Usefulness of a Virtual Reality Percutaneous Trigeminal Rhizotomy Simulator in Neurosurgical Training

Sophia F. Shakur, MD*
Cristian J. Luciano, PhD‡§
Patrick Kania, BS§
Ben Z. Roitberg, MD¶
P. Pat Banerjee, PhD‡§
Konstantin V. Slavin, MD*
Jeffrey Sorenson, MD||
Fady T. Charbel, MD*§
Ali Alaraj, MD*

*Department of Neurosurgery, University of Illinois at Chicago, Chicago, Illinois; ‡Department of Mechanical and Industrial Engineering, University of Illinois at Chicago, Chicago, Illinois; §ImmersiveTouch, Inc., Westmont, Illinois; ¶Section of Neurosurgery, Department of Surgery, University of Chicago, Chicago, Illinois; ||Semmes Murphey Neurologic and Spine Institute, Memphis, Tennessee

Correspondence:
Ali Alaraj, MD,
Department of Neurosurgery,
University of Illinois at Chicago,
912 South Wood Street, MC-799,
Chicago, IL 60612.
E-mail: alaraj@uic.edu

Received, January 31, 2015.
Accepted, April 21, 2015.
Published Online, June 22, 2015.

BACKGROUND: Simulation-based training may be incorporated into neurosurgery in the future.

OBJECTIVE: To assess the usefulness of a novel haptics-based virtual reality percutaneous trigeminal rhizotomy simulator.

METHODS: A real-time augmented reality simulator for percutaneous trigeminal rhizotomy was developed using the ImmersiveTouch platform. Ninety-two neurosurgery residents tested the simulator at American Association of Neurological Surgeons Top Gun 2014. Postgraduate year (PGY), number of fluoroscopy shots, the distance from the ideal entry point, and the distance from the ideal target were recorded by the system during each simulation session. Final performance score was calculated considering the number of fluoroscopy shots and distances from entry and target points (a lower score is better). The impact of PGY level on residents' performance was analyzed.

RESULTS: Seventy-one residents provided their PGY-level and simulator performance data; 38% were senior residents and 62% were junior residents. The mean distance from the entry point (9.4 mm vs 12.6 mm, $P = .01$), the distance from the target (12.0 mm vs 15.2 mm, $P = .16$), and final score (31.1 vs 37.7, $P = .02$) were lower in senior than in junior residents. The mean number of fluoroscopy shots (9.8 vs 10.0, $P = .88$) was similar in these 2 groups. Linear regression analysis showed that increasing PGY level is significantly associated with a decreased distance from the ideal entry point ($P = .001$), a shorter distance from target ($P = .05$), a better final score ($P = .007$), but not number of fluoroscopy shots ($P = .52$).

CONCLUSION: Because technical performance of percutaneous rhizotomy increases with training, we proposed that the skills in performing the procedure in our virtual reality model would also increase with PGY level, if our simulator models the actual procedure. Our results confirm this hypothesis and demonstrate construct validity.

KEY WORDS: Haptic, Resident, Rhizotomy, Simulator, Trigeminal, Virtual reality

Operative Neurosurgery 11:420–425, 2015 DOI: 10.1227/NEU.0000000000000853

Simulation technologies provide important educational tools to gain new surgical skills, maintain proficiency, and minimize operative complications.[1,2] Consequently, simulation-based training in general surgery has been mandated by the Accreditation Council for Graduate Medical Education and may be incorporated into neurosurgical training in the near future.[3,4] Indeed, learning through simulation is particularly critical in neurosurgical residency in which work hours are restricted, the technical learning curve is steep, and technical errors are costly.[5-7] As a result, we recently developed a novel haptics-based virtual reality percutaneous trigeminal rhizotomy simulator.

Trigeminal neuralgia is a disease characterized by paroxysmal attacks of sharp, lancinating pain in the distribution of the trigeminal nerve and is estimated to have an incidence of 12.6 per 100000 person-years.[8] Surgical treatment options include percutaneous rhizotomies that cause controlled

ABBREVIATION: PGY, postgraduate year injury to the trigeminal nerve, ganglion, or root with heat (radiofrequency rhizotomy); glycerol injection (glycerol rhizotomy); and mechanical compression (balloon compression). The Gasserian ganglion and nerve root fibers are accessed by inserting a needle in the cheek and through the foramen ovale using fluoroscopic guidance. Cannulation of the foramen ovale can be technically challenging, and complications associated with misplacement of the needle include internal carotid artery injury, cranial nerve damage, and cerebrospinal fluid fistula formation.[8-10]

Because technical performance of percutaneous trigeminal rhizotomy increases with training, we created a real-time augmented reality simulator for percutaneous trigeminal rhizotomy using the ImmersiveTouch platform (ImmersiveTouch, Inc, Westmont, Illinois). Our hypothesis is that skills in performing the procedure in our virtual reality model will also increase with resident postgraduate year (PGY) level, if our simulator is a good model of the actual procedure. In this study, we tested our hypothesis by assessing the relationship between PGY level and resident performance on the simulator that was measured based on parameters such as the number of fluoroscopy shots, the distance from the ideal entry point, and the distance from the ideal target.

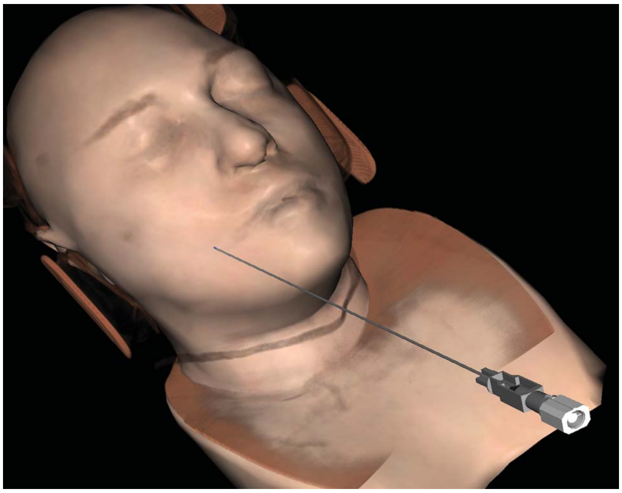

FIGURE 1. *A 3-dimensional stereoscopic immersive virtual reality model of the skull and head for percutaneous rhizotomy simulation. The user identifies the surface anatomic landmarks for needle entrance through the cheek.*

METHODS

Percutaneous Trigeminal Rhizotomy Module Creation

The percutaneous trigeminal rhizotomy module runs on the ImmersiveTouch workstation, which uses a monitor-mirror system, previously described, to provide a hologram-like projection of 3-dimensional (3-D) anatomy.[11] This rhizotomy module was constructed from multiple existing modules for the ImmersiveTouch platform, including ventriculostomy, bone drilling, pedicle screw placement, vertebroplasty, and lumbar puncture.[12-17] To create the percutaneous rhizotomy module, an original computed tomography scan dataset from a real patient was used. Models were displayed as polygonal meshes and volumetric renderings.

At the workstation, the user reaches in with both hands behind a half-silvered mirror to enter an interactive stereoscopic immersive environment containing the patient's 3-D imaging and various tools. High-resolution visualization and head- and hand-tracking are provided. Wearing a head-tracking device allows the user to have a fully immersive experience of the macroscopic portions of the rhizotomy procedure, such as needle puncture and insertion.

This rhizotomy simulation exercise involves finding the anatomic landmarks for the needle entrance through the cheek (Figure 1). The trajectory of the needle (toward the foramen ovale) can be adjusted using real-time fluoroscopic imaging (lateral x-ray) that appears on the side of the screen (Figure 2). Submental vertex x-ray was not available to trainees during this study but has since been incorporated into our simulator. The combination of tactile feedback, ie, the feeling of the bone as opposed to soft tissues, and fluoroscopic guidance attempts to make the module representative of the real procedure. After insertion, the needle is frozen in place when the trainee believes that the tip is at the foramen ovale. The needle then turns green if it is in the correct location or red if it missed the target or bypassed it. The trainee can use the virtual scissors to cut through the 3-D model and visualize the location of the tip of the needle relative to the ideal target (Figure 3).

Percutaneous Trigeminal Rhizotomy Residents' Trial

A total of 92 neurosurgery residents tested the simulator at the American Association of Neurological Surgeons Top Gun 2014 competition. Seventy-one residents from 50 different institutions in the United States and abroad provided their PGY level. All residents watched a live demonstration in which the operator showed the procedure only once, and the residents did not have any practice time on the simulator before their session. The number of fluoroscopy shots, the distance from the ideal entry point, and the distance from the ideal target (center of the foramen ovale) were recorded by the system during each simulation session. The final performance score was calculated as the number of fluoroscopy shots + the distance from the ideal entry point + the distance from the ideal target (a lower score is better). Accuracy was defined as the distance from the ideal entry point + the distance from the ideal target (a lower score is better). The goal of the simulation is to be as close to the ideal

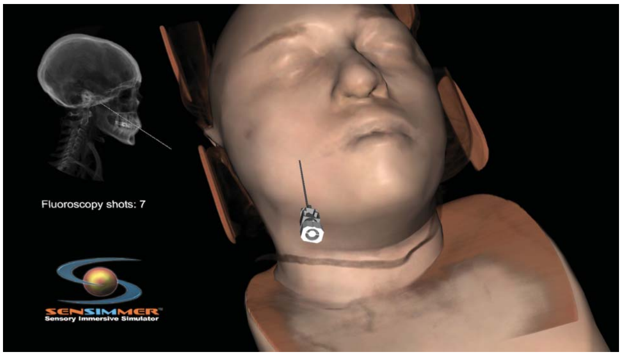

FIGURE 2. *Real-time fluoroscopic image guidance. The trajectory of the needle (toward the foramen ovale) can be adjusted using real-time fluoroscopic imaging (lateral x-ray) that appears on the side of the screen. The number of fluoroscopy shots is also recorded.*

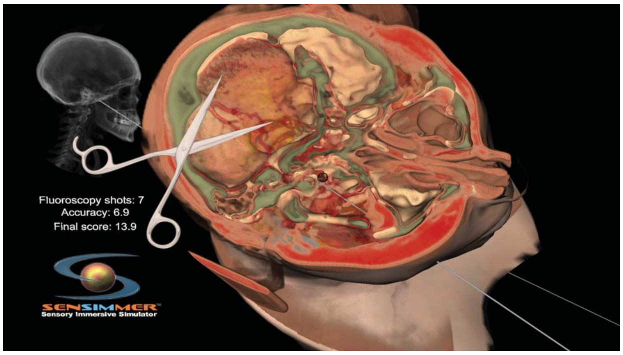

FIGURE 3. *Virtual scissors used to cut through the 3-dimensional model and visualize the location of the tip of the needle relative to the ideal target at the end of the simulation session.*

entry point and ideal target while using the least fluoroscopy possible, thereby demonstrating knowledge of the location of the foramen ovale. The impact of PGY level on the residents' performance was analyzed.

Statistical Analysis

Mean comparisons between junior and senior residents were made using the independent 2-tailed Student *t* test. Univariate analysis to assess the relationship between PGY level and the number of fluoroscopy shots, the distance from the ideal entry point, the distance from the ideal target, the final score, and accuracy was performed using linear regression. All analyses were performed with SPSS software Version 22 (IBM, Inc, Armonk, New York).

RESULTS

Participant Characteristics

Sixty-two percent (n = 44/71) of participants were junior residents (PGY levels 1-3) and 38% (n = 27/71) were senior residents (PGY levels 4-7). The mean PGY level among the 71 residents was 3.9 ± 1.8, the median was 4.0, and the range was 1 to 7. Participant characteristics are outlined in Table.

TABLE. Summary of Participant Characteristics and Simulator Performance Data[a]

Participants (N = 71)	
No. (%) of juniors, PGY levels 1-3	44 (62)
No. (%) of seniors, PGY levels 4-7	27 (38)
Simulator performance of all participants	
Mean ± SD distance from the ideal entry point (median, range), mm	10.6 ± 5.1 (9.9, 2.9-23.7)
Mean ± SD distance from ideal target (median, range), mm	13.2 ± 9.2 (12.6, 1.8-71.4)
Mean no. ± SD of fluoroscopy shots (median, range)	9.8 ± 5.6 (8.0, 0-25)
Mean ± SD final score (median, range)	33.6 ± 11.2 (32.1, 14.2-87.4)
Mean ± SD accuracy (median, range)	23.8 ± 11.0 (23.1, 8.2-87.4)

[a]PGY, postgraduate year.

Mean Comparisons Between Junior and Senior Residents

The comparison between junior and senior resident performance on the simulator is shown in Figure 4. The mean distance from the ideal entry point was 9.4 ± 5.1 mm among senior residents and was significantly higher among junior residents (12.6 ± 4.5, *P* = .01). This difference was also reflected by a better mean final score (31.1 ± 9.0 vs 37.7 ± 13.3, *P* = .02) and improved mean accuracy (21.4 ± 7.8 vs 27.8 ± 14.0, *P* = .02) among senior residents. However, there was no significant difference in the number of fluoroscopy shots (9.8 ± 5.7 vs 10.0 ± 5.3, *P* = .88) or the mean distance from the ideal target (12.0 ± 6.2 mm vs 15.2 ± 12.5 mm, *P* = .16) in senior vs junior residents.

Linear Regression Analysis of PGY Level vs Performance on the Simulator

Linear regression analysis assessing the relationship between PGY level and performance on the simulator revealed that

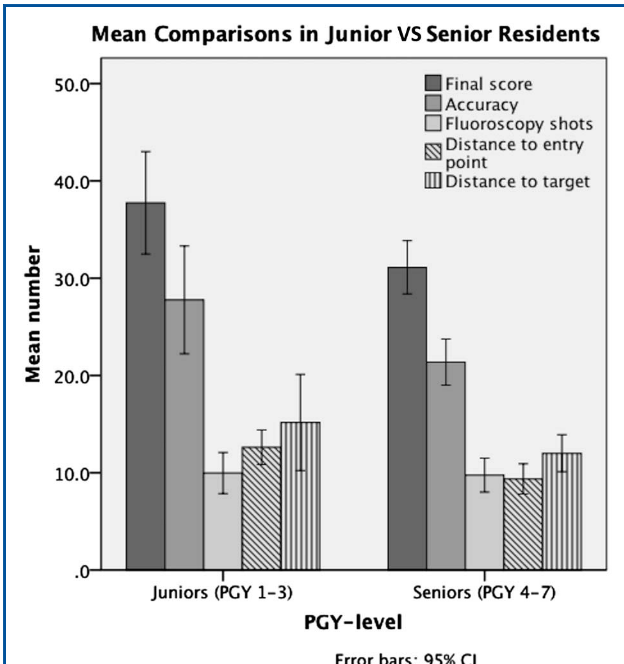

FIGURE 4. *A comparison of junior and senior resident performance on the simulator. The mean distance from the ideal entry point was significantly lower in senior residents (P = .008), and senior residents had significantly better final scores (P = .02) and accuracy (P = .02). The number of fluoroscopy shots was not significantly different between the 2 groups (P = .88), and mean distance from the ideal target was lower in seniors but not significantly (P = .16). PGY, postgraduate year.*

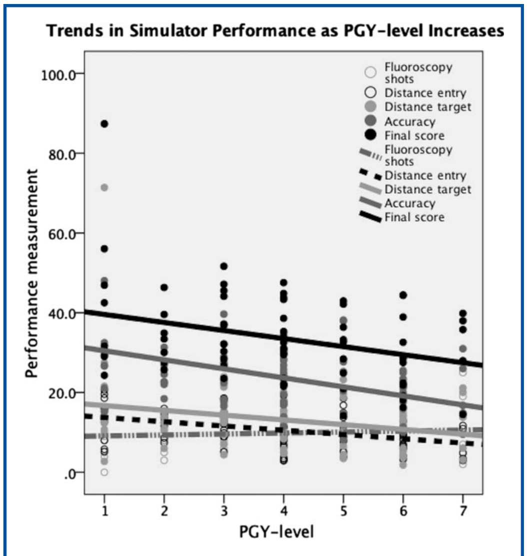

FIGURE 5. *Trends in performance on the simulator as PGY level increases. Increasing PGY level is significantly associated with decreased distance from the ideal entry point (P = .001), a shorter distance from the ideal target (P = .05), a better final score (P = .007), and improved accuracy (P = .002), but not the number of fluoroscopy shots (P = .52). PGY, postgraduate year.*

increasing PGY level is significantly associated with a decreased distance from the ideal entry point (R^2 = 0.14, P = .001), shorter distance from the ideal target (R^2 = 0.05, P = .05), better final score (R^2 = 0.10, P = .007), and improved accuracy (R^2 = 0.14, P = .002) (Figure 5). On the other hand, the number of fluoroscopy shots was not significantly associated with PGY level (R^2 = 0.006, P = .52). A distribution of final scores according to PGY level is provided in Figure 6.

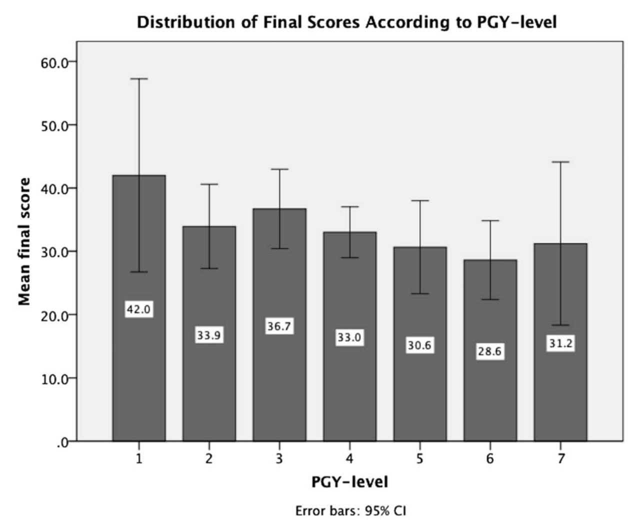

FIGURE 6. *Distribution of final scores according to PGY level. Mean final score improves with higher PGY level. CI, confidence interval; PGY, post-graduate year.*

DISCUSSION

Traditionally, percutaneous trigeminal rhizotomy is performed using the Hartel approach, which is a technique based on surface landmarks.[18] Specifically, the ideal entry point is approximately 2.5 cm lateral to the corner of the mouth on the symptomatic side. The foramen ovale is approximated by the intersection of the midpupillary line and a point one-third of the distance from the tragus of the ear to the lateral canthus of the eye. The trajectory of the needle is within the plane of the zygomatic arch approximately 2.5 cm anterior to the tragus of the ear and toward the medial aspect of the ipsilateral pupil. Complementary use of fluoroscopic image guidance has also become standard practice. On the lateral view, the needle is directed toward the intersection of the clivus and petrous bone.[18] Mastering performance of percutaneous trigeminal rhizotomy, then, requires identification of key surface landmarks and familiarity with radiographic cues.

Acquisition of the technical skills outlined earlier has been dependent on solely surgical experience until now. Consequently, in patients with complicated anatomic variants and a difficult-to-access foramen ovale, surgeons have become more heavily reliant on newer image guidance adjuncts.[19-22] For example, Lin et al[19] recently reported a 73.8% successful cannulation rate in 42 consecutive patients who underwent percutaneous trigeminal rhizotomy using intraoperative computed tomography with integrated neuronavigation. Additionally, Bohnstedt et al[20] described their experience using the Medtronic O-arm (Littleton, Massachusetts) in 4 patients, without the need for preoperative imaging or head fixation. It is important to recognize, however, that these studies show that target visualization does not guarantee successful cannulation and that image guidance is not a substitute for technical skill.

Simulation technologies provide educational tools to hone technical skills in a controlled learning environment outside the operating room.[1,2] To the authors' knowledge, there is currently no other fully immersive haptics-based virtual reality trigeminal rhizotomy simulator. Previously, Li et al[23] reported on their development of a prototype Web-based virtual reality trigeminal rhizotomy simulator. This program allows trainees to identify surface landmarks and provides visual but not tactile feedback once the foramen ovale is cannulated. It was designed to be a basic simulator to be widely available and efficiently run online. No other simulators of the trigeminal rhizotomy procedure have been reported in the literature.

In this study, we assessed the usefulness of a novel virtual reality percutaneous trigeminal rhizotomy simulator, built on the ImmersiveTouch platform, in neurosurgical training. Resident performance on the simulator was based on measured components that also comprise the Hartel approach used in the real procedure, namely, the distance from the ideal entry point and the distance from the ideal target. We found that, on average, senior residents are able to place the needle closer to the ideal entry point and target compared with junior residents. Linear regression analysis also demonstrated a significant correlation between increasing PGY level and a shorter distance from the ideal entry point ($R^2 = 0.14$, $P = .001$) and target ($R^2 = 0.05$, $P = .05$). Because the technical skills used to perform the actual rhizotomy procedure are largely gained through surgical experience and performance on our simulator improves with neurosurgical training, we posit that our simulator may be used to gauge technical proficiency in trigeminal rhizotomy as well as to refine the skills needed in the actual surgery. In addition, our results may be used to establish goal scores for future trainees to strive toward when practicing on the simulator. The level of training was not significantly associated with the number of fluoroscopy shots taken ($R^2 = 0.006$, $P = .52$), which can be interpreted in a number of ways, including fluoroscopy being an advantage for seniors who are familiar with the radiographic landmarks, or, if residents did not find the simulated fluoroscopy helpful because it was not realistic enough and lacked other more typically used views like submental vertex, then seniors probably did better due to increased knowledge and experience with identifying the key surface landmarks. Finally, the suboptimal performance of residents on this task highlights the need for such simulation technologies to ensure adequate training in performing percutaneous trigeminal procedures.

Here, we introduced a real-time augmented reality simulator for percutaneous trigeminal rhizotomy and performed a validation experiment with a neurosurgery resident trial. More complete validation would require analysis of actual surgical outcomes among participants randomized into 2 groups—a group that trains on the simulator and another group that does not. Also, our simulator was tested during the Top Gun competition rather than in a controlled learning environment, which may have affected resident performance. Whether the use of the simulator in an educational setting would yield similar results is unknown, but the simulator's primary use is as a didactic tool, and so additional data on resident performance may be obtained once it is fully implemented into resident training. Another possible limitation of this study is that the number of participants in the junior and senior resident groups was not equal and operative experience with trigeminal rhizotomy varied. Although the frequency with which each resident had previously performed the procedure was not known, and therefore was not taken into account in the analysis, we were able to show the usefulness of this percutaneous trigeminal rhizotomy simulator in the longitudinal evaluation of neurosurgery residents, as simulator performance will be expected to improve with increased PGY level.

CONCLUSION

Because technical performance of percutaneous trigeminal rhizotomy improves with training, we hypothesized that skills in performing the procedure in our virtual reality model would also improve with PGY level if our simulator models the actual procedure. Our results confirm this hypothesis and demonstrate construct validity.

Disclosures

Dr Alaraj is the recipient of an NIH research grant. Dr Banerjee is the recipient of an NIH research grant and has ownership interest in ImmersiveTouch, Inc. Dr Charbel is the recipient of an NIH research grant and is a consultant for ImmersiveTouch, Inc. Dr Luciano is the recipient of an NIH research grant and has ownership interest in ImmersiveTouch, Inc. Dr Roitberg is the recipient of an NIH research grant. The other authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

REFERENCES

1. Issenberg SB, McGaghie WC, Petrusa ER, Lee Gordon D, Scalese RJ. Features and uses of high-fidelity medical simulations that lead to effective learning: a BEME systematic review. *Med Teach.* 2005;27(1):10-28.
2. Kirkman MA. Deliberate practice, domain-specific expertise, and implications for surgical education in current climes. *J Surg Educ.* 2013;70(3):309-317.
3. Kirkman MA, Ahmed M, Albert AF, Wilson MH, Nandi D, Sevdalis N. The use of simulation in neurosurgical education and training. *J Neurosurg.* 2014;121(2):228-246.
4. Ganju A, Aoun SG, Daou MR, et al. The role of simulation in neurosurgical education: a survey of 99 United States neurosurgery program directors. *World Neurosurg.* 2013;80(5):e1-e8.
5. Philibert I, Friedmann P, Williams WT. ACGME work group on resident duty hours: Accreditation Council for Graduate Medical Education: new requirements for resident duty hours. *JAMA*. 2002;288(9):1112-1114.
6. Hoh BL, Neal DW, Kleinhenz DT, Hoh DJ, Mocco J, Barker FG II. Higher complications and no improvement in mortality in the ACGME resident duty-hour restriction era: an analysis of more than 107,000 neurosurgical trauma patients in the nationwide inpatient sample database. *Neurosurgery*. 2012;70(6):1369-1382.
7. Jagannathan J, Vates GE, Pouratian N, et al. Impact of the Accreditation Council for Graduate Medical Education work-hour regulations on neurosurgical resident education and productivity. *J Neurosurg.* 2009;110(5):820-827.
8. Shakur SF, Bhansali A, Mian AY, Rosseau GL. Neurosurgical treatment of trigeminal neuralgia. *Dis Mon.* 2011;57(10):570-582.
9. Cappabianca P, Spaziante R, Graziussi G, et al. Percutaneous retrogasserian glycerol rhizolysis for treatment of trigeminal neuralgia. Technique and results in 191 patients. *J Neurosurg Sci.* 1995;39(1):37-45.
10. Kaplan M, Erol FS, Ozveren MF, Topsakal C, Sam B, Tekdemir I. Review of complications due to foramen ovale puncture. *J Clin Neurosci.* 2007;14(6):563-568.
11. Lemole GM Jr, Banerjee PP, Luciano C, Neckrysh S, Charbel FT. Virtual reality in neurosurgical education: part-task ventriculostomy simulation with dynamic visual and haptic feedback. *Neurosurgery*. 2007;61(1):142-148.
12. Alaraj A, Charbel FT, Birk D, et al. Role of cranial and spinal virtual and augmented reality simulation using immersive touch modules in neurosurgical training. *Neurosurgery*. 2013;72(suppl 1):115-123.
13. Banerjee PP, Luciano CJ, Lemole GM Jr, Charbel FT, Oh MY. Accuracy of ventriculotomy catheter placement using a head- and hand-tracked high-resolution virtual reality simulator with haptic feedback. *J Neurosurg.* 2007;107(3):515-521.
14. Luciano CJ, Banerjee PP, Sorenson JM, et al. Percutaneous spinal fixation simulation with virtual reality and haptics. *Neurosurgery*. 2013;72(suppl 1):89-96.
15. Alaraj A, Lemole MG, Finkle JH, et al. Virtual reality training in neurosurgery: review of current status and future applications. *Surg Neurol Int.* 2011;2:52.
16. Yudkowsky R, Luciano C, Banerjee P, et al. Practice on an augmented reality/haptic simulator and library of virtual brains improves residents' ability to perform a ventriculostomy. *Simul Healthc.* 2013;8(1):25-31.
17. Alaraj A, Luciano CJ, Bailey DP, et al. Virtual reality cerebral aneurysm clipping simulation with real-time haptic feedback. *Neurosurgery*. 2015;11(suppl 2):52-58.

18. Zampella EJ, Brown JA, Azmi H. Percutaneous techniques for trigeminal neuralgia. In: Schulder M, ed. *Handbook of Stereotactic and Functional Neurosurgery*. 1st ed. Boca Raton, FL: CRC Press; 2003:395-408.
19. Lin MH, Lee MH, Wang TC, et al. Foramen ovale cannulation guided by intra-operative computed tomography with integrated neuronavigation for the treatment of trigeminal neuralgia. *Acta Neurochir.* 2011;153(8):1593-1599.
20. Bohnstedt BN, Tubbs RS, Cohen-Gadol AA. The use of intraoperative navigation for percutaneous procedures at the skull base including a difficult-to-access foramen ovale. *Neurosurgery*. 2012;70(2 suppl operative):177-180.
21. Meng FG, Wu CY, Liu YG, Liu L. Virtual reality imaging technique in percutaneous radiofrequency rhizotomy for intractable trigeminal neuralgia. *J Clin Neurosci.* 2009;16(3):449-451.
22. Van Buyten JP, Smet I, Van de Kelft E. Electromagnetic navigation technology for more precise electrode placement in the foramen ovale: a technical report. *Neuromodulation*. 2009;12(3):244-249.
23. Li Y, Brodlie K, Phillips N. Web-based VR training simulator for percutaneous rhizotomy. *Stud Health Technol Inform.* 2000;70:175-181.

Acknowledgments

The authors thank Dr David E. Connor Jr, of Neurosurgery Arkansas, Little Rock, for assistance in collecting the data and Annesha R. Banerjee, of the University of Illinois, Urbana-Champaign, for some of the initial data analysis.

COMMENT

The authors demonstrate the use of a virtual reality simulator for percutaneously cannulating the foramen ovale. This is another step in improving our ability to partially train residents in technical skills outside of the operating room to both improve their learning curve and reduce risk to patients. In this study, residents did not use the stimulator to learn, only to compete in a skills competition, so the authors have no data on the effectiveness of the stimulator as a learning tool (showing improvement in either the simulated or actual task). Moreover, the study did not include the ability to use simulated fluoroscopy in a submental-vertex view, which is frequently used to help guide a needle into the foramen ovale. Last, the suboptimal resident performance on this task highlights the need to emphasize the role that percutaneous trigeminal procedures have in the treatment of trigeminal neuralgia and continue to ensure that residents are properly trained in these techniques so that they can confidently offer them to patients when they are in practice.

Joshua Rosenow
Chicago, Illinois