Simulated Spinal Cerebrospinal Fluid Leak Repair: An Educational Model With Didactic and Technical Components

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BACKGROUND: In the era of surgical resident work hour restrictions, the traditional apprenticeship model may provide fewer hours for neurosurgical residents to hone technical skills. Spinal dura mater closure or repair is 1 skill that is infrequently encountered, and persistent cerebrospinal fluid leaks are a potential morbidity.

OBJECTIVE: To establish an educational curriculum to train residents in spinal dura mater closure with a novel durotomy repair model.

METHODS: The Congress of Neurological Surgeons has developed a simulation-based model for durotomy closure with the ongoing efforts of their simulation educational committee. The core curriculum consists of didactic training materials and a technical simulation model of dural repair for the lumbar spine.

RESULTS: Didactic pretest scores ranged from 4/11 (36%) to 10/11 (91%). Posttest scores ranged from 8/11 (73%) to 11/11 (100%). Overall, didactic improvements were demonstrated by all participants, with a mean improvement between pre- and posttest scores of 1.17 (18.5%; P = .02). The technical component consisted of 11 durotomy closures by 6 participants, where 4 participants performed multiple durotomies. Mean time to closure of the durotomy ranged from 490 to 546 seconds in the first and second closures, respectively (P = .66), whereby the median leak rate improved from 14 to 7 (P = .34). There were also demonstrative technical improvements by all.

CONCLUSION: Simulated spinal dura mater repair appears to be a potentially valuable tool in the education of neurosurgery residents. The combination of a didactic and technical assessment appears to be synergistic in terms of educational development.

KEY WORDS: Cerebrospinal fluid repair, Durotomy, Neurosurgery simulation, Resident training

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The Congress of Neurological Surgeons' (CNS) global mission is to enhance health and improve lives worldwide through the advancement of education and scientific exchange. One powerful method to accomplish this mission is to improve the quality and efficiency of neurosurgical resident education. Owing to several factors, the present traditional apprenticeship educational model provides fewer hours for neurosurgical residents training than when this model was first established. Proficiency of technical skills has been shown to be quantity-related, where increased exposure results in improved skills.[1,2] Spinal dura mater breaches with resultant cerebrospinal fluid leaks are a recognized complication in spinal surgery. Dural repair and closure require considerable familiarity with dural anatomy, tissue consistency, and fine surgical technique in a closed space to achieve technical effectiveness. With fewer hours of real-time operative training, obtaining excellence in adequate, timely, and watertight primary dural closure will be at a significant risk.

ABBREVIATIONS: CNS, Congress of Neurological Surgeons; **PGY,** postgraduate year

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Technical simulators are increasingly being used to provide training for specific skills when opportunities to learn those skills are not otherwise readily available. A theoretical advantage to increasing skill-set experiences with a technical simulator is that there is a potential decreased exposure risk to the patient, because the technical components should be at a higher level when implemented. This is especially advantageous for durotomy repair, because the technical components are unique in spinal surgery, and there is a risk for persistent cerebrospinal fluid (CSF) leak and pseudomeningocele with improper dural closure. Furthermore, given that the risks of nerve root or spinal cord injury from dural repair are present, resident participation in CSF leak closure is historically low.

Significant advances in the methodology of teaching and training medically based procedures through the use of simulation devices has gained widespread acceptance in many surgical or procedural-based practices.[3-7] However, in neurological surgery, there are relatively few simulator models that are available. The CNS simulation committee therefore designed and integrated several spine simulation modules as a component of the neurosurgical simulation curriculum. In order to enhance and maximize this educational experience, each simulator was developed to specifically meet curricular goals. The simulators were introduced as part of a 2-hour module incorporating both didactic and technical training components.

This article details one of these models, the CSF leak/spinal dura mater repair educational model. Spinal dural repair through suturing in the setting of a spinal dural laceration is a technically demanding surgical skill. Through the repetitive use of a physical simulation model of open spinal dural repair, we proposed to objectively measure the ability of neurosurgical residents and gauge their level of improvement with this skill set. The goal of our model is to demonstrate improved proficiency of the residents in performing dural closure within the confinements of exposure typically seen in the operative setting. Attaining a fundamental skill set by using such a simulator may help to simultaneously improve the technical skills of trainees and operative outcomes.

PATIENTS AND METHODS

The dural repair module was developed to educate residents in techniques to improve speed and quality of dural closure. The framework of this educational model included didactic and practical, simulator-based components. The course participants completed an 11-question written pretest to assess current knowledge of relevant spinal anatomy, knowledge of CSF repair techniques, and complications associated with inadequate dural closure. Questions were vetted through the spine subcommittee of the CNS Simulation Committee. Residents then completed a detailed didactic educational curriculum reviewing and enforcing these concepts. The technical skills of participants were then assessed with a spinal CSF leak repair simulator. This model was adapted and modified from a physical simulation model previously validated and described elsewhere in the literature by 1 senior author (P.A.).[8] Specifically, a sawbone reproduction of the lumbar spine from L1 to sacrum was obtained and a L3 laminectomy performed (Sawbones Worldwide, Vashon Island, Washington). Numerous synthetic materials were tested to obtain a tissue consistency similar to spinal dura mater. A dural substitute (DURA-GUARD, Synovis, Surgical, St. Paul, Minnesota) was identified that closely mimicked the textural properties of native dura. This was then individually manually fashioned into a watertight tube and placed within the spinal canal to serve as a thecal sac. Both proximal and distal ends of the simulated thecal sac were occluded by an inflated 14F Foley catheter balloon (Figure 1). The caudal Foley catheter was clamped, while the proximal Foley catheter was connected to an elevated 1-L bag of normal saline with an intervening drip chamber and clamp. Unclamping the proximal clamp allowed the saline reservoir to fill the thecal sac, thus creating a closed system with a pressure gradient dependent on the height of the saline reservoir, which was adjustable.

The flow rate of saline into the closed simulated thecal sac system was calculated by determining the number of drops per minute of saline from the reservoir into the drip chamber. Baseline leak rates were identified with the reservoir set at a pressure of 20 mL of water to mimic normal CSF pressure. This was done to standardize the pressure of fluid across the closure repair, and the pressure could be increased or decreased to test the quality of the dural closure.

With baseline system measurements recorded, a longitudinal dural incision of 1.5 cm was created within the site of the L3 laminectomy bed in the center of the thecal sac (Figure 2). This altered the pressure gradient and increased the CSF flow and amount of fluid released. The participant then used a 6-0 GORE-TEX suture to perform a running dural closure (Figure 3). This performance was measured and graded on 2 criteria: speed of closure and quality of closure. Speed of closure was measured by recording the time in seconds from the initiation of the first suture to the completion of the closure with securing the final knot. The quality of the closure was assessed by measuring the difference in the postclosure saline chamber drip rate compared to the baseline drip rate. Achieving a postclosure drip rate equal to the baseline drip rate represents a watertight closure at a pressure of 20 mL of water (Figure 4).

For the technical component of the durotomy repair on the simulator, participants attempted the dural closure of the standard length (1.5 cm) without a time restriction (see **Video 1, Supplemental Digital Content 1,** http://www.youtube.com/watch?v=09REBkLOyXw). Throughout the technical component, instructors aided the participants with surgical technique and again reinforced basic concepts of neurosurgical anatomy and pathophysiology.

Statistical analysis of predidactic and postdidactic scores as well as improvement on subsequent durotomy closures was analyzed via

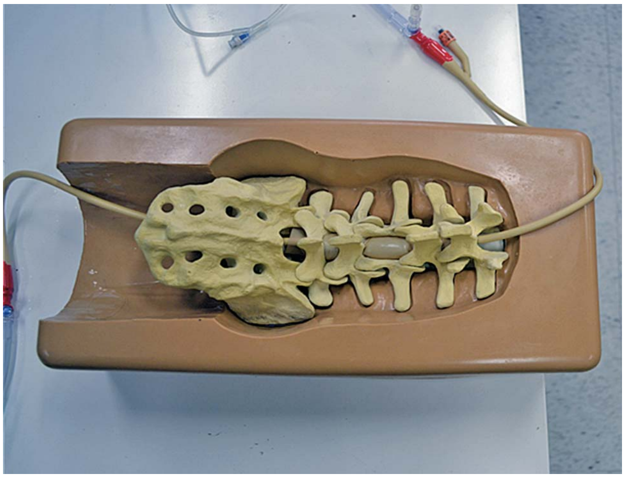

FIGURE 1. *The standard durotomy repair model. An L3 laminectomy demonstrated a dural tube, held open by rostral and caudal Foley pressure cuffs.*

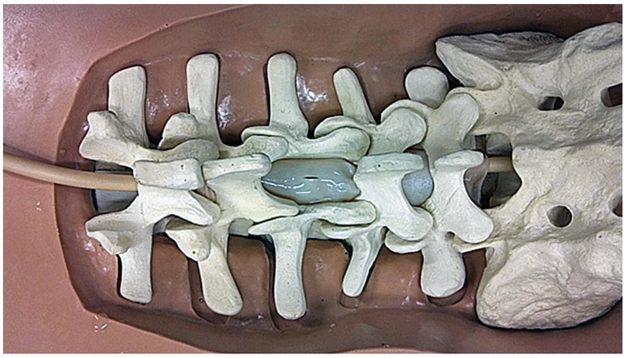

FIGURE 2. *A 1.5-cm durotomy is made for practice closure.*

FIGURE 4. *Dural repair model demonstrating dural closure, under fluid pressure. Performance is gauged by recording leak rates after each closure, measured in drips per second from the saline bag.*

a software package (JMP statistical software, edition 8.0.1, www.jmp.com) with the matched-pairs method. Statistical significance was defined as having an α-value of less than .05.

RESULTS

The spinal dural CSF leak repair educational module was used at the 2012 CNS simulation course held in the Chicago convention center at the CNS annual meeting. Six participants were included in the analysis, including 4 neurosurgery residents: postgraduate year (PGY) 2, PGY3, PGY4, and PGY5, 1 retired neurosurgeon (>10 years retirement), and 1 physician assistant without previous dural closure experience. All of the neurosurgeons were male (5 of 6 participants). There was 1 American resident and 1 physician assistant practicing in the United States, while the rest were international participants.

In the didactic portion of the educational module, the pretest scores ranged from 4/11 (36%) to 10/11 (91%). Overall, improvement was demonstrated by all applicants (Table 1), with posttest scores ranging from 8/11 (73%) to 11/11 (100%). The mean pretest didactic scores were 6.33, and the mean posttest didactic score was 7.50 with a mean improvement of 1.17 (18.5%, P = .02). Two participants demonstrated the greatest change from pretest to posttest written scores, improving from 4 to 10/11 (150%) and 6 to 9/11 (50%). One applicant failed to complete the module because of time constraints and did not take the posttest.

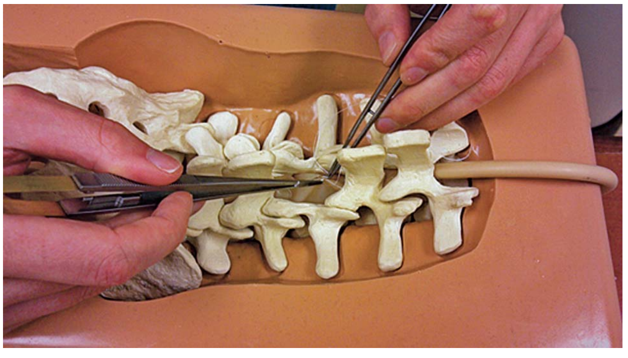

FIGURE 3. *Participants are then timed on their closure of a durotomy of a set length, which is then timed and compared over several trials.*

In the technical portion of the module, there were 11 durotomy closures for the 6 participants with timing of the repairs ranging from 4 minutes 14 seconds to 15 minutes (Table 2). Four participants performed more than 1 attempt at durotomy closure. For the applicants who completed multiple closures, there was improvement observed with repeated attempts. The leak rate change, calculated by the difference between drip rate from reservoir with the dura intact and after the repair was completed, measured the fidelity of the dural closure. Results ranged from 5 to 70 drips (in the fluid column) per 30 seconds. Improvement among the neurosurgery residents was evident. Mean time to closure of the durotomy ranged from 490 to 546 seconds in the first and second closures, respectively (P = .66), whereby the median leak rate improved from 14 to 7 (P = .34). There were also demonstrative technical improvements by all.

DISCUSSION

Neurosurgeons frequently encounter spinal dural breaches during spinal surgery. Etiologies range from traumatic injuries as seen after burst fractures, to congenital dural defects or arachnoid cysts as well as iatrogenic dural openings. The rate of incidental spinal durotomy varies in the literature.[9-16] Takahashi et al[9] reported 4% of lumbar spinal cases had dural defects in 1014 cases. However, with revision lumbar surgery, the reported rates are even higher with incidences noted between 13% and 15.9%.[13,17,18]

The performance of surgical procedures requires a detailed understanding of the anatomy along with proper technical skills. The dural repair educational module is a novel way to illustrate important didactic concepts to the participants, because all participants improved in scores of didactic tests. In addition to

TABLE 1. Participant Quiz Scores[a]

Participant	Postgraduate Level, y	Pretest Score, n correct	Posttest Score, n correct	Test Score Change, n (% improvement)
1	2	4/11	n/a	n/a
2	3	7/11	8/11	1 (14)
3	4	10/11	11/11	1 (10)
4	n/a (retired)	7/11	9/11	2 (28.6)
5	n/a (pa)	6/11	9/11	3 (50)
6	5	4/11	10/11	6 (150)
Mean	—	6.33	7.5	1.17 (18.5)

[a]n/a, not available; pa, physician assistant.

the didactic components, this module also illustrated that, in a very short period of time, quantitative improvements in the fidelity and speed of the durotomy repair can also occur. This was shown by the decrease in the time to complete the set length of durotomy closure from a mean of 490 to 456 seconds (P = .66), as well as the decrease in the drip or leak rate nearly back to the baseline scores. Furthermore, this model was very concise and efficient in terms of hours required for training. Other benefits of this model include its portability and potential to be used at any time by the resident, because its use does not require supervision by an attending physician.

In general, applicants reported a perceived increase in the ease of closure with time spent on the model, for which a trend can be seen. This was not the case with 1 applicant, who reported no previous exposure at all to dural closure. Although statistically significant improvement was not achieved in the technical evaluation of the spinal fluid repair model, this may have been due to the limited time allotted for this simulation at the CNS Conference, as well as a limitation in the supply of materials available. Further attempts to validate the efficacy of this simulator in improving surgical skills will be done internally among residents in a single-institution neurosurgery program, as well as across multiple centers. It is likely that the results did not show statistical improvements in the time to durotomy closure because of the variability in the participant skill and the small sample size. The bias introduced by having few participants of varying abilities can be overcome by stratifying performance by resident training level and performing a subgroup analysis in this manner. Another consideration is the duration of time to closure of the durotomy showed an increase in several cases. This could be best explained by the shift in the resident's attention from speed to accuracy, upon noting the shortcomings in their durotomy closure, which was evidenced by the improved leak rate.

The chief limitation for implementing this model is the cost of the dural substitute, which is the main component that must be replaced after use, and has a short shelf-life. Other drawbacks include that the dural substitute in use is not identical in character to the dura mater in vivo. However, among a variety of substitutes tested, the "Dura-Guard" was felt to provide the most realistic tactile feedback for suturing and handling with instruments. The

TABLE 2. Dural Closure Performances[a]

Participant	Postgraduate level, y	Closure Times, s	First-Leak Rate, drip/30 s	Second-Leak Rate, drip/30 s	Leak Rate Change,[b] drip/30 s
1	2	15	n/a	n/a	n/a
2 (trial 1)	3	263	2	15	13
2 (trial 2)	3	313	14	21	7
2 (trial 3)	3	326	26	33	7
3 (trial 1)	4	254	47	87	40
3 (trial 2)	4	381	14	20	6
4 (trial 1)	n/a (retired)	606	2	n/a	n/a
4 (trial 2)	n/a (retired)	430	6	11	5
5 (trial 1)	n/a (pa)	840	10	80	70
5 (trial 2)	n/a (pa)	700	6	n/a	n/a
6	5	716	23	41	18

[a]n/a, not available; pa, physician assistant.
[b]Leak Rate Change is determined to find the true leak rate (baseline rate minus final closure rate), which can be used to give a value comparable to the first-leak rate.

Foley catheters are readily available and provide an adequate seal for the fluid in the dural tube, but this results in a continual baseline leak rate. After a durotomy is made, the pressure to the system drops precipitously, until a dural closure is made. Once the closure is made, the fluid fills the tube and attempts to equilibrate based on the pressure of the height of the saline bag. The lack of steady pulsatile fluid loss and quick loss of fluid pressure do not adequately mimic CSF dynamics in vivo. As the model is improved, the next step would be to make the fluid circuit a truly closed one, such that the system could be completely clamped at the rostral and caudal ends without a fluid leak.

Other improvements to the model may significantly enhance the experience. The sawbones model (Figure 1) does not simulate the often narrow corridor that is encountered by deep wounds caused by obesity, or the paraspinal musculature and soft tissues of the spine. Also, adding to the difficulty and frustration of durotomy closures are blood products that flood the field, making continuous visualization of the durotomy tedious. The addition of nerve roots to simulate their proximity to the closure is another possibility to increase the realism that adds to the risk of the repair. Further training models should be included in the future that simulate dural closure in a tubular retractor or a simulated narrow operating corridor. Finally, formalization of the evaluation process for the technical portion of the course may improve the ability to obtain validation data for the model. All course participants should complete a pretraining assessment of dural closure time and postclosure drip rate, followed by a defined period of guided simulator practice, to be followed by a post-training assessment of speed and quality of dural closure. This may require extension of the module to longer than the currently allotted 2 hours to provide ample time for these assessments and training period.

CONCLUSION

Repair of spinal dura mater is a valuable tool in the education of neurosurgery residents to decrease CSF leak rate and improve the speed of closure. The implementation of a didactic program in tandem with a technical simulator has the potential to be beneficial in resident education.

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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