motor score ($P = .0002$) and the length of the lesion on MRI ($P = .002$). Neuropathic pain (3.5) had a significant relationship with patient age ($P = .02$) and the length of the lesion on MRI ($P = .04$). The surgical approach (front, back, circumferential), the number of skeletal segments in which there was spinal stenosis, and the timing of decompression were not determinants of outcome.

Several postacute care outcome studies have described motor recovery and functional outcome in patients with ATCCS.^{22,24,28,33,40,41,82-85} In 1971, without elaborating on the exact pathology, imaging studies and treatment, Bosch et al⁸⁶ reported on the long-term ambulation, hand function and sphincter control of 42 patients with ATCCS. As indicated in Table 1, there was a universal trend towards improvement of ambulation, manual dexterity, and sphincter control following acute hospitalization and in-patient rehabilitation for ATCCS. The authors observed that there was a paradoxical loss of neurological function, primarily ambulation skills and pyramidal tract involvement, at late follow up in 24% of patients who initially demonstrated neurological improvement after ATCCS ("chronic central cord syndrome").

In 1977, Shrosbree⁸⁷ reported on the functional outcome of a group of 90 heterogeneous patients with ATCCS who were treated conservatively. The initial severity of the patient's motor deficits dictated long-term outcome, including walking ability. Only 22% of patients with severe motor deficits upon admission became independent walkers; all had residual deficits in the

hands. Two distinct groups of patients were recognized in this study: Younger patients (<50 years of age) who typically suffered from fracture subluxation injuries, and older patients who experienced ATCCS associated with spinal stenosis without bony injury.

In a 1990 retrospective investigation, Penrod et al⁸⁴ studied the effect of age on ambulation and activities of daily living in 51 patients with ATCCS. Ambulation at follow up was noted in 29 of 30 patients <50 years of age (97%), compared to seven of seventeen ATCCS patients older than 50 years (41%) ($P < .002$). Younger patients showed significantly more independence in activities of daily living and sphincter control. In a similar study also published in 1990, Roth et al⁷⁸ identified a better prospect for recovery in younger ATCCS patients. They compared Modified Barthel Index scores upon admission to rehabilitation and those obtained at discharge.

Tow and Kong⁸⁵ in 1998 retrospectively studied the long-term motor recovery and the functional outcomes of 73 patients with ATCCS. In their study, younger patients, those without spasticity, and those with a higher initial Modified Barthel Index had better functional outcome scores at late follow up.

In 2005, Dvorak et al²⁸ studied ASIA motor scores and FIM in a cohort of 72 patients whose clinical data were collected in a prospective manner. Forty-five of 72 patients suffered either a disc herniation (2 patients) or a fracture subluxation injury (43 patients). Twenty-five patients suffered from spinal stenosis without bony fracture. The investigators did not elaborate on the surgical management of their cohort; however, 41 patients were treated with surgery. Mean ASIA motor scores at follow up (92.3) correlated with mean ASIA motor scores at admission (58.7, $P = .0001$), formal education ($P = .0001$), and the absence of spasticity ($P = .0001$) at follow up. Patient FIM was positively correlated with higher ASIA motor scores at admission ($P = .0009$), formal education ($P = .02$), the absence of comorbidities ($P = .04$), the absence of spasticity, and younger age ($P = .007$). Independent ambulation was reported in 86% of patients at late follow up. Patient reported outcome (SF-36) improved in those with more formal education ($P = .0000$), fewer comorbidities ($P = .009$), the absence of spasticity ($P = .03$), and anterior column fractures as a cause of ATCCS ($P = .03$).

Aito et al²² in 2007 offered a retrospective review of 82 patients with ATCCS. They did not find surgery to be a significant predictor of neurological outcome (ASIA Impairment Scale) or

TABLE 1. Function Attained Following Central Cord Lesion⁸⁶

	Admission %	Discharge %	Follow up %
Ambulation	33.3	77	59 ^a
Hand Function	26	42	56
Bladder Function	17	...	53
Bowel Function	9.5	...	53

^a24% with late longtract deterioration: "chronic central cord syndrome."

TABLE 2. Evidentiary Table: Management of ATCCS

Citation	Description of Study	Evidence Class	Conclusions
Aarabi, ¹⁹ <i>J Neurosurg Spine</i> , 2011	Retrospective study of prospectively collected data on 42 patients with ATCCS for spinal stenosis who were operated on and followed for one year. The relationship of follow-up AMS, FIM, manual dexterity, and dysesthetic pain were correlated with admission AMS, age, maximum canal compromise (MCC), maximum spinal cord compression (MSCC), length of signal change on MRI, time past injury and surgery, sagittal diameter of spinal canal, number of stenotic motion segments, surgery, and mechanism of injury.	III	The AMS was significantly correlated to the admission ASIA motor score ($P = 0.003$), the midsagittal diameter ($P = 0.02$) and MCC ($P = 0.02$). FIM at one year follow-up (111.1) was significantly influenced by the admission ASIA motor score ($P = 0.03$), MCC ($P = 0.02$), and age ($P = 0.02$). Manual dexterity at one year follow up (64.4%) significantly correlated with the admission ASIA motor score ($P = 0.0002$) and length of lesion on MR imaging ($P = 0.002$). Neuropathic pain (3.5) had a significant relationship with patient age ($P = 0.02$) and the length of the lesion on MR imaging ($P = 0.04$). Surgical approach, mechanism of injury age, and the timing of decompression within 48 hours and after 48 hours of injury were not significant players in this study.
Fehlings, ⁹⁹ <i>Spine</i> , 2010	Survey of 971 spine surgeons in reference to the timing of surgical decompression in spinal cord injuries.	III	While up to 80% of the responders agreed with surgical decompression of the spinal cord within 24 hours, there was no consensus in surgical decompression in ATCCS due to spinal stenosis.
Hohl, ³⁰ <i>Spine</i> , 2010	Retrospective study of 37 patients with ATCCS to determine predictive factors in motor FIM at 12 months.	III	ASIA Motor Score ($P < 0.013$) and signal change on MRI ($P < 0.007$) were predictors of motor FIM at 1 year.
Lenahan, ³¹ <i>Spine</i> , 2010	Ambispective review of Spine Trauma Study Group cohort of 73 patients comparing motor and functional recovery 6 and 12 months following spinal cord decompression following ATCCS associated with spinal stenosis.	III	At 6 months and 12 months follow up patients ($n = 17$) who were decompressed within 24 hours did much better in AMS, AIS, and total FIM score than those decompressed after 24 hours of injury ($n = 56$).
Stevens, ³⁵ <i>Spine Journal</i> , 2010	Retrospective review of the timing of decompression in ATCCS (within 24 and after 24 hours).	III	Sixteen patients were decompressed within 24 hours and 34 patients received decompression after 24 hours. Timing of decompression did not affect outcome.
Chen, ²⁶ <i>J Neurosurg Spine</i> , 2009	Retrospective review of 49 patients who had surgical decompression of spinal cord within 4 days and after 4 days in ATCCS.	III	The timing of surgical decompression did not affect motor or functional outcome (AMS, WISCI).
Lenahan, ⁸² <i>Eur Spine</i> , 2009	Retrospective review of 50 patients with ATCCS who were followed for a mean of 42.2 months.	III	Absolute and relative improvement were greatest in patients < 50 years of age.
Miranda, ⁴⁰ <i>J Neurosurg Sci</i> , 2008	Retrospective review of motor score improvement in 15 patients with ATCCS.	III	The length of spinal cord edema significantly correlated with initial motor score (T2-weighted hyperintensity in serial MR studies).
Aito, ²² <i>Spinal Cord</i> , 2007	Retrospective review of 82 patients with ATCCS who were treated surgically (45%) or conservatively (55%). These included 44 patients with spinal stenosis.	III	Patients older than 65 had less neuropathic pain. Surgical decompression did not affect outcome.
Dvorak, ²⁸ <i>Spine</i> , 2005	Retrospective review of 70 patients with ATCCS. 25 patients had spinal stenosis, 43 fracture subluxations, and 2 herniated disc.	III	AMS at follow up related to AAMS, level of education, and spasticity. FIM at follow up related to AAMS, education, comorbidities, and spasticity.

(Continues)

TABLE 2. Continued

Citation	Description of Study	Evidence Class	Conclusions
Song, ⁵³ <i>J Clin Neurosci</i> , 2005	Retrospective review of 22 patients with ATCCS who had surgery.	III	Surgical decompression improved neurological status and prevented delayed neurological deterioration.
Guest, ²⁹ <i>J Neurosurg</i> , 2002	Retrospective review of motor recovery in 50 patients with ATCCS. The cohort included 24 patients with spinal stenosis, 16 herniated discs, and 10 fracture dislocations.	III	Early surgery (within 24 hours) enhanced recovery of motor recovery in fracture dislocations but did not have much effect on spinal stenosis due to disc osteophyte complex.
Dai, ⁶² <i>Spine</i> , 2000	Retrospective review of 24 patients with ATCCS due to disc herniation.	III	Increased age had a negative effect on functional outcome.
Tow, ⁸⁵ <i>Spinal Cord</i> , 1998	Retrospective review of 73 patients with ATCCS who had a mean of 51 days of follow up.	III	Patients with better admission Modified Barthel Index, younger age and less spasticity had better functional outcome.
Newey, ³² <i>J Bone Joint Surg Br</i> , 2000	Retrospective review of 32 patients with ATCCS managed conservatively.	III	Improvement seen in most patients over time. Older patients had worse outcome.
Chen, ⁸¹ <i>Spine</i> , 1998	Retrospective review of 37 patients with ACSI with preexisting spondylosis. Many with central cord injury pattern. MRI assessment of compression, cord injury. 16 managed with surgical decompression, 21 medically.	III	MRI modality of choice to image cord compression/injury. Surgical decompression associated with more rapid improvement, shorter hospital and rehabilitation stay. No difference in outcome at 2year follow up.
Chen, ²⁷ <i>Surg Neurol</i> , 1997	Retrospective review of 114 patients with ATCCS. This cohort consisted of 28 surgical and 86 medical patients.	III	Younger patients had better recovery.
Waters, ⁴¹ <i>Spinal Cord</i> , 1996	Prospective multicenter study of 19 patients with ATCCS due to spinal stenosis.	III	On the average natural rate of recovery was doubling of ASIA motor scores at one year of follow up.
Bridle, ²⁴ <i>Paraplegia</i> , 1990	Retrospective evaluation of 18 patients with ATCCS for pain, hand dexterity, and occupational performance.	III	Significant difference was found between males and females on the MPIs.
Penrod, ⁸⁴ <i>Arch Phys Med Rehab</i> , 1990	Retrospective review of ADL in 51 patients with ATCCS.	III	ADL, ambulation, and bladder function better in younger patients.
Roth, ³³ <i>Arch Phys Med Rehab</i> , 1990	Retrospective evaluation of 81 patients with ATCCS including 63% fracture dislocations.	III	Younger patients had better rehabilitation outcome on Modified Barthel Index.
Merriam, ³⁹ <i>J Trauma</i> , 1986	Retrospective review of 77 patients with ATCCS. No patients with surgical decompression, 30 underwent late stabilization and fusion.	III	Marked variation among patients and injury patterns. Most improved. Outcome related to age and severity of initial injury.
Bose, ²³ <i>Neurosurgery</i> , 1984	Retrospective study of 28 patients with ATCCS including 19 patients with extension injury. 14 patients were treated conservatively and 14 had surgery.	III	Surgical intervention was safe at discharge; operated patients did better than the conservatively treated group.
Brodkey, ²⁵ <i>Surg Neurol</i> , 1980	Seven patients with anterior cord compression were decompressed in a subacute fashion	III	All patients improved clinically very rapidly.
Shrosbree, ⁸⁷ <i>Paraplegia</i> , 1977	Retrospective review with late follow up of 99 patients with ATCCS managed conservatively.	III	Two groups identified. Younger patients with flexion rotation injuries. Older patients with hyperextension injuries. Outcome related to age and severity of initial injury.
Bosch, ⁸⁶ <i>JAMA</i> , 1971	Retrospective review and long-term follow-up of 42 patients with ATCCS managed conservatively.	III	Most patients improved over time; 75% regained ambulatory skills, 56% regained functional hands, and 10/42 patients had late deterioration after initial gains ("chronic central cord syndrome").

(Continues)

TABLE 2. Continued

Citation	Description of Study	Evidence Class	Conclusions
Schneider, ⁵ <i>J Neurol Neurosurg Psychiatry</i> , 1958	Retrospective review of 12 additional patients with ATCCS. Eleven managed expectantly, 1 managed with surgical decompression 13 hours after injury.	III	Two age groups of patients. Young patients with fracture dislocation injuries. Older patients with hyperextension injuries often without bony vertebral damage. Most patients improved. Expectant management is ideal treatment.
Schneider, ³ <i>J Neurosurg</i> , 1954	Review of 14 cases of ATCCS: 8 personal and 6 from the literature. This cohort was a mixed bag of discosteophyte complex and fracture dislocations.	III	It was recommended that surgery should not be performed in ATCCS.
Schneider, ² <i>J Neurosurg</i> , 1951	Retrospective review of 2 patients with disc herniation and central cord syndrome.	III	Significant improvement in one of two patients following surgery.

functional outcome (FIM and WISCI). They described 38 patients with ATCCS who were treated with surgery, most often for a disc herniation or fracture subluxation injury. Forty-four patients were treated without surgical intervention. All patients in this latter group had ATCCS associated with spinal stenosis without bony injury. Lack of congruity of the two patient groups makes it impossible to draw meaningful conclusions about the effect of surgery on neurological and functional outcomes. Overall, younger ATCCS patients did better at 18 months follow up (mean). Patients older than 65 years of age reported less neuropathic pain.

Since the first publication of the “Guidelines for the Management of Acute Cervical Spine and Spinal Cord Injuries,” the management of ATCCS has remained controversial.^{19,22,23,26-28,31,38,45,62,84} The heterogeneity of this group of patients makes any firm conclusion about the management of ATCCS virtually impossible.^{19,21,22,26,28} Based on a current review of the literature, there seem to be four distinct groups of patients who manifest the clinical features of ATCCS. These groups are characterized by different biomechanics, pathology, and their response to surgical and medical treatment. Approximately 10% of patients with ATCCS have MRI evidence of signal change within the spinal cord with no other radiographic abnormality.¹⁹ It is recommended that these patients be managed medically. Roughly 20% of patients present with an acute disc herniation as the cause of ATCCS.^{26,27,62,86} Surgical intervention is recommended for this group. Nearly 30% of patients with ATCCS have cervical spine skeletal injuries in the form of fracture subluxation injuries.^{22,23,27,28,81} In this group of patients, early re-alignment of the spinal column (closed or open) with spinal cord decompression is recommended. The last group of patients (approximately 40%) have spinal stenosis without evidence of bony or ligamentous injury.^{2,5,19,21-23,26-28,37,53,82,88} It is in this group of patients that the management of ATCCS remains the most controversial.^{2,5,19,22,23,26-28,31,37,42,43,73,76,78,81,85,88-93} The variable degree of spontaneous recovery of neurological function in patients with ATCCS due to spinal stenosis without bony injury compromises the study of surgical vs medical management strategies.^{2,5,22,24,25,34,84} Data are summarized in Table 2.

SUMMARY

Class III medical evidence supports the aggressive medical management including ICU care of all patients with a spinal cord injury, including those with ATCCS. Class III medical evidence suggests that surgery for ATCCS is safe and appears to be efficacious (in conjunction with medical management) for patients with focal cord compression, or to provide operative reduction and internal fixation and fusion of cervical spinal fracture dislocation injuries. The role of surgery for patients with ATCCS with long segment cord compression/injury or with spinal stenosis without bony injury remains a subject of debate in the literature.^{19,23,26,27,31,37,38,81,94-101} Patient age and comorbidities are important factors when considering surgical treatment for patients with ATCCS.^{19,22,26,28-29,33,35,81,84,85}

KEY ISSUES FOR FUTURE INVESTIGATION

A prospective, controlled, randomized, or case control investigation of patients with ATCCS due to spinal stenosis without bony fracture treated with aggressive medical therapy alone (intensive care unit management, blood pressure augmentation, closed fracture dislocation reduction), compared to patients managed with aggressive medical therapy and early surgical decompression of the spinal cord would provide Class II medical evidence on this important topic.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Management of Pediatric Cervical Spine and Spinal Cord Injuries

Curtis J. Rozzelle, MD*
Bizhan Aarabi, MD, FRCSC‡
Sanjay S. Dhall, MD§
Daniel E. Gelb, MD¶
R. John Hurlbert, MD, PhD, FRCSC||
Timothy C. Ryken, MD, MS#
Nicholas Theodore, MD**
Beverly C. Walters, MD, MSc, FRCSC‡‡§§
Mark N. Hadley, MD‡‡

*Division of Neurological Surgery, Children's Hospital of Alabama University of Alabama at Birmingham, Birmingham Alabama; ‡Department of Neurosurgery, University of Maryland, Baltimore, Maryland; §Department of Neurosurgery, Emory University, Atlanta, Georgia; ¶Department of Orthopaedics, University of Maryland, Baltimore, Maryland; ||Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada; #Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa; **Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona; ‡‡Division of Neurological Surgery, University of Alabama at Birmingham, Birmingham, Alabama; §§Department of Neurosciences, Inova Health System, Falls Church, Virginia

Correspondence:

Mark N. Hadley, MD, FACS,
 UAB Division of Neurological Surgery,
 510 – 20th St S, FOT 1030,
 Birmingham, AL 35294-3410.
 E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS:

Diagnostic:

Level I:

- Computed tomographic (CT) imaging to determine the condyle-C1 interval (CCI) for pediatric patients with potential atlanto-occipital dislocation (AOD) is recommended.

Level II:

- Cervical spine imaging is not recommended in children who are > 3 years of age and who have experienced trauma and who:
 - are alert,
 - have no neurological deficit,
 - have no midline cervical tenderness,
 - have no painful distracting injury,
 - do not have unexplained hypotension,
 - and are not intoxicated.
- Cervical spine imaging is not recommended in children who are < 3 years of age who have experienced trauma and who:
 - have a Glasgow Coma Scale (GCS) > 13,
 - have no neurological deficit,
 - have no midline cervical tenderness,

- have no painful distracting injury,
- are not intoxicated,
- do not have unexplained hypotension,
- and do not have motor vehicle collision (MVC), a fall from a height > 10 feet, or non-accidental trauma (NAT) as a known or suspected mechanism of injury.
- Cervical spine radiographs or high resolution CT is recommended for children who have experienced trauma and who do not meet either set of criteria above.
- Three-position CT with C1-C2 motion analysis to confirm and classify the diagnosis is recommended for children suspected of having atlantoaxial rotatory fixation (AARF).

Level III:

- Anteroposterior (AP) and lateral cervical spine radiography or high-resolution CT is recommended to assess the cervical spine in children < 9 years of age.
- AP, lateral, and open-mouth cervical spine radiography or high-resolution CT is recommended to assess the cervical spine in children 9 years of age and older.
- High resolution CT scan with attention to the suspected level of neurological injury is recommended to exclude occult fractures or to evaluate regions not adequately visualized on plain radiographs.
- Flexion and extension cervical radiographs or fluoroscopy are recommended to exclude gross ligamentous instability when there remains a suspicion of cervical spinal instability following static radiographs or CT scan.
- Magnetic resonance imaging (MRI) of the cervical spine is recommended to exclude spinal cord or nerve root compression, evaluate

ABBREVIATIONS: AP, anteroposterior; AARF, atlantoaxial rotatory fixation; AOD, atlanto-occipital dislocation; CCI, condyle-C1 interval; CCR, Canadian C-spine Rule; DGZ, diagnostic grey zone; FVC, forced vital capacity; GCS, Glasgow Coma Scale; MVC, motor vehicle collision; NAT, non-accidental trauma; NEXUS, National Emergency X-Radiography Utilization Study; SCIWORA, spinal cord injury without radiographic abnormality; TAS, transarticular screw TAS

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ligamentous integrity, or provide information regarding neurological prognosis.

Treatment

Level III:

- Thoracic elevation or an occipital recess is recommended in children < 8 years of age to prevent flexion of the head and neck when restrained supine on an otherwise flat backboard for better neutral alignment and immobilization of the cervical spine.
- Closed reduction and halo immobilization are recommended for injuries of the C2 synchondrosis in children < 7 years of age.
- Reduction with manipulation or halter traction is recommended for patients with acute AARF (< 4 weeks duration) that does not reduce spontaneously. Reduction with halter or tong/halter traction is recommended for patients with chronic AARF (> 4 weeks duration).
- Internal fixation and fusion are recommended in patients with recurrent and/or irreducible AARF.
- Consideration of primary operative therapy is recommended for isolated ligamentous injuries of the cervical spine and unstable or irreducible fractures or dislocations with associated deformity.
- Operative therapy is recommended for cervical spine injuries that fail non-operative management.

RATIONALE

There are distinct, unique aspects of the management of children with potential injuries of the cervical spinal column and cervical spinal cord compared to adult patients that warrant specific recommendations. The methods of pre-hospital immobilization necessary to approximate "neutral" cervical spinal alignment in a young child differ from those methods commonly employed for adults. The spinal injury patterns among young children differ from those that occur in adults. The diagnostic studies and images necessary to exclude a cervical spine injury in a child may be different than in the adult as well. The interpretation of pediatric radiographic studies must be made with knowledge of age-related development of the osseous and ligamentous anatomy. Methods of reduction, stabilization, and subsequent treatment, surgical and non-surgical, must be customized to each child, taking into account the child's degree of physical maturation and his/her specific injury. The purpose of this review is to address the unique aspects of children with real or potential cervical spinal injuries, and provide recommendations regarding their management.

SEARCH CRITERIA

Incorporating and expanding upon the first iteration of these guidelines,¹ a National Library of Medicine (PubMed)

computerized literature search from 1966 to 2011 was undertaken using Medical Subject Headings in combination with "spinal cord injuries" and "child" and yielded 1125 citations. These citations were reviewed in combination with "cervical vertebra," "spinal injuries," and "child" which yielded 197 citations. Non-English language citations were deleted. The remaining abstracts were reviewed for those that described children who had sustained or were being evaluated for a cervical spinal cord or cervical spinal column injury. Articles describing the clinical aspects and management of children were used to generate these guidelines. Case reports were excluded. Of the 80 articles meeting selection criteria, 1 provided Class I medical evidence for diagnostic imaging in AOD. In addition, there were 10 Class II medical evidence studies addressing diagnostic imaging in children. There was only 1 Class II medical evidence study concerning treatment. All remaining articles were case series representing Class III medical evidence. Summaries of these 80 articles are provided in Evidentiary Table format (Tables 1-2).

SCIENTIFIC FOUNDATION

Pre-Hospital Immobilization

The primary goal of pre-hospital management of pediatric patients with potential cervical spine or spinal cord injury is to prevent further injury. Along with assuring an adequate airway, ventilation, and perfusion, spinal immobilization likely plays an important role in preventing further injury to the vertebral column and spinal cord. Immobilization of the child's cervical spine in the neutral position is desired. To achieve neutral alignment of the cervical spine in children < 8 years of age, allowances must be made for the relatively large head compared to the torso, which forces the neck into a position of flexion when the head and torso are supine on a flat surface.² Nypaver and Treloar² prospectively evaluated 40 children < 8 years of age seen in an emergency room for reasons other than head and neck trauma and assessed them with respect to neutral positioning upon a backboard. They found that all 40 children required elevation of the torso to eliminate positional neck flexion and achieve neutral alignment as determined by 2 independent observers. The mean amount of elevation required was 25 mm. Children < 4 years of age required greater elevation than those 4 years of age or older ($P < .05$). Because of these findings, it was recommended that children < 8 years of age requiring immobilization either 1) have the torso elevated or 2) place the head in an occipital recess to achieve a more neutral position for immobilization of the cervical spine. In a separate report, Treloar and Nypaver³ similarly found that semi-rigid cervical collars placed on children < 8 years of age did not prevent this positional forced flexion when placed supine on standard, rigid spinal boards.

Herzenberg et al⁴ studied 10 children < 7 years of age with cervical spine injuries who were positioned on a backboard. All had anterior angulations or translation at the injured segment that was reduced by allowing neck extension into a more neutral position. They suggested that alignment of the patient's external

auditory meatus with his/her shoulders would help to achieve neutral cervical spine positioning.

However, Curran et al⁵ found no correlation with age regarding degree of cervical kyphosis identified in children transported on backboards. They did note however, that 30% of children had $> 10^\circ$ of kyphosis as determined by Cobb angle measurements between C2 and C6. No specific technique or device allowed superior neutral positioning of the cervical spine in patients they studied. None of their patients were immobilized on boards with an occipital recess or thoracic padding.

Huerta et al⁶ evaluated a variety of immobilization devices on children, infants, and child-sized mannequins. They concluded that no collar provided “acceptable immobilization” when used alone. They found that the combination of a modified half-spine board, rigid cervical collar, and tape was the most effective means of immobilization of the cervical spine for transport in children.

Shafermeyer et al,⁷ however, cautioned that immobilization techniques that employ taping across the torso to secure the child to the spine board may have deleterious effects on respiratory function. They studied 51 healthy children, ages 6 to 15 years by measuring forced vital capacity (FVC). FVC dropped when going from the upright to supine position. Taping across the torso to secure the volunteer to the spine board caused further reductions in FVC of 41% to 96% (mean 80%), compared to the supine FVC without tape. The authors cautioned that this restriction of FVC might be enough to create respiratory insufficiency in some trauma patients.

In summary, when spinal immobilization is indicated for children for transportation, the type of immobilization should take into account the child's age and physical maturity. It should allow for the relatively larger head with respect to the torso in younger children. While ideal spinal immobilization of pediatric trauma victims appears to be provided by a combination of a spinal board, rigid collar, and tape, these immobilization techniques may negatively influence the child's respiratory function.

Imaging

Following immobilization and transport to an acute care facility, initial clinical evaluation and medical/hemodynamic support, the need for and type of imaging assessment must be determined and performed. Several authors have evaluated the indications for radiographic assessment of children with a potential cervical spinal injury.^{8,9} Laham et al⁹ investigated the role of cervical spine x-ray evaluation of 268 children with apparent isolated head injuries. They retrospectively divided the children into high ($n = 133$) and low-risk ($n = 135$) groups. High-risk characteristics were children incapable of verbal communication either because of age (< 2 years of age) or head injury, and those children with neck pain. They employed the “3-view approach” of anteroposterior (AP), lateral, and open-mouth radiographs. They discovered no cervical spine injuries in the low-risk group but discovered 10 in the high-risk group (7.5%). The authors concluded that cervical spine

radiographs are not necessary in children with isolated head injuries who can communicate and have no neck pain or neurological deficit. Bohn et al⁸ emphasized that unexplained hypotension or absent vital signs in childhood trauma victims are likely to be from a severe cervical cord injury. Therefore, they advocate suspicion for a cervical spinal cord injury in children with either multisystem trauma, or an isolated head injury presenting with hypotension or cardiopulmonary arrest.

Viccellio et al¹⁰ evaluated the cervical spines in children < 18 years of age utilizing the National Emergency X-Radiography Utilization Study (NEXUS^{Ref.}) decision instrument in a Class II prospective multicenter study. They employed 5 low-risk criteria. These criteria were the absence of: 1) midline cervical tenderness, 2) evidence of intoxication, 3) altered level of alertness, 4) focal neurological deficit, and 5) other painful distracting injury. Radiographs were obtained at the discretion of the treating physician. When radiographs were obtained a minimum of 3-views was obtained. Only those patients who obtained radiographs were included in the study. If all 5 criteria were met, the child was considered low-risk. If any one of the 5 criteria were present the child was considered high-risk. Three thousand and sixty-five children were evaluated. Of these, 603 fulfilled the low-risk criteria. None of these 603 children defined as low-risk had a documented cervical spine injury by radiographic evaluation. Thirty injuries (0.98%) were documented in children not fulfilling the low-risk criteria. They concluded that applying the NEXUS criteria to children would reduce cervical spine radiograph use by 20% and not result in missed injuries. They cautioned that they had relatively small numbers of young children < 2 years of age ($n = 88$). Statistically, this created large confidence intervals for the sensitivity of their instrument when applied to younger children. From this Class II study, they “cautiously” endorsed the application of NEXUS criteria in children, particularly those from zero to 9 years of age. Their conclusions are consistent with the Class III evidence previously described by Laham et al⁹ on this topic.

A NEXUS-based pediatric (0-18 years) cervical spine clearance protocol was evaluated by Anderson et al¹¹ in a Class II prospective multicenter trial, using historical controls. Plain radiographs were obtained on all children presenting in a cervical collar. Children > 3 years old with normal radiographs who met all 5 NEXUS low-risk criteria were “cleared.” All others required additional imaging, neurosurgical consultation, or both. Cervical spine injury detection rates were equivalent with historical controls and no late injuries were detected. Use of the protocol “increased the number of cervical spines cleared by non-neurosurgical personnel by nearly 60%.” The protocol design and study did not, however, allow for any cervical spine clearance without radiography.

In a parallel Class II prospective study at the same institutions, Anderson et al¹² evaluated a cervical spine clearance protocol designed for trauma patients aged < 3 years. All children underwent plain radiography (AP and lateral views) and CT scans only if radiographic findings were inadequate or suspicious for an injury. If initial imaging was negative, further evaluation

depended on the patient's airway status (intubated or not) and included clinical factors, dynamic radiography, and/or MRI. MRI scans were reserved for patients with signs of spinal cord injury, intubation/obtundation for > 48 hours, or persistent neck pain with range of motion. Application of this protocol resulted in cervical spine clearance of 575 noncommunicative children < 3 years old over a 5-year period without any missed injuries detected. CT scans were necessary in only 14% of cases and MRI in 10%. The authors recognize that the low incidence of injuries (28 of 575) limits the statistical strength of their findings.

Garton et al¹³ evaluated NEXUS criteria retrospectively in 190 consecutive pediatric cervical spine injury cases with particular attention to younger children. In their Class II analysis, application of NEXUS criteria to determine the need for c-spine imaging would not have missed any injuries in the 157 patients older than 8 years. Applying NEXUS criteria to the 33 patients aged < 8 years, however, would have missed 2 injuries (94% sensitivity). Also in children < 8 years old they reported a higher sensitivity for combination plain radiography/occiput-C3 CT scan compared with plain radiography/flexion/extension views (sensitivity, 94% vs 81%).

Both NEXUS low-risk criteria and the Canadian C-spine Rule (CCR) were assessed retrospectively by Ehrlich et al¹⁴ in children < 10 years of age. Both protocols would have missed clinically important cervical spine injuries in the imaged cohort. Sensitivity and specificity were 43% and 96% for NEXUS, and 86% and 94% for CCR, respectively. They concluded that neither protocol is sensitive or specific enough to be used as designed for young children.

Pieretti-Vanmarcke et al¹⁵ performed a Class II multi-institutional review of 12 537 blunt trauma cases < 3 years of age to identify clinical predictors of cervical spine injury (n = 83). Four independent predictors of cervical spine injury were reported to be significant: (GCS < 14; GCSe = 1; motor vehicle crash; age 2 to 3 years [by definition, a patient with GCSe = 1 must have a total GCS < 14 so these 2 predictors can be combined]). Using the weighted scoring system reported for these predictors, a child < 3 years old presenting after blunt trauma with a GCS > 13 and any non-MVC mechanism has only a 0.07% chance of having a cervical spine injury. (NPV = 99.93%). This is comparable to the probability of missing an injury when using appropriate imaging. The only 5 outliers they encountered had neck splinting, associated facial/skull fractures, and/or documented loss of consciousness compounding their assessment.

Another study focused on c-spine injury in very young children was reported by Katz et al.¹⁶ They reviewed 905 consecutive infants (<12 months of age) presenting after minor (low impact) head trauma and found only 2 c-spine injuries, both due to non-accidental trauma (NAT). Low impact head trauma was defined as any mechanism other than MVC or a fall from > 10 feet. They concluded that routine c-spine imaging in this population has very low diagnostic yield unless NAT is suspected.

Hutchings et al¹⁷ reviewed c-spine clearance methods retrospectively in 115 consecutive obtunded major trauma patients <16 years of age. No protocol was used during the 7-year study period.¹⁷ Six c-spine injuries were identified by a variety of screening methods. CT imaging alone was found to have 100% sensitivity and 100% specificity in this population, although the validity of this finding is undermined somewhat by the low incidence of injury.

The need for and utility of open-mouth odontoid views in pediatric trauma victims has been questioned (6,59).^{18,19} Swischuk et al¹⁹ surveyed 984 pediatric radiologists to determine how many injuries were missed on lateral cervical spine radiographs, yet detected on an open-mouth view (59). There were 432 responses. One hundred and sixty-one respondents did not routinely use open-mouth views. Of the 271 that obtained open-mouth views in young children, 191 (70%) would not persist beyond a single attempt. Seventy-one radiologists (26%) would make up to 5 attempts to obtain an adequate image. Twenty-eight of the 432 respondents (7%) reported missing a total of 46 fractures on the lateral view that were detected on the open-mouth view. The types of injuries were not classified (ie, odontoid vs C1 injury). The authors calculated a missed fracture rate of 0.007 per year per radiologist in their study. They concluded that the open-mouth view x-ray might not be needed routinely in children < 5 years of age. Buhs et al¹⁸ also investigated the utility of open mouth views in children. They performed a multi-institutional retrospective review of a large metropolitan population of patients < 16 years of age who were assessed for cervical spine trauma over a 10-year period. Fifty-one children with cervical spinal injuries were identified. The lateral cervical spine radiograph made the diagnosis in 13 of 15 children < 9 years of age. In none of the 15 younger patients did the open-mouth view provide the diagnosis. In only 1 of 36 patients in the 9 to 16 years of age group was the open mouth view the key diagnostic study (a type III odontoid injury). The authors concluded that the open mouth view radiograph is not necessary for clearing the cervical spine in children < 9 years of age.

Lui et al,²⁰ in their review of 22 children with C1-C2 injuries, commented that flexion and extension radiographs were required to "identify the instability" of traumatic injuries to the dens in 4 of 12 children with odontoid fractures, and in 6 of 9 children with purely ligamentous injuries resulting in atlantoaxial dislocation. The authors did not state whether an abnormality on the static radiograph led to the dynamic studies, or whether the initial static studies were normal. Because they did not describe flexion and extension x-rays as part of their "routine" for the assessment of children with potential cervical spine injuries, it is likely that some imaging or clinical finding prompted the decision to obtain dynamic films in these children.

The experience of Ruge et al²¹ highlighted the propensity for upper cervical injuries in children under the age of 9 years. They reported no injuries below C3. Evans and Bethem²² described 24 children with cervical spine injuries. In half of the patients, the injury was at C3 or higher.²² Givens et al,²³ however, described

the occurrence of important injuries occurring at all levels of the cervical spine in young children. They described 34 children with cervical spine injuries. There was no correlation of level of injury with age. Two of the children they managed had injuries at C7-T1. Hence, it would be dangerous to assume that lower cervical spine injuries do not occur in young children, and irresponsible to discount the need for adequate imaging of the lower cervical spine and cervical-thoracic junction in these young patients.

Scarrow et al²⁴ attempted to define a protocol to evaluate the cervical spine in obtunded children following trauma. They utilized somatosensory-evoked responses during flexion and extension fluoroscopy. Of the 15 children evaluated with this protocol, none showed pathological motion during flexion and extension fluoroscopy. Three children were thought to have a change in the evoked responses during flexion and extension. Only 1 of the 3 children with an abnormal evoked response underwent MRI that was normal. Their investigation failed to demonstrate any utility for evoked responses, flexion and extension fluoroscopy, or MRI of the cervical spine in the evaluation of the cervical spine in children with altered mental status following trauma. Larger numbers of children investigated in this manner might define a role for 1 or more of these diagnostic maneuvers, but as yet there is no evidence to support their use.

Ralston et al²⁵ retrospectively analyzed the cervical spine radiographs of 129 children who had flexion and extension x-rays performed after an initial static radiograph. They found that if the static radiograph was normal or depicted only loss of lordosis, only the flexion and extension views would reveal no abnormality. The authors concluded that the value of the dynamic radiographs was confirmation of cervical spinal stability when there was a questionable finding on the static, lateral radiograph.²⁵

The interpretation of cervical spine x-rays must account for the age and anatomical maturation of the patient. Common normal findings on cervical spine radiographs obtained on young children are pseudosubluxation of C2 on C3, overriding of the anterior atlas in relation to the odontoid on extension, exaggerated atlanto-dens intervals, and the radiolucent synchondrosis between the odontoid and C2 body. These normal findings can be mistaken for acute traumatic injuries in children following trauma. Cattell and Filtzer²⁶ obtained lateral cervical radiographs in neutral, flexion, and extension in 160 randomly selected children who had no history of trauma or head and neck problems. The subjects' ages ranged from 1 to 16 years with 10 children for each year of age. They found a 24% incidence of moderate to marked C2 on C3 subluxation in children between 1 and 7 years of age. Thirty-two of 70 children (46%) < 8 years of age had 3.0 mm or more of anterior-posterior motion of C2 on C3 on flexion and extension radiographs. Fourteen percent of all children had radiographic pseudosubluxation of C3 on C4. Twenty percent of children from 1 to 7 years of age had an atlanto-dens interval of 3 millimeters or greater. Overriding of the anterior arch of the atlas on the odontoid was present in 20% of children < 8 years old. The synchondrosis between the odontoid and axis body was

noted as a lucency in all children imaged up to the age of 4 years. The synchondrosis remained visible in half the children up to 11 years of age. The authors also described an absence of the normal cervical lordosis in 14% of subjects, most commonly in the 8- to 16-year-old age groups. Shaw et al²⁷ in a retrospective review of cervical spine x-rays in 138 children < 16 years of age who were evaluated following trauma, found a 22% incidence of radiographic pseudosubluxation of C2 on C3. The only factor that correlated with the presence of pseudosubluxation in their study was patient age. The pseudosubluxation group had a median age of 6.5 years vs 9.0 years in the group without this finding. It was identified, however, in children as old as 14 years of age. Intubation status, injury severity score, and gender had no correlation with pseudosubluxation of C2 on C3. To differentiate between physiological and traumatic subluxations, they recommend a method that involves drawing a line through the posterior arches of C1 and C3. In the circumstance of pseudosubluxation of C2 on C3, the C1-C3 line should pass through, touch, or lie up to 1 mm anterior to the anterior cortex of the posterior arch of C2. If the anterior cortex of the posterior arch of C2 is 2.0 mm or more behind the line, then a true dislocation (rather than pseudosubluxation) should be assumed.

Keiper et al²⁸ reviewed their experience of employing MRI in the evaluation of children with clinical evidence of cervical spine trauma who had no evidence of fracture by plain radiographs or CT, but who had persistent or delayed symptoms, or instability. There were 16 abnormal MRI examinations in 52 children. Posterior soft tissue and ligamentous changes were described as the most common abnormalities. Only 1 child had a bulging disc. Four of these 52 children underwent surgical treatment. In each of the 4 surgical cases, the MRI findings led the surgeon to stabilize more levels than otherwise would have been undertaken without the MRI information. Davis et al²⁹ described the use of MRI in evaluating pediatric spinal cord injury in 15 patients, and found it did not reveal any lesion that would warrant surgical decompression. They did note, however, that MRI findings did correlate with neurological outcome. Evidence of hematomyelia was associated with permanent neurological loss. While little information is available on this subject, it appears that pre-operative MRI of children with unstable cervical spinal injuries, who require surgical stabilization, may affect the specifics of the surgical management.

Except for the review of obtunded major trauma patients by Hutchings et al¹⁷ discussed above, there are few studies that have systematically reviewed the role of CT in the evaluation of the cervical spines of pediatric patients following trauma. In children < 10 years of age with cervical spinal injuries, the majority of patients will have ligamentous injuries without fracture.³⁰⁻³⁴ In older children with cervical spinal injuries, the incidence of a fracture is much greater than ligamentous injury without fracture, 80% vs 20% respectively.^{10,22} Therefore, normal osseous anatomy as depicted on an axial CT image should not be used alone to exclude injury to the pediatric cervical spine. In 1989, Schleeauf et al³⁵ concluded that CT should not be relied

upon to exclude ligamentous injuries in a series of pediatric and adult trauma patients. They reported 2 false negative CT studies in patients with C1-C2 ligamentous injuries in their study of the merits of CT to evaluate the cervical spine in high-risk trauma patients. The authors favored CT for the evaluation of regions that could not be viewed adequately with plain radiographs (eg, C7-T1), and for the investigation of the osseous integrity of specific vertebra suspicious for fracture on plain radiographs.³⁵ In a focused study in pediatric patients with potential AOD, Pang et al proposed the CCI as a sensitive diagnostic measurement of AOD as determined on CT imaging. They analyzed and compared CCI from sagittal and coronal reformatted CT images of the craniovertebral junction of 89 children without AOD and 16 children with AOD. They found the CCI to have sensitivity and specificity of 100% compared to “standard” tests on plain films that had a sensitivity between 25% and 50% and a specificity between 10% and 60%. They concluded that the CCI criterion has the highest diagnostic sensitivity and specificity for AOD among all radiographic methods. Their work provided Class I medical evidence for the diagnosis of AOD among pediatric patients.^{36,37}

In a series consisting almost entirely of adults, the role of helical CT in the evaluation of the cervical spine in “high-risk” patients following severe, blunt, multisystem trauma has been prospectively studied.³⁸ The plain spine radiographs and CT images were reviewed by a radiologist blinded to the patients and their history. The investigators found 20 cervical spine injuries (12 stable, 8 unstable) in 58 patients (34%). Eight of these injuries (5 stable, 3 unstable) were not detected on plain radiographs. The authors concluded that helical cervical spinal CT should be utilized to assess the cervical spine in high-risk trauma patients. In young children in whom the entire cervical spine is often easily and accurately visualized on plain x-ray studies, the need for cervical spinal helical CT is likely not as great. In older high-risk children who have spinal biomechanics and injury patterns more consistent with those of adult trauma patients, helical CT of the cervical spine may be fruitful.

In summary, to “clear” a child’s cervical spine, Class II and Class III evidence supports obtaining screening cervical spine imaging in children who have experienced trauma and cannot communicate because of age or head injury, have a neurological deficit, have neck pain, have a painful distracting injury, or are intoxicated. Additionally, children who have experienced trauma that are non-communicative due to age (< 3 years old) and have motor vehicle collision, fall from a height > 10 feet, or suspected NAT as mechanisms, or GCS < 14 should have screening cervical spine imaging performed. In children who are alert, have no neurological deficit, no midline cervical tenderness, no painful distracting injury, and are not intoxicated, cervical spine imaging is not necessary to exclude cervical spine injury.^{9,10} Unexplained hypotension should raise the suspicion of a spinal cord injury. Screening cervical spine imaging for children may consist of adequate AP and lateral radiographs (\pm open mouth odontoid) or high resolution CT scanning. Open-mouth views of the odontoid

do not appear to be useful in children < 9 years of age. Open-mouth views should be attempted in children 9 years of age and older. Flexion and extension studies (fluoroscopy or radiographs) are likely to be unrevealing in children with static radiographs proven to be normal. Dynamic studies should be considered, however, when the static radiographs or the child’s clinical findings suggest but do not definitively demonstrate cervical spinal instability. CT studies of the cervical spine are not necessary to “clear” the entire cervical spine in most children, and should be employed judiciously to define bony anatomy at specific levels, except in the case of potential AOD. For this latter entity, Class I medical evidence supports the use of CT as the preferred modality. MRI may provide important information about ligamentous injury that may influence surgical management, and may provide prognostic information regarding existing neurological deficits.

Injury Management

Injury patterns that have a strong predilection for or are unique to children merit discussion because of the specialized management paradigms employed to treat them. Spinal cord injury without radiographic abnormality (SCIWORA, including “spinal cord concussion”) and atlanto-occipital dislocation injuries have been addressed in other sections (see SCIWORA guideline chapter, see Atlanto-occipital dislocation guideline chapter). Spinal cord injuries secondary to birth-related trauma and epiphysiolysis of the axis are injuries unique to children. Common but not unique to children are C1-C2 rotary subluxation injuries. These entities will be discussed below in light of the available literature. It should be noted that there is no information provided in the literature describing the medical management of pediatric patients with spinal cord injuries. The issue of steroid administration following acute pediatric spinal cord injury, for example, has not been addressed. While prospective, randomized clinical trials such as NASCIS II and NASCIS III have evaluated pharmacological therapy following acute spinal cord injury, children younger than 13 years of age were excluded from study.³⁹

Neonatal Spinal Cord Injury

Birth injuries of the spinal cord occur approximately 1 per 60 000 births.¹⁰ The most common level of injury is upper cervical followed by cervicothoracic.⁴⁰ Mackinnon et al⁴⁰ described 22 neonates with birth-related spinal cord injuries. The diagnosis was defined by the following criteria: clinical findings of acute cord injury for at least 1 day and evidence of spinal cord or spinal column injury by imaging or electrophysiological studies. Fourteen neonates had upper cervical injuries, 6 had cervicothoracic injuries, and 2 had thoracolumbar injuries. All upper cervical cord injuries were associated with cephalic presentation and the use of forceps for rotational maneuvers. Cervicothoracic injuries were associated with the breech presentation. All infants had signs of “spinal shock,” defined as flaccidity, no spontaneous

motion and no deep tendon reflexes. Of the 9 infants with upper cervical injuries surviving longer than 3 months, 7 were alive at last follow-up. Six of these 7 are dependent upon mechanical ventilation. The 2 neonates with upper cervical injuries who had breathing movements on day 1 of life were the only 2 thought to have satisfactory outcomes. All survivors with upper cervical cord injuries whose first respiratory effort was beyond the first 24 hours of life have remained ventilator dependent. Only 2 children of 6 who sustained cervicothoracic spinal cord injuries lived and both remained paraplegic. One required long-term mechanical ventilation. Hypoxic and ischemic encephalopathy was noted in 9 of 14 newborns with upper cervical cord injuries, and in 1 of 6 with a cervicothoracic cord injury. The authors did not describe any treatment provided for the underlying spinal column or cord injury, or whether survivors experienced progression of any spinal deformities.

Menticoglou et al,⁴¹ drawing partly from the same patient data as Mackinnon et al,⁴⁰ reported 15 neonates with birth-related upper cervical spinal cord injuries. All were associated with cephalic deliveries requiring rotational maneuvers with forceps. All but 1 child was apneic at birth with quadriplegia. There is no description of post-injury spinal column or spinal cord management, medical or surgical, in their report.

Rossitch and Oakes⁴² described 5 neonates with birth-related spinal cord injuries. They reported that incorrect diagnoses were made in 4. They consisted of Werdnig-Hoffmann syndrome, occult myelodysplasia, and birth asphyxia. Only 1 neonate had an abnormal plain radiograph (atlanto-occipital dislocation). They provided no description of the management of the spinal cord or column injuries in these 5 neonates.

Fotter et al⁴³ reported the use of bedside ultrasound to diagnose neonatal spinal cord injury. They found excellent correlation with MRI studies with respect to the extent of cord injury in their 2 cases.

Pang and Hanley⁴⁴ provide the only description of an external immobilization device for neonates. They described a thermo-plastic molded device that is contoured to the occiput, neck, and thorax. Velcro straps cross the forehead and torso, securing the infant and immobilizing the spinal column.

In summary, cervical instability following birth-related spinal cord injury is not addressed in the literature. The extremely high mortality rate associated with birth-related spinal cord injury may have generated therapeutic nihilism for this entity, hence the lack of aggressive management. The literature suggests that the presentation of apnea with flaccid quadriplegia following cephalic presentation with forceps manipulation is the hallmark of upper cervical spinal cord injury. Absence of respiratory effort within the first 24 hours of life is associated with dependence upon long-term mechanical ventilation. It appears reasonable to treat these neonates with spinal immobilization for a presumed cervical spinal injury. The method and length of immobilization remains arbitrary.

Odontoid Epiphysiolysis

The neurocentral synchondrosis of C2 that may not fuse completely until age 7 years represents a vulnerable site of injury in young children.⁴⁵ The lateral cervical spine radiograph is the

diagnostic imaging modality of choice to depict this injury. It will often reveal the odontoid process to be angulated anteriorly, and rarely posteriorly.⁴⁶ While injuries to the neurocentral or subdental synchondrosis may be seen in children up to 7 years of age, it most commonly occurs in pre-school aged children.⁴⁷ Mandabach et al⁴⁷ described 13 children with odontoid injuries ranging in age from 9 months to 7 years. They reported that 8 of 10 children who were initially managed with halo immobilization alone achieved stable fusion. The average time to fusion was 13 weeks with a range of 10 to 18 weeks. Because the injury occurs through the epiphysis, it has a high likelihood of healing if closed reduction and immobilization are employed. In their review, Mandabach et al⁴⁷ cited several other reports describing the successful treatment of young children with odontoid injuries who were managed with a variety of external immobilization devices. Sherk et al⁴⁶ reported 11 children with odontoid injuries and reviewed an additional 24 from the literature. Only 1 of these 35 children required surgical fusion. More recently, Fassett et al⁴⁸ reported a meta-analysis of 55 odontoid synchondrosis fractures, including the Mandabach and Sherk series' plus 4 new cases. Closed reduction and immobilization was performed initially in 45 cases, resulting in stable fusion in 42 (93%). Most were immobilized with halo (n = 20) or Minerva jacket (n = 20). Surgical fusion was performed in 8 cases; 4 as initial treatment, 3 following immobilization failure, and 1 after a delayed diagnosis. All reported posterior C1-2 fusion (n = 6) and motion preservation procedures (1 odontoid screw and 1 temporary posterior wiring) achieved stable fusion without complications.⁴⁸

While the literature describes the use of Minerva jackets, soft collars, hard collars, and the halo vest as means of external immobilization to achieve successful fusion in young children with odontoid injuries, the halo is the most widely employed immobilization device in the contemporary literature for these injuries, followed closely by the Minerva.⁴⁶⁻⁴⁹

To obtain injury reduction in these children, Mandabach et al⁴⁷ advocates the application of the halo device under ketamine anesthesia followed by realignment of the dens utilizing C-arm fluoroscopy. Other reports describe using traction to obtain alignment, before immobilizing the child in an external orthosis.⁴⁵ Compared to halo application and immediate reduction and immobilization, traction requires a period of bed rest and is associated with the potential risk of over-distraction.⁴⁷

The literature is scant regarding the operative treatment of C2 epiphysiolysis. Most reports describe employing operative internal fixation and fusion only if external immobilization has failed to maintain reduction or achieve stability. Reinges et al⁵⁰ noted that only 3 "young" children have been reported in the literature having odontoid injuries primarily treated with surgical stabilization. This underscores the near universal application of external immobilization as the primary means of treating odontoid injuries in young children. Odent et al⁴⁹ reported that of the 15 young children with odontoid injuries they managed, 3 that were treated with surgical stabilization and fusion experienced complications. The other 12 children with similar injuries

managed non-operatively all did well. Wang et al⁵¹ described using anterior odontoid screw fixation as the primary treatment option in a 3-year-old child with C2 epiphysiolysis. A hard cervical collar was used postoperatively. Halo immobilization was not used either preoperatively or postoperatively. They successfully employed anterior odontoid screw fixation as the primary treatment in 2 older children (ages 10 and 14 years) followed by hard collar immobilization. It is likely that these 2 children had true type II odontoid fractures and not C2 epiphysiolysis. Likewise, Godard et al⁵² performed anterior odontoid screw fixation in a 2-year-old child with a severe head injury. They used skeletal traction to align the fracture pre-operatively. The rationale for proceeding to operative stabilization without an attempt at treatment with external immobilization was to avoid the halo orthosis, and to allow for more aggressive physiotherapy in this severely injured child. They believe that anterior odontoid screw fixation is advantageous because no motion segments are fused, normal motion is preserved, and the need for halo immobilization is obviated. Fassett et al⁴⁸ advocate for external immobilization as primary treatment, even though 4 cases in their meta-analysis received primary surgical treatment.

For management of injuries of the C2 neurocentral synchondrosis, the literature supports the use of closed reduction and external immobilization for approximately 10 weeks. This strategy is associated with an 80% fusion success rate.⁴⁶⁻⁴⁹ While primary surgical stabilization of this injury has been reported, the experience in the literature is limited. Surgical stabilization appears to play a role when external immobilization is unable to maintain alignment of the odontoid atop the C2 body. While both anterior and posterior surgical approaches have been successfully employed in this setting, there are more reports describing posterior C1-2 techniques than reports describing anterior operative techniques.⁴⁶⁻⁵²

Atlantoaxial Rotatory Subluxation or Fixation

Fixed rotatory subluxation of the atlantoaxial complex (AARF) is not unique to children but is more common during childhood. AARF may present following minor trauma, in association with an upper respiratory infection, or without an identifiable inciting event. The head is rotated to one side with the head tilted to the other side causing the so-called "cock-robin" appearance. The child is unable to turn his/her head past the midline. Attempts to move the neck are often painful. The neurological status is almost always normal.⁵³⁻⁵⁷

It can be difficult to differentiate AARF from other causes of head rotation on clinical grounds alone. Several reports describe the radiographic characterization and diagnosis of this entity. Fieldings and Hawkins⁵⁸ described 17 children and adults with "atlantoaxial rotatory subluxation," and classified their dislocations into 4 types based on radiographic features. Type I was the most common type, identified in 8 of the 17 patients. It was described as unilateral anterior rotation of the atlas pivoting around the dens with a competent transverse ligament. Type II was identified in 5 patients. It was described as unilateral anterior

subluxation of the atlas with the pivot being the contralateral C1-C2 facet. The atlanto-dens interval is increased to no > 5.0 mm. Type III is described as anterior subluxation of both C1 facets with an incompetent transverse ligament. Type IV is posterior displacement of C1 relative to C2 with an absent or hypoplastic odontoid process.

Kawabe et al⁵⁹ reviewed the radiographs of a series of 17 children with C1-C2 rotatory subluxation and classified them according to Fieldings and Hawkins. There were 10 Type I, 5 Type II, 2 Type III, and no Type IV subluxations in their experience. CT has been employed to help define the C1-C2 complex in cases of suspected rotatory subluxation. Kowalski et al⁵⁴ demonstrated the superiority of dynamic CT studies compared to information obtained with static CT studies. They compared the CT scans of 8 patients with C1-C2 pathology to CT studies of 6 normal subjects. The CT scans obtained with normal subjects maximally rotating their heads could not be differentiated from the CT scans of those with known C1-C2 rotatory subluxation. When the CT scans were performed with the head rotated as far as possible to the contralateral side, CT studies of normal subjects could be easily differentiated from those performed on patients with rotatory subluxation.

Type I and Type II subluxation account for the vast majority of rotatory atlantoaxial subluxations in reports describing these injuries. Grøgaard et al⁶⁰ and Subach et al⁵⁶ have published retrospective reviews on the success of conservative therapies in children presenting early following C1-C2 rotatory subluxation. Grøgaard et al⁶⁰ described 8 children who presented within 5 days of subluxation, and 1 child who presented 8 weeks after injury. All were successfully treated with closed reduction and immobilization. The child presenting late required 1 week of skeletal traction to achieve reduction, and was ultimately treated with halo immobilization for 10 weeks. The children who presented early had their injuries reduced with manual manipulation. They were treated in a hard collar for 4 to 6 weeks. Two patients had recurrent subluxation. Both were reduced and treated successfully without surgical intervention. Subach et al⁵⁶ reported 20 children with C1-C2 rotatory subluxation, in whom 4 injuries reduced spontaneously. Injury reduction was accomplished in 15 of 16 patients treated with traction for a mean duration of 4 days. Six children required fusion because of recurrent subluxation (n = 5) or irreducible subluxation (n = 1). No child experienced recurrent subluxation if reduced within 21 days of symptom onset.

El-Khoury et al⁶¹ reported 3 children who presented within 24 hours of traumatic rotatory subluxation. All 3 were successfully treated with traction or manual reduction within 24 hours of presentation. One child experienced recurrent subluxation the next day that was successfully reduced manually. External orthoses were used from 10 weeks to 4 months. Phillips et al⁴ reviewed 23 children with C1-C2 rotatory subluxation. Sixteen children were seen within 1 month of subluxation onset, and experienced either spontaneous reduction or were reduced with traction. Of 7 children presenting with a duration of symptoms

> 1 month, 1 subluxation was irreducible, and 4 recurred after initial reduction. Schwarz described 4 children who presented > 3 months after the onset of C1-C2 rotatory subluxation.⁶² Two children had irreducible subluxations. One child had recurrent subluxation despite the use of a Minerva cast. Only 1 child had successful treatment with closed reduction and a Minerva cast immobilization for 8 weeks. These experiences highlight the ease and success of non-surgical management for these injuries when the subluxation is treated early rather than late. If the subluxation is easily reducible and treated early, 4 weeks in a rigid collar appears to be sufficient for healing. Because C1-C2 rotatory subluxation can reduce spontaneously in the first week, traction or manipulation can be reserved for those subluxations that do not reduce spontaneously in the first few days. The use of more restrictive external immobilization devices (eg halo vest, Minerva cast) for longer periods of treatment up to 4 months has been described in those children presenting late, or those who have recurrent subluxations.⁵⁵

Operative treatment for C1-C2 rotatory subluxations has been reserved for recurrent subluxations or those that cannot be reduced by closed means. Subach et al⁵⁶ operated on 6 of the 20 children they reported with rotatory subluxation using these indications. They employed a posterior approach and accomplished atlantoaxial fusion. They had no complications and all fusions were successful.

In the most comprehensive study of this condition to date, Pang and Li applied a C1-C2 motion analysis protocol to 3-position dynamic CT scans performed prospectively on 40 children with clinically suspected AARF and compared those findings to 21 normal controls described previously.^{57,63} The protocol is too complex to elucidate here, but it reliably distinguished all cases of AARF from normal controls. A classification system derived from the motion analysis protocol identified 5 distinct groups (3 types of AARF “diagnostic grey zone” or DGZ, and normal), and reportedly aided in selecting appropriate treatment regimens according to AARF type. Concurrently, Pang and Li⁶⁴ reported an analysis of 29 cases of AARF diagnosed and classified prospectively per their protocol (8 type I cases; 11 type II; 10 type III), and managed according to an algorithm that incorporates their classification scheme. Diagnosis and management of 6 DGZ cases are also reported. Basically, all cases of AARF were managed initially with traction reduction and immobilization (halo or Guilford brace). Those that could not be reduced ($n = 3$) and those that recurred following HALO immobilization ($n = 3$) received posterior C1-C2 fusion. DGZ patients were treated symptomatically and restudied after 2 weeks, leading either to normalization or treatment with halter traction if still symptomatic or dynamic CT motion analysis findings worsened. They concluded that type I AARF correlated with delayed treatment and was least likely to respond to conservative management. Prolonged duration of AARF and type I motion analysis also correlated with recurrence of AARF after traction and immobilization. Their exhaustive analysis of AARF provides Class II diagnostic and Class III treatment medical evidence.

In summary, the diagnosis of atlantoaxial rotatory fixation is suggested when findings of a “cock-robin” appearance are present, and the patient is unable to turn the head past midline to the contralateral side, and experiences spasm of the contralateral (opposite the side to which the chin is turned) sternocleidomastoid muscle.⁵⁵ Plain cervical spine radiographs may reveal the lateral mass of C1 rotated anterior to the odontoid on a lateral view. The AP radiograph may demonstrate rotation of the spinous processes toward the ipsilateral side in a compensatory motion to restore alignment. If the diagnosis of AARF is suspected after clinical examination and plain radiographic study, a dynamic CT study should be obtained and analyzed using the Pang protocol. It appears that the longer AARF is present before attempted treatment, the less likely reduction can be accomplished. Even if reduction is accomplished in these chronic injuries, it is less likely to be maintained. Therefore, acute AARF (< 4 weeks duration) that does not reduce spontaneously should undergo attempted reduction with manipulation or halter traction. Chronic AARF (4 weeks duration or more) should undergo attempted reduction with halter or tong/halo traction. Reductions achieved with manipulation or halter traction should be immobilized with a cervicothoracic brace, while those requiring tong/halo traction should be kept in a halo. The subsequent period of immobilization should be proportional to the length of time that the subluxation was present before treatment. Surgical arthrodesis can be considered for those with irreducible subluxations, recurrent subluxations, or subluxations present for > 3 months duration.

Therapeutic Cervical Spine Immobilization

Once an injury to the pediatric cervical spine has been diagnosed, some form of external immobilization is usually necessary to allow for either application of traction to restore alignment or to immobilize the spine to allow for healing of the injury. This section will discuss the literature available concerning methods of skeletal traction in children, and various external orthoses used to immobilize the pediatric cervical spine.

Traction for the purpose of restoring alignment or reducing neural compression in children is rarely addressed in the literature. Unique concerns of cervical traction in children exist because of the relatively thinner skull with a higher likelihood of inner skull table penetration, lighter body weight which provides less counter force to traction, more elastic ligaments, and less well-developed musculature, increasing the potential for over-distraction. The placement of bilateral pairs of parietal burr holes and passing 22 gauge wire through them to provide a point of fixation for traction has been described for infants with cervical spinal injuries. Gaufin and Goodman⁶⁵ reported a series of 3 infants with cervical injuries, 2 of whom had injuries reduced in this fashion. Up to 9 pounds was used in a 10-week-old infant and a 16-month-old boy. They experienced no complications with 14 and 41 days of traction, respectively. Other techniques of cervical traction application in children are not described in the literature.

Mubarak et al⁶⁶ described halo application in infants for the purpose of immobilization but not halo-ring traction. They

described 3 infants ages 7 months, 16 months, and 24 months. Ten pins were used in each child. The pins in the youngest child were “inserted to finger tightness only,” while the older children had 2 inch/pounds of torque applied. The children were maintained in the halo devices for 2 to 3 and a half months. Only the youngest child had a minor complication of frontal pin site infection, necessitating removal of 2 anterior pins.

Marks et al⁶⁷ described 8 children ages 3 months to 12 years who were immobilized in halo vests for 6 weeks to 12 months with a mean duration of 2 months. Only 3 of these children had cervical spinal instability. Five had thoracic spinal disorders. The only complication they reported was the need to remove and replace the vest when a foreign body became lodged under the vest. Dormans et al³¹ reported on 37 children ages 3 to 12 years that they managed in halo immobilization devices. They had a 68% complication rate. Pin-site infections were most common. They arbitrarily divided their patient population into those < 10 years of age and those 10 years or older. Purulent pin site infections occurred more commonly in the older group. Loosening of pins occurred more commonly in the younger group. Both loosening and infection occurred more often at the anterior pin sites. They also reported 1 incident of dural penetration and 1 transient supraorbital nerve injury. Baum et al⁶⁸ compared halo use complications in children and adults. The complication rates in their series were 8% for adults and 39 percent among children. The complications reported for the children were one skull penetration and 4 pin site infections. While the halo device appears to provide adequate immobilization of the cervical spine in children, there is a higher rate of minor complications compared to halo use with adults.

Gaskill and Marlin⁶⁹ described 6 children ages 2 years to 4 years who had cervical spinal instability managed with a thermoplastic Minerva orthosis as an alternative to a halo immobilization device. Two of the children they described had halo devices removed because of complications before being placed in Minerva orthoses. The authors described no problems with eating or with activities of daily living in these children. Only 1 child had a minor complication from Minerva use, a site of skin breakdown. The authors concluded that immobilization with a thermoplastic Minerva orthosis offered a reliable and satisfactory alternative to halo immobilization in young children.

Benzel et al⁷⁰ analyzed cervical motion during spinal immobilization in adults serially treated with halo and Minerva devices. They found that the Minerva offered superior immobilization at all intersegmental levels of the cervical spine with the exception of C1-C2. While this study was carried out in adults with cervical spine instability, it underscores the utility of the Minerva device as a cervical immobilization device. Because a great proportion of pediatric cervical spine injuries occur between the occiput and C2, the Minerva device may not be ideal for many pediatric cervical spine injuries.

In summary, the physical properties of young skin, skull thickness, and small body size likely contribute to the higher complication rate among children who require traction or long-term

cervical spinal immobilization compared to adults. The literature includes descriptions of options available for reduction and immobilization of cervical spine injuries in children, but does not provide evidence for a single best method.

Surgical Treatment

There are no reports in the literature that address the topic of early vs late surgical decompression following acute pediatric cervical spinal cord injury. Pediatric spinal injuries account for only 5% of all vertebral column injuries. Since the initial publication of “Guidelines for the Management of Acute Cervical Spine and Spinal Injuries,” the preponderance of the recent treatment literature describes surgical management techniques in case series format. Gluf et al⁷¹ reported a retrospective review of 67 consecutive C1-C2 transarticular screw (TAS) fixation cases (127 screws) in patients < 16 years old for various indications. Trauma was the indication for 24 cases and radiographic fusion was achieved in every case. The overall complication rate was 10.4%, including 2 vertebral artery injuries—neither of which caused a permanent neurological deficit. Klimo et al⁷² reported a series of 78 patients treated surgically for os odontoideum; 56% (n = 44) presented following trauma and 63% (n = 49) were < 21 years of age. Posterior C1-C2 fusions were performed in 75 patients, O-C2 fusions in 2, and an odontoid screw was placed in 1. All patients except the odontoid screw recipient had at least 1 TAS placed with no major complications and a radiographic fusion rate of 100%.

Heuer et al⁷³ described their experience with the Goel-Harms internal fixation technique in 6 children undergoing posterior C1-C2 fusion for os odontoideum. All 6 achieved radiographic fusion and no complications were reported. Chamoun et al reported on 7 pediatric cervical spine fusion procedures supplemented with axial and subaxial translamina screw fixation. Trauma was the surgical indication in 3 cases; all 7 achieved radiographic fusion. One patient experienced prolonged dysphagia due to a malpositioned C1 lateral mass screw. Couture et al⁷⁴ reviewed 22 cases of pediatric occipitocervical fusion with internal fixation using the “Wasatch loop.” All 6 cases performed to stabilize traumatic instability led to radiographic fusion without major complications or the need for revision surgery. Most recently, Hankinson et al⁷⁵ reported a prospective multicenter comparison of internal fixation techniques (Class II) for pediatric occipitocervical fusion surgery. Traumatic instability was the indication for 22 of the 77 procedures analyzed. The internal fixation techniques compared were 1) O-C2 instrumentation without direct fixation of C1; 2) C1 and C2 instrumentation without TAS fixation; and 3) any TAS fixation. Their analysis revealed 100% radiographic fusion rates in all groups and no significant difference in complication rates among the 3 fixation techniques. They reported 3 vertebral artery injuries, 2 in the TAS group and 1 in the C1-C2 instrumentation group.

The remaining noteworthy reports describing management of pediatric cervical spine and spinal cord injuries are all Class III case series. Parisini et al⁷⁶ reported 12 cervical spine fractures in a series

TABLE 1. Evidentiary Table: Diagnosis of Pediatric SCI

Authors & Year	Description of Study	Class of Data	Conclusions
Anderson et al, ¹² <i>JNS: Peds</i> , 2010	Multicenter prospective assessment of a c-spine clearance protocol for patients aged 0 to 3 years (n = 575)	II	Clinical and plain radiographic findings were sufficient to clear the majority of c-spines in non-communicative children. CT scans were required in 14% and MRI in only 10%, using this protocol.
Katz et al, ¹⁶ <i>JNS: Peds</i> , 2010	Retrospective review of CSI in 905 patients < 1 year of age presenting with minor (low-impact) head trauma	II	Only 2 infants (0.2%) were found to have a CSI and the mechanism was NAT in both. Routine c-spine imaging has very low diagnostic yield unless NAT is suspected.
Ehrlich et al, ¹⁴ <i>J Ped Surg</i> , 2009	Retrospective case-control comparison of CCR and NEXUS low-risk criteria in determining the need for c-spine radiography in patients < 11 years of age	II	Both criteria would have missed c-spine injuries and both are not sensitive or specific enough to be applied to pediatric patients as designed.
Pieretti-Vanmarcke et al, ¹⁵ <i>Trauma</i> , 2009	Multi-institutional retrospective review of 12 537 blunt trauma cases < 3 years of age to identify clinical predictors of cervical spine injury (n = 83)	II	Four independent predictors of CSI were identified: GCS < 14, GCSeve = 1, motor vehicle crash, and age 2 years or older. A score of < 2 had a negative predictive value of 99.93% in ruling out CSI.
Hutchings et al, ¹⁷ <i>Trauma</i> , 2009	Retrospective review of c-spine clearance modalities in 115 pediatric major trauma admissions (all obtunded)	III	CT scan demonstrated 100% sensitivity and specificity with positive and negative predictive values of 1.0 for all spinal regions.
Garton et al, ⁸⁵ <i>Neurosurgery</i> , 2008	Retrospective evaluation of NEXUS criteria on 190 consecutive pediatric cervical spine injuries	II	NEXUS criteria applied to children < 8 years of age would have missed 2/33 injuries but missed none in patients > 8 years old. Occiput-C3 CT scan may provide better diagnostic yield in young children than flexion/extension radiographs.
Pang et al, ³⁶ <i>Neurosurgery</i> , 2007	CT evaluation of CCI in 89 normal children and 16 children with AOD	I	"Standard" tests 25 to 50% sensitivity, 10 to 60% specificity; CCI 100% sensitivity, 100% specificity for AOD.
Anderson et al, ¹¹ <i>JNS: Peds</i> , 2006	Prospective evaluation of a NEXUS-based pediatric c-spine clearance protocol (n = 937) compared to historical "control" (n = 936)	II	The protocol used safely facilitated c-spine clearance by non-neurosurgical personnel while it reduced the need for neurosurgical consultation by 60%.
Pang et al, ⁶³ <i>Neurosurgery</i> , 2005	Prospective multicenter evaluation of 3-position CT scan C1-C2 motion analysis protocol to diagnose and classify AARF in 40 children compared to 21 normal controls	II	AARF reliably diagnosed by protocol and classified to help select best management regimen.
Slack et al, ⁸⁶ <i>Emerg Med J</i> , 2004	Systematic review of Class II and III pediatric trauma c-spine imaging studies.	II	Conclusions similar to those in previous <i>Guidelines for Management of Acute Cervical Spine Injuries</i> .
Hernandez et al, ⁸⁷ <i>Emerg Rad</i> , 2003	Retrospective review of 147 ER c-spine CT scans in patients < 5 years of age	III	All 4 injuries identified from 147 scans were evident on initial plain radiography.

(Continues)

TABLE 1. Continued

Authors & Year	Description of Study	Class of Data	Conclusions
Viccellio et al, ¹⁰ <i>Pediatrics</i> , 2001	Prospective multicenter evaluation of cervical spine radiographs obtained in 3065 children incurring trauma. Low-risk criteria of absence of: neck tenderness, painful distracting injury, altered alertness, neurological deficit, or intoxication	II	No child fulfilling all 5 low-risk criteria had a cervical spine injury. Radiographs may not be necessary to clear the cervical spine in children fulfilling all 5 criteria.
Ralston et al, ²⁵ <i>Academ Emer Med</i> , 2001	Blinded review of 129 children with blunt cervical trauma who had flexion and extension radiographs	II	Flexion and extension views with normal cervical spine radiographs or with only loss of cervical lordosis did not unmask any new abnormalities.
Buhs et al, ¹⁸ <i>J Ped Surg</i> , 2000	Multi-institutional review of pediatric cervical spine injuries and the radiographs needed to achieve a diagnosis	III	Lateral cervical radiograph was diagnostic in 13 of 15 children < 9 years old. In no child < 9 years old was the open mouth view the diagnostic study. Only 1 of 36 children older than 9 years had open-mouth view as the diagnostic study.
Swischuk et al, ¹⁹ <i>Pediatr Radiol</i> , 2000	Survey of pediatric radiologists regarding use of open mouth view of the odontoid	III	Less than 50% response. Approximately 40% of respondents did not employ open mouth views in children.
Scarrow et al, ²⁴ <i>Pediatr Neurosurg</i> , 1999	Performed flexion/extension cervical fluoroscopy with SSEP monitoring in 15 comatose pediatric patients	III	None had radiographic abnormalities. Three children had changes in the SSEP's. One of these 3 children was studied with MR and it was normal.
Shaw et al, ²⁷ <i>Clin Radiol</i> , 1999	Retrospective review of the cervical radiographs 138 trauma patients under 16 years old	III	Twenty-two percent incidence of pseudosubluxation of C2 on C3. Median age of pseudosubluxation group was 6.5 years vs 9 years for those without pseudosubluxation.
Berne et al, ³⁸ <i>J Trauma</i> , 1999	58 patients with severe blunt trauma underwent helical CT of entire cervical spine	III	Twenty had cervical spine injuries. Plain radiographs missed 8 injuries. CT missed 2 injuries.
Keiper et al, ²⁸ <i>Neurorad</i> , 1998	Retrospective review evaluating 52 children by MR with suspected cervical spine trauma or instability without fracture	III	There were 16 abnormal studies. The most common abnormality was posterior ligamentous injury. Four children underwent surgical stabilization. The MR findings caused the surgeon to extend his length of stabilization in all 4 cases.
Davis PC et al, ²⁹ <i>AJNR</i> , 1993	Retrospective review of 15 children with spinal cord injury underwent MR 12 hours to 2 months after injury, 7 with SCIWORA	III	MR correlated with prognosis. Hemorrhagic cord contusions and cord "infarction" were associated with permanent deficits. No compressive lesions in SCIWORA cases. Normal MR was associated with no myelopathy.
Schleehauf et al, ³⁵ <i>Ann Emerg Med</i> , 1989	104 "high-risk" patients underwent CT as screening tool for cervical spine injury	III	Sensitivity overall was 0.78. Sensitivity was 1.0 for unstable injuries not able to be seen by plain radiographs. Two upper cervical subluxations without fracture were missed.
Kawabe et al, ⁵⁹ <i>J Pediatr Orthop</i> , 1989	Review of the radiology of 17 children with C1-2 rotatory subluxation	III	Classified according to Fielding and Hawkins as 10 type I, 5 type II, 2 type III, and no type IV.

(Continues)

TABLE 1. Continued

Authors & Year	Description of Study	Class of Data	Conclusions
Kowalski et al, ⁵⁴ <i>AJR</i> , 1987	Eight patients with occipitoatlantoaxial problems and 6 normal subjects were studied with CT	III	CT looked similar for those with C1-2 rotatory subluxation to normal subjects with their heads maximally turned. CT with the head turned to the contralateral side differentiated rotatory subluxation from normals and spasmodic torticollis.
Cattell and Filtzer, ²⁶ <i>J Bone Joint Surg</i> , 1965	Lateral upright cervical radiographs in neutral, flexion, and extension in 160 randomly selected children ages 1 to 16 years	II	C2-3 subluxation was moderate to marked in 24% predominantly in children < 8 years of age. The atlanto-dens interval was 3 mm or more during flexion in 20% of children < 8 years of age.

of 44 pediatric traumatic spinal injuries. Of 6 unstable cervical fractures (3 with SCI), 4 were treated primarily with posterior fusion procedures and 2 with external immobilization (halo and Minerva). Those treated surgically had no residual deformity at last follow-up (9-23 years), while the 2 managed conservatively had residual kyphosis of 18° and 24°. Dogan et al⁷⁷ reported a single center retrospective series of 51 pediatric subaxial cervical spine injuries collected over a 6-year period.⁷⁷ Forty-one injuries were in children aged 9 to 16 years and only 10 in children under 9 years old. Thirty-three children were treated non-surgically (7 halo; 26 rigid cervical orthosis), and 18 children age 8 to 16 years underwent a wide variety of stabilization/fusion procedures. There were no surgery-related deaths or complications and no one in either group developed delayed instability, although 3 patients expired and 6 were lost to long-term follow-up. They concluded that subaxial injuries tend to occur in older children, can usually be managed conservatively, and that surgical treatment appears to be safe and effective. Lastly, Duhem et al⁷⁸ described their single center retrospective experience with 28 unstable pediatric upper c-spine injuries over 28 years. Seven were treated surgically, all of whom achieved stable radiographic fusion with no surgery-related deaths or complications. None of the 28 patients experienced a neurologic decline during or after treatment. In conclusion, the authors favor surgical intervention for patients with “signs of medullary compression, significant spine deformation, dynamic instability, and an age higher than 8 years.”

Earlier reports describing the management of pediatric spinal injuries have been offered by Turgut et al,⁸⁰ Finch and Barnes,⁷⁹ and Elaraky, et al.⁵³ These authors managed pediatric spinal injuries operatively in 17%, 25%, and 30% of patients, respectively. The report by Elaraky et al⁵³ in 2000, suggests that operative treatment of pediatric cervical spine injuries is being utilized more frequently than in the past. Specific details of the operative management including timing of intervention, the approach (anterior vs posterior), and the method of internal fixation as an adjunct to fusion are scarce in the literature. Finch

and Barnes⁷⁹ employed primary operative stabilization in most children they managed with ligamentous injuries of the cervical spine. They stated that while external immobilization may have resulted in ligamentous healing, they elected to internally fixate and fuse such injuries. They based their approach on 2 cases of ligamentous injuries of the cervical spine that they managed with external immobilization, which failed to heal, that later required operative fusion. Shaked et al⁸¹ described 6 children ages 3 years to 14 years who had cervical spine injuries that they treated surgically via an anterior approach. They reported successful fusion with good alignment and normal cervical spine growth in follow-up for all 6 children. The procedure varied (ie total or partial corpectomy vs discectomy only) depending on the pathology. All underwent autograft fusion without instrumentation. The authors described severe hyperflexion injury with fracture and avulsion of the vertebral body, fracture-dislocation with disruption of the posterior elements and disc, and major anatomic deformity of the cervical spine with cord compression as indications for an anterior approach.

Pennecot et al⁸² described 16 children with ligamentous injuries of the cervical spine. They managed minor ligamentous injuries (atlanto-dens interval of 5.0 mm to 7.0 mm, or interspinous widening without dislocation or neurological deficit) with reduction and immobilization. Of 11 children with injuries below C2, 8 required operative treatment with fusion via a posterior approach. They used interspinous wiring techniques in younger children (preschool aged), and posterior plates and screws in older children as adjuncts to fusion. All had successful fusion at last follow-up. All children were immobilized in a plaster or halo cast postoperatively. Similarly, Koop et al⁸³ described 13 children with acute cervical spine injuries who required posterior arthrodesis and halo immobilization. They reported successful fusion in 12 patients. The single failure was associated with use of allograft fusion substrate. All the other children were treated with autologous grafts. Internal fixation with wire was employed in only 2 children. Halo immobilization was utilized for an average

TABLE 2. Evidentiary Table: Treatment of Pediatric SCI

Authors & Year	Description of Study	Class of Data	Conclusions
Hankinson et al, ⁷⁵ <i>JNS: Peds</i> , 2010	Multicenter retrospective comparison of O-C2 fusion rates with or without direct C1 instrumentation (total n = 77; trauma = 22)	II	One hundred percent radiographic fusion rates were reported in both groups with no significant difference in complication rates. Excellent O-C fusion rates can be achieved without direct instrumentation of C1.
Couture et al, ⁷⁴ <i>JNS: Peds</i> , 2010	Retrospective case series of 22 children who underwent O-C fusion using "Wasatch loop" instrumentation	III	Trauma was the indication in 6 cases, radiographic fusion was achieved in 100%, 3 non-trauma cases required revision surgery, and no major complications occurred.
Chamoun et al, ⁸⁸ <i>Neurosurgery</i> , 2009	Report of 7 pediatric cervical spine fusions (3 for trauma) using axial and subaxial translaminar screw fixation	III	Radiographic fusion was achieved in 100% and 1 patient experienced prolonged dysphagia due to C1 lateral mass screw malposition.
Heuer et al, ⁷³ <i>Eur Spine J</i> , 2009	Retrospective series of 6 C1-C2 posterior fusions in children using Goel-Harms internal fixation constructs	III	Although none were acutely posttraumatic, all had os odontoideum, all achieved radiographic fusion, and no major complications were reported.
Klimo et al, ⁸⁹ <i>JNS: Peds</i> , 2008	Retrospective review of 78 patients treated surgically for os odontoideum, traumatic presentation occurred in 56% and 63% were ≤ 20 years old	III	All underwent posterior C1-C2 fusion with transarticular screw fixation (except 1 odontoid screw and 2 O-C2 fusions), radiographic fusion was achieved in 100%, and no major complications occurred.
Duhem et al, ⁷⁸ <i>Childs Nerv Syst</i> , 2008	Single center retrospective review of 28 cases of unstable pediatric upper c-spine injuries over a 28-year period	III	Seven patients were managed surgically and all achieved radiographic fusion on late follow-up. None of the 28 experienced a neurologic decline during or after treatment. Two of 5 incomplete SCI cases normalized.
Dogan et al, ⁷⁷ <i>Neurosurg Focus</i> , 2006	Single center retrospective review of 51 pediatric subaxial cervical spine injuries over a 6-year period	III	Conservative management was successful for 64%, while 36% required surgery. No deaths or complications were attributed to surgical intervention.
Fassett et al, ⁴⁸ <i>Neurosurg Focus</i> , 2006	Meta-analysis of odontoid synchondrosis fractures: 7 series' totaling 55 cases	III	Ninety-three percent of fractures initially managed with external immobilization (HALO or Minerva) attained fusion without surgery.
Pang et al, ⁶⁴ <i>Neurosurgery</i> , 2005	Prospective case series of 29 children with AARF diagnosed, classified, and managed per the authors' protocol	III	Prolonged delay in treatment may adversely affect C1-C2 rotatory dynamics. Type I AARF correlated with delayed treatment and need for HALO immobilization ± posterior C1-C2 fusion.
Gluf et al, ⁷¹ <i>JNS: Spine</i> , 2005	Retrospective case series of 67 C1-C2 transarticular screw fixations in patients < 16 years of age	III	Trauma was the indication in 24 cases, radiographic fusion was achieved in 100%, and 2 asymptomatic vertebral artery injuries were observed.
Parisini et al, ⁷⁶ <i>Spine</i> , 2002	Retrospective case series of 44 pediatric spine fractures (12 cervical) with mean follow-up of 18 years	III	Four unstable c-spine fractures (2 with SCI) managed conservatively developed late deformity. Stable fractures managed conservatively healed without deformity.

(Continues)

TABLE 2. Continued

Authors & Year	Description of Study	Class of Data	Conclusions
Meyer et al, ⁹⁰ <i>Acta Neurochir</i> , 2001	Retrospective case series of 13 cervical spine fusion procedures in 11 children—8 for post-traumatic instability	III	Radiographic fusion occurred in 100%, 3 transient neurologic deteriorations occurred, and 2 developed “bystander fusion.”
Eleraky et al, ⁵³ <i>J Neurosurg (Spine)</i> , 2000	Retrospective review of 102 children with cervical spinal injuries	III	Thirty children (30%) were treated surgically.
Odent et al, ⁴⁹ <i>J Ped Ortho</i> , 1999	Review of 15 young children with odontoid injuries	III	Six with neurological deficits had cervicothoracic cord injuries. External immobilization was a successful primary therapy. Three children who were operated upon as their primary therapy experienced complications.
Schwarz, ⁶² <i>Arch Orthop Trauma Surg</i> , 1998	A review of 4 children presenting at least 3 months after the onset of C1-2 rotatory subluxation	III	Two children had irreducible subluxations. One child had recurrent subluxation in a Minerva cast. One child was successfully treated with closed reduction and 8 weeks in a Minerva cast.
Subach et al, ⁵⁶ <i>Spine</i> , 1998	A review of 20 children with C1-2 rotatory subluxation	III	Four reduced spontaneously. Fifteen of 16 treated with traction reduced in a mean of 4 days. Six children required fusion because of recurrent subluxation or irreducible subluxation. No child experienced recurrent subluxation if reduced within 21 days of symptom onset.
Finch and Barnes, ⁷⁹ <i>J Ped Ortho</i> , 1998	Retrospective review of 32 children with major cervical spine injuries	III	Eight children (25%) were treated surgically. All achieved union or radiological stability. No neurological deterioration from surgery or closed reduction. Operated on ligamentous injuries.
Reinges et al, ⁵⁰ <i>Child Nerv Sys</i> , 1998	Report of primary C1-2 fusion in a young child with an odontoid injury and lower cervical cord injury	III	No neurological improvement. Successful fusion.
Treloar and Nypaver, ³ <i>Ped Emer Care</i> , 1997	They measured cervical spine flexion in children with semi-rigid collars on spinal boards	III	Semi-rigid collars did not prevent the cervical spine from being forced into flexion in children < 8 years old when on a spinal board.
Lui TN et al, ²⁰ <i>J Trauma</i> , 1996	Retrospective review of C1-2 injuries in 22 children; 12 children had odontoid injuries (OI), 9 children had ligamentous injuries (atlantoaxial dislocations) only	III	Flexion/extension radiographs needed to diagnose 4 OI and 6 atlanto-axial dislocations (AAD). Nine of 12 OI reduced easily. Five of 7 OI treated successfully with halo. Two OI operated immediately. Two OI failed external immobilization. Five AAD initially treated with surgical fusion. Two AAD initially treated with halo required surgical stabilization.
Givens et al, ²³ <i>J Trauma</i> , 1996	Review of 34 children with cervical spine injuries over a 3-year period	III	Eighteen injuries occurred below C3. The level of injury did not correlate with age. Young age is not associated with exclusively upper cervical spine injuries.
Turgut et al, ⁸⁰ <i>Eur Spine J</i> , 1996	Retrospective review of 82 children with spinal cord or column injuries	III	Fourteen children (17%) were treated surgically.

(Continues)

TABLE 2. Continued

Authors & Year	Description of Study	Class of Data	Conclusions
Dormans et al, ³¹ <i>J Bone Joint Surg</i> , 1995	A review of 37 children with halo rings and vests ages 3 to 16 yearsArbitrarily divided into those < 10 years old, and older	III	Overall 68% complication rate. Pin-site infection was the most common complication. Purulent infections occurred more frequently in the older group. Both loosening and infection occurred more frequently in the anterior pin sites.
Menticoglou et al, ⁴¹ <i>Obstet Gyn</i> , 1995	Retrospective case series of 15 neonates with birth-related high cervical cord injuries	III	All 15 were cephalic presentations in which forceps and attempted rotation were employed. All but one were apneic at birth.
Curran et al, ⁵ <i>J Trauma</i> , 1995	Prospective study of 118 children who arrived immobilized to a single emergency room,the cervical spine alignment was measured and compared to age and type of immobilization	II	No correlation with degree of kyphosis or lordosis was found with age. Thirty percent had a kyphosis of > 10°. No single immobilization technique was superior.
Schwarz et al, ⁸⁴ <i>Injury</i> , 1994	Review of 10 children with vertebral fractures and kyphotic angulation	III	The kyphotic angulation remained unchanged or worsened when external immobilization alone (n = 7) or dorsal fusion (n = 1) was employed. Only those undergoing a ventral fusion (n = 2) had a stable reduction of the kyphotic deformity.
Nypaver and Treloar, ² <i>Ann Emer Med</i> , 1994	40 children were placed on spine boards and observers judged whether the cervical spine was in the "neutral" position Children 4 years of age or younger required the greatest amount of elevation.	III	Children < 8 years of age required torso elevation to achieve neutral alignment
Laham JL et al, ⁹ <i>Pediatr Neurosurg</i> , 1994	Divided head-injured children into high (< 2 years of age, non-communicative, or with neck pain) and low risk groups for cervical spine injury	III	No cervical spine injuries detected in the low-risk group. Ten injuries (7.5%) were detected in the high-risk group.
Fotter et al, ⁴³ <i>Ped Radiol</i> , 1994	Report of birth-related spinal cord injuries imaged with ultrasound and MRI	III	A neonate with complete injury had normal plain radiographs with spinal ultrasound showing inhomogeneous echogenicity and disrupted cord surface. A neonate with an incomplete injury had intact cord surface with increased cord echogenicity . MRI corroborated these findings.
Marks et al, ⁶⁷ <i>Arch Orthop Trauma Surg</i> , 1993	Review of 8 children, ages 3 months to 12 years, immobilized in a halo jacket for 6 weeks to 12 months (mean 2 months)	III	The only complication was a jacket change was required for a foreign body (coin). Only 3 of these children had cervical instability.
Shacked et al, ⁸¹ <i>Clin Orthop</i> , 1993	Retrospective review of 6 children (3 to 14 years old) with cervical spine injuries treated via an anterior approach	III	Autograft without instrumentation following corpectomy was used. They were stabilized postoperatively with hard collar or Minerva cast. All with solid fusions, good alignment, and normal cervical growth. Follow-up 3 to 8 years.

(Continues)

TABLE 2. Continued

Authors & Year	Description of Study	Class of Data	Conclusions
Grøgaard et al, ⁶⁰ <i>Arch Orthop Trauma Surg</i> , 1993	Atlanto-axial rotatory subluxation described in 9 children, 8 diagnosed within 5 days, 1 diagnosed after 8 weeks	III	Eight children were treated successfully with "mild" traction and then a collar for 4 to 6 weeks. The 1 child presenting late required 1 week of traction for reduction. There were 2 redislocations. All eventually healed in alignment without surgery.
Mandabach et al, ⁴⁷ <i>Pediatr Neurosurg</i> , 1993	13 children with axis injuries were reviewed, 10 were treated primarily with closed reduction and halo immobilization	III	Eight of the 10 treated primarily with closed reduction and halo immobilization fused. Two required surgical stabilization and fusion.
MacKinnon et al, ⁴⁰ <i>J Pediatr</i> , 1993	Retrospective case series of 22 neonates with birth-related spinal cord injuries, they excluded neonates with SCIWORA	III	All 14 with high cervical injuries had cephalic presentations with attempted forceps rotation. All 6 with cervicothoracic injuries had breech presentations. Both neonates with thoracolumbar injuries were premature.
Rossitch and Oakes, ⁴² <i>Pediatr Neurosurg</i> 1992	Retrospective review of 5 neonates with perinatal spinal cord injury, no flexion/extension views reported	III	Four of the 5 had no abnormality on static spinal radiographs. Respiratory insufficiency and hypotonia were common signs. Myelograms were unrevealing. All 3 with high cervical injuries died by age 3 years.
Osenbach and Menezes, ³⁴ <i>Neurosurgery</i> 1992	Retrospective review of 179 children with spinal injuries	III	Fifty-nine (33%) underwent surgical treatment for irreducible unstable injuries. 83% of those treated surgically were 9 years of age or older. No child with complete or severe partial myelopathy regained useful function.
Rathbone et al, ⁹¹ <i>J Ped Orthop</i> , 1992	Retrospective review of 12 children with presumed spinal cord concussion during athletics were investigated for the presence of cervical stenosis	III	Three had a Torg ratio < 0.8 and 4 had a canal AP diameter < 13.4 mm. MRI was not used to evaluate for stenosis.
Hamilton and Myles, ³³ <i>J Neurosurg</i> , 1992	Retrospective review of all pediatric spinal injuries over 14-year period, 73 children had cervical injuries	III	Surgery was performed in 26% of children. Thirteen percent of children with fracture and no subluxation, 50% with subluxation alone, and 57% with fracture and subluxation were treated surgically. Of 39 children with complete myelopathy, 4 improved 1 or 2 Frankel grades.
Schafermeyer et al, ⁹² <i>Ann Emer Med</i> , 1991	Forced vital capacity (FVC) was studied in healthy children when upright, supine, and supine taped to a spinal board	III	Taping the child to the spinal board caused FVC to drop to 41% to 96% (mean 80%) of supine FVC.
Bohn et al, ⁸ <i>J Trauma</i> , 1990	16 of 19 children presenting with absent vital signs or severe hypotension unexplained by blood loss underwent postmortem examination	III	Thirteen of 16 had cord laceration or transection. Two of these children had a normal cervical radiograph.
Gaskill and Marlin, ⁶⁹ <i>Pediatr Neurosurg</i> , 1990	6 children ages 2 to 4 years were placed in Minerva jackets for cervical spine instability	III	One child had skin breakdown of the chin. Eating and other daily activities were not impaired. Two were placed in Minerva jackets after complications of halo ring and vest immobilization.

(Continues)

TABLE 2. Continued

Authors & Year	Description of Study	Class of Data	Conclusions
Phillips et al, ⁵⁵ <i>J Bone Joint Surg</i> , 1989	A review of 23 children with C1-2 rotatory subluxation	III	Sixteen children seen within 1 month of onset had either spontaneous reduction or reduced with traction. Of the 7 children presenting with > 1 month of symptoms, 1 subluxation was irreducible, and 4 had recurrent subluxations.
Benzel et al, ⁷⁰ <i>J Neurosurg</i> , 1989	A comparison of cervical motion of injured patients (only 1 child) immobilized in halo and Minerva jackets	III	The Minerva jacket allowed less motion than the halo jacket at every level except C1-2.
Baum et al, ⁶⁸ <i>Spine</i> , 1989	A review comparing the halo complications 13 children and 80 adults	III	Thirty-nine percent complication rate in children vs 8% in adults. The children had 4 pin-site infections and 1 inner table skull pin penetration.
Mubarak et al, ⁶⁶ <i>J Ped Ortho</i> , 1989	Review of 3 children < 2 years old who were placed in halo rings for 2 to 3 ½ months	III	Ten pins tightened "finger-tight" in a 7-month-old, and 2 in/lb in a 16- and 24-month-old. Two of 3 developed minor pin site infections necessitating pin removal.
Herzenberg et al, ⁴ <i>J Bone Joint Surg</i> , 1989	Reported 10 children < 7 years of age with cervical spine injuries positioned on a flat backboard	III	The injuries were anteriorly angulated or translated when on a flat backboard because the head was in forced into flexion. Elevating the torso allowed for more neutral alignment and reduction of the injured segment.
Evans and Bethem, ²² <i>J Ped Ortho</i> , 1989	Review of 24 consecutive cervical spine injuries in children 18 years old or less	III	Half of the children had injuries at C3 or above. One child was treated with laminectomy and 2 with fusion. Fractures healed in 21 of 22 with nonoperative therapy.
Birney and Hanley, ⁹³ <i>Spine</i> , 1989	Retrospective review of 61 children with cervical spine injuries, 23 of these injuries were C1-2 rotatory subluxation	III	Rotatory subluxation unassociated with neurological deficit. The deformity resolved with halter traction (n = 10) or cervical bracing. One child had a recurrence.
			A child with transverse ligament disruption was treated successfully with a soft collar only.
Hadley et al, ³² <i>J Neurosurg</i> , 1988	Retrospective review of 122 children with spinal injuries There were 97 cervical injuries	III	Only 12 cervical injuries were treated surgically.
Huerta et al, ⁶ <i>Ann Emer Med</i> , 1987	They evaluated the immobilization of commercially available infant and pediatric cervical collars	III	No collar used alone provided acceptable immobilization. The use of a modified half-spine board, rigid collar, and tape provided the best immobilization.
Pennecot et al, ⁸² <i>J Ped Ortho</i> , 1984	Review of 16 children with ligamentous injuries of the cervical spine, 5 with C1-2 injuries	III	Of the 11 children with injuries below C2, 8 underwent surgical stabilization. They recommended a 3-month trial of external immobilization in children with ligamentous injuries but no neurological deficit or dislocation.

(Continues)

TABLE 2. Continued

Authors & Year	Description of Study	Class of Data	Conclusions
El-Khoury et al, ⁶¹ <i>J Bone Joint Surg</i> , 1984	A review of 3 children with C1-2 rotatory subluxation	III	All 3 were treated successfully with traction or manual reduction within 24 hours of presentation. One child had recurrent subluxation the next day and was treated successfully with manual reduction. External orthoses were used for 10 weeks, 3, and 4 months, respectively.
Koop et al, ⁸³ <i>J Bone Joint Surg</i> , 1984	Retrospective review of 13 children with cervical instability treated with posterior arthrodesis and halo immobilization, only 3 had traumatic lesions	III	One failed fusion when bank-bone was used. Others successfully fused with autogenous iliac crest or rib. Internal wiring used in 2 children. Average halo immobilization was 150 days.
Sherk et al, ⁴⁶ <i>J Bone Joint Surg (Am)</i> , 1978	Report of 11 children with odontoid injuries, and review of 24 from the literature	III	Majority of injured odontoids are angled anteriorly. All but 1 child was treated successfully with external immobilization.
Fielding and Hawkins, ⁵⁸ <i>J Bone Joint Surg</i> , 1977	The radiographic findings of 17 patients with atlanto-axial rotatory fixation are described and classified into 4 types	III	Four classes of C1-2 rotatory subluxation were described, types I-IV. Type I: odontoid acts as pivot with competent transverse ligament; type II: 1 lateral articular process acts as pivot with up to 5 mm of anterior displacement; type III: both C1 inferior facets are subluxed anteriorly with > 5 mm of anterior displacement which suggests an incompetent transverse ligament; type IV: posterior displacement with absent or incompetent odontoid.
Gaufin and Goodman, ⁶⁵ <i>J Neurosurg</i> , 1975	A review of 3 children < 20 months old with cervical spine injuries, 2 of these children were treated with traction delivered via 22 gauge wire placed through bilateral parietal burr holes	III	Successful traction applied to the 10-week-old and 16-month-old child. Up to 9 pounds was used in the 10-week-old infant. No complications were encountered with the traction in place for 14 and 41 days, respectively.

of 150 days. They reduced the length of post-operative halo immobilization to 100 days in their most recent cases. They commented that careful technique allowed successful posterior fusion in children with minimal complications. Schwarz et al⁸⁴ described 10 children with traumatic cervical kyphosis. Two children who underwent anterior reconstruction with fusion had successful deformity reduction. All others managed with either external immobilization with or without traction (n = 7) or posterior fusion (n = 1) had either progression of the post-traumatic deformity or a stable unreduced kyphotic angulation.

In summary, pediatric spinal injuries are relatively infrequent. The vast majority are managed non-operatively. Selection criteria for operative intervention in children with cervical spine injuries are difficult to glean from the literature. Anatomic reduction of deformity, stabilization of unstable injuries and decompression of the spinal cord, and isolated ligamentous injuries associated with

deformity are indications for surgical treatment cited by various authors.^{20,51,79,81-84} These numerous reports provide Class III medical evidence.

SUMMARY

The available medical literature supports only 1 Level I recommendation for the management of pediatric patients with cervical spine or spinal cord injuries, specifically related to the diagnosis of patients with potential AOD. Level II and III diagnostic and level III treatment recommendations are supported by the remaining medical evidence. The literature suggests that obtaining neutral cervical spine alignment in a child may be difficult when standard backboards are used. The determination that a child does not have a cervical spine injury can be made on clinical grounds alone is supported by Class II and Class III

medical evidence. When the child is alert and communicative and is without neurological deficit, neck tenderness, painful distracting injury, or intoxication, cervical radiographs are not necessary to exclude cervical spinal injury. When cervical spine radiographs are utilized to verify or rule out a cervical spinal injury in children < 9 years of age, only lateral and AP cervical spine views need be obtained. The traditional 3-view x-ray assessment may increase the sensitivity of plain spine radiographs in children 9 years of age and older. High resolution CT scan of the cervical spine provides more than adequate visualization of the cervical spine, but is not necessary in most children. CT and MRI are most appropriately used in selected cases to provide additional diagnostic information regarding a known or suspected injury (eg, CT for AOD) or to further assess the spine/spinal cord in an obtunded child. The vast majority of pediatric cervical spine injuries can be effectively treated non-operatively. The most effective immobilization appears to be accomplished with either halo devices or Minerva jackets. Halo immobilization is associated with acceptable but considerable minor morbidity in children, typically pin site infection and pin loosening. The only specific pediatric cervical spine injury for which medical evidence supports a particular treatment paradigm is an odontoid injury in children < 7 years of age. These children are effectively treated with closed reduction and immobilization. Primarily ligamentous injuries of the cervical spine in children may heal with external immobilization alone, but are associated with a relatively high rate of persistent or progressive deformity when treated non-operatively. Pharmacological therapy and intensive care unit management schemes for children with spinal cord injuries have not been described in the literature.

KEY ISSUES FOR FUTURE INVESTIGATION

Prospective epidemiological data may be the best source of information that could lead to methods of prevention by identifying the more common mechanisms of spinal injury in children. Future studies involving pediatric cervical spine injury patients should be multi-institutional because of the small numbers of these injuries treated at any single institution. A prospective analysis defining the indications and methods for cervical spine clearance in young children (< 9 years of age) would be a valuable addition to the literature. The role of flexion and extension radiographs is poorly defined in the literature. A prospective evaluation of their sensitivity and specificity for spinal column injury in specific clinical scenarios would be a valuable addition to the literature. The incidence and clinical significance of complications of cervical spine injuries in children, such as syringomyelia and vertebral artery injury, are unknown and could be better defined by prospective study among investigators at multiple institutions.

More common injuries, such as odontoid injuries, should be studied prospectively in a randomized fashion (eg closed reduction and immobilization vs surgical stabilization/fusion). Prospectively collected data would provide the basis for case-control or other

comparative studies to generate Class II medical evidence on these important topics.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Spinal Cord Injury Without Radiographic Abnormality (SCIWORA)

Curtis J. Rozzelle, MD*

Bizhan Aarabi, MD, FRCSC‡

Sanjay S. Dhall, MD§

Daniel E. Gelb, MD¶

R. John Hurlbert, MD, PhD,
FRCSC||

Timothy C. Ryken, MD, MS#

Nicholas Theodore, MD**

Beverly C. Walters, MD, MSc,
FRCSC‡§§

Mark N. Hadley, MD‡‡

*Division of Neurological Surgery, Children's Hospital of Alabama, University of Alabama at Birmingham, Birmingham, Alabama; ‡Department of Neurosurgery; and ¶Department of Orthopaedics, University of Maryland, Baltimore, Maryland; §Department of Neurosurgery, Emory University, Atlanta, Georgia; ||Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada; #Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa; **Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona; ‡‡Division of Neurological Surgery, University of Alabama at Birmingham, Birmingham, Alabama; §§Department of Neurosciences, Inova Health System, Falls Church, Virginia

Correspondence:

Mark N. Hadley, MD, FACS,
UAB Division of Neurological Surgery,
510 – 20th St S, FOT 1030,
Birmingham, AL 35294-3410.
E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS

Diagnosis:

Level III:

- Magnetic resonance imaging of the region of suspected neurological injury is recommended in a patient with spinal cord injury without radiographic abnormality (SCIWORA).
- Radiographic screening of the entire spinal column is recommended.
- Assessment of spinal stability in a SCIWORA patient is recommended with flexion-extension radiographs in the acute setting and at late follow-up, even in the presence of a magnetic resonance imaging negative for extraneural injury.
- Neither spinal angiography nor myelography is recommended in the evaluation of patients with SCIWORA.

Treatment:

Level III:

- External immobilization of the spinal segment of injury is recommended for up to 12 weeks.
- Early discontinuation of external immobilization is recommended for patients who become asymptomatic and in whom spinal stability is confirmed with flexion and extension radiographs.
- Avoidance of “high-risk” activities for up to 6 months following SCIWORA is recommended.

ABBREVIATIONS: SCIWORA, spinal cord injury without radiographic abnormality; SSEP, somatosensory evoked potential

RATIONALE

Diagnosis

Pang and Wilberger¹ defined the term spinal cord injury without radiographic abnormality (SCIWORA) in 1982 as “objective signs of myelopathy as a result of trauma” with no evidence of fracture or ligamentous instability on plain spine radiographs and tomography. The definition specifically excluded all magnetic resonance imaging (MRI) findings and any injuries from penetrating trauma, electric shock, and obstetrical complications and those associated with congenital spinal anomalies.⁵ Although many practitioners may consider this diagnostic terminology anachronistic in light of the current near-universal availability of MRI, pediatric neurosurgeons continue to refer to this predominantly pediatric phenomenon as SCIWORA.

In their original article, Pang and Wilberger¹ cautioned, “If the early warning signs of transient symptoms could be recognized and promptly acted upon before the onset of neurological signs, the tragic fate of some of these children might be duly averted.” Hamilton and Myles,² Osenbach and Menezes,³ and Pang and Wilberger¹⁻³ have documented the delayed onset of SCIWORA in children as late as 4 days following injury. Therefore, a concern is whether a child with a normal neurological examination but with a history of transient neurological symptoms or persisting subjective neurological symptoms referable to traumatic myelopathy should be assigned the diagnosis of SCIWORA and managed accordingly, despite the absence of “objective signs of myelopathy.”

Pang and Pollack⁴ have recommended obtaining a computed tomography scan focused at the neurological level of injury to exclude an occult

fracture in a child with a neurological deficit referable to the spinal cord without abnormalities on plain radiographs of the spine. In addition, dynamic flexion and extension radiographs or fluoroscopy has been advocated to exclude pathological intersegmental motion consistent with ligamentous injury without fracture. If paraspinal muscle spasm, pain, or uncooperation prevents dynamic studies, they recommended external immobilization until the child can cooperatively flex and extend the spine for dynamic x-ray assessment. The finding of fracture, subluxation, or abnormal intersegmental motion at the level of neurological injury excludes SCIWORA as a diagnosis. In the initial report by Pang and Wilberger,¹ 1 of 24 children showed pathological motion on initial dynamic radiographs. By their own definition of SCIWORA, this 1 child would not be diagnosed with SCIWORA because the initial flexion and extension radiographs were abnormal. Although concern exists for the development of pathological intersegmental motion in children with SCIWORA following normal flexion and extension studies, there has been no documentation of such instability ever developing.

MRI findings in children with SCIWORA have spanned the spectrum from normal to complete cord disruption, along with evidence of ligamentous and disk injury in some.⁵⁻⁷ Possible roles for MRI of children with SCIWORA include identifying of signal change or intramedullary injury, excluding compressive lesions of the cord or roots or spinal ligamentous disruption that might warrant surgical intervention, guiding treatment regarding length of external immobilization, and/or determining when to allow patients to return to full activity.

Pang⁷ has also recommended somatosensory evoked potential (SSEP) screening of children with presumed SCIWORA. Possible roles for SSEPs in children with presumed SCIWORA include detecting subtle posterior column dysfunction when clinical findings are inconclusive, evaluating head-injured, comatose, or pharmacologically paralyzed children, distinguishing between intracranial, spinal, or peripheral nerve injuries, and/or providing a baseline MRI examination for comparison with subsequent evaluations.

Treatment

Because subluxation and/or malalignment are, by definition, absent in SCIWORA, the mainstay of treatment has been immobilization and avoidance of activity that may either lead to exacerbation of the present injury or increase the potential for recurrent injury. Medical management issues such as blood pressure support and pharmacological therapy are of concern to this population as well and have been addressed in other guidelines. (Of note, the often-cited prospective studies of pharmacological therapy in the treatment of acute spinal cord injuries did not include children < 13 years of age.⁸)

Pang and Pollack⁴ originally recommended 12 weeks of external immobilization to allow adequate time for the healing of the presumed ligamentous strain/injury and to prevent exacerbation of the myelopathy. Conversely, Bosch et al⁹ found no evidence that bracing prevents recurrent SCIWORA and therefore recommended bracing only on a case-by-case basis. It is unclear, however,

what role immobilization plays in this population once dynamic radiographs have confirmed the absence of instability. The duration of and even the need for immobilization remain debatable given the current literature. If the incidence of delayed pathological intersegmental motion in children with SCIWORA who have been proven to have normal dynamic radiographs approaches zero, then the role of spinal immobilization for SCIWORA patients needs to be considered in light of the available literature. If (normal) physiological motion of the spinal column can potentiate spinal cord injury (SCIWORA) in these patients when there is no malalignment, subluxation, or lesion causing cord compression, then immobilization may be warranted in these patients.

Prognosis

SCIWORA has been shown to be associated with a high incidence of complete neurological injuries, particularly in children < 9 years of age. Hadley et al¹⁰ reported 4 complete injuries in 6 children < 10 years of age with SCIWORA. The regions of complete injury tend to be cervical and upper thoracic. Pang and Wilberger¹ and Pang⁷ found the presenting neurological examination to relate strongly to outcome. Some data suggest that MRI abnormalities (or lack of abnormalities) of the cord may be more predictive of outcome than presenting neurological status.¹¹⁻¹³ Because no child has been documented to develop spinal instability following the diagnosis of SCIWORA and has, by definition, normal flexion and extension radiographs, there has been little impetus to define predictors of instability. On the other hand, children have been documented to suffer recurrent SCIWORA,^{7,14} and predictors of a "high-risk" subgroup of children with SCIWORA for recurrent injury may exist. The guidelines author group of the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons have previously produced a medical evidence-based guideline on this topic.¹⁵ The purpose of this updated review is to provide a contemporary analysis of the literature on the diagnosis and treatment of SCIWORA since that original publication.

SEARCH CRITERIA

A National Library of Medicine (PubMed) computerized literature search from 1966 to 2011 was undertaken using Medical Subject Headings in combination with "spinal cord injury": "pediatric," "spinal cord concussion," "cervical cord neurapraxia," and "SCIWORA." Approximately 188 citations were acquired. Non-English language citations were deleted. Articles written in English were reviewed for those that identified children who incurred an SCIWORA. Those articles that described the clinical aspects and management of children with SCIWORA were used to generate these guidelines. Case reports were excluded from review. Of the 19 articles meeting selection criteria, none provided Class I or Class II medical evidence. All were case series representing Class III medical evidence. Summaries of these 19 articles are provided in Evidentiary Table format (Table 1).

TABLE 1. Evidentiary Table: Spinal Cord Injury Without Radiographic Abnormality^a

Reference	Description of Study	Evidence Class	Conclusions
Liao et al, ²³ <i>Journal of Neurosurgery</i> , 2005	Retrospective review of 9 SCIWORA patients < 8 y of age correlating MRI findings with neurological outcomes	III	Prognosis correlated with MRI findings. Spinal cord transection and contusion were associated with severe, permanent deficits; normal MRI findings were associated with complete recovery.
Pang, ⁷ <i>Neurosurgery</i> , 2004	Retrospective review of 95 pediatric SCIWORA cases (77 cervical, 18 thoracic; includes 55 reported in 1989); MRI and SSEP used to evaluate latter portion of the series	III	46 "severe" injuries, 49 "mild" injuries. Age < 8 y associated with more severe injuries. SSEPs more sensitive than MRI in SCIWORA evaluation. Transient deficit or "symptom only" with normal MRI and SSEP treated in collar for 1-2 wk; all others with 12 wk of Guilford brace; no recurrent injuries.
Bosch et al, ⁹ <i>Spine</i> , 2002	Retrospective review of 189 cases of pediatric SCIWORA over 35 y	III	Recurrent SCIWORA occurred in 21/189 cases and was not prevented by rigid bracing/immobilization after occult instability was properly ruled out.
Dare et al, ¹¹ <i>Journal of Neurosurgery</i> , 2002	Retrospective review of 20 pediatric SCIWORA cases evaluated with "early" MRI	III	MRI abnormalities seen only in those with complete neurological deficits (2/20). Conventional MRI sequences may lack sensitivity in cases of partial or transient deficits owing to SCIWORA.
Eleraky et al, ¹⁶ <i>Journal of Neurosurgery</i> , 2000	Retrospective review of 102 children with cervical spinal injuries; young (0-9 y) compared with older children; MRI performed in 12/18 children with SCIWORA	III	SCIWORA in 18%. MRI findings did not alter management (external immobilization).
Turgut et al, ²⁶ <i>European Spine Journal</i> , 1996	Retrospective review of 11 of 82 children with spinal injuries with SCIWORA	III	SCIWORA represented 13% of spinal injuries in children.
Grabb and Pang, ¹³ <i>Neurosurgery</i> 1994	Retrospective review of 7 children with SCIWORA who underwent MRI; neurological status at presentation and follow-up was correlated to MRI findings	III	No compressive lesions found. Prognosis correlated with MRI findings. Hematomyelia involving > 50% of cord diameter was associated with permanent severe deficits. Lesser degrees of hematomyelia and edema only were associated with incomplete recovery, and normal MRI predicted full recovery.
Davis et al, ¹² <i>AJNR: American Journal of Neuroradiology</i> , 1993	Retrospective review of 15 children with spinal cord injury who underwent MRI 12 h to 2 mo after injury, 7 with SCIWORA	III	MRI correlated with prognosis. Hemorrhagic cord contusions and cord "infarction" were associated with permanent deficits. No compressive lesions in SCIWORA cases. Normal MRI was associated with no myelopathy.
Hamilton and Myles, ² <i>Journal of Neurosurgery</i> , 1992	Retrospective review of 174 pediatric spinal injuries over 14-y period	III	SCIWORA represented 13% of spinal injuries. Of children 0 to 9 y of age with spinal injuries, 42% had SCIWORA, whereas of children 10 to 14 y of age, only 14% had SCIWORA.
Osenbach and Menezes, ²⁵ <i>Neurosurgery</i> 1992	Retrospective review of 34/179 children with spinal injuries with SCIWORA	III	SCIWORA represented 19% of spinal injuries in children. Younger children (< 9 y) had higher incidence of SCIWORA.
Rathbone et al, ²⁷ <i>Journal of Pediatric Orthopedics</i> , 1992	Retrospective review of 12 children with presumed spinal cord concussion during athletics investigated for the presence of cervical stenosis	III	3 had a Torg ratio < 0.8 and 4 had a canal anteroposterior diameter < 13.4 mm. MRI was not used to evaluate for stenosis.

(Continues)

TABLE 1. Continued

Reference	Description of Study	Evidence Class	Conclusions
Rossitch and Oakes, ¹⁷ <i>Pediatric Neurosurgery</i> , 1992	Retrospective review of 5 neonates with perinatal spinal cord injury; 4 of the 5 had no abnormality on static spinal radiographs; no flexion/extension views reported; Myelograms were unrevealing.	III	Perinatal spinal cord injury often has normal radiographs. The neonates are often initially misdiagnosed. Respiratory insufficiency and hypotonia are common signs.
Dickman et al, ⁶ <i>Journal of Spinal Disorders</i> , 1991	Retrospective review of 26 children with SCIWORA over 19-y period; clinical and epidemiological features were analyzed	III	SCIWORA 16% of spinal injuries in children. Motor vehicle accident was most common mechanism. 7 children had MRI. 5 were normal studies, 2 showed cord signal abnormalities. Younger children tended to have more severe injuries.
Osenbach and Menezes, ³ <i>Pediatric Neuroscience</i> , 1989	Retrospective review of 31 children with SCIWORA	III	26 cervical and 5 thoracic injuries. Complete cord injury in 12. Delayed onset of deficits in 7. No surgical lesions found by MRI or computed tomography- myelography. Spinal angiograms done in 4 thoracic cases were normal. No delayed instability at follow-up.
Pang and Pollack, ⁴ <i>Journal of Trauma</i> , 1989	Retrospective review of 55 children with SCIWORA (43 cervical, 12 thoracic); clinical profiles reported to illustrate syndrome	III	22 "severe" injuries, 33 "mild" injuries. Age < 8 y associated with more severe injuries. 8 cases of recurrent injury from 3 d to 10 wk after initial injury. No recurrent injuries with 12 wk of Guilford brace.
Hadley et al, ¹⁰ <i>Journal of Neurosurgery</i> , 1988	Retrospective review of 122 children with spinal injuries; young (0-9 y) compared with older children	III	17% with SCIWORA. Higher incidence of SCIWORA in patients 0-9 y of age vs 10-16 y of age. 5 studied with MRI, no abnormalities detected.
Pollack et al, ¹⁴ <i>Journal of Neurosurgery</i> , 1988	Retrospective review of 8 children with recurrent SCIWORA compared with 12 children treated with longer immobilization	III	Recurrent SCIWORA occurred from 3 d to 10 wk after initial injury. Recurrent injuries were more severe. No recurrent injuries with 12 wk of Guilford brace.
Ruge et al, ¹⁸ <i>Journal of Neurosurgery</i> , 1988	Retrospective review comparing patients 0-3 y of age to 4-12 y of age with spinal injury	III	n = 47; 21% with SCIWORA.
Pang and Wilberger, ¹ <i>Journal of Neurosurgery</i> , 1982	Retrospective review of 24 children with SCIWORA	III	1 child with instability on flexion/extension at 1 wk.

^aMRI, magnetic resonance imaging; SCIWORA, spinal cord injury without radiographic abnormality; SSEP, somatosensory evoked potential.

SCIENTIFIC FOUNDATION

One concern is whether the child with a normal neurological examination and either a history of transient neurological deficit (ie, paraparesis or quadriparesis) or persisting subjective symptoms (ie, numbness or dysesthesias) would be a candidate for the diagnosis of SCIWORA. Pang and Wilberger¹ described 13 of their 24 children to have a "latent" period from 30 minutes to 4 days (mean, 1.2 days) before the onset of objective sensorimotor deficits. All 13 of these children had transient subjective complaints at the time of their initial trauma that cleared within 1 hour before their subsequent

neurological decline. Those who developed mild neurological deficits often improved to normal, and those who developed severe neurological deficits were often left with permanent neurological dysfunction. Hamilton and Myles,² Osenbach and Menezes,³ and Pang and Pollack⁴ also reported a 22%, 23%, and 27% incidence, respectively, of delayed onset of myelopathy within their series of children with SCIWORA. Dickman et al,⁶ Eleraky and associates,¹⁶ and Hadley et al¹⁰ described no child having a latent period of neurological normalcy following injury. The observations of delayed deterioration by different investigators, however, raises the concern that any child presenting with a history of transient neurological

deficit or symptoms following an appropriate mechanism of injury may be considered for the diagnosis of SCIWORA despite the absence of objective evidence of myelopathy on the initial neurological examination.

Pang and Wilberger¹ reported 1 child of 24 whom they managed who demonstrated pathological intersegmental spinal motion on flexion and extension radiographs 1 week after injury, following resolution of that child's neck pain and paraspinal muscle spasm. By definition, this child would not be considered to have had SCIWORA because the initial flexion and extension radiographs were abnormal. That child was treated successfully with external immobilization alone for 8 weeks. No child with SCIWORA has been documented in the literature to have had normal dynamic radiographs and then subsequently develop intersegmental instability.

In 1994, a series of 7 children with SCIWORA were demonstrated to have ligamentous, disk, and intramedullary abnormalities identified on MRI.¹³ Soft-tissue findings consisted of anterior longitudinal ligament disruption in association with a hyperextension injury, posterior longitudinal ligament disruption, and a non-compressive C2-3 disk herniation associated with lateral flexion and 1 case of C6-7 disk abnormality associated with hyperflexion. Intramedullary findings reported included cord transection and rostral stump hemorrhage, severe hematomyelia, a minor intramedullary hemorrhage, and edema without hemorrhage. Davis et al¹² described 7 children with SCIWORA who were imaged with MRI. They described no abnormalities of muscles, ligaments, or disks but correlated the presence of intramedullary hemorrhage or cord "infarction" with permanent neurological deficit. The lack of intramedullary findings correlated with a normal neurological outcome. Dickman et al⁶ commented on 7 children with SCIWORA who were imaged with MRI. Five of the 7 studies revealed no abnormality, and 2 studies documented intramedullary signal changes. Osenbach and Menezes³ commented in their series of childhood SCIWORA that MRI and computed tomography-myelography performed on their patients did not demonstrate a single compressive lesion. In addition, they performed spinal arteriograms in 4 of 5 children with thoracic SCIWORA and found no angiographic abnormalities. Rossitch and Oakes¹⁷ performed myelograms on neonates and found no abnormalities that changed their management. Hadley et al¹⁵ obtained MRIs before 1988 on 5 children with SCIWORA and identified no abnormalities. Dare et al¹¹ reviewed early MRI studies on 20 consecutive pediatric SCIWORA patients from 1992 to 1999, reporting abnormalities only in those with complete neurologic deficits. These reports and their results need to be viewed in the context of the technology and image quality available at the time of investigation.

SSEP evaluations of pediatric SCIWORA have been reported by Pang.⁷ In his series of 50 pediatric SCIWORA patients evaluated with both MRI and SSEPs, the SSEPs demonstrated abnormalities more frequently than MRI for both permanent and transient deficits.

Pang⁷ is the only investigator to report any alteration in the clinical management of pediatric SCIWORA based on MRI/SSEP findings. No child with MRI-documented ligamentous injury and

SCIWORA has developed spinal instability, early or delayed. There has been no correlation between the ligamentous findings on MRI in SCIWORA patients and subsequent spinal instability to date. The appearance of the spinal cord on MRI does provide prognostic information regarding ultimate neurological outcome.

Hadley et al¹⁰ noted a 16% incidence of multiple noncontiguous injuries of the spine or spinal cord in children with any type of spinal column or spinal cord injury. Ruge et al had a similar incidence (17%) of multiple levels of spinal injury in children. Although neither of these 2 studies dealt with an isolated population of children with SCIWORA, they provide consistent observations that 1 in 6 children with spinal trauma will have multiple levels of injury. Pang and Wilberger¹ reported 1 of 24 children with a second-level injury (L2 Chance fracture) who had a T6 neural injury (SCIWORA), but they did not obtain complete spine radiographs on every child. Pollina and Li¹⁹ reported 1 case of tandem SCIWORA with distinct cervical and thoracolumbar junction lesions identified on MRI. Because of these observations, one should consider radiographs of the entire spinal column when any traumatic spinal injury is identified in a child, SCIWORA or otherwise.

In the initial series of children with SCIWORA reported by Pang and Wilberger,¹ treatment routinely consisted of 4 weeks of external immobilization with a "cervical collar" for cervical injuries. In cases of thoracic injury, if repeat plain radiographs showed no abnormality following 1 week of bed rest, the child was mobilized without a brace. In a later report in 1989, Pang and Pollack⁴ recommended 12 weeks of external immobilization for SCIWORA patients to allow healing of the presumed ligamentous strain/injury and to prevent exacerbation of the myelopathy. They also advocated external immobilization for this time frame to prevent recurrent injury during the healing phase. They reported 7 children who sustained recurrent SCIWORA of greater severity with lesser degrees of force when external immobilization was removed before 12 weeks or they were allowed to participate in activities against physician advice within 6 months of the initial injury. For these reasons, they recommend 12 weeks of external immobilization and 12 additional weeks of activity restriction following SCIWORA. In his updated series, Pang⁷ recommends immobilization with a "hard collar" in cases of transient deficits (< 24 hours) or "symptoms only," provided that both MRI and SSEPs are normal. Those patients are then reevaluated after 1 to 2 weeks.

Dickman et al⁶ Eleraky et al,¹⁶ and Hadley and colleagues¹⁰ reported no neurological deterioration in any patient with SCIWORA following admission or discharge. None of these 3 reports described the length of time children with SCIWORA were immobilized. Bosch et al⁹ reviewed 189 cases of pediatric SCIWORA over 35 years, reporting no instances of neurologic deterioration and no benefit to bracing because it did not appear to reduce the frequency of recurrent SCIWORA. It has not been routine among treating physicians to prescribe 12 weeks of immobilization for children with SCIWORA.⁵ Although the single report by Pollack et al¹⁴ describes recurrent SCIWORA within 12 weeks of the original injury, this has not been validated by other observations.⁹ Because MRI evaluation was not available

for those with recurrent injury, it is not known whether certain MRI characteristics (eg, ligamentous disruption) could predict an “at-risk” group for recurrent SCIWORA.

Additional case series of mild, transient SCIWORA have been reported using different terminology, namely “spinal cord concussion” or “cervical cord neurapraxia.”¹⁹⁻²² The diagnostic criteria for these entities fall within the definition of SCIWORA and further require that the symptoms/deficits resolve within 48 to 72 hours. Most of the patients in these reports are adolescents and young adults injured during athletic activities, especially American tackle football. Many of these series report an association between radiographically documented spinal stenosis and recurrent episodes²⁰⁻²²; however, Pang asserts that “congenital cervical stenosis and resultant [spinal cord injury], such as in young athletes, most definitely should be excluded from the SCIWORA umbrella” (D. Pang, MD, personal communication, November 2010).⁷ Return-to-play recommendations proposed in these reports are arbitrary, controversial, and beyond the scope of these guidelines.

While Pang and Wilberger¹ reported that in their series neurological outcome correlated with the presenting neurological status, the MRI appearance of the spinal cord has been shown to be predictive of neurological outcome in children with SCIWORA.^{7,11-13,23} Absence of signal change within the cord is associated with an excellent outcome. Signal change consistent with edema or microhemorrhages, but not frank hematomyelia, is associated with significant improvement of neurological function over time. The presence of frank hematomyelia or cord disruption is associated with a severe, permanent neurological injury.¹¹⁻¹³ The correlation of neurological outcome with spinal cord MRI findings in SCIWORA remains consistent with the findings in much larger numbers of patients with spinal cord injury (non-SCIWORA) who have been studied with MRI.^{4,23} Recognized prognostic factors related to SCIWORA are summarized in Table 2.

SUMMARY

SCIWORA is a widely recognized form of spinal cord injury, occurring almost exclusively in children, and is characterized by the absence of any radiographically evident fracture, dislocation, or malalignment. Children presenting with a history of transient neurological signs or symptoms referable to the spinal cord after a traumatic event, despite the absence of objective neurological

deficits with normal radiographs, may develop SCIWORA in a delayed fashion.

No child with SCIWORA has developed pathological intersegmental motion with instability when early flexion and extension radiographs have been normal.

MRI has not identified any abnormal findings in a child with SCIWORA when the management scheme would be changed by the results of the MRI. Similarly, no child with SCIWORA in whom a subsequent MRI has documented ligamentous injury has developed evidence of spinal instability.

Treatment consisting of cervicothoracic bracing for patients with cervical-level SCIWORA for 12 weeks and avoidance of activities that encourage flexion and extension of the neck for an additional 12 weeks has not been associated with recurrent injury. Patients with normal MRI and SSEP findings following transient deficits or “symptoms only” may be managed with a cervical collar for 1 to 2 weeks.

The spinal cord findings on MRI provide prognostic information regarding long-term neurological outcome in patients with SCIWORA. Myelography and angiography have no defined role in the evaluation of children with SCIWORA.

KEY ISSUES FOR FUTURE INVESTIGATION

The treatment end points of spinal immobilization and activity restriction for patients with SCIWORA have been arbitrarily chosen. MRI may be helpful to guide the duration of immobilization and activity restriction for that child. For example, the absence of ligamentous injury by MRI may indicate that there is no need for external immobilization or activity restriction. It has been observed that SCIWORA can recur despite the absence of demonstrable spinal instability and may not be prevented by bracing. A study that obtained MRI on all children with SCIWORA and followed up their clinical status longitudinally may highlight the utility of MRI in the management of children who go on to develop recurrent SCIWORA.

The literature provides little guidance as to the likelihood for subsequent catastrophic injury in children presenting with SCIWORA of any severity who are found to have a preexisting spinal or neurological abnormality such as congenital cervical stenosis or a Chiari malformation.^{19,21,24} Longitudinal clinical follow-up of SCIWORA patients of this type may provide information to appropriately counsel these children.

TABLE 2. Recognized Prognostic Factors in SCIWORA^a

Spinal cord injury without radiographic abnormality presenting with a complete or severe neurologic deficit has a poor prognosis.
Mild, partial spinal cord injury without radiographic abnormality (spinal cord concussion) usually recovers to normal function.
Recurrent spinal cord injury without radiographic abnormality appears to be rare and usually occurs within 2 weeks of presentation.
Magnetic resonance imaging evidence of spinal cord disruption or major hemorrhage is strongly associated with complete or severe neurologic deficit and carries a poor prognosis.
A normal magnetic resonance image of the region of neurological injury is associated with a favorable prognosis.

^aSCIWORA, spinal cord injury without radiographic abnormality.

There are no data to elucidate the role of age in the success or failure of various treatments for this condition. This could be undertaken in a longitudinal study of a patient population of reasonable size. Serious attempts to address the topics above cannot be forthcoming from a single institution or investigator because of the relatively low numbers of children who sustain SCIWORA annually.^{25,26} A multiple-institution protocol-directed study of SCIWORA patients may provide answers to some of the questions that accompany this unique spinal cord injury subtype.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Management of Vertebral Artery Injuries Following Non-Penetrating Cervical Trauma

Mark R. Harrigan, MD*

Mark N. Hadley, MD*

Sanjay S. Dhall, MD†

Beverly C. Walters, MD, MSc, FRCSC*‡

Bizhan Aarabi, MD, FRCSC§

Daniel E. Gelb, MD||

R. John Hurlbert, MD, PhD, FRCSC#

Curtis J. Rozzelle, MD**

Timothy C. Ryken, MD, MS‡‡

Nicholas Theodore, MD§§

*Division of Neurological Surgery, University of Alabama at Birmingham, Birmingham, Alabama; ‡Department of Neurosciences, Inova Health System, Falls Church, Virginia; §Department of Neurosurgery, University of Maryland, Baltimore, Maryland; ¶Department of Neurosurgery, Emory University, Atlanta, Georgia; ||Department of Orthopaedics, University of Maryland, Baltimore, Maryland; #Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada; **Division of Neurological Surgery, Children's Hospital of Alabama University of Alabama at Birmingham, Birmingham, Alabama; ‡‡Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa; §§Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona

Correspondence:

Mark N. Hadley, MD, FACS,
UAB Division of Neurological Surgery,
510 – 20th Street South, FOT 1030,
Birmingham, AL 35294-3410.
E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS

Diagnostic

Level I

- Computed tomographic angiography (CTA) is recommended as a screening tool in selected patients after blunt cervical trauma who meet the modified Denver Screening Criteria for suspected vertebral artery injury (VAI).

Level III

- Conventional catheter angiography is recommended for the diagnosis of VAI in selected patients after blunt cervical trauma, particularly if concurrent endovascular therapy is a potential consideration, and can be undertaken in circumstances in which CTA is not available.
- Magnetic resonance imaging is recommended for the diagnosis of VAI after blunt cervical trauma in patients with a complete spinal cord injury or vertebral subluxation injuries.

Treatment

Level III

- It is recommended that the choice of therapy for patients with VAI—anticoagulation therapy vs antiplatelet therapy vs no treatment—be individualized based on the patient's vertebral artery

injury, the associated injuries, and the risk of bleeding.

- The role of endovascular therapy in VAI has yet to be defined; therefore, no recommendation regarding its use in the treatment of VAI can be offered.

RATIONALE

The association of cerebrovascular insufficiency and cervical fracture was first described by Suechting et al¹ in a patient with Wallenburg's syndrome occurring 4 days after a C5-C6 fracture-dislocation. Although Schneider et al² implicated vertebral artery injury at the site of dislocation as a cause of ischemia, Gurdjian et al³ suggested that unilateral vertebral artery occlusions might be asymptomatic. Subsequent articles^{4,5,6} described larger series of patients with asymptomatic VAI after blunt cervical trauma. However, in 2000, Biffel et al⁷ published a prospective study of 38 patients with VAI diagnosed by angiography. They identified more frequent strokes in patients not initially treated with intravenous heparin anticoagulation despite an initially asymptomatic VAI. Fractures through the foramen transversarium, facet fracture-dislocation, or vertebral subluxation are almost always seen in patients with VAI.⁵⁻¹¹ A cadaveric study¹² demonstrated progressive vertebral occlusion with greater degrees of flexion-distraction injury, confirming this clinical observation.

In 2002, the guidelines author group of the Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons reviewed the medical evidence on this topic, and produced and published a guideline on The Management of Vertebral Artery

ABBREVIATIONS: BCVI, blunt cerebrovascular injuries; DSA, digital subtraction angiography; PPV, positive predictive value; NPV, negative predictive value; VAI, vertebral artery injury

Injuries after Non-penetrating Cervical Trauma.¹³ The current review was undertaken to update the medical evidence on the diagnostic and treatment recommendations for VAI after blunt cervical trauma. Specific questions that were addressed include: the clinical and radiographic criteria used to prompt diagnostic evaluation, appropriate diagnostic tests for identifying VAI, the treatment of VAI (observation compared to anticoagulation with heparin or to aspirin therapy), and the potential role of endovascular techniques for patients with VAI.

SEARCH CRITERIA

A National Library of Medicine (PubMed) computerized literature search of publications from 1966 to 2011 was performed using the following headings: vertebral artery injury, vertebral artery dissection, cervical fracture, and cervical dislocation. The search was limited to the English language and human subjects and identified 2226 citations. The titles and abstracts of these references were reviewed to determine relevance. Isolated case reports, small case series, editorials, letters to the editor, and review articles were eliminated. The bibliographies of the resulting full-text articles were searched for other relevant citations. A total of 37 articles met inclusion criteria and 21 key citations are summarized in Evidentiary Table format.

SCIENTIFIC FOUNDATION

Diagnosis

The diagnosis of VAI can be made with a variety of imaging studies. Angiography has been the traditional “de facto” gold standard imaging technique utilized to diagnose VAI, and was used for most patients in the studies reviewed for the 2002 guidelines publication on the Management of Vertebral Artery Injuries.¹³

Biffi et al⁷ reported the largest prospective study using angiography in 2000, selecting patients from 7205 blunt trauma victims using specific clinical and radiographic criteria, subsequently known as the Denver Screening criteria. “Symptomatic” patients were selected for angiography if they had facial hemorrhage (bleeding from mouth, nose, ears), cervical bruit (in those younger than 50 years of age), expanding cervical hematoma, cerebral infarction by computed tomography (CT), or lateralizing neurological deficit. “Asymptomatic” patients were selected for angiography if they had cervical hyperextension/rotation or hyperflexion injuries, closed head injury with diffuse axonal injury, near hanging, seat belt or other soft tissue injuries to the neck, basilar skull fractures extending into the carotid canal, and cervical vertebral body fractures or distraction injuries. Between 350 and 400 angiograms were performed, identifying 38 patients with VAI. However, neither the exact number of angiograms performed nor the number of patients meeting the various criteria without VAI were reported. As a result, sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of the selection criteria could not be

determined. Cervical spine injuries were observed in 27 of 38 patients with VAI, including fractures through the foramen transversarium in 4, facet dislocations in 6 patients, vertebral subluxations in 2, and more than 1 of these injuries in 2 patients. Twenty-nine patients had unilateral VAI (18 left, 11 right); 9 had bilateral VAI. A vascular injury scale was used to stratify patients into 5 categories:

Grade I - arterial dissections with less than 25% luminal narrowing.

Grade II - arterial dissections with more than 25% luminal narrowing.

Grade III - pseudoaneurysm of the vertebral artery.

Grade IV - occlusion of the vertebral artery.

Grade V - vertebral artery transection.

Seven patients died, of whom 5 had bilateral VAI (Grade I), and 2 had unilateral VAI (1 Grade I, 1 Grade IV). Three patients with either no neurological deficit or mild deficit had bilateral VAI. The authors concluded that stroke incidence and neurological outcome appeared independently of the grade of vertebral artery injury.

Another prospective study by Willis et al⁶ in 1994 identified 30 patients with midcervical fractures and/or dislocation injuries considered criteria for angiographic assessment. However, only 26 patients who met the criteria agreed to proceed with angiography. Twelve patients sustained VAI demonstrated by angiography (6 left occlusion, 3 right occlusion, 1 left intimal flap, 1 left pseudoaneurysm, and 1 left dissection). The authors provided sufficient data regarding the presence of foramen transversarium fracture, facet dislocation, and subluxation to determine the utility of these radiographic findings in identifying patients with VAI. The calculated sensitivity, specificity, PPV, and NPV of foramen transversarium fracture, facet dislocation, and vertebral subluxation as criteria for VAI are listed in Table 1. Any combination of foramen transversarium fracture, facet dislocation, and/or vertebral subluxation revealed a calculated sensitivity for identifying VAI of 92% and a specificity of 0%. The positive predictive value of the presence of any of the 3 criteria and VAI was 44%. The negative predictive value was 50%.

Alternatively, magnetic resonance angiography (MRA) has been used as a noninvasive means to diagnose VAI. Weller et al¹⁰ prospectively examined 12 patients with nonpenetrating cervical trauma who sustained fractures through the foramen transversarium. Three patients had unilateral vertebral artery occlusion

TABLE 1. Accuracy of Potential Imaging Indicators of Vertebral Artery Injury

	Sensitivity %	Specificity %	PPV %	NPV %
Foramen transversarium fracture	58	36	44	50
Facet dislocation	42	57	45	53
Vertebral subluxation	67	29	80	50

and 1 had focal narrowing, all at the site of fracture. MRA was not performed on the 26 patients without these fractures. In 1997, Giacobetti et al⁸ prospectively evaluated all patients admitted with cervical spine injuries with MRA. Twelve of 61 patients had vertebral artery occlusion demonstrated by MRA and all injuries were unilateral (6 left, 6 right). Although 7 of 12 patients with VAI had flexion-distraction injuries with facet dislocations, the types of cervical spinal injuries sustained by the 49 patients with normal MRA were not reported. Since none of these 4 articles⁸⁻¹¹ provided sufficient information regarding the types of injury and results of vertebral artery imaging in the entire population of patients studied, sensitivity, specificity, positive predictive value, and negative predictive value of the injury types could not be determined. All 4 provide Class III medical evidence on the value of MRA in the diagnosis of VAI.

In 1995, Friedman et al⁵ prospectively examined 37 patients admitted with “major” blunt cervical spine injuries using MRA and compared these patients with a size-matched control group of patients without a history of cervical trauma (Table 2). Nine patients had VAI (6 unilateral occlusion, 2 narrow, 1 bilateral injury). Both vertebral arteries were visualized in all 37 control subjects. Complete spinal cord injuries were observed in 12 of 37 patients with cervical trauma, 6 of whom had VAI ($P < .02$; chi-square test). More than 3 millimeters of vertebral subluxation was observed in 13 of the 37 patients, 5 of whom had VAI ($P < .14$; chi-square test).

Friedman et al’s report provides Class I medical evidence for the presence of VAI in association with complete spinal cord injury and with cervical vertebral subluxation, and yet provides Class III medical evidence on the ability of MRA to diagnose VAI after blunt trauma.

Other diagnostic modalities have also been used to identify VAI. CT with intravenous contrast demonstrated a unilateral vertebral artery occlusion in 1 patient with a Jefferson fracture, which was subsequently confirmed by angiography.¹⁴ Duplex sonography has also been used to diagnose VAI.¹⁵⁻¹⁷ Angiography has occasionally been used to confirm the results of MRA or ultrasonography, but there has not been a study comparing ultrasonography with angiography in the diagnosis of VAI.

The use of CTA as a screening tool for VAI has expanded exponentially since the original guideline on the management of vertebral artery injuries was published in 2002. In 2002, Miller et al¹⁸ prospectively compared catheter angiography screening in 143 patients with suspected blunt cerebrovascular injuries (BCVI) to CTA and MRA in selected (but not all) patients. They noted that CTA identified 53% of VAI found on catheter angiography. MRA identified 47% of VAI confirmed by catheter angiography.

In 2006, Eastman and colleagues prospectively compared CTA to catheter angiography as a screening tool for vascular injuries in the neck in 146 trauma patients who met the Modified Denver Screening Criteria (Table 3).¹⁹

They determined that the sensitivity, specificity, and positive and negative predictive value of CTA for blunt cervical vascular

injury were 97.7%, 100%, 100%, and 99.3%. They concluded that CTA had an accuracy of 99.3% for a cervical vascular injury following blunt trauma. For patients meeting the Modified Denver Screening Criteria, CTA has almost 100% accuracy. Their report provides Class I medical evidence on the utility of CTA to diagnose vascular injuries. CTA can, therefore, be considered the new gold standard reference test for VAI in patients who have sustained blunt trauma.

In 2006, Biffl et al²⁰ adopted a “liberal screening protocol” for BCVI, and screened 331 trauma patients with CTA. They identified 20 vascular injuries in 18 patients with CTA (5.4%) confirmed by angiography, of which 11 were carotid injuries and 9 were vertebral artery injuries (2.4% incidence of VAI). None of the patients who had normal CTAs went on to develop clinical evidence of vascular injury, providing supportive evidence for CTA as an accurate and reliable screening tool for VAI.

Utter et al²¹ studied 372 trauma patients who underwent screening CTAs and noted a 16% incidence of vertebral artery and a 10% incidence of carotid artery injuries. Digital subtraction angiography (DSA) was performed in 82 patients. Their 2002 retrospective review identified concordance between CTA and DSA in 80 of the 82 patients; 1 had artifact on CTA images that hindered diagnosis, and the second patient had a previously existing vascular anomaly not related to trauma. The authors concluded that CTA is accurate and supplants DSA as a screening tool for VAI.

In 2006, Berne and colleagues reported their experience with screening CTA for BCVI in 435 trauma victims.²² They noted a much lower incidence of vascular injury: 1.2% of all blunt trauma patients and 5.5% among trauma patients who met the modified Denver (Biffl) Screening Criteria and had CTAs performed. They reported that no patient with a negative CTA went on to develop symptoms or signs of a missed vascular injury. That same year, Schneider et al²³ evaluated 1313 blunt trauma patients. One hundred thirty-seven CTA studies were performed. The incidence of blunt vascular neck injuries in their series was 1.4%. Only 23 patients underwent angiography to confirm or refute the CTA findings. The calculated sensitivity and specificity of CTA to detect a vascular injury in this study was 65% and 50%, respectively. No attempt was made to define the accuracy of CTA to identify isolated vertebral artery injuries after trauma. Like the report of Berne et al,²⁴ no patient with a negative CTA developed symptoms or signs of a missed vascular injury. The authors concluded that CTA is an effective means to assess blunt vascular injuries after trauma.

In 2007, Malhotra and colleagues studied 92 blunt trauma patients who underwent both CTA and DSA for potential BCVI.²⁵ They calculated that CTA had sensitivity, specificity, and positive and negative predictive values of 74%, 86%, 65%, and 90%, respectively. Of 119 patients who underwent screening CTA, 3 patients refused consent for angiography and 24 patients were excluded from DSA due to the risk of contrast nephropathy. The authors concluded that CTA is less accurate than DSA for the identification of VAI and could not reliably be used to

TABLE 2. Accuracy of Potential Clinical and Imaging Indicators of Vertebral Artery Injury

	Sensitivity %	Specificity %	PPV %	NPV %
Complete spinal cord injury	67	79	50	88
Vertebral subluxation	56	71	38	83

exclude a blunt vascular injury. Of note, 20% of the CTAs in this study were suboptimal and uninterpretable, a finding not reported in other studies. The loss of 27 patients for consent/nephropathy concerns and the loss of 20% of the CTA studies performed due to poor image quality reduced the quality of the medical evidence the authors offered from Class I to Class III. Despite this, the negative predictive value of 90% that the authors calculated in their study supports the value of a negative CTA in indicating the absence of a clinically significant VAI.

Catheter angiography remains the practical “de facto” gold standard for diagnosis of vertebral artery injury after trauma. However, catheter angiography is an invasive and labor-intensive procedure, is not always readily available, and has a low, but finite risk. CTA, on the other hand, is non-invasive, easily performed, readily available, and has lower risk than catheter angiography. CTA has been compared to catheter angiography in patients who have sustained trauma and who meet screening criteria for suspicion of blunt vascular injury. As discussed above, there is Class I and supportive Class III medical evidence documenting the accuracy, and specifically, the negative predictive value, for the use of CTA as a screening tool for the assessment of patients with potential VAI. The low incidence of VAI after blunt cervical trauma and the relatively benign natural history of a documented traumatic vertebral artery injury, however, raise the question of the utility of screening all asymptomatic blunt trauma patients with the potential of VAI. For these reasons, it is recommended that CTA to assess for the potential of traumatic VAI be used on

a selective basis. Catheter angiography remains a valuable diagnostic tool for the detection of VAI in selected patients based on Class III medical evidence, particularly if concurrent endovascular therapy is a potential consideration. The evidence used to develop these recommendations is shown in Table 4.

Treatment

Traumatic VAI of any injury grade has the potential to cause distal posterior circulation ischemia or stroke. For this reason, anticoagulation or antiplatelet therapy to reduce the risk of stroke following known VAI must be considered. Traumatic VAI occurs in multiple injured trauma patients and is more likely to occur in association with the most severe cervical spine and spinal cord injuries—all of which represent relative contraindications to anticoagulation and antiplatelet therapies in the treatment of potential posterior distribution stroke. For these reasons, multiple investigators have examined treatment options for trauma patients with VAI including anticoagulation with heparin, oral antiplatelet agents, and observation alone.^{5-7,11,18,20,22,26-28}

The previous iteration of the medical evidence-based Guideline¹³ on this subject, published in 2002, failed to identify Class I or Class II medical evidence in support for the various treatment strategies for traumatic VAI, or for any treatment at all. The previous review did identify a 31% incidence of complications ascribed to intravenous heparin therapy (anticoagulation) in the literature on the treatment of VAI, 6 of which (14%) were significant hemorrhages.

The current review identified 10 contemporary citations in which the treatment of VAI after trauma was investigated. All 10 provide Class III medical evidence on this topic. It appears that many of the strokes attributable to VAI occur at the time of injury and are identified during the initial work up. A common pattern in the literature, identified by Fusco and Harrigan,²⁹ is that these patients are typically included in the “no treatment group” because their ischemic event occurred prior to treatment. The “no treatment group,” including those patients with early stroke, is then compared to the “treatment group,” a population not burdened with early stroke and/or death. This distorted logic and prejudicial assignment strategy limits the ability to identify a consistent or scientifically valid treatment strategy for VAI.²⁹

In 2000, Biffle et al⁷ identified 38 patients with blunt traumatic VAI by catheter angiography. They reported 9 patients who had posterior circulation strokes (24%) during the course of their study. There was no correlation between vertebral artery injury grade and stroke. The authors did not describe the incidence of stroke from the initial injury, identified at the time of the diagnostic workup. They did report 3 patients who had stroke before treatment who were subsequently treated with intravenous heparin. They described 3 asymptomatic patients treated with heparin to prevent stroke who went on to develop a posterior circulation stroke during anticoagulation therapy. They offered no details on the 3 other patients with stroke. They described 21 asymptomatic patients treated with heparin. Three had a stroke (14%). Conversely, 6 of 17 patients (35%) suffered a stroke

TABLE 3. Modified Denver Screening Criteria for BCVI^{a,b}

Lateralizing neurologic deficit (not explained by CT head)
• Infarct on CT head scan
• Cervical hematoma (nonexpanding)
• Massive epistaxis
• Anisocoria/Homer's syndrome
• Glasgow Coma Scale score <8 without significant CT findings
• Cervical spine fracture
• Basilar skull fracture
• Severe facial fracture (LeFort II or III only)
• Seatbelt sign above clavicle
• Cervical bruit or thrill

^aAdapted from: Biffi WL, Moore EE, Offner PJ, et al. Optimizing screening for blunt cerebrovascular injuries. *Am J Surg*, 178:517 to 522, 1999.³⁷

^bCT, computed tomography.

before or without heparin therapy, but the relationship of the stroke to the initial injury was not explained. Two patients sustained hemorrhagic strokes while receiving heparin therapy.

Miller et al, in 2001, identified 75 patients with blunt traumatic carotid artery injuries and 50 patients with blunt traumatic VAI with 4 vessel angiography.³⁰ Six patients with VAI presented with posterior ischemia/stroke. Sixty-four percent were identified following BCI screening protocols. Thirty-nine asymptomatic patients with VAI were treated (31 heparin, 8 aspirin). The incidence of posterior circulation stroke after treatment was 2.6% (1 patient assumed, but not stated, to be on aspirin therapy). The authors described 5 patients with complications related to heparin therapy among 65 treated with heparin (8%), but did not select out those with VAI. They erroneously reported a 54% stroke rate for untreated VAI. The authors concluded that anticoagulation therapy is effective for acute traumatic VAI. This study provides Class III medical evidence for the treatment of VAI with either heparin or aspirin, but offers no comparison to a “no treatment” group.

In 2002, Miller et al¹⁸ described 43 patients with VAI diagnosed by digital subtraction angiography. Patients were treated with heparin anticoagulation ($n = 8$), aspirin only ($n = 24$), aspirin and clopidogrel ($n = 8$), or no treatment ($n = 3$). No patient experienced a posterior circulation stroke in the 2-year patient accrual period with limited follow up. They compared these results to their previously published cohort³⁰ (see above). Severe hemorrhagic complications were noted in 2 patients receiving anticoagulation. One patient on aspirin-only therapy developed bleeding from a gastric ulcer. The authors concluded that asymptomatic patients with VAI should be treated with systemic anticoagulation, this despite a higher hemorrhagic risk with the use of heparin in both of their series, and the absence of a future stroke in patients who were assigned to “no treatment.” Their report offers Class III medical evidence on this issue.

Beletsky et al³¹ described 116 patients with cervical arterial dissections, 67 vertebral, and 49 carotid artery lesions. In their 2003 report, 68 injuries were due to blunt cervical trauma. In the 105 patients with complete follow up, the stroke rate was 8.3% for those treated with intravenous anticoagulation vs 12.4% among patients treated with aspirin (not statistically significant, $P = .63$). The authors did not select out or separately report treatment strategies, numbers of patients, or stroke incidence in patients with isolated VAI.

In 2006, Schneidereit et al²³ performed 137 CTA studies in evaluation of blunt vascular neck injuries after trauma. They found an incidence of blunt vascular neck injuries of 1.4%. Thirteen patients with VAI were treated with anticoagulation (3), antiplatelet therapy (4), endovascular treatment (3), endovascular and antiplatelet therapy (2), or no treatment (1). No patient had neurological sequelae due to VAI or a complication of treatment. Length of treatment and follow up were not specified. The Beletsky et al and Schneidereit et al studies offer Class III medical evidence on treatment for VAI. No treatment recommendations can be derived from either study.

In 2009, Eastman et al³² published a follow-up study to their 2006 study documenting the merits and accuracy of CTA to

identify BCI, including VAI following blunt trauma. They identified 19 VAI patients in their contemporary cohort. Nine patients were treated with antiplatelet therapy, 3 patients with anticoagulation, 1 with embolization, and 6 patients received no treatment. One of the 19 patients had a stroke (5.3%), a patient with multiple associated injuries who received no treatment until the stroke occurred and then was treated with antiplatelet therapy thereafter. No other data are provided. In comparison, the stroke rate following VAI in their earlier cohort when catheter angiography was used to diagnose BCI was 18.2%. The authors concluded that CTA in the contemporary workup of patients with BCI reduces the time to diagnosis, and subsequently time to treatment, reducing the effective stroke rate following BCI including VAI. This report provides Class III medical evidence on treatment for VAI. No specific treatment recommendations can be offered from the medical evidence provided in their study.

Berne and Norwood reported on blunt injuries to the vertebral artery (BVI) in 2009.²² Forty-four patients out of 8292 admissions following blunt trauma were found to have BVI diagnosed by CTA. Two patients were treated with anticoagulation, 19 were treated with aspirin only, 2 with dual antiplatelet agents (clopidogrel and aspirin), 10 were treated with endovascular therapy \pm antiplatelet agents, and 11 patients received no treatment. Four patients developed a stroke and 3 of those 4 patients died. The overall mortality in their series was 16% (7 of 44 patients), but BVI mortality was identified in only the 3 patients described above. These patients were the most severely injured patients, 2 with bilateral VA occlusion, and 1 with a VA transection. The authors concluded that despite an aggressive screening and individualized treatment protocol for BVI, they had very few potentially preventable BVI-related strokes and deaths. They were unable to conclude that either screening or treatment of any kind improved outcome from BVI. No recommendations on treatment could be derived from their report.

Cothren et al²⁶ in 2009 described a retrospective review of a prospective database in comparison of anticoagulation and antiplatelet agents in the treatment of BCIs. Two-hundred eighty-two asymptomatic patients were treated with heparin (192), aspirin (67), or aspirin and/or clopidogrel (23). One hundred seven asymptomatic patients with BCI were not treated. The reported stroke rate in the treated group was 0.5%. The stroke rate in the “no treatment” group was 21.5%. The authors offer Class II medical evidence in favor of treatment for BCIs. Regrettably, the authors did not offer specifics on the timing or the significance of “stroke” in the 10 “asymptomatic” VAI patients found to have a stroke in the “no treatment” group. Several of these patients had incidental, asymptomatic imaging findings of stroke on follow-up CT studies. Late comparative imaging to assess for silent stroke/asymptomatic stroke was not routinely accomplished in the vast majority of study patients ($>80\%$). Follow-up of patients beyond discharge was “limited.” For these reasons and others, this report offers Class III medical evidence on the treatment of VAI after injury. The authors did report serious bleeding complications in 8 patients treated with heparin, adding to the body of evidence that heparin therapy after

TABLE 4. Evidentiary Table: Diagnosis of Vertebral Artery Injury^a

Malhotra et al, ²⁶ <i>Ann Surg</i> , 2007	Prospective comparison 92 trauma patients who underwent both CTA and DSA.	III	Sensitivity, specificity, positive and negative predictive values of CTA were 74%, 86%, 65%, and 90%, respectively. No accuracy data for VAI specifically.
Schneiderei et al, ²⁴ <i>J Trauma</i> , 2006	Prospective study of CTA to identify blunt vascular neck injuries after trauma	III	Sensitivity, specificity, positive and negative predictive values of CTA were 65%, 50%, 65%, and 94%, respectively. No accuracy data provided for VAI specifically.
Berne et al, ²⁵ <i>J Trauma</i> , 2006	Retrospective review of 435 patients who underwent CTA for suspected BCVI.	III	1.2% incidence of BCVI among all trauma victims. 5.5% incidence among those meeting Biffle criteria. None of the patients with normal CTA went on to have signs/symptoms of missed injury.
Utter et al, ²² <i>J Am Coll Surg</i> , 2006	Retrospective review of 82 patients with normal CTA who underwent confirmatory DSA.	III	92% negative predictive value for CTA. Transverse foramen fractures most predictive of vertebral artery injury.
Biffel et al, ²¹ <i>J Trauma</i> , 2006	Prospective review of 331 patients who underwent CTA for suspected BCVI.	III	5.4% incidence of BCVI, specifically 2.4% incidence of VAI among those who met screening criteria. None of the patients with normal CTA went on to have signs/symptoms of missed injury.
Eastman et al, ²⁰ <i>J Trauma</i> , 2006	Prospective comparison of CTA and catheter angiography in 146 trauma patients.	I	Sensitivity, specificity, positive predictive value, and negative predictive value of CTA were 97.7%, 100%, and 100%, respectively. Accuracy of CTA for VAI was 99.3%.
Miller et al, ¹⁹ <i>Ann Surg</i> , 2002	Prospective nonrandomized comparison of CA to CTA and MRA screening in 216 trauma patients.	III	Sensitivity of CTA and MRA were 53% and 47%, respectively.
Weller et al, ¹¹ <i>J Trauma</i> , 1999	Prospective MRA in 12 patients with foramen transversarium fractures.	III	Three of 12 had VA occlusion; all remained asymptomatic on aspirin. One of 12 with stenosis had delayed syncope on aspirin, resolved with brief intravenous heparin followed by aspirin.
Giacobetti et al, ⁹ <i>Spine</i> , 1997	Prospective study with MRA in 61 patients with cervical injuries found 12 patients with VA occlusion.	III	One of 4 with transverse foramen fractures had occlusion. Six of 15 with facet dislocation had occlusion. Three of 12 with transient blurred vision resolved with 3-month anticoagulation.
Friedman et al, ⁶ <i>AJR Am J Roentgenol</i> , 1995	Prospective study of 37 patients with nonpenetrating cervical trauma found 9 VA injuries by MRA.	III	Fifty percent of patients with complete cord injuries had VA injury vs 12% of patients with incomplete cord injuries ($P < .02$). Five of 13 patients with >3 mm subluxation had VA injuries vs 4 of 24 patients with <3 mm subluxation. One patient with bilateral VA injuries died of large cerebellar infarct (bilateral foramen transversarium fractures). Eight asymptomatic (1 of 8 with anticoagulation also had carotid occlusion).
Woodring et al, ¹² <i>J Trauma</i> , 1993	Retrospective study of 216 patients with cervical fractures showed 52 with TP fractures. Eight had angio.	III	Seventy-eight percent of TP fractures extended into foramen transversarium. Four of 8 patients had occlusion, 3 of 8 had dissection, 1 of each had stroke that improved with anticoagulation. Three asymptomatic patients treated with anticoagulation.

^aBCVI, blunt cerebrovascular injuries; CA, contrast angiography; CTA, computed tomographic angiography; DSA, digital subtraction angiography; MRA, magnetic resonance angiography; TP, transverse process; VAI, vertebral artery injury.

TABLE 5. Evidentiary Table: Treatment of Vertebral Artery Injury^a

Citation	Description of Study	Evidence Class	Conclusions
Franz et al, ²⁸ <i>Vascular & Endovascular Surgery</i> , 2010	Retrospective follow up of 29 BCVI patients, 24 with VAI after discharge.	III	No neurological sequelae in any patient with follow up.
	Treatment for VAI included anticoagulation (6), antiplatelet (6), anticoagulation + antiplatelet (10), and no treatment (10).		No complications of therapy.
	Twelve patients with VAI with follow-up mean 9.2 weeks. Specifics of their treatment not reported.		
Stein et al, ²⁷ <i>J Trauma</i> , 2009	Retrospective study of 147 pts with BCVI treated with endovascular management, antiplatelet agents, anticoagulants, a combination, or no treatment.	III	Significantly higher risk of stroke with no treatment BCVI (25.8% vs 3.5%).
			Stroke rate of VAI = 8.2%, but 2 had stroke after initial injury, 3 others incidental or asymptomatic.
	Sixty-eight patients with VAI.		One-third of patients not candidates for treatment.
			Treatment appears to reduce stroke risk for BCVI, but no therapy recommendations offered for VAI.
Cothren et al, ²⁶ <i>Ann Surg</i> , 2009	Retrospective comparison in 282 asymptomatic BCVI patients treated with heparin, aspirin, and aspirin + plavix, vs no treatment.	II for BCVI, III for VAI	Significantly higher rate of stroke for BCVI with no treatment (21.5% vs 0.5%).
			Equivalence between anticoagulation and antiplatelet regimens.
			No routine follow-up screening and limited follow up.
			No specifics offered for VAI.
Berne and Norwood, ²² <i>J Trauma</i> , 2009	Forty-four patients with VAI by CTA out of 8292 admits.	III	Increased bleed complications with heparin.
	Two treated with anticoagulation, 19 aspirin, 2 dual antiplatelet, 10 with endovascular/antiplatelet, and 10 no treatment.		Aggressive screening and individualized treatment failed to prevent VAI stroke and death.
	Four strokes from VAI, 3 on admission with most severe injuries.		No recommendations on treatment for VAI.
Eastman et al, ¹⁸ <i>J Trauma</i> , 2009	Follow-up study on CTA for BCVI including 19 patients with VAI.	III	CTA to diagnose BCVI (including VAI) reduces time to diagnosis and treatment.
	Stroke rate for BCVI = 15.2% in prior study with DSA to diagnose BCVI.		
	Stroke rate for BCVI = 3.8% with CTA to diagnose BCVI.		No evidence in support of treatment recommendations offered for VAI.
	Nine VAI patients treated with antiplatelet, 3 with anticoagulation, 1 endovascular, and 6 no treatment.		
Schneiderei et al, ²³ <i>J Trauma</i> , 2006	One stroke (5.3%)	III	
	137 CTA studies to assess for blunt vascular neck injuries.		No conclusive treatment recommendations for VAI offered.
	Incidence 1.4%.		

(Continues)

TABLE 5. Continued

Citation	Description of Study	Evidence Class	Conclusions
	Thirteen patients with VAI treated with anticoagulation (3), antiplatelet (4), endovascular (3), endovascular and antiplatelet (2), and no treatment (1).		
	No neurological sequelae from VAI.		
	Length of treatment and follow up not specified.		
Beletsky et al, ³¹ <i>Stroke</i> , 2003	Nonrandomized comparison of aspirin and anticoagulants in 116 patients with traumatic and atraumatic dissection BCVI injuries.	III	Rate of stroke with ASA was 12.4% vs 8% with anticoagulation (not statistically significant, $P = .63$).
	Stroke rate in 105 patients with follow up = 8.3%.		No conclusive treatment recommendations for VAI offered.
	No specific data on patients with traumatic VAI.		
Miller et al, ¹⁸ <i>Ann Surg</i> , 2002	Prospective screening identified 43 patients with VAI diagnosed by DSA, treated with anticoagulation (8), aspirin (24), aspirin and clopidogrel (8), or no treatment (3).	III	Authors favor treatment of VAI with anticoagulation despite increased risk of bleeding complications and absence of stroke with other treatments including "no treatment."
	No stroke in variable follow-up period.		
	Two bleeding complications with heparin.		
Miller et al, ³⁰ <i>J Trauma</i> , 2001	Retrospective analysis of prospective database on screening for BCVI.	III	Authors concluded anticoagulation is effective treatment for VAI despite increase in complications.
	Seventy-five blunt carotid injury patients.		
	Fifty patients with VAI.		
	Six VAI patients presented with stroke.		No comparison with "no treatment" group.
	Thirty-nine asymptomatic VAI patients treated with heparin (31) or aspirin (8).		
	One posterior circulation stroke (2.6%) while on aspirin.		
	Five hemorrhagic complications with heparin.		
Biffi et al, ⁷ 2000, <i>Ann Surg</i>	Prospective angiography screening for BCVI identified 38 patients with VAI.	III	Three of 21 asymptomatic patients treated with heparin had stroke (14%) vs 6 of 17 patients without heparin had stroke (35%) (not statistically significant, $P = .13$).
			Three strokes from initial injury.
	Nine patients with postcirculation stroke (24%).		Three strokes on heparin therapy, 2 of which were hemorrhagic.
			Three strokes, no data offered.

^aBCVI, blunt cerebrovascular injuries; CTA, computed tomographic angiography; DSA, digital subtraction angiography; VAI, vertebral artery injury.

BCVI has higher risk than that associated with antiplatelet therapy in the treatment of BCVI.

Stein et al,²⁷ also published in 2009, reported on 147 patients with BCVI after trauma. Sixty-eight of these patients sustained VAI, 5 of whom had posterior circulation strokes (8.2%). Two of these patients had stroke from VAI at the time of imaging/diagnosis (both died). The other 3 patients had "asymptomatic"

incidental strokes identified on follow-up imaging while hospitalized. The 2 early fatal strokes were counted in the "no treatment" group. The true incidence of "asymptomatic stroke" could not be discerned from the study because routine, follow-up surveillance of all study patients was not accomplished. Treatment groups in Stein et al's study included anticoagulation ($n = 8$), antiplatelet agents ($n = 23$), endovascular therapy ($n = 12$), endovascular and

antiplatelet therapy (n = 4), and no treatment (n = 21). Complications of therapy were not offered. The authors concluded that nearly one-third of the patients with BCVI are not candidates for treatment. In their experience, treatment appeared to reduce the risk of stroke following BCVI, but could not offer a specific recommendation on treatment for BCVI once it is identified.

In 2010, Franz et al²⁸ described retrospective follow up of 29 BCVI patients following discharge from their initial blunt trauma injury hospitalization. Twelve of 24 patients who sustained acute traumatic VAI returned for follow-up assessment, with a mean follow up of 9.2 weeks following discharge. Therapy for the original 24 patients with VAI included anticoagulation (6), antiplatelet therapy (4), anticoagulation and antiplatelet therapy (10), and no treatment (4). No patient seen in follow up had neurological sequelae attributable to VAI. There were no reported complaints or complications of therapy.

In several studies, patients with VAI were reimaged to determine whether disease progression or resolution occurred after treatment for vertebral artery injury. Biffi et al⁷ reported follow-up angiography on 21 patients. Of 16 patients treated with heparin, 2 improved to a lesser grade of vascular injury and 4 worsened to a poorer grade. Of 5 patients not receiving heparin, 1 improved and 3 had worse vascular injury grades. Vaccaro et al³³ found reconstitution in 1 of 6 vertebral artery injuries by MRA 12 days after the original diagnosis. This patient was not treated with anticoagulation.³³ The remaining 5 still had vertebral artery occlusion more than 1 year later, including 2 treated with anticoagulation. Willis et al⁶ described the results of follow-up angiography in 3 patients with VAI. One patient with a pseudoaneurysm received 1 week of intravenous heparin followed by aspirin; the pseudoaneurysm had slightly enlarged 7 days after treatment was begun, but had disappeared on angiography performed 6 weeks later. One patient treated with intravenous heparin for a vertebral artery dissection had an asymptomatic occlusion of the artery demonstrated by angiography 2 days later; the heparin was subsequently discontinued. The third patient was treated with intravenous heparin for a vertebral artery intimal flap. That patient had a normal vertebral angiogram 10 days later. Thibodeaux et al¹⁷ found a patent vertebral artery 6 months after a VAI dissection was diagnosed; this patient was not anticoagulated. Sim et al¹⁶ reported delayed Duplex sonography in 11 patients with a history of facet dislocation, but unknown vertebral artery status at the time of the original cervical spine injury. Two of these studies demonstrated VAI: 1 with persistent cervical spinal dislocation had vertebral occlusion, and 1 patient with a reduced cervical injury had vertebral artery stenosis. Stein and colleagues found that of the treated VAI patients in their series, 23.5% were radiographically improved and 76.5% were stable at early follow up, as compared to 66.7% improved and 33.3% stable in the untreated group. They concluded that few VAI lesions progress and most improve radiographically, regardless of whether or how they are treated.²⁷

More recently, endovascular intervention has been described for the management of blunt cerebrovascular injury, particularly in

cases of traumatic pseudoaneurysm, dissection, and fistulae.³⁴⁻³⁶ However, the need for dual antiplatelet therapy after endovascular procedures and their potential for bleeding complications is a relative contraindication to the application of endovascular therapy in multiple injury trauma patients with VAI. The evidence used to develop these recommendations is shown in Table 5.

SUMMARY

The incidence of vertebral artery injury may be as high as 11% after nonpenetrating cervical spinal trauma in patients meeting specific clinical and physical exam criteria. The modified Denver Screening Criteria for BCVI are the most commonly used.^{19,37} Many patients with VAI have complete spinal cord injuries, fractures through the foramen transversarium, cervical spinal facet dislocation injuries, and/or vertebral subluxation, but many patients with these spinal and spinal cord injuries have normal vertebral arteries when imaged, thus reducing the specificity of these injury patterns with respect to VAI. Many comparative studies in which sensitivity, specificity, and positive and negative predictive value have been, or can be, calculated examined various tests against each other, but not against the gold standard of intravenous catheter angiography, thereby producing Class III medical evidence. However, recent literature providing Class I medical evidence does support CTA as a highly accurate alternative to catheter angiography for screening for VAI in blunt injury trauma patients, with a very high negative predictive value.^{19,21,24}

It appears that a significant number of the symptomatic strokes resulting in neurological deficits following VAI are attributable to the initial blunt traumatic injury. The majority of patients with VAI are asymptomatic, including a number of patients with incidental cerebellar and posterior circulation strokes found on imaging studies at the time of diagnosis or in follow-up. To date, there has been no definitive longitudinal study defining the stroke risk of VAI, asymptomatic or otherwise, among patients being treated for known VAI and/or among patients receiving “no treatment” for known VAI. There is no Class I or Class II medical evidence on the issue of therapy for VAI. Class III medical evidence suggests that a small number of patients with VAI will develop a posterior circulation stroke in delayed fashion beyond deficits associated with the initial traumatic injury. While no conclusive medical evidence supports treatment for VAI, most clinicians support treatment for patients with symptomatic VAI with either anticoagulation or antiplatelet therapy. Because of an increased relative risk of hemorrhagic complications from anticoagulation therapy for VAI, without clear superior efficacy,^{7,13,18,26,30} anticoagulation therapy is not considered ideal treatment in multiple trauma patients with VAI, symptomatic or asymptomatic. Antiplatelet therapy (aspirin the most studied) appears to be a safe and comparable option for symptomatic patients with VAI after blunt trauma.

No treatment or antiplatelet therapy appears to be a comparable option for the treatment of asymptomatic patients with documented VAI. Because antiplatelet therapy has the potential to

reduce future stroke risk, treatment with aspirin for documented VAI after trauma should be considered in patients if there exist no contraindications to antiplatelet therapy. At present, the choice of therapy, if any, for patients with VAI should be individualized based on the patient's vertebral artery injuries, associated traumatic injuries, and the relative risk of bleeding associated with that form of therapy.

KEY ISSUES FOR FUTURE INVESTIGATION

A multicenter, randomized, prospective study comparing anticoagulation with intravenous heparin to antiplatelet agents to no treatment in asymptomatic patients with VAI is recommended to determine which method of treatment of these injuries, if any, is most efficacious. Studies to assess the role of endovascular intervention in patients with VAI are needed to determine the application and merits of endovascular therapy to this acute traumatic vascular disorder.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Deep Venous Thrombosis and Thromboembolism in Patients With Cervical Spinal Cord Injuries

Sanjay S. Dhall, MD*

Mark N. Hadley, MD‡

Bizhan Aarabi, MD, FRCSCS

Daniel E. Gelb, MD¶

R. John Hurlbert, MD, PhD,
FRCSC||

Curtis J. Rozzelle, MD#

Timothy C. Ryken, MD, MS**

Nicholas Theodore, MD‡‡

Beverly C. Walters, MD, MSc,
FRCSC‡§§

*Department of Neurosurgery, Emory University, Atlanta, Georgia; ‡Division of Neurological Surgery, and #Division of Neurological Surgery, Children's Hospital of Alabama, University of Alabama at Birmingham, Birmingham, Alabama; §Department of Neurosurgery, and ¶Department of Orthopaedics, University of Maryland, Baltimore, Maryland; ||Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada; **Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa; ‡‡Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona; §§Department of Neurosciences, Inova Health System, Falls Church, Virginia

Correspondence:

Mark N. Hadley, MD, FACS,
UAB Division of Neurological Surgery,
510 – 20th Street South, FOT 1030,
Birmingham, AL 35294-3410.
E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS

Prophylaxis:

Level I

- Prophylactic treatment of venous thromboembolism (VTE) in patients with severe motor deficits due to spinal cord injury is recommended.
- The use of low molecular weight heparins, rotating beds, or a combination of modalities is recommended as a prophylactic treatment strategy.
- Low dose heparin in combination with pneumatic compression stockings or electrical stimulation is recommended as a prophylactic treatment strategy.

Level II

- Low dose heparin therapy alone is not recommended as a prophylactic treatment strategy.
- Oral anticoagulation alone is not recommended as a prophylactic treatment strategy.
- Early administration of VTE prophylaxis (within 72 hours) is recommended.
- A 3-month duration of prophylactic treatment for deep vein thrombosis (DVT) and pulmonary embolism (PE) is recommended.

ABBREVIATIONS: **ASCI**, acute spinal cord injury; **DVT**, deep venous thrombosis; **IVC**, inferior vena cava; **IV**, intravenous; **LMWH**, low molecular weight heparins; **PE**, pulmonary embolism; **SCI**, spinal cord injury; **UFH**, unfractionated heparin; **VOP**, venous occlusion plethysmography; **VTE**, venous thromboembolism

Level III

- Vena cava filters are not recommended as a routine prophylactic measure, but are recommended for select patients who fail anticoagulation or who are not candidates for anticoagulation and/or mechanical devices.

Diagnosis:

Level III

- Duplex Doppler ultrasound, impedance plethysmography, venous occlusion plethysmography, venography, and the clinical examination are recommended for use as diagnostic tests for DVT in the spinal cord injured population.

RATIONALE

DVT and PE collectively considered as VTE are problems frequently encountered in patients who have sustained cervical spinal cord injuries. Several means of prophylaxis and treatment are available, including anticoagulation, pneumatic compression devices, and vena cava filters. In 2002, the guidelines author group of the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons (AANS) and the Congress of Neurological Surgeons (CNS) produced a medical evidence-based guideline on this important topic.¹ The purpose of this current evidence-based review is to update, evaluate, and rank the literature on the methods of prevention, identification, and treatment of VTE complications in patients following acute cervical spinal cord injury published since 2002.

SEARCH CRITERIA

A National Library of Medicine (PubMed) computerized literature search from 1966

through 2011 was performed using Medical Subject Headings in combination with “spinal cord injury”: “deep venous thrombosis” “pulmonary embolism” and “thromboembolism.” The search was limited to human studies reported in the English language. This resulted in 599 citations. Duplicate references, reviews, letters, and tangential reports were discarded. The bibliographies of these citations were analyzed for additional potential contributions. Finally, the author group found 45 citations describing the diagnosis, prophylaxis or treatment of thromboembolic disease in adult spinal cord injured patients make up the basis for this guideline and are summarized in Evidentiary Table format (Table). Supporting references included 4 evidence-based reviews on VTE prophylaxis and treatment in a variety of patient populations. Finally, several series dealing with VTE in general trauma patients with results germane to a discussion of spinal cord injured patients are included in the bibliography as supporting documents.

SCIENTIFIC FOUNDATION

The incidence of thromboembolic complications in the untreated spinal cord injury (SCI) population is high. Depending upon injury severity, patient age, and the methods used to diagnose a thromboembolism, the incidence of thromboembolic events ranges from 7% to 100% in reported series of patients receiving either no prophylaxis or inadequate prophylaxis.²⁻¹⁴ Substantial morbidity and mortality has been associated with the occurrence of DVT and PE events in the SCI population.^{15,16,55-57}

Prophylaxis

Prophylactic therapy has been shown to be effective for the prevention of DVT and PE. In a small randomized study, Becker et al¹⁷ demonstrated that the use of rotating beds during the first 10 days following SCI decreased the incidence of DVT and provided Class I medical evidence on this subject. Four of 5 control patients were diagnosed with DVT (by fibrinogen screening) compared to 1 of 10 treated patients. The use of low dose heparin (5000 units given via subcutaneous injection twice or 3 times daily) has been described by several authors.^{3,6,7,12,18-20} Hachen¹⁹ published the results of a retrospective historical comparison of low dose heparin vs oral anticoagulation in a group of 120 SCI patients. He found a lower incidence of thromboembolic events in the low dose heparin group compared to the oral anticoagulation group. In 1977, Casas et al¹⁸ reported the results of a prospective assessment of low dose heparin in SCI patients. They administered heparin for a mean period of 66 days in 18 SCI patients and noted no thromboembolic events as detected by clinical examination. Watson reported a lower incidence of thromboembolic events with the use of low dose heparin when compared to no prophylaxis in a retrospective historical cohort study.²⁰ Frisbie and Sasahara, however, found that low dose heparin did not affect the incidence of DVT in a prospective study of 32 SCI patients compared to treatment with twice daily physical therapy

alone. These authors felt that the lack of effect was due to the very low incidence of DVT in their control group compared to other series because of the aggressive physical therapy paradigm employed in their patients. Although they performed screening venous occlusion plethysmography (VOP) with confirmatory venography weekly, the incidence of DVT was only 7% in both groups, suggesting that the treatments were equivalent in their study.⁴ This low incidence of DVT is substantially lower than that reported by 2 separate groups of investigators a decade later.^{6,7} In 1992, Kulkarni et al reported the much higher incidence of DVT (26%) and of PE (9%) in a group of 100 SCI patients prospectively treated with low-dose heparin.⁷ In 1993, Gunduz et al reported a 53% incidence of DVT confirmed by venography in 31 patients they managed with SCI treated with low dose heparin.⁶ In a study published in 1999, Powell et al noted that the incidence of DVT in 189 SCI patients receiving prophylaxis was significantly lower than that identified in SCI patients who did not receive prophylaxis, 4.1% vs 16.4%, respectively. Their comparative study provides supportive Class II medical evidence in favor of DVT prophylaxis. They reported that DVT in the prophylaxis group occurred in patients who received low dose heparin alone.¹²

Several studies have demonstrated that better prophylactic therapies than low dose heparin exist.^{5,9,21} Green et al⁵ published a randomized controlled study comparing low dose vs adjusted dose heparin (dose adjusted to APTT 1.5 times normal) in SCI patients. They found that patients treated with adjusted dose heparin had fewer thromboembolic events (7% vs 31%) during the course of their 10-week study, but had a higher incidence of bleeding complications. Merli et al²¹ in 1988 reported their findings of the additive protective effects of electrical stimulation in combination with low dose heparin, heparin alone, and placebo in 48 SCI patients treated for 4 weeks duration. In this Class I prospective, randomized medical evidence trial, they found that the heparin therapy alone group had a similar incidence of DVT compared to the placebo group. The combination of low dose heparin and electrical stimulation significantly decreased the incidence of DVT (1 of 15 patients compared to the other 2 treatment groups (8/16 low dose heparin alone, and 8/17 placebo, $P < .05$), providing Class I medical evidence on this issue.²¹ In 1992, this same group reported that heparin in combination with pneumatic stockings was equal to the effectiveness of heparin plus electrical stimulation.⁹ The heparin in combination with electrical stimulation group and the placebo group for this comparison were a historical cohort, rendering the medical evidence provided Class III. Winemiller et al²² studied a large series of 428 SCI patients with a multivariate analysis and found that the use of pneumatic compression devices for 6 weeks duration was associated with a significant decrease in thromboembolic events (odds ratio of 0.5 [95% CI 0.28-0.90]). Low dose heparin treatment seemed to have a protective effect as well; however, the effect of heparin alone was not statistically significant.

Recently, low molecular weight heparins (LMWH) have been studied as prophylactic therapy for thromboembolism in SCI

patients. Green et al²³ treated a series of SCI patients with 8 weeks of LMWH (tinzaparin) and compared the results with a historical cohort of patients treated with low dose or adjusted dose heparin. They found that the use of LMWH compared favorably with the use of either heparin dosing regimen in terms of fewer thromboembolic events, (16 events in 79 patients in the heparin group vs 7 events among 68 patients in the LMWH group, $P = .15$). Patients treated with LMWH had a significant decrease in bleeding complications (9 of 79 in the heparin group vs 1 of 68 in the LMWH group, $P = .04$).²³ More recently, Harris et al²⁴ performed a retrospective study of LMWH (enoxaparin) administration in a series of 105 patients with spinal injuries. Forty of their 105 patients suffered neurologically complete injuries. No patient exhibited clinical or ultrasound evidence of DVT and no patient suffered a PE treated with LMWH.²⁴ Roussi et al²⁵ reported a 9% incidence of DVT in a study involving 69 SCI patients receiving LMWH, testimony to the fact that no prophylactic therapy is 100% effective.

In 2003, the Spinal Cord Injury Thromboprophylaxis Investigators reported their study that randomized 476 acute SCI patients to unfractionated heparin (UFH) plus intermittent pneumatic compression or to enoxaparin as VTE prophylaxis strategies. The study was sponsored by the enoxaparin manufacturer. All but 107 patients were excluded from analysis due to “protocol deviations, bleeding and/or other adverse clinical events, thrombocytopenia and/or other adverse laboratory findings, withdrawal of consent, and intercurrent illness.” Though they found no significant difference in the incidence of thromboembolism between the treatment groups (63.3% vs 65.5%, respectively), they did note a significantly lower incidence of PE in the enoxaparin group (5.2%) vs the UFH + IPC group (18.4%). Due to the high exclusion rate, the medical evidence provided by this study is downgraded to Class III.²⁶

In 2003, this same group prospectively examined the incidence of VTE in SCI patients in the rehabilitation phase (2 weeks after injury) who received either enoxaparin or UFH for 6 weeks. Of the 172 patients in their study, they excluded 53 due to “protocol deviations, bleeding and/or other adverse clinical events, thrombocytopenia and/or other adverse laboratory findings, withdrawal of consent, and intercurrent illness.” In the remaining patients, they found a lower incidence of thromboembolic complications in patients treated with enoxaparin (21.7% vs 8.5%; $P = .052$). Due to the high exclusion rate, the medical evidence provided by this study is downgraded to Class III.²⁷

In 2004, Hebbeler and colleagues²⁸ compared once daily dosing (40 mg) of enoxaparin to twice daily (30 mg each) dosing and found no significant difference in the incidence of thromboembolic complications among SCI patients in the rehabilitation setting. In 2005, Green et al²⁹ compared the incidence of DVT in SCI patients treated from 1992 to 1995 to SCI patients they treated from 1999 to 2003, and found a significant decrease from 21% in the group of patients treated in the early 1990s compared to 7.9% in the latter series managed in the early 2000s. They concluded that the decline in the

incidence of venous thromboembolism in their 2 patient series coincided with their transition from unfractionated heparin to LMWH used for prophylaxis. In 2007, Slavik et al³⁰ performed a retrospective cohort study comparing enoxaparin to dalteparin in 135 patients with orthopedic trauma and/or spinal cord injury (73 with SCI). They found that the incidence of VTE was 1.8% and 9.7% in the enoxaparin and dalteparin patients, respectively, but reported that this difference was not statistically significant ($P = .103$).³⁰ In 2010, Arnold et al³¹ performed a retrospective cohort study comparing unfractionated heparin to enoxaparin in 476 trauma patients, including 24 with spinal cord injury. Proximal lower extremity DVTs were detected in 16 patients in the enoxaparin group (6.75%) and in 17 patients in the UFH group (7.11%). Among the 24 SCI patients, however, the authors found the incidence of DVT in the enoxaparin group to be 36.4% compared to 15.4% in the UFH treated group ($P = .357$). The authors concluded that UFH was equally effective as enoxaparin as prophylaxis against DVT in their study, and far less expensive.³¹ These 4 retrospective studies offer Class III medical evidence on the use of UFH, dalteparin and enoxaparin as prophylaxis for DVT²⁸⁻³¹; however, the study populations were heterogeneous and difficult to compare. Many patients in these various studies were managed with chemical prophylaxis and other prophylactic modalities, yet others were managed with chemical prophylaxis alone; therefore, conclusions regarding these agents as stand-alone therapy cannot be made.

Prophylaxis: Inferior Vena Cava Filters

The use of inferior vena cava (IVC) filters as prophylactic devices for thromboembolism has been advocated.³²⁻³⁵ Wilson et al³⁵ placed caval filters in 15 SCI patients who were concurrently treated with either low dose heparin or pneumatic stockings. None suffered a PE during a 1-year follow-up period. The reported 1-year patency rate of the IVC was 81%. The authors noted that their results are superior to those from a historical cohort of 111 patients treated without IVC filters.³⁵ Seven of the cohort patients suffered a PE; however, 6 of the 7 were not receiving any prophylaxis at the time of their PE. The single patient they described who had a PE while receiving DVT prophylaxis suffered a gunshot blast injury to the spine.³⁵ Khansarinia and colleagues³³ described a historical cohort study of 108 general trauma patients treated with prophylactic IVC filters. None of these patients suffered a PE. They compared this group to another historical cohort of 216 patients treated (apparently) with either low dose heparin or pneumatic compression devices prior to the use of IVC filters. Thirteen of these 216 suffered a PE, 9 of which were fatal.³³ The mortality among the filter treatment group was lower than the mortality of the control group, but the difference was not significant (16% vs 22%).³³ Tola et al³⁶ have shown that percutaneous IVC filter placement in the intensive care unit setting is safe and is less costly than IVC filter placement in the operating room or the radiology suite. These authors suggest that IVC interruption is an effective means to prevent PE.

The placement of IVC filters is not without complications. Balshi et al, Kinney et al, and others have described distal migration, intraperitoneal erosion, and symptomatic IVC occlusion in patients with SCI treated with IVC filters.³⁷⁻³⁹ Balshi et al³⁷ have hypothesized that quadriplegic patients are at higher risk for complications from IVC filter placement due to loss of abdominal muscle tone, as well as their requisite use of the “quad cough” maneuver.

In 2009, Gorman and colleagues⁴⁰ performed a retrospective chart review of 114 patients with SCI, 47% of whom were treated with prophylactic IVC filter placement. All SCI patients received either LMWH or heparin prophylaxis. The IVC filter group had significantly more DVTs (20.4%) when compared to the group without filters (5.4%). Interestingly, only 1 patient suffered from PE; that patient had received a prophylactic IVC filter.

Timing and Duration of Prophylaxis

The vast majority of VTE events appear to occur within the first 2 to 3 months following injury. Naso described his experience with 4 patients with PE in a group of 43 SCI patients. All 4 PE events were documented within 3 months of injury.⁴¹ Perkasht et al reported an 18% incidence of thromboembolism in a series of 48 patients with acute spinal cord injury and 2 patients with transverse myelitis. Only 1 patient had a new onset PE 3 months after injury; 2 other patients had recurrent PE 3 months after injury due to existing DVT.¹¹ Lamb et al⁸ determined that the risk of thromboembolic events in their series of 287 SCI patients was 10%. The vast majority of events occurred within the first 6 months following injury. Twenty-two of 28 events they documented occurred within the first 3 months of injury. El Masri and Silver³ reported 21 documented events of PE in a series of 102 spinal injured patients. Twenty of 21 events occurred within the first 3 months following SCI. A pulmonary embolism occurred in a patient with a history of PE whose therapeutic anticoagulation was discontinued for gallbladder surgery.³ DeVivo et al⁴² described a 500-fold risk of dying from PE in the first month following acute SCI, compared to age- and gender-matched non-injured patients. This risk decreased with time, but remained approximately 20 times greater than that for normative controls 6 months following SCI.⁴² McKinley et al⁴³ studied chronic spinal injured patients in a rehabilitation center setting and found an incidence of DVT of 2.1% in the first year following injury. This incidence dropped to between 0.5% and 1% per year thereafter.⁴³ The collective data from these 6 studies provide confirming evidence that the great majority of thromboembolic events (DVT and PE) occur within the first 3 months after acute SCI and is considered Class II medical evidence.^{3,8,11,41-43} Prolonged prophylactic anticoagulation therapy is not without risk, and is associated with bleeding complications.^{5,23} The vast majority of studies addressing prophylactic treatment for DVT and PE have utilized treatment courses of 8 to 12 weeks duration with success. In 2002, Aito and colleagues⁴⁴ studied 275 patients admitted to their institution with acute SCI (ASCI) who were screened for

DVT with color Doppler ultrasonography at admission and at 30 to 45 days, or when clinically indicated. They found only 2% of patients admitted within 72 hours had DVT compared to 26% among patients admitted between 8 and 28 days after injury. Remarkably, none of the delayed admission group patients were prophylactically treated with sequential compression devices prior to admission. These authors provide Class II medical evidence that the early application of both chemical and mechanical prophylaxis reduces the incidence of DVT in patients with acute SCI.⁴⁴

In 2009, Ploumis et al⁴⁵ surveyed 25 spine surgeons to obtain a consensus on the use of pharmacologic thromboprophylaxis following spinal injury. The consensus was that postoperative pharmacologic thromboprophylaxis was unnecessary in patients with cervical spinal injuries without SCI; however, it was recommended in instances of cervical spine trauma with SCI or patients treated with anterior thoracolumbar procedures, irrespective of SCI. It was recommended that pharmacologic thromboprophylaxis be initiated preoperatively as soon as possible in patients with SCI and in cases requiring a delay in surgical treatment. Pharmacologic prophylaxis was recommended to be administered for at least 3 months post-injury.⁴⁵

For these reasons, it is recommended that prophylactic treatment be continued for 8 to 12 weeks in spinal cord injury patients without other major risk factors for DVT and PE. Prophylactic treatment may be discontinued earlier in patients with useful motor function in the lower extremities, as these patients appear to be at less risk for DVT and PE.^{10,16}

Diagnosis

The diagnosis of DVT in various studies has been made based on the clinical examination, Doppler ultrasound examination, impedance plethysmography, venous occlusion plethysmography (VOP), venography, fibrinogen scanning, or by D-Dimer measurement.^{2-7,10,11,17,19,21,41,42,46-50} There is no established “gold standard” examination for DVT. Venography has been considered the best test, but is too inaccurate, is not possible in all patients, is invasive, and expensive.⁵¹ Gunduz et al⁶ report a 10% incidence of adverse effects from venography including post-venographic phlebitis and allergic reactions. Doppler ultrasound examination and VOP are both less invasive, less expensive, and more broadly applicable.^{12,51} The sensitivity and specificity of these examinations when compared with venography has been generally reported to range from 80% to 100%. Chu et al⁵² compared Doppler ultrasound and VOP with the clinical examination and found all 3 to agree 100% of the time in a small series of 21 patients. Perkasht and colleagues¹¹ studied a series of 48 SCI patients with daily physical examinations and weekly VOP. They found that the sensitivity of the clinical examination compared to VOP was 89%. The specificity was 88%, the negative predictive value was 97%, and the positive predictive value was 62% in their study. Other authors have described the increased sensitivity of fibrinogen scanning and the use of D-Dimer measurements for the diagnosis of DVT.^{25,53}

TABLE. Evidentiary Table: Deep Vein Thrombosis and Venous Thromboembolism

Citation	Description of Study	Evidence Class	Conclusions
Arnold et al, ³¹ <i>Am Surg</i> , 2010	Retrospective chart review comparing UFH to LMWH in 476 trauma patients, 24 with SCI.	III	Overall risk of DVT in enoxaparin group was 6.75% compared to 7.11% in UFH group. In SCI patients, risk of DVT 36.4% with enoxaparin vs 15.4% with UFH.
Gorman et al, ⁴⁰ <i>J Trauma</i> , 2009	Retrospective chart review comparing prophylactic IVC filter in 47% of 114 patients.	III	Higher incidence (20.4% vs 5.2%) of DVT in IVC filter group; only PE case in filter group.
Slavik et al, ³⁰ <i>J Trauma</i> , 2007	Retrospective cohort study comparing dalteparin (LMWH) qday to enoxaparin BID in acute SCI and major orthopedic trauma.	III	Incident VTE in dalteparin 9.7% vs 1.6% for enoxaparin ($P = 0.103$).
Green et al, ²⁹ <i>Am J Phys Med Rehabil</i> , 2005	Comparison of DVT rates in ASCI populations from 1992 to 1995 vs 1999 to 2003.	III	Drop from 21% to 7.9% DVT rate, coincided with transition to LMWH from UFH.
Hebbeler et al, ²⁸ <i>J Spinal Cord Med</i> , 2004	Retrospective chart review comparing once-daily to twice daily enoxaparin during rehabilitation after SCI.	III	Equal effectiveness.
<i>Spinal Cord Injury Thromboprophylaxis Investigators</i> , ²⁶ 2003	Prospective multicenter comparison of UFH to LMWH in rehabilitation phase (2 weeks post SCI).	III	21.7% VTE in UFH group vs 8.5% in LMWH group ($P = .052$).
<i>Spinal Cord Injury Thromboprophylaxis Investigators</i> , ²⁷ 2003	Prospective multicenter randomization of 476 acute SCI patients to either UFH + SCDs or enoxaparin. Only 107 "assessable" patients.	III	High exclusion rate. Similar incidence of DVT, but significantly lower PE in enoxaparin (<i>study funded by enoxaparin manufacturer</i>).
Aito et al, ⁴⁴ <i>Spinal Cord</i> , 2002	Prospective observation of early (<72 hr) vs late (mean 12 days) initiation of mechanical and chemical DVT prophylaxis in 275 patients.	II	High exclusion rate. 26% DVTs in delayed group compared to 2% in early group.
Chen et al, ⁵⁵ <i>Arch Phys Med and Rehab</i> , 1999	Huge population of SCI patients (1649) studied from admission to rehab (mean 19 days) to discharge (mean 50 days). Incidence of DVT + PE declining over time but remains 6.1% despite prophylaxis.	III	DVT/PE still problems despite prophylaxis. (See McKinley for follow-up).
McKinley et al, ⁴³ <i>Arch Phys Med Rehabil</i> , 1999	Chronic SCI population studied. Incidence of DVT highest during first year (2.1%) but then drops off to 0.5-1% per year thereafter.	III	Risk of DVT/PE highest during first year following injury and then risk drops significantly.
Powell et al, ¹² <i>Arch Phys Med Rehab</i> , 1999	Incidence of DVT in SCI population ($n = 189$) on transfer to rehab dx with ultrasound was 4.1% in group who received prophylaxis vs 16.4% in group without prophylaxis. In prophylaxis group, DVTs only occurred in pts receiving heparin alone.	II	Prophylaxis decreases incidence of DVT in SCI population. Heparin alone was the least effective treatment measure.
Roussi et al, ²⁵ <i>Spinal Cord</i> , 1999	6 of 67 (9%) of SCI patients developed DVT despite prophylaxis with LMWH.	III	Incidence of DVT despite prophylaxis with LMWH 9%.
	D-Dimer had 100% negative predictive value compared to duplex Doppler. (However, specificity only 34% and PPV 13%).		D-Dimer is sensitive but not specific test for DVT.
Winemiller et al, ²² <i>Journal of Spinal Cord Medicine</i> , 1999	Retrospective case-cohort study of 428 patients. TE occurred in 19.6%. Compression stockings and sequential compression devices lowered risk of TE. Effects of low dose heparin were seen in first 14 days but were not significant. TEs all occurred in first 150 days.	III	SCD and stockings reduce risk of thromboembolism. Low dose heparin may be effective in first 14 days following injury.

(Continues)

TABLE. Continued

Citation	Description of Study	Evidence Class	Conclusions
Tomaio et al, ⁵⁶ <i>Journal of Spinal Cord Medicine</i> , 1998	Enoxaparin (LMWH) vs heparin use for initial DVT treatment in group of 6 SCI patients.	III	Enoxaparin was cost effective alternative to IV heparin for initial treatment of DVT.
Harris et al, ²⁴ <i>Am J of Phys Med and Rehab</i> , 1996	Retrospective study of enoxaparin (LMWH) in 105 SCI pts. (one third intact, 40 complete). No clinical DVT/PE in 105, no ultrasound evidence in 60.	III	Enoxaparin is safe and effective for DVT prophylaxis in the SCI patient.
Khansarinia et al, ³³ <i>Journal of Vascular Surgery</i> , 1995	Retrospective historical cohort comparison of prophylactic PGF in 324 general trauma patients. PGF group had fewer PE than control group.	III	Greenfield filter safe and effective for PE prophylaxis in general trauma population.
Geerts et al, ¹⁶ <i>New England Journal of Medicine</i> , 1994	Prospective evaluation of 716 trauma patients (no prophylaxis) with VOP and venography. Incidence of DVT in SCI population (n = 66) was 62%.	III	DVT is very common in SCI patients if no prophylaxis used.
Wilson et al, ³⁵ <i>Neurosurgery</i> , 1994	Inserted Caval filters in 15 SCI patients. None had DVT or PE in 1 year. Claims this result superior to historical controls (No evidence presented to support this claim). One-year patency rate was 81%.	III	Insertion of caval filters appears to be safe in SCI patients.
Green et al, ²³ <i>Archives of Physical Medicine and Rehabilitation</i> , 1994	Historical cohort comparison of LMWH and standard and adjusted dose heparin prophylaxis. Trauma patients treated with 8 week course of LMWH had fewer thromboembolic complications than those treated with heparin, $P = 0.15$.	III	LMWH may be safer and more effective for prophylaxis than mini dose or adjusted dose heparin.
Gündüz et al, ⁶ <i>Paraplegia</i> , 1993	31 SCI patients on low dose heparin therapy underwent venography. Incidence of DVT was 53.3%.	III	Incidence of DVT high in SCI patients despite low dose heparin (therapy started on rehab unit).
Burns et al, ² <i>Journal of Trauma</i> , 1993	Prospective assessment of DVT in high risk trauma patients with US. Found incidence of 21% (12/57) despite low dose heparin or pneumatic boots in 85%.	III	DVT is common despite use of low dose heparin or pneumatic boots.
Lamb et al, ⁸ <i>J Am Paraplegia Soc</i> , 1993	287 chronically injured SCI patients followed. Overall incidence of thromboembolic events was 10%, vast majority of events in first 6 months, 22 of 28 in first 3 months after SCI.	III	Prophylactic therapy not necessary beyond 6 months in SCI population.
Kulkarni et al, ⁷ <i>Paraplegia</i> , 1992	100 SCI patients prospectively treated with low dose heparin. 26% incidence of clinically detected DVT (9% PE) noted.	III	DVT and PE incidence significant despite low dose sq heparin.
Merli et al, <i>Paraplegia</i> , 1992 ⁹	Heparin plus pneumatic stockings equal to historical controls of heparin plus stimulation and better than historical controls of heparin or placebo in SCI patients.	II	Low dose heparin plus pneumatic hose safe effective as DVT prophylaxis in SCI patients.
Waring and Karunas, ¹⁴ <i>Paraplegia</i> , 1991	Large database (1419) of SCI patients. Incidence of DVT was 14.5%, PE 4.6%. Severity of injury was a predictor of DVT and age was a predictor of PE. No mention made of prophylactic measures.	III	DVT and PE are significant problems in SCI population. Age and injury severity need to be addressed in studies comparing treatment modalities.

(Continues)

TABLE. Continued

Citation	Description of Study	Evidence Class	Conclusions
Yelnik et al, ⁵⁰ <i>Paraplegia</i> , 1991	Prospective study of 127 SCI patients with phlebography. 29/127 had DVT on admission to rehab unit. Of 87 patients with initially negative studies, 12 developed DVT despite prophylaxis for up to 80 days.	III	Incidence of DVT in SCI population is high and high risk period extends to end of third month. Authors recommend periodic screening with phlebography.
Balshi et al, ³⁷ <i>Journal of Vascular Surgery</i> , 1989	Case series of 13 quadriplegic patients who had vena caval filters placed for DVT or PE.	III	Filter placement may be associated with significant long-term morbidity in the SCI population, particularly those requiring aggressive pulmonary toilet.
	Abnormalities of the filter were detected in 5/11 patients who had follow-up X-rays. Two patients required laparotomy to remove filters, 4 had distal migration, and 2 had narrowing of diameter associated with caval occlusion. Nine of these 11 patients were treated with the "quad cough" technique.		
DeVivo et al, ⁴² <i>Arch Intern Med</i> , 1989	Epidemiological study of causes of death for SCI patients. Highest ratios of actual to expected causes of death were for pneumonia, PE, and septicemia. The risk ratio for TE dropped significantly from 1-month post injury (SMR 500) to > 6 months post injury (SMR 20).	III	TE is a significant problem for patients who survive SCI. Biggest period of risk is in first few months following injury, but risk continues even after 6 months.
Green et al, ⁵ <i>JAMA</i> , 1988	RCT of Low dose vs adjusted dose heparin in SCI patients. Rate of TE lower in adjusted dose group (7% vs 31%) (intent to treat p = ns), but also had higher rate of bleeding complications (7 of 29).	I	Adjusted dose heparin more effective than low dose heparin, bleeding more common in adjusted dose group.
Merli et al, ²¹ <i>Arch Phys Med Rehabil</i> , 1988	Prospective randomized trial of placebo vs mini dose heparin vs heparin plus electrical stimulation in group of 48 SCI patients.	I	Low dose heparin no better than placebo, heparin plus electrical stimulation much better for DVT prophylaxis in SCI patients.
	Heparin group = placebo group at 50%, stim group significantly fewer DVT		
Weingarden et al, ⁵⁷ <i>Paraplegia</i> , 1988	Retrospective review of 148 SCI patients. Ten had documented DVT or PE. Of 6 patients who had adequate records, all 6 had fever as a presenting sign, 4 had no other clinical signs recorded.	III	Fever may indicate thromboembolic disease in SCI patients.
	All episodes occurred in first 12 weeks.		
Becker et al, ¹⁷ <i>Neurosurgery</i> , 1987	Randomized trial of rotating vs non-rotating beds in the acute setting following SCI (10 days), N = 15.	I	Rotating beds reduce the incidence of DVT during the first 10 days following SCI.
	Plethysmography and fibrinogen leg scans used.		
Tator et al, ¹³ <i>Canadian Journal of Neurological Sciences</i> , 1987	17% incidence of DVT in series of 208 SCI patients. Incidence was higher in operated patients (23%) compared to non operated (10%). Use of prophylaxis is not mentioned.	III	Patients requiring surgery may have higher incidence of DVT.

(Continues)

TABLE. Continued

Citation	Description of Study	Evidence Class	Conclusions
Chu et al, ⁵² <i>Archives of Physical Medicine and Rehabilitation</i> , 1985	Comparison between doppler US, Venous occlusion plethysmography and clinical exam in SCI patients. All had sensitivity and specificity of 100% in small (n = 21) series. Overall incidence 19%. (Class III because no gold standard used).	III	Doppler US, VOP, and clinical examination all good for diagnosis of DVT.
Myllynen et al, ¹⁰ <i>Journal of Trauma</i> , 1985	Compared incidence of DVT in immobilized spinal injured patients with and without paralysis. Those with paralysis had a 100% DVT incidence (fibrinogen scan) vs 0% for patients immobilized following spinal fracture without paralysis.	III	Incidence of DVT is very high in SCI patients and is not totally dependent on immobilization.
El Masri and Silver, ³ <i>Paraplegia</i> , 1981	Retrospective review of 102 patients with SCI. There were 21 episodes of PE in 19 patients. Twenty of 21 PTE occurred in first 3 months after SCI.	III	Authors cite efficacy of oral anticoagulation. They recommend prolonged treatment (up to 6 months) in patients with obesity or prior history of DVT.
	No patient with PE was adequately anticoagulated at the time of the PE (oral phenindione). Only 8/19 patients had evidence of DVT by exam or VOP.		
Frisbie and Sasahara, ⁴ <i>Paraplegia</i> , 1981	Small prospective controlled study of Low dose (5000 F06D BID) heparin vs Control group. No difference in incidence of DVT noted (only 7% in each group). Authors suggest protective effect of frequent physiotherapy.	II	No difference between low dose heparin and control groups in SCI patients receiving twice daily physiotherapy.
Perkash et al, ⁴⁸ <i>Paraplegia</i> , 1980	Treatment of 8 patients with thromboembolism discussed. Authors used heparin followed by coumadin with reasonable results.	III	Anticoagulation is effective treatment for SCI patients with thromboembolism.
Perkash et al, ¹¹ <i>Paraplegia</i> , 1978	Incidence of thromboembolism in 48 SCI patients was 18%.	III	Clinical examination appears to be quite good for detection of DVT in subacute setting. Period of risk may extend beyond 12 weeks.
	Clinical exam sensitivity 89%, specificity 88%, NPV 97%, PPV 62%.		
	One third of thromboembolic events occurred >12 weeks following injury.		
Watson, ⁴⁹ <i>Paraplegia</i> , 1978	Retrospective historical cohort study looking at low dose heparin vs no prophylaxis.	III	Heparin group had fewer TE complications. No TE events after 3 months despite prophylaxis cessation at 3 months.
Casas et al, ¹⁸ <i>Paraplegia</i> , 1977	Prospective assessment of low dose heparin in 18/21 patients with SCI (mean duration 66 days). No patient treated had symptomatic DVT or PE. No use of US/PG/venography.	III	Low dose heparin may be useful for prevention of symptomatic DVT.
Todd et al, ⁵³ <i>Paraplegia</i> , 1976	Used VOP, Fibrinogen scan and venography to study 20 SCI patients for 60 days. Fibrinogen scan was positive in all patients but was confirmed by another test in only half of the cases.	III	DVT is common in SCI population.
Hachen, ¹⁹ <i>Paraplegia</i> , 1974	Cohort controlled trial of low-dose heparin (5000003F t.i.d.) vs oral warfarin in SCI patients. Heparin group had significantly fewer TE events.	II	Low dose SQ heparin better than oral warfarin for prophylaxis following acute SCI.

(Continues)

TABLE. Continued

Citation	Description of Study	Evidence Class	Conclusions
Naso, ⁴¹ <i>Arch Phys Med Rehab</i> , 1974	PE occurred in 4/26 patients with acute (<3 months) SCI but none occurred in 17 patients with chronic (>3 months) SCI.	III	SCI patients primarily at risk during first 3 months following injury.
Watson, ²⁰ <i>Paraplegia</i> , 1968	Incidence of thromboembolic complications per year ranges from 8 to 40% in same unit (no prophylaxis).	III	Thromboembolic complications are a significant problem and there is variability year to year despite identical treatment strategies.

*ASCI, acute spinal cord injury; DVT, deep venous thrombosis; IVC, inferior vena cava; IV, intravenous; LMWH, low molecular weight heparins; NPV, negative predictive value; PE, pulmonary embolism; PG, phlebography; PGF, percutaneous Greenfield filter; PPV, positive predictive value; SCD, sequential compression device; SCI, spinal cord injury; SQ, subcutaneous; TE, thromboembolic; UFH, unfractionated heparin; US, ultrasound; VOP, venous occlusion plethysmography; VTE, venous thromboembolism.

Increased sensitivity is associated with decreased specificity. For example, Roussi et al²⁵ reported 100% sensitivity and 100% negative predictive value with D-Dimer determinations compared to Doppler ultrasound and the clinical examination. The specificity of D-Dimer was only 34%, and the positive predictive value was only 13%. Similarly, Todd et al⁵³ found that fibrinogen scanning was positive in all 20 patients studied in a prospective fashion. However, the diagnosis of DVT was confirmed by another test in only half of the cases. Akman and colleagues came to similar conclusions when they studied the D-Dimer assay in 68 patients with stroke, spinal cord injury, and head injury. The specificity and positive predictive value were low, at 55.3% and 48.7%, respectively. However, they reported the test to be 95.2% sensitive, with a 96.2% negative predictive value, suggesting it has value for excluding a diagnosis of VTE.⁵⁴

Overall, no single test is completely applicable, accurate, and sensitive for the detection of DVT in the SCI patient population. Furthermore, a substantial number of patients who suffer from PE are found to have negative lower extremity venograms. The Consortium for Spinal Cord Medicine has recommended the use of ultrasound for the study of patients with suspected DVT, and venography when clinical suspicion is strong and the ultrasound examination is negative.¹⁶ In 2008, the American College of Chest Physicians recommended serial Doppler ultrasonography in spinal cord injury patients. Based upon the reported literature on this subject, Class III medical evidence suggests that each of these diagnostic tests for DVT has merit, each with limitations as noted above.

SUMMARY

Thromboembolic disease is a common occurrence in patients who have sustained a cervical spinal cord injury and is associated with significant morbidity. Class I medical evidence exists demonstrating the efficacy of several means of prophylaxis for the prevention of thromboembolic events. Therefore, patients with SCI should be treated with a regimen aimed at VTE prophylaxis.

Although low dose heparin therapy has been reported to be effective as prophylaxis for thromboembolism in several Class III studies, other Class I, Class II, and Class III medical evidence

indicates that better alternatives than low dose heparin therapy exist. These alternatives include the use of low molecular weight heparin, adjusted dose heparin, or anticoagulation in conjunction with rotating beds, pneumatic compression devices or electrical stimulation. Oral anticoagulation alone does not appear to be as effective as these other measures used for prophylaxis.

There appears to be a DVT prophylaxis benefit to early anticoagulation in acute spinal cord injury patients. Class II medical evidence supports beginning mechanical and chemical prophylaxis upon admission after SCI and holding chemical prophylaxis 1 day prior to and 1 day following surgical intervention.

The incidence of thromboembolic events appears to decrease over time and the prolonged use of anticoagulant therapy is associated with a definite incidence of bleeding complications. There are multiple reports of the beneficial effects of the prophylaxis therapy for 6 to 12 weeks following spinal cord injury. Class II medical evidence indicates that the majority of thromboembolic events occur in the first 3 months following acute SCI and very few occur thereafter. For these reasons, it is recommended that prophylactic therapy be discontinued after 3 months unless the patient is at high risk for a future VTE event (previous thromboembolic events, obesity, advanced age). It is reasonable to discontinue therapy earlier in patients with retained lower extremity motor function after spinal cord injury, as the incidence of thromboembolic events in these patients is substantially lower than among those patients with motor complete injuries.

Although the guidelines author group concluded that caval filters appeared to be efficacious for the prevention of PE in SCI patients in the 2002 guideline on this topic, more recent medical evidence suggests that prophylactic filters may be more morbid than initially believed. Caval filters still have a role for SCI patients who have suffered thromboembolic events despite anticoagulation, and for SCI patients with contraindications to anticoagulation and/or the use of pneumatic compression devices.

There are several methods available for the diagnosis of DVT. Venography has long been considered the best test, but is invasive, not applicable to all patients, and is associated with intrinsic morbidity. Duplex Doppler ultrasound, impedance plethysmography, venous occlusion plethysmography and the clinical examination have been

reported to have sensitivities of approximately 90% and are non-invasive. It is recommended that these noninvasive tests be used for the diagnosis of DVT in SCI patients and that venography to diagnose DVT be reserved for the rare situation when clinical suspicion is high and the results of ultrasound or plethysmography testing are negative.

KEY ISSUES FOR FUTURE INVESTIGATION

Although thromboembolic events in the SCI patient are associated with significant morbidity, no study has demonstrated improved outcomes in SCI patients as a result of surveillance testing for them. A prospective study evaluating 6-month outcomes in patients treated with prophylaxis with or without surveillance ultrasound imaging would be a substantial and potentially cost-saving contribution to the literature.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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Nutritional Support After Spinal Cord Injury

Sanjay S. Dhall, MD*

Mark N. Hadley, MD‡

Bizhan Aarabi, MD, FRCS

Daniel E. Gelb, MD¶

R. John Hurlbert, MD, PhD,
FRCS||

Curtis J. Rozzelle, MD#

Timothy C. Ryken, MD, MS**

Nicholas Theodore, MD‡‡

Beverly C. Walters, MD, MSc,
FRCS‡‡‡

*Department of Neurosurgery, Emory University, Atlanta, Georgia; ‡Division of Neurological Surgery, University of Alabama at Birmingham, Birmingham, Alabama; §Department of Neurosurgery, University of Maryland, Baltimore, Maryland; ¶Department of Orthopaedics, University of Maryland, Baltimore, Maryland; ||Department of Clinical Neurosciences, University of Calgary Spine Program, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada; #Division of Neurological Surgery, Children's Hospital of Alabama University of Alabama at Birmingham, Birmingham, Alabama; **Iowa Spine & Brain Institute, University of Iowa, Waterloo/Iowa City, Iowa; ‡‡Division of Neurological Surgery, Barrow Neurological Institute, Phoenix, Arizona; ‡‡‡Department of Neurosciences, Inova Health System, Falls Church, Virginia

Correspondence:

Mark N. Hadley, MD, FACS,
UAB Division of Neurological Surgery,
510 – 20th Street South, FOT 1030,
Birmingham, AL 35294-3410.
E-mail: mhadley@uabmc.edu

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RECOMMENDATIONS

Level II

- Indirect calorimetry as the best means to determine the caloric needs of spinal cord injury patients is recommended.

Level III

- Nutritional support of spinal cord injury (SCI) patients is recommended as soon as feasible. It appears that early enteral nutrition (initiated within 72 hours) is safe, but has not been shown to affect neurological outcome, the length of stay, or the incidence of complications in patients with acute SCI.

RATIONALE

Hypermetabolism, an accelerated catabolic rate, and rampant nitrogen losses are consistent sequelae to major trauma, particularly acute traumatic brain injury and acute SCI.¹⁻⁷ A well-documented hypermetabolic, catabolic injury cascade is initiated immediately after central nervous system injury, which results in depletion of whole body energy stores, loss of lean muscle mass, reduced protein synthesis, and ultimately in loss of gastrointestinal mucosal integrity and compromise of immune competence.^{2,3,5-9} Severely injured brain and spinal cord injury patients, therefore, are at risk for prolonged nitrogen losses and advanced malnutrition within 2 to 3 weeks following injury with resultant increased susceptibility for infection, impaired wound healing, and difficulty weaning from mechanical ventilation.^{3-7,10} These

factors added to the inherent immobility, denervation, and muscle atrophy associated with spinal cord injury provide the rationale for nutritional support of spinal cord injured patients following trauma. The guidelines author group of the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons provided a medical evidence-based guideline on this topic in 2002.¹¹ The current review is undertaken to update the medical evidence on this important issue since that original publication.

SEARCH CRITERIA

A National Library of Medicine (PubMed) computerized literature search from 1966 to 2011 was undertaken using Medical Subject Headings in combination with “spinal cord injury”: nutrition (138 citations) and nutritional support (73 citations). Non-English language and duplicate citations were deleted. Titles and abstracts of the remaining publications were reviewed. A focused search on the specific issue of nutrition and human patients with acute spinal cord injuries identified 16 citations. Relevant manuscripts and reviews describing nutritional support of head-injured patients and several reports describing the nutritional status of chronic SCI patients are included in the bibliography. These efforts identified 7 Class III medical evidence studies, which describe metabolism, nitrogen wasting and the effect of feeding on nitrogen balance, and serum biochemistries in patients after acute SCI. Four of the 7 citations offer Class II medical evidence on indirect calorimetry to assess energy expenditure after SCI. All 7 are summarized in Evidentiary Table format (Table). There were no studies that examined the effects of nutritional support on neurological outcome following acute SCI.

ABBREVIATIONS: REE, resting energy expenditure; SCI, spinal cord injury; TBI, traumatic brain injury

SCIENTIFIC FOUNDATION

Hypermetabolism, catabolism and accelerated nitrogen losses are well-recognized complications that follow traumatic injury.^{3,6,7,12} They have been identified and studied in human patients who have sustained traumatic brain and spinal cord injuries. A number of publications have described the increased energy requirements and nitrogen losses of patients following acute head injury.^{1,3,5,7,9,12-15} Fewer studies have focused on hypermetabolism, catabolism, and nitrogen losses following acute SCI.^{4,7,10,16,17} While there are metabolic similarities between isolated traumatic brain injury and severely isolated SCI, it appears there may be important biological differences between the 2 central nervous system (CNS) injury types that have bearing on supplemental nutritional therapy.^{4-8,16,17}

Severe head injury is associated with a resting energy expenditure (REE) of approximately 140% of predicted normal basal energy expenditure.^{3,5,7,12-15} Indirect calorimetry is the most widely used reliable means to determine individual energy requirements in hospitalized patients after traumatic injury.^{3,5-7} It requires the use of a portable metabolic cart and employs a technique that measures respiratory gas exchange and the rate of oxygen utilization in a given patient. It provides an estimate of energy expenditure by the patient by determining the known caloric yield from 1 liter of oxygen based on differences in oxygen consumption and carbon dioxide production. It is performed at the bedside in the intensive care unit in severely injured patients. Metabolic expenditure is expressed as a percent of normal basal energy expenditure at rest (predicted). Indirect calorimetry is typically performed once daily for the first several days post injury and periodically thereafter.^{3,5-7} The Harris-Benedict equation, with activity and stress of injury variables, has been shown to predict energy expenditure after traumatic brain injury (TBI) with reasonable accuracy without indirect calorimetry.^{3,6,7,16,17}

Nutritional support of head-injured patients is typically begun within days of admission and is guided by the metabolic information provided by indirect calorimetry and by predicted energy expenditure values derived by equation. Hypermetabolism, accelerated catabolism, and excessive nitrogen losses continue for at least 2 weeks after injury.^{2,3,5,7,12,13} The exact duration of this response to injury is unknown, may vary among similar patients, and can be affected by other traumatic injuries, pancreatitis, infection, or sepsis.^{3,5-7,18} Nutritional support in this setting is designed to provide nitrogen-rich, high-energy supplemental fuel to blunt excess catabolism and preserve energy stores, muscle mass, gastrointestinal integrity, and immune competence.^{3,5-7,10} Nitrogen balance is difficult and often impossible to achieve, particularly within the first week of injury.^{1,3,4,16,17} Matching nutritional replacement with caloric needs has therefore become the primary goal of nutritional therapy.

The extent of neuronal connectivity and the neurogenic stimuli (muscle tone) to the musculoskeletal system appears important to the level of metabolic expenditure after CNS injury.^{4-7,16,17,19-23} Agitated, combative head-injured patients, for example, can have REEs as high as 200% of expected basal energy expenditure

levels.^{3,5,7,12} Conversely, pharmacological paralysis of head-injured patients has been associated with reductions in resting energy expenditure by 20% to 30%.^{3,5,7,12} Patients who have sustained isolated acute SCI often have increased metabolic expenditure compared to normative energy expenditure levels.^{4-8,16,17} However, because of the paralysis and flaccidity associated with acute SCI, measured resting energy expenditure (REE) values in these patients are considerably lower than those predicted by the Harris-Benedict equation based on age, sex, body surface area, activity, and injury severity.^{6,15-17,21} Patients with the greatest neurological deficits and the least muscle tone after SCI (high cervical level quadriplegic patients) have lower measured REE values than those found in patients with incomplete spinal injuries or lower spinal cord injuries (thoracic level paraplegic patients).^{1,4,6,7,16,17} Kaufman et al,⁴ in 1985, described their experience with 8 acute SCI patients managed at the University of Texas. They noted accelerated nitrogen losses and ongoing negative nitrogen balance greater than expected. Differences in initial and follow-up nutritional assessments revealed deterioration in nutritional status during the 2-week period of observation, partly due to inadequate supply of protein and calories. Infective complications and prolonged respiratory support were common. The authors concluded that muscle atrophy might play an important role in the accelerated nitrogen losses they identified in patients with paralysis due to complete spinal cord injury, and that improved nutritional support might reduce medical complications following acute SCI. In 1989, Kolpek et al²⁴ compared urinary urea nitrogen excretion and measured energy expenditure between 7 head trauma and 7 spinal cord injury patients. They found that the difference in urinary urea nitrogen excretion between the 2 groups of patients was equivocal. When they compared the measured energy expenditure to the predicted energy expenditure, they found the ratio was 0.56 for SCI patients and 1.4 for head injury patients.

Young, Ott, and Rapp⁷ reported 4 quadriplegic acute SCI patients that they assessed with indirect calorimetry. They found that indirect calorimetry provided more accurate REE values for their patients compared to Harris-Benedict equation estimates, even Harris-Benedict equation estimates without incorporating injury and activity factors. They too noted marked daily nitrogen losses and negative nitrogen balance in their SCI patients. They concluded that equation estimates of REE of SCI patients overestimate metabolic expenditure and emphasized the importance of indirect calorimetry in predicting energy expenditure following acute SCI.

Kearns et al¹⁶ prospectively assessed and provided nutritional support to 10 acute SCI patients that they managed and monitored for 4 weeks. Their 1992 report documents the use of indirect calorimetry to determine REE and provide matched caloric supplementation. All patients had isolated SCI without associated head injury or other organ system trauma. Initial measured resting energy expenditures were 10% below predicted REE levels. All patients experienced exaggerated nitrogen and 3-methylhistidine losses indicating excessive lean body mass and muscle loss. A 10% decrease in body weight accompanied these losses despite caloric replacement matched to or exceeding measured REE values for

TABLE. Evidentiary Table: Nutritional Support^a

Citation	Description of Study	Evidence Class	Conclusions
Dvorak et al, ²⁷ <i>Spine</i> , 2004	Randomized to early (<72 hrs) or late (>120) enteral feeding in 17 acute cervical SCI patients.	III	No differences in the incidence of infection, nutritional status, feeding complications, number of ventilator hours, or length of stay.
Rowan et al, ²⁶ <i>Injury</i> , 2003	Retrospective review of 33 patients with acute SCI, 27 received early enteral feeding (0.5-4.8 days).	III	No major complications seen with early enteral feeding.
Cruse JM et al, ⁸ <i>J Spinal Cord Medicine</i> , 2000	Comparison of nutritional, immune, endocrine status in 15 acute SCI patients vs 16 matched controls.	III (II for indirect calorimetry)	SCI patients have hormonal changes, poor nutritional status, and decreased immune function compared to controls.
Rodriguez DJ et al, ⁶ <i>Spinal Cord</i> , 1997	Prospective assessment and treatment of 12 acute SCI patients.	III (II for indirect calorimetry)	REE less than predicted, marked "obligatory" nitrogen losses due to flaccidity and atrophy of denervated muscle after SCI.
Kearns PJ et al, ¹⁶ <i>J Parenteral Enteral Nutrition</i> , 1992	Prospective assessment of 10 acute SCI patients over 4-week period of observation.	III (II for indirect calorimetry)	Exaggerated nitrogen and 3MeH excretion marked weight loss. Lower REE than predicted after SCI.
Young B et al, ¹⁵ <i>Critical Care Clinics</i> , 1987	Four acute SCI patients assessed via indirect calorimetry.	III (II for indirect calorimetry)	Indirect calorimetry best means to determine energy expenditure after acute SCI.
Kaufman HH et al, ⁴ <i>Neurosurgery</i> , 1985	Assessment of nutritional status of 8 SCI patients over 2-week period of observation.	III	Deterioration in nutritional status despite attempted treatment. Marked nitrogen losses. Increased infectious and respiratory complications.

^aREE, resting energy expenditure; SCI, spinal cord injury.

each patient. The specifics of nutrition administration (mix and route of delivery) were not presented. The authors noted an increase in REE over time in part due to reductions in body weight and in part due to return of muscle tone. The authors concluded that acute isolated SCI is associated with lower REE values compared to predicted values. Acute SCI patients have exaggerated nitrogen and 3-methylhistidine losses due to atrophy of denervated muscle. They attributed the reduced metabolic activity seen in these patients to the flaccidity of denervated musculature after severe SCI and noted that as muscle loss and weight reductions progress, REE increases, particularly if recovery of motor function and/or return of muscle tone occurs.

Rodriguez et al⁶ studied the metabolic response to SCI in 12 acute trauma patients. Assessment and nutritional support were instituted immediately after injury and continued for 4 weeks post injury. Harris-Benedict estimations of energy expenditure were compared to values obtained from indirect calorimetry in each patient. All patients had accelerated nitrogen losses and negative nitrogen balance. Eleven of 12 patients had negative nitrogen balance for the entire 4 weeks of therapy despite matched caloric replacement. The single patient in whom nitrogen balance was realized had an incomplete SCI. The Harris-Benedict equation with

an activity factor of 1.2 and a stress/injury factor of 1.6 consistently overestimated energy expenditure in these 12 patients and would have resulted in excessive feeding. The authors concluded that large nitrogen losses after severe SCI are "obligatory" as a result of atrophy and wasting of denervated musculature below the level of injury. Patients with complete traumatic myelopathy had greater obligatory nitrogen losses than patients with incomplete spinal cord injuries. They recommended that indirect calorimetry be used as the energy expenditure assessment method after SCI, particularly in the early post-injury period. If the Harris-Benedict equation is used in these patients in this setting, they recommend that the activity factor should be eliminated and the stress/injury factor of the equation should be reduced.

Three different author groups^{6,15,16} provide consistent medical evidence that equation estimates of REE for SCI patients overestimate energy expenditure. All provide convincing comparative evidence that indirect calorimetry is the most accurate means to assess energy expenditure in SCI patients.^{6,15,16} For these reasons and because the differences are substantial and the medical evidence is consistently positive in all 3 published studies, indirect calorimetry as the most reliable means to assess REE in SCI patients is upgraded to Class II medical evidence.

Cruse et al¹⁰ examined the neurological, immune, endocrine, and nutritional status of 15 male SCI patients and compared them to 16 healthy age-matched control subjects. The timing of assessment in relation to SCI for each patient was not specified. Their report described decreased natural and adaptive immune responses in the SCI patient population beginning within 2 weeks of injury that reached a nadir 3 months after injury. They noted increased ACTH and plasma cortisol levels; decreased zinc, albumin, and prealbumin serum levels; surface marker changes in both lymphocytes and granulocytes; and decreased adhesion molecule binding ability after SCI compared to healthy control patients. They concluded that patients with severe acute SCI have decreased immune function, impaired nutritional status and a decreased number of adhesion molecules, all of which occur within weeks after acute injury. The authors note that these hormonal alterations, nutritional deficiencies, and changes in immune function may increase susceptibility to infection and may contribute to delayed wound healing.

The change in energy expenditure identified in patients following acute SCI appears to persist long after the initial injury and recovery phase.^{6,19-23,25} Several investigators have noted long-standing reductions in REE in spinal cord injury patients, reductions that correlate to the degree of neurological injury and the extent of lean body mass loss after paralysis.^{6,19-23,25} Cox et al²¹ measured energy expenditure in stable nonacute SCI patients in the rehabilitation setting. They reported that quadriplegic patients required 22.7 kcal/kg/day compared to 27.9 kcal/kg/day for paraplegic patients they studied. Most investigators conclude that equation methods to estimate energy expenditure in SCI patients are inaccurate, both in the acute and chronic settings.^{7,17,22,23,25}

The literature on nutritional support for head injury patients supports using the enteral route for nutritional supplementation if the gut is functional.^{3,5-7,12,13,17} This general policy appears to have been followed by investigators of nutritional support for acute SCI patients.^{4,6,7,16} The potential benefits of enteral feeding over parenteral delivery include maintenance of gut integrity and function, reduced expense, lower risk of infection and avoidance of intravenous catheter-related complications.^{3,5-7,12,13,17} Naso-duodenal or nasojejunal feeding tubes usually allow full caloric, high-nitrogen, high-volume feeding within days of injury. In patients with bowel injury, mechanical bowel obstruction, or prolonged ileus, it is recommended that parenteral nutrition be initiated until the bowel recovers and conversion to enteral nutrition can be accomplished.^{3,5-7,13}

Since the publication of the original guidelines on this topic, there have been 2 studies published comparing early to late enteral feeding in patients with acute SCI. Rowan et al²⁶ published a retrospective study of a group of 33 patients who received enteral feeding at a median of 2 days (range 0.5-4.8 days) following admission. The most common reason for interruption of enteral feeds was high gastric aspirates, which occurred in 67% of patients. Two patients developed ileus, requiring conversion from nasogastric to nasojejunal feeding tubes. Dvorak et al²⁷ prospectively randomized 17 acute SCI patients to either early (less than 72 hours) or late (greater than 120 hours) enteral feeding. While they found no difference in

the incidence of infection, nutritional status, feeding complications, number of ventilator hours, or length of stay between the 2 groups, the numbers in each treatment group were too few to draw meaningful conclusions.

There has been no report assessing the mix or composition of nutritional supplementation for SCI patients. The literature on nutritional support for head injury patients suggests beginning with a high nitrogen enteral or parenteral solution containing at least 15% of calories as protein, no greater than 15% glucose/dextrose, a minimum of 4% of total energy needs as essential fatty acids, and the addition of vitamins, essential elements, and trace minerals.^{3,5-7,9,14,15}

There has been no study published that has examined the effect of nutritional support on neurological outcome following acute SCI.

SUMMARY

Alterations in metabolism occur after acute SCI, but the marked hypermetabolic response seen after acute traumatic brain injury appears to be blunted in SCI patients by the flaccidity of denervated musculature after spinal cord transection/injury. As a result, REE is lower than predicted after acute SCI. Equation estimates of REE in these patients have proven to be inaccurate. Comparative Class II medical evidence supports the use of indirect calorimetry as the recommended technique to assess energy expenditure in both the acute and chronic settings among patients with SCI.

Protein catabolism does occur after acute, severe SCI, and marked losses in lean body mass due to muscle atrophy result in huge nitrogen losses, prolonged negative nitrogen balance, and rapid weight loss. Nutritional support of the SCI patient to meet caloric and nitrogen needs, not to achieve nitrogen balance, is safe and may reduce the deleterious effects of the catabolic, nitrogen wasting process that occurs after acute spinal cord injury. It appears that early enteral nutrition (initiated within 72 hours) is safe, but has not been shown to affect neurological outcome, the length of stay, or the incidence of complications in patients with acute SCI.

KEY ISSUES FOR FUTURE INVESTIGATION

An assessment of the timing, route of administration, and the composition of nutritional therapy on outcome, both neurological and medical, should be performed. This could be accomplished with a multicenter case control study.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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