

Neurosurgical Training With a Novel Cervical Spine Simulator: Posterior Foraminotomy and Laminectomy

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BACKGROUND: Neurosurgical residents have traditionally been instructed on surgical techniques and procedures through an apprenticeship model. Currently, there has been research and interest in expanding the neurosurgical education model.

OBJECTIVE: To establish a posterior cervical decompression educational curriculum with a novel cervical simulation model.

METHODS: The Congress of Neurological Surgeons developed a simulation committee to explore and develop simulation-based models. The educational curriculum was developed to have didactic and technical components with the incorporation of simulation models. Through numerous reiterations, a posterior cervical decompression model was developed and a 2-hour education curriculum was established.

RESULTS: Individual's level of training varied, with 5 postgraduate year (PGY) 2 participants, 1 PGY-3 participant, 2 PGY-5 participants, and 1 attending, with the majority being international participants (6 of 9, 67%). Didactic scores overall improved (7 of 9, 78%). The technical scores of all participants improved from 11 to 24 (mean, 14.1) to 19 to 25 (mean, 22.4). Overall, in the posterior cervical decompression simulator, there was a significant improvement in the didactic scores ($P = .005$) and the technical scores ($P = .02$).

CONCLUSION: The posterior cervical decompression simulation model appears to be a valuable tool in educating neurosurgery residents in the aspects of this procedure. The combination of a didactic and technical assessment is a useful teaching strategy in terms of educational development.

KEY WORDS: Foraminotomy, Posterior cervical, Simulator, Spine

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Neurosurgical residents have traditionally been instructed on surgical techniques and procedures through an apprenticeship model. Although this teaching modality has evolved over several centuries, there are many apparent deficiencies with this learning strategy. Recently and potentially as a consequence of the resident duty hour restrictions,^{1,2} these inadequacies have been magnified as a result of the

resident's loss of direct procedural exposure time and experience. A concurrent issue is that patient populations have questioned their involvement in the apprentice educational model specifically in terms of exposure to risks. Over the last several decades, there have been significant advances in the methodology of teaching and training medically based procedures through the use of simulation devices. The result has been a further redefining of the medical and surgical educational curriculum.

In the neurological surgical subspecialty, there has been a paucity of neurosurgical simulator devices; this is particularly apparent in the spine discipline, where the fewest models are available. At the onset of this project, there were no established spinal simulation devices and educational curricula aside from present basic physical models such as sawbones and cadaveric models.

ABBREVIATIONS: CNS, Congress of Neurological Surgeons; OSATS, objective structured assessment of technical skill; PCD, posterior cervical decompression; PGY, postgraduate year

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Prior educational models that have gained popularity in recent years consisted of primarily cadaveric models in which common techniques with spinal instrumentation and stabilization were practiced. However, the focus in this model was a disease-oriented one, and the goal was decompression of the nerve root and neural elements. The Congress of Neurological Surgeons (CNS) Simulation Committee therefore designed and integrated 4 spine simulation modules that included didactic and technical educational components. This article details one of these models, the posterior cervical foraminotomy and laminectomy educational model and curriculum.

METHODS

The CNS Simulation Committee performed an assessment of the available spinal simulation devices through inquiries with experts in the simulation field, literature searches, and an Internet analysis. A computerized PubMed search (<http://www.ncbi.nlm.nih.gov/>) was performed in July 2011 for the terms “neurosurgical simulator” and “spinal surgery simulator.” The conclusions were that there were limited spinal simulator devices and that no models had dedicated educational platforms.

The CNS spine simulation team, under the guidance of Drs Ashwini Sharan and James Harrop and through the assistance of Stryker Spine (Kalamazoo, Michigan) and its subsidiary, Phacon Corporation (Leipzig, Germany), collaborated on a new cervical spine simulator. Phacon had experience in cranial simulation models in that it had developed an image-guided posterior skull base system (See Posterior Fossa Physical Model Chapter). Phacon, with the direct guidance and tutelage of simulation members, assembled and created a posterior cervical decompression (PCD) model (Figure 1).

This model was first deployed in 2010 on a subset of residents as a baseline assessment trial. Based on this initial feedback and information from simulation experts and the CNS simulation team, numerous modifications were incorporated into several later versions. Once a detailed physical posterior cervical spinal model was created, attention was then focused on the overall educational experience and objectives. This new model was constructed with several innovations not previously used in simulator development within the field of neurosurgery. The cervical spine anatomy was modeled from continuous 1-mm slice image acquisition from a computed tomography scan. Three-dimensional printing³ using a rapid prototype was then used to create replicated physical models to those specifications.

The bone was further modeled to reflect both the harness of cortical bone and the interstices of cancellous bone. With the help of Phacon,

iteratively created spine models were provided for use with standard operating room drills and rongeurs. The samples were graded by multiple residents and faculty, and then a hybrid model was constructed that was incorporated into the 3-dimensional design. Phacon also created special tools that could be tracked via a standard Webcam that would allow the equivalent of navigation and real-time updates on a 3-axial-image set. Finally, any additional pressure on the spinal cord or nerve roots was recorded by added pressure circuits that relayed changes via USB to the companion laptop. These structures were designed to be pressure sensitive to track the number of and pressure scale contacts of the drill and rongeurs. A defined curriculum was established, and members from the spinal education community constructed an integrated set of both didactic and technical components.

In earlier simulation postcourse evaluations and surveys, the participants noted a preference for modules that had defined goals/objectives and a formal detailed outline of the course curriculum. This information was incorporated into each simulation module. Each simulator education module was designed to take approximately 120 minutes to complete. This allowed a regulated rotation schedule. In addition, all the simulation modules had 7 specific educational sections or portions. These could be broadly categorized as either a didactic or a technical component (Table). The didactic component consisted of questions on spinal anatomy and facts. These questions were adapted and modified after being tested on several selected neurosurgery residents as part of a pilot program. This pretest assessment was followed by a quick didactic session on basic principles of cervical anatomy (15 minutes), which was followed by an explanation of the simulation device (5-10 minutes). The posterior cervical module had 15 questions, and scores were graded as either correct, receiving 1 point, or incorrect, receiving a score of 0.

For the technical component of the spine module, there was a pretest assessment in which the individual performed a foraminotomy of the left C8 nerve root. This individual was graded on a predefined technical assessment form, which was based on the objective structured assessment of technical skill (OSATS; Figure 2).⁴ The technical grading sheet had 5 scores (1-5) with 1 being the lowest and 5 being the highest; total scores could range between 5 and 25. A detailed case with plain films, computed tomography scan, and magnetic resonance images was then presented that illustrated the concepts explained in the didactic session. This case presentation emphasized understanding of surgical anatomy, and participants were then asked to complete a C3-C6 laminectomy on the simulation model with the assistance of the power drills and suction devices (see Video 1, Supplemental Digital Content 1, <http://youtube.com/KAdHu7SRJBw>, showing the cervical laminectomy and foraminotomy simulator



FIGURE 1. *The posterior cervical foraminotomy and laminectomy model.*

TABLE. Module Itinerary in a 2-Hour Time Block^a

Activity	Duration, min
Written pretest on arrival	5
Quick didactic on the basics of cervical anatomy	15
Explanation of simulator	10
Practical pretest on arrival	10
Hands-on training, interaction with faculty	60
Written posttest	5
Posttest evaluation	10

^aThe posterior cervical foraminotomy and laminectomy module sample didactic is shown as presented annually at the Congress of Neurological Surgeons.

Anatomic levels				
1	2	3	4	5
Did not define levels, and operated on incorrect levels (C8 nerve root decompressed)		Correct levels but no radiographs		Correct levels
Use of the Drill				
1	2	3	4	5
Poor handling and manipulation		Appropriate choice of drill but somewhat mediocre and awkward handling		Appropriate choice of drills with proficient and fluid motion
Removal of Lamina				
1	2	3	4	5
Inability to maneuver the en bloc lamina for safe removal		Somewhat awkward removal of lamina		Appropriate, efficient removal of lamina
Decompression of Neural Elements				
1	2	3	4	5
Potential damage to underlying tissue/dura		- No damage to underlying tissue/dura - Suboptimal decompression		- No damage to underlying tissue/dura - Optimal decompression
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

FIGURE 2. A sample objective structured assessment of technical skill table for grading the didactic cervical foraminotomy.

setup, along with its ease of use and the safe practice of posterior cervical techniques with the high-speed drill).

The faculty (same individual for entire course) was encouraged to interact with the resident at this portion of the curriculum. Specific focus during the simulation exercise was centered on surgical approaches, instruments, techniques, and potential complications. The C3-C6 laminectomy procedure was allocated 60 minutes. The participant’s technical abilities at the end of this 60-minute session were scored again with a second graded technical sheet based on the OSATS (Figure 3). Once the participant concluded with the technical aspects of the module, a didactic posttest was performed. This consisted of the same initial pretest questions, but the questions were reorganized in a random manner. Once the posttest was completed, the attendee and instructor reviewed any incorrect responses and reinforced the basic principles of the module.

Because of the small sample sizes, a statistical analysis was performed with Microsoft Excel (version 14.0.6129.5000) with a Fisher exact test.

RESULTS

The PCD simulation module was used at the 2012 CNS simulation course held in the Chicago (Illinois) convention center at the CNS Annual Meeting. Nine neurosurgery residents rotated through and completed the PCD simulation model. The individ-

ual’s level of training varied, with 5 participants in postgraduate year (PGY) 2, 1 participant in PGY-3, 2 participants in PGY-5, and 1 attending. There was a preponderance of male participants (8 men and 1 woman). The majority were international participants (6 of 9, 67%), as opposed to residents from US residency programs.

In this PCD model, the didactic pretest scores ranged from 60% (9 of 15) to 100% (15 of 15). There was an overall improvement, with 78% (7 of 9) of the individual posttest didactic scores better than pretest scores. The greatest level of improvement was 20% in 2 residents’ scores (from 9 to 12 of 15 and from 10 to 13 of 15). Two individuals’ didactic scores did not change during the course; 1 participant had a perfect score (15/15), and the other scored 13 of 15. The presimulator technical scores ranged from 11 to 24 (mean, 14.1), and the postprocedure technical scores ranged from 19 to 25 (mean, 22.4). All participants were graded as technically improving, with a mean increase of 9 points (range, 11-20). All of the C3-C6 laminectomy procedures were completed within the allocated time slots (45 minutes) with a range of 15 to 45 minutes. The individual who completed it within 15 minutes was also graded a 100% (25 of 25) score. Overall, in the PCD simulator, there was a significant improvement in the didactic score ($P = .005$) and the technical score ($P = .02$).

Place retractors & Exposure of Column				
1	2	3	4	5
Inadequate exposure of column		Suboptimal dissection, exposure of spinal column		Appropriate incision and exposure of spinal column
Use of the Drill				
1	2	3	4	5
Poor handling and manipulation		Appropriate choice of drill but somewhat mediocre and awkward handling		Appropriate choice of drills with proficient and fluid motion
Removal of Lamina				
1	2	3	4	5
Inability to maneuver the en bloc lamina for safe removal		Somewhat awkward removal of lamina		Appropriate, efficient removal of lamina
Decompression of Neural Elements				
1	2	3	4	5
Potential damage to underlying tissue/dura		- No damage to underlying tissue/dura - Suboptimal decompression		- No damage to underlying tissue/dura - Optimal decompression
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

FIGURE 3. A sample objective structured assessment of technical skill table for grading the didactic cervical laminectomy from C3 to C6.

DISCUSSION

The apprenticeship model of neurosurgical training and education created lengthy work days, altered sleep patterns, and potentially a limited educational environment, all of which may have an adverse effect on surgical proficiency. Ganju et al⁵ reported this effect on 7 neurosurgery residents. Specifically, the residents had a statistically significant technical decline when tested in the postcall period ($P < .3$, $P < .4$, and $P < .2$ for movement smoothness, time elapsed, and cognitive errors, respectively). In addition to other concerns such as the famous Libby Zion case,² the Accreditation Council for Graduate Medical Education instituted a resident work hour restriction after a prolonged inquiry. This has potentially created an improved education environment but has overall reduced the time available for teaching and education.⁶

One area that was particularly affected by the reduction in resident work hours is technical applications such as training and overall operative and procedure experience.^{7,8} Kairys et al⁸ reported this significant decline in the operative experience of general surgery residents after the initiation of work hour restrictions. It is important to note that contradicting evidence points to no change in overall case volume as a function of decreased work hours.⁹ In fact, a systematic review of 56 studies

shows no significant case volume change after the implementation of work hour restrictions.

However, this effect was directly illustrated in the experience and exposure of cases by the residents at select institutions. Specifically, there was a significant decline in the total number of major operations performed (from 930 to 909, 2.3%; $P < .001$). The chief resident's operative experience decreased the greatest, from 252 to 231 cases (8.3% decrease; $P < .001$).⁸ This decline in chief resident case numbers also had an indirect effect on other junior resident's education because "operative cases reported by graduating residents in the roles of first assistant and teaching assistant declined dramatically."⁸

The neurosurgery educational community, as a result of these increasing demands and challenges, has been receptive to incorporating simulation into its educational armamentarium and curriculum.¹⁰⁻¹⁷ CNS, an organization with a principal mission of neurosurgical education, has placed significant resources in the use of a simulation in their educational platform to advance surgical skills and to enhance quality patient care.^{18,19} As part of this mission, the CNS has sought for there to be not only a simulation component but also a didactic and a technical component. CNS therefore organized a free neurosurgical multisubspecialty

simulation course for international and US neurosurgery residents with the overall goal of facilitating resident education. Several physical and virtual simulators were obtained, and then a dedicated educational platform was constructed.

The didactic learning component was quantified through a written pretest and posttest analysis. After successful completion of the posterior cervical simulator 2-hour module, including the dedicated didactic session, there was a significant correlation with improved knowledge ($P = .01$). Specifically, the posttest didactic results noted that 78% of individuals (7 of 9) improved. Two individuals had the greatest improvement of 20% (from 9 to 12 of 15 and from 10 to 13 of 15). Overall, this is not surprising in that the residents were engaged throughout the educational module and had specific goals and objectives. These objective metrics validate the residents' educational improvement, which is particularly impressive in view of the small number of only 9 participants.

The OSATS was introduced in 1997 and has served as a benchmark for assessing technical surgical skill.⁴ This measurement tool has been shown to be valuable in numerous simulation technical grading evaluations.²⁰⁻²³ The OSATS was modified so that it would incorporate the features relevant to this specific neurosurgery spine simulator course. The OSATS tool was easy to grade and illustrated the significant improvement in technical scores ($P = .02$). Every participant illustrated technical improvement, with a mean increase of 9 points (range, 11-20).

Temporally, all of the C3-C6 procedures were completed within the 45 minutes allocated. However, there was variability in the residents' skills and ability to complete the task, as illustrated by the significant range in time to completion (15 to 45 minutes). The 1 resident who completed the task within 15 minutes had a technical grade of 100% (25 of 25). This individual was a senior resident (PGY-5) with a very high exposure to surgical techniques and extensive experience in posterior cervical laminectomies. Despite the very small sample size, there was a trend between improvement and level of training in the technical component of the simulator, as illustrated in the linear regression analysis (Figure 4).

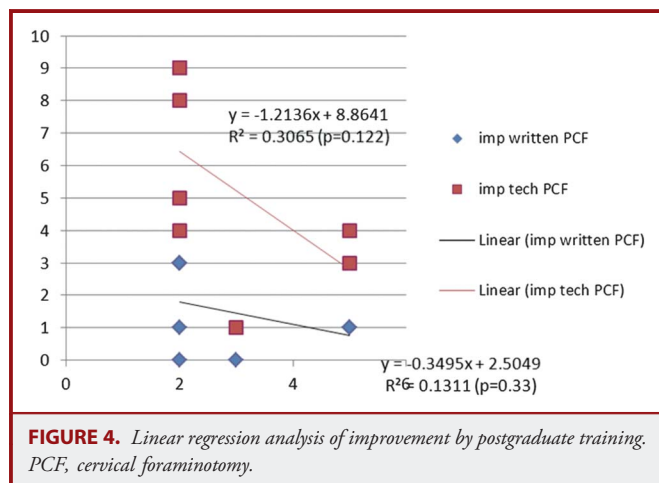


FIGURE 4. Linear regression analysis of improvement by postgraduate training. PCF, cervical foraminotomy.

This study suffered from several obvious limitations. Study participants were scarce, and more simulator trials are needed to allow a general understanding of the ability of the cervical spine simulator to improve resident surgical abilities. Furthermore, a future study would show the translational benefit from laboratory simulation to the intraoperative setting. At the present, further steps to validate this simulator would require more residents of a similar skill level, perhaps even a multi-institutional comparison of multiple residents with several different instructors. The limitation of this educational tool quickly becomes the cost of the sawbones model, which can be used only once. This equipment was custom fabricated for the specific use by the CNS; therefore, the price is a major limiting factor for distribution to a greater resident audience.

CONCLUSION

The PCD simulation model appears to be a valuable tool in the education of neurosurgery residents in the aspects of this procedure. The combination of a didactic and technical assessment appears to be synergistic in terms of educational development.

Disclosures

Dr Rezaei is currently the President of the Congress of Neurological Surgeons. 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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