Developing an Anterior Cervical Diskectomy and Fusion Simulator for Neurosurgical Resident Training

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BACKGROUND: Surgical simulators are useful in many surgical disciplines to augment residency training. Duty hour restrictions and increasing emphasis on patient safety and attending oversight have changed neurosurgical education from the traditional apprenticeship model. The Congress of Neurological Surgeons Simulation Committee has been developing neurosurgical simulators for the purpose of enhancing resident education and assessing proficiency.

OBJECTIVE: To review the initial experience with an anterior cervical diskectomy and fusion (ACDF) simulator.

METHODS: The first ACDF training module was implemented at the 2012 Congress of Neurological Surgeons Annual Meeting. The 90-minute curriculum included a written pretest, didactics, a practical pretest on the simulator, hands-on training, a written posttest, a practical posttest, and postcourse feedback. Didactic material covered clinical indications for ACDF, comparison with other cervical procedures, surgical anatomy and approach, principles of arthrodesis and spinal fixation, and complication management. Written pretests and posttests were administered to assess baseline knowledge and evidence of improvement after the module. Qualitative evaluation of individual performance on the practical (simulator) portion was included.

RESULTS: Three neurosurgery residents, 2 senior medical students, and 1 attending neurosurgeon participated in the course. The pretest scores were an average 9.2 (range, 6-13). Posttest scores improved to 11.0 (range, 9-13; $P = .03$).

CONCLUSION: Initial experience with the ACDF simulator suggests that it may represent a meaningful training module for residents. Simulation will be an important training modality for residents to practice surgical technique and for teachers to assess competency. Further development of an ACDF simulator and didactic curriculum will require additional verification of simulator validity and reliability.

KEY WORDS: Anterior cervical diskectomy and fusion, Residency education, Simulator, Spine surgery, Training

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Surgical training of residents has changed dramatically over the last 10 years. These changes have been driven by the introduction of resident work hour restrictions, increased legal and ethical concerns for patient safety, increased emphasis on senior surgeon oversight, and increased scrutiny of operating room time.[1] Current surgical trainees are now faced with the challenge of mastering surgical techniques with a smaller case volume and less hands-on experience.[2,3] Likewise, neurosurgery faculty at training programs have faced similar obstacles in ensuring that trainees gain adequate proficiency at technically challenging procedures without placing patients at unacceptable risk. Neurosurgery training has traditionally used an apprenticeship model; however, ensuring adequate exposure to complex operative techniques under modern constraints has become increasingly difficult.

ABBREVIATIONS: ACDF, anterior cervical diskectomy and fusion; **CNS,** Congress of Neurological Surgeons; **OSATS,** objective-structured assessment of technical skill

Graduate medical training programs must demonstrate that trainees achieve competency

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to deliver safe and effective patient care by objectively documenting developmental progress along specified milestones. These milestones represent standardized metrics for evaluating residents. These milestones ultimately will ensure trainees' knowledge, competence, and technical proficiency for advancing in their training program with the goal of independent practice. Particularly with respect to surgical disciplines, universal standardization of milestones, performance measures, and minimum required surgical case logs is challenging, depending on the inherent variability of practice patterns, patient referrals, and modern constraints of the resident duty hour restrictions. Virtual reality and simulation training technologies provide an additional educational resource for addressing these logistical challenges.

Simulation technology has been widely used in military and aviation training, providing an opportunity to practice high-risk, technically demanding skills in a safe environment.[4-8] Advances in simulation training have gone beyond a procedural skill set, incorporating decision making, problem solving, and judgment into a complex training environment.[4] Many of the general surgery disciplines have incorporated simulation or virtual reality training models into the training curriculum, allowing trainees to safely develop surgical proficiency and to practice the psychomotor skills that are directly applicable to live procedures.[9-14] Although neurosurgery has begun to explore the use of simulation models in resident training, the quality of evidence supporting its efficacy remains limited and requires further in-depth verification of simulator validity and reliability.[15] The Congress of Neurological Surgeons (CNS) Simulation Committee has been actively working toward developing comprehensive neurosurgical simulators and training modules for the purpose of enhancing residency education and assessing operative proficiency. A number of cranial, endovascular, and spine surgical simulators have already been used; however, an anterior cervical diskectomy and fusion (ACDF) simulator had not previously been developed. At the 2012 annual CNS meeting, the ACDF simulation module was included as part of the simulation course. In this report, we review our initial experience with this model.

METHODS

The CNS Simulation Committee performed an assessment of the available spine simulation devices through inquires with experts in the simulation field, literature searches, and Internet analysis. The conclusion was that there were limited spine simulator devices and no models with dedicated educational platforms. Under the guidance of Daniel Hoh, James Harrop, and Aruna Ganju, a curriculum was created to both teach and assess performance of an ACDF using both didactic material and a physical model simulator.

Didactic material covered clinical indications for ACDF, comparison with other cervical decompression and/or fusion procedures, surgical anatomy and approach, principles of arthrodesis (including graft selection) and spinal fixation, and complication management. Case presentations with interpretation and review of relevant imaging were also discussed. Written 13-question pretests and posttests were administered to assess baseline fund of knowledge and postsession improvement.

The physical model simulator is composed of a Medtronic (Memphis, Tennessee) proprietary mix of compounds in the silicone family formulated to capture the tactile feel of the soft-tissue structures and tissue planes of the anterior cervical region (Figure 1A and 1B). The spinal column is composed primarily of a polyurethane mixture to simulate the bony vertebra, ligaments, and disk. It is designed to handle drills, curettes, Kerrison rongeurs, distraction posts, and anterior cervical screws and plates with mechanical properties similar to the human vertebral column. The simulator spine can be removed (eg, after diskectomy and placement of spinal fixation), and a new, unused specimen can be inserted for use. In contrast to the posterior cervical fusion model described elsewhere in this supplement, the current iteration of the ACDF model does not have representation of dura, cerebrospinal fluid, or neural elements.

Surgical instruments for exposure, diskectomy, drilling (Stryker, Kalamazoo, Michigan), and decompression were available (Figures 2A-2C). For arthrodesis and spinal fixation, interbody inserts and standard anterior cervical plate and screw instrumentation (Medtronic; Figure 3) were also provided.

Course participants used loupe magnification and overhead lights to simulate standard operating room visualization. An ACDF-specific,

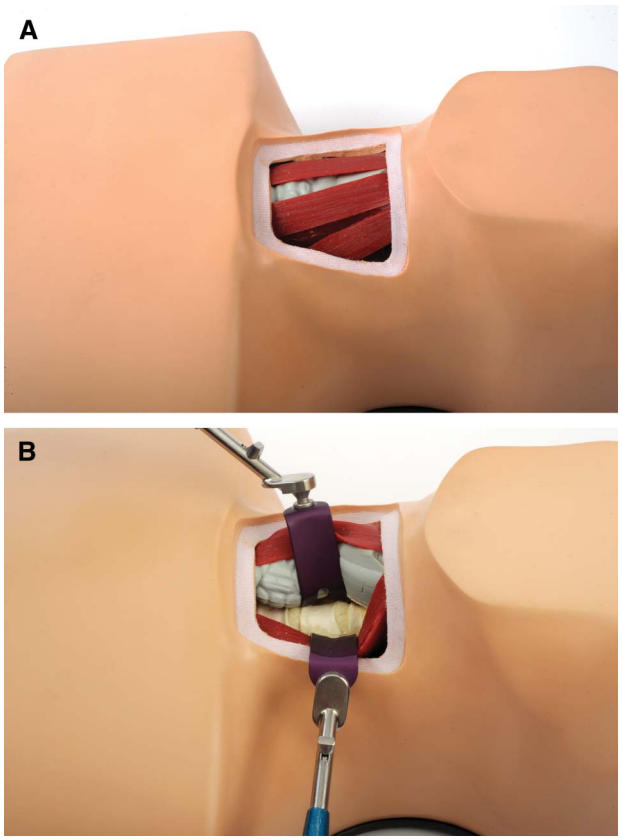

FIGURE 1. **A**, *photograph demonstrating the physical model simulator of the anterior cervical diskectomy and fusion training module. The strap muscles of the anterior neck (red) can be seen overlying the midline trachea (gray).* **B**, *photograph demonstrating blunt dissection of the anterior neck with handheld retractors mobilizing midline and lateral structures. Images provided courtesy of Medtronic, Inc.*

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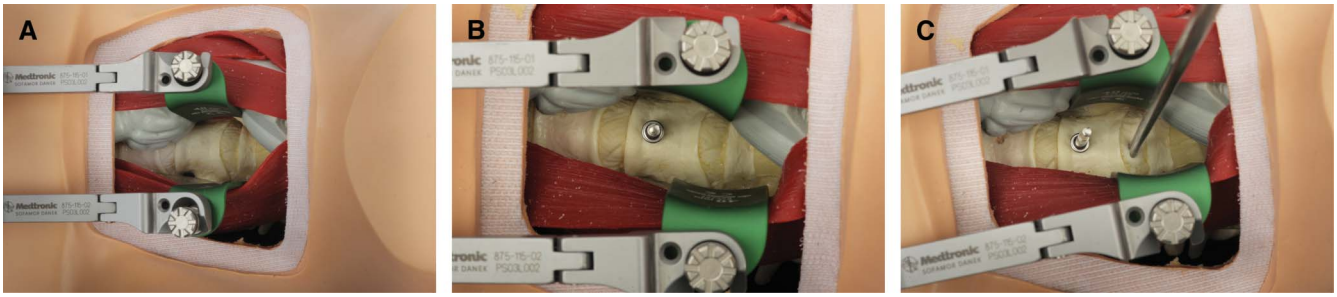

FIGURE 2. *A, deep-bladed retractors inserted under a "cuff" of the longus colli with closer visualization of the underlying vertebral column.* **B**, *closer view after placement of deep retractors with a distraction post inserted into the caudal vertebral body before the diskectomy.* **C**, *using a Kerrison rongeur to perform a standard diskectomy. Images provided courtesy of Medtronic, Inc.*

objective-structured assessment of technical skill (OSATS; Figure 4A and 4B) was created to grade each individual on the technical component of the ACDF module (diskectomy/decompression and arthrodesis/spinal fixation). The individual was graded on technical skill by assessing 5 items in regard to the anterior exposure and decompression and 5 items related to the arthrodesis and spinal fixation. Each item was further graded on a 5-point scale. Although individual OSATS scores were used for trainee feedback, they were not recorded or reported for this pilot iteration because of a lack of uniform data collection.

The entire curriculum was allotted 90 minutes (Figure 5) for the written pretest, didactics, practical pretest on the simulator, hands-on training, written posttest, practical posttest evaluation, and postcourse feedback with review of written and practical evaluations. The ACDF course faculty consisted of 2 fellowship-trained spine neurosurgeons (Hoh and Ganju) who interacted with trainees throughout the didactic and technical portions of the curriculum.

RESULTS

Three neurosurgery residents (postgraduate years 1, 2, and 5), 2 senior medical students, and 1 attending neurosurgeon (program director for residency training program) participated in the course.

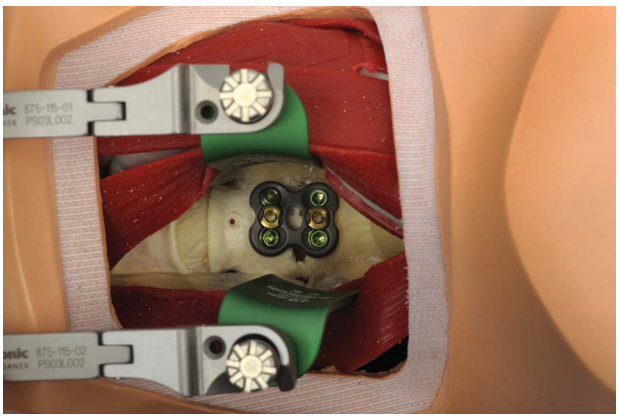

FIGURE 3. *View of the physical model after diskectomy, insertion of an interbody graft, and anterior plate fixation. Images provided courtesy of Medtronic, Inc.*

There were 3 male and 3 female participants. The pretest scores were an average 9.2 (70.5% of the maximum score; range, 6-13; Table). Posttest scores improved to an average 11.0 (84.6% of maximum score; range, 9-13; $P = .03$). There was 1 perfect score on the pretest by the attending neurosurgeon, who also had a perfect score on the posttest. With that score eliminated, the scores improved from 8.4 to 10.6 ($P = .02$). Four of 5 scores improved from the pretest to the posttest among medical students and residents by an average 21%. One of 5 scores did not improve; a fifth-year neurosurgery resident scored 12 of 13 (92.3%) on both the pretest and posttest.

DISCUSSION

The number of spine operations performed in the United States annually has increased in the past decade, with an estimated 100 000 patients undergoing cervical spine procedures annually.[16] Among cervical spine surgeries, ACDF is a common operation performed for decompression or arthrodesis for a variety of indications.[17] Although many of the technical nuances of ACDF, particularly with respect to arthrodesis and spinal fixation, have evolved since the initial description of the Cloward procedure, the basic surgical techniques for anterior approach and neural decompression have remained relatively unchanged.[18-21] Although not considered a technically demanding procedure, ACDF requires the trainee to gain proficiency in multiple areas, including understanding natural tissue planes, appreciating the variable tolerance of structures to manipulation and retraction, achieving hemostasis, and decompressing neural elements. ACDF is often considered to be an ideal procedure for resident training because of the broad spectrum of surgical skills that can be gained during this procedure. Exposure to ACDF early in residency training allows the development of requisite neurosurgical skills, whereas performance of ACDF late in training allows one to demonstrate independent proficiency.

There are several issues related to the use of this operation as a tool for resident training and proficiency assessment. ACDF is quite distinct from other dorsal spine surgeries with little shared surgical spinal anatomy. All dorsal procedures, whether in the

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A

Anatomic levels				
1	2	3	4	5
Did not define level/ operated on incorrect level; poor ability to correlate clinical history/ exam with anatomic level		Correct level but no confirmatory radiograph; basic ability to correlate clinical history/ exam with anatomic level		Correct level with confirmatory radiograph; can appropriately correlate clinical history/ exam with anatomic level
Use of the Drill				
1	2	3	4	5
Poor handling and manipulation		Appropriate use of drill but somewhat mediocre and awkward handling		Appropriate use of drill with proficient and fluid motion
Discectomy				
1	2	3	4	5
Unclear understanding how to handle curettes, kerrisons		Somewhat awkward handling of curettes, kerrisons		Efficient removal of disc using appropriate instruments
Decompression of Neural Elements				
1	2	3	4	5
Potential damage to underlying tissue/dura		No damage to underlying tissue/dura Suboptimal decompression, failure to confirm decompression		No damage to underlying tissue/dura Confirms optimal decompression with nerve hook
Respect for Elements (skill with tools)				
1	2	3	4	5
Inappropriate use of force Frequently damages the tissue		Occasional accidental damage to the tissue		Highly proficient tissue handling Minimal damage

B

Placement of distraction posts				
1	2	3	4	5
Places post in inappropriate location and trajectory		Places post in appropriate location but inappropriate trajectory		Places post in both appropriate location and trajectory
Interbody Graft Placement				
1	2	3	4	5
Selects inappropriate graft size, shape; inappropriate use of force when inserting graft; poor understanding of principles of arthrodesis		Selects appropriate graft size and/or shape; moderate difficulty in graft insertion; basic understanding of principles of arthrodesis		Expert selection of graft size, shape; Fluid and efficient graft insertion with proper placement; demonstrates thorough understanding of principles of arthrodesis
Anterior plate placement				
1	2	3	4	5
Selects inappropriate sized plate, inappropriate centering of plate		Selects either inappropriately sized plate OR inappropriately centers plate		Optimal plate position and size
Screw placement				
1	2	3	4	5
Inappropriate screw entry site and trajectory; unclear understanding of different screw types, lengths		Appropriate screw entry site, suboptimal trajectory; moderate understanding of screw types, lengths		Appropriate screw entry site and optimal trajectory; expert understanding of screw types, lengths
Operative Flow and Overall Surgical Efficiency				
1	2	3	4	5
Frequent pauses and hesitation Many wasted movements Loses time +++		Good progression Few unnecessary movements Loses minimal time +		Effortless operative flow Economy of time and movement

FIGURE 4. **A**, *anterior cervical diskectomy and fusion (ACDF)–specific objective-structured assessment of technical skill (OSATS) for diskectomy and decompression.* **B**, *ACDF-specific OSATS for interbody arthrodesis and anterior plate fixation.*

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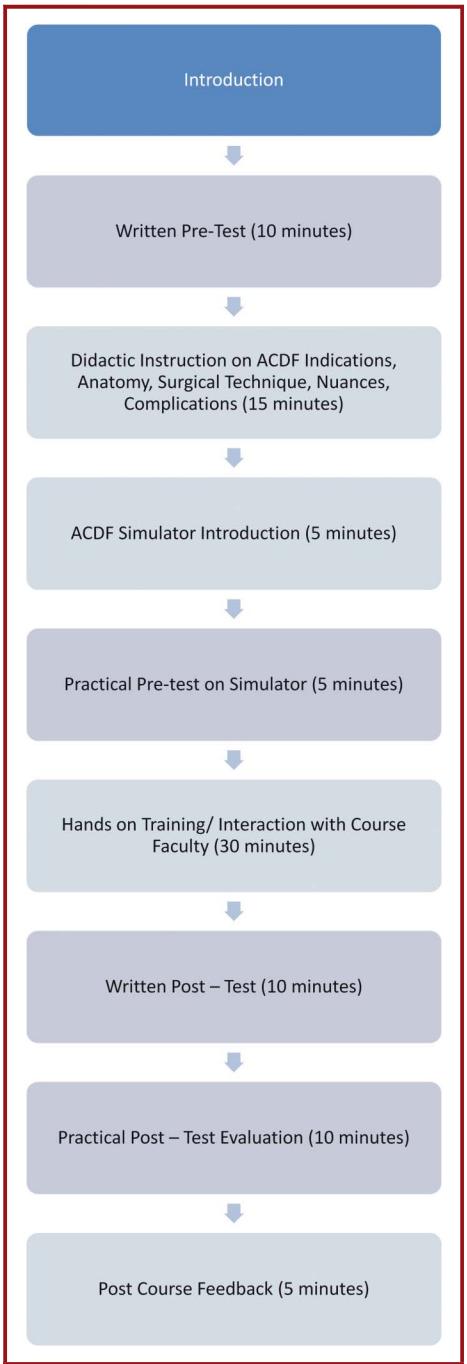

FIGURE 5. *Anterior cervical diskectomy and fusion (ACDF) simulator training module curriculum (90 minutes) including pretest, didactics, technical exercise, and posttest.*

cervical, thoracic, or lumbar region, share the same surgical anatomy and considerations. Therefore, residents benefit from the cumulative effect of added repetitive practice when performing dorsal spine surgery, regardless of spinal level. Alternatively, gaining proficiency in performing an ACDF generally occurs only through increased exposure and graded autonomy during this specific operation. Posterior surgery also lends itself well to instructor and trainee surgeons working in tandem, affording the opportunity for residents to observe, assist, and perform their side of the procedure with direct supervision. ACDF, however, is inherently a single-primary-surgeon operation with the second surgeon often relegated to the assistant role. Residents early in their training may not have the same hands-on experience in an ACDF as they may have in a dorsal spine operation.

Surgical simulation has emerged as a potentially effective teaching modality for training residents in surgical techniques outside the constraints of the operating room. Surgical simulation offers the benefit of gaining surgical experience in a safe environment without the potential risk to patients. Simulation allows residents to operate independently and to make surgical decisions without introducing any of the ethical dilemmas that may arise when treating an actual patient.[22] Simulators also allow trainees to engage in deliberate, repetitive practice to promote accuracy and retention and ultimately to gain self-sufficiency. Ideally, simulators can also create complex surgical scenarios, forcing the resident to learn and rehearse management of these difficult situations in a training environment before encountering them in real life. Surgical simulation further provides a means for assessing competency and readiness for advancement and identifying deficiencies that may warrant remediation.[4,17]

Laparoscopic and endoscopic surgical simulators are already well established for general surgical resident training.[23-26] In a review of these simulators, Carter et al[27] concluded that for surgical simulators to be effective, they must follow the basic principles of assessment that include alignment with the learning content, validity, and reliability. In other words, instruction of a particular surgical task on a simulator must result in acquiring the skills to perform the same procedural task in the operating room. For a simulator to be valid, it must provide an environment that closely approximates the environment in which the actual surgery is eventually performed, mimicking the visual-spatial, real-time,[27] and haptic feedback[7] characteristics of the live procedure. Ultimately, reliability of a simulator as a competency assessment tool requires consistent results with minimal errors of measurement.[27]

Neurosurgery is in its infancy in regard to the implementation of simulation in residency training. Multiple reports on neurosurgery simulation models have provided promising [28-31]evidence that repetitive exposure and learned psychomotor skills reliably transfer to improve the workflow for real surgical procedures.[32] Previous spine surgical simulators have focused largely on techniques for posterior thoracolumbar spinal instrumentation.[6,8] The 2012 CNS Annual Meeting was the first pilot implementation and assessment of an ACDF training module as part of the CNS simulation course curriculum. Attendee representation (aside from 1 attending neurosurgeon) was shifted more toward junior-level neurosurgical residents and medical students. Therefore, the attendees had an appropriate but limited

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TABLE. Training Level and Pretest and Posttest Scores for the 6 Participants[a]

Participant	Highest-Level Training	Pretest Score	Posttest Score	*P* Value[b]	*P* Value[c]
1	Medical student	7	9	.03	.02
2	Medical student	6	9		
3	PGY-1	7	10		
4	PGY-2	10	13		
5	PGY-5	12	12		
6	Attending	13	13		

[a]PGY, postgraduate year.
[b]Represents difference in pretest and posttest scores for all 6 participants.
[c]Represents difference in pretest and posttest score for 5 residents/medical students (excluding 1 attending neurosurgeon participant).

baseline fund of knowledge as reflected by their low initial written pretest scores. The didactic portion of the training module consisted of interactive instructional material directed toward clinical indications, case presentation, surgical anatomy, approaches and techniques, principles of arthrodesis and spinal fixation, and complication management. Although the sample size was small, validation of the didactic portion of the module was demonstrated by a significant improvement across participants in the written posttest assessment.

The practical portion of the module consisted of instruction and practice on the physical model simulator. One benefit of the physical model simulator was the opportunity for trainees to practice psychomotor skills using standard surgical instruments, including the high-speed drill, suction, retractors, Kerrison rongeurs, and microdissectors, while using loupe magnification. However, it became evident that the physical model bore the least resemblance to the actual surgical environment with respect to certain elements. Namely, the anterior cervical exposure, tissue planes, and visceral and vascular structures were not optimally re-created. In addition, the tolerance of soft-tissue structures (eg, esophagus, trachea, carotid artery) to dissection, manipulation, and retraction was not optimally represented; this deficiency compromises the ability of the trainee to learn this critical step. Despite this clear limitation, once the exposure was obtained and the deep retractors were placed, the steps of diskectomy, high-speed drilling, and grafting and instrumentation in the simulator mimicked visuospatial psychomotor tasks required to perform actual surgery.

Overall, the initial experience with the ACDF simulator was positive, yet there were several clear caveats. The validity and reliability of the practical portion of the ACDF training module are still unknown and require further trainee testing with evaluation of residents at varying postgraduate levels. The trainees who attended the course were assessed qualitatively on their performance. However, the OSATS scores were not universally graded across all attendees. As a result, the pilot OSATS data are not reported here because of the potential for interexaminer variability. Future assessment of this ACDF simulation module will focus on OSATS data collection to establish interexaminer agreement and to better characterize the validity of the module with respect to trainee performance relative to postgraduate level and experience.

The physical model simulator would benefit from continued refinement with respect to better re-creation of the tissue characteristics, particularly in regard to the anterior neck exposure. Incorporation of real-time intraoperative conditions such as bleeding or cerebrospinal fluid leak would add fidelity. Representation of underlying neural structures and the inclusion of haptic technology to quantitatively assess forces transmitted to the spinal cord and dura during decompression would further enhance simulator validity and provide an additional valuable performance metric.

Finally, this first iteration of the ACDF simulation module is limited by its lack of anatomic variability. One potential drawback of the current physical model is that trainees may only become proficient performing the surgical procedure specific for the presented anatomy. Future iterations of this module will broaden the complement of physical models to represent the spectrum of pathoanatomic variation that exists clinically. In doing so, this should improve the trainee's ability to translate and adapt surgical techniques learned during simulation to real spinal conditions.

CONCLUSION

Surgical simulators are becoming an increasingly significant component of surgical resident education both for training and for standardized assessment of proficiency and milestone achievement. Currently, neurosurgical simulators, whether virtual reality or physical model simulators, exist for a select number of neurosurgical procedures. Most are still imperfect and in need of realignment with learning content; others have yet to be verified for validity and reliability. A common limitation of current simulators is the accurate re-creation of real-time intraoperative situations such as bleeding or response of tissues to manipulation and deformation. Ongoing evaluation of neurosurgical simulators for reliability of trainee assessment is necessary before widespread implementation.

ACDF is a vital procedure in the neurosurgeon's armamentarium. The current training environment is such that traditional

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learning in the operating room will likely be insufficient, and surgical simulation will be an important adjunct training tool. Further development of a reliable ACDF surgical simulator and training module will complement current resident education and may eventually serve as a tool to help evaluate surgical proficiency.

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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