12 Competency Assessment in Virtual Reality-Based Simulation in Neurosurgical Training

Laura Stone McGuire and Ali Alaraj

Competency Assessment Post-simulation in Neurosurgical Training

Interest in implementing VR simulation in graduate medical education has grown over the past decade, especially within surgical specialties. For instance, the use of VR simulators in general surgery training has been well-studied, and research examining its use for laparoscopic cholecystectomy practice demonstrated that those groups who practiced with the simulator were less likely to have errors or make critical mistakes and completed the procedure quicker [1].

Similarly, the inclusion of VR simulators in neurosurgical training has expanded recently, and its goals are multifold. VR simulation provides a safe environment to practice technical skills with no risk to the patient, which becomes an increasingly important objective as advocacy for transparency in patient surgical outcomes and the involvement of residents in cases has progressed [2, 3]. The development of surgical skills among trainees on a lifelike model for a variety of procedures within a safe environment to improve patient outcomes encaptures the overall purpose of incorporating VR simulation into residency [4]. Multiple VR simulators have been produced in an effort to address these needs, including but not limited to Surgical Theater ®, NeuroTouch ®, Simbionix ® ANGIO Mentor ™, and ImmersiveTouch ®. These technologies will be discussed in more detail in other chapters. Additionally, the Congress of Neurological Surgeons (CNS) established a Simulation Committee in 2010 and recently published an overview of a simulator-based educational curriculum, including vascular, cranial, and spine components [5]. This committee aimed to create both virtual reality and physical simulations to maximize resident education, improving outcomes both safely and efficiently, and using an algorithm to standardize assessments among participants.

Procedures

VR simulators overall provide training on a variety of neurosurgical procedures along a spectrum of complexity, and the performance of these procedures as well as structured curriculums has been studied among neurosurgical residents. Among spine-based techniques, a 90-min curriculum on the anterior cervical discectomy and fusion with written and practical pretests, didactics and hands-on training, and subsequent posttests has been published, indicating improvement from baseline scores among participants [6]. Another study examined a 2-h educational

L. S. McGuire · A. Alaraj (✉)
Department of Neurosurgery, University of Illinois at Chicago, Chicago, IL, USA
e-mail: lmcguir1@uic.edu; Alaraj@uic.edu

A. Alaraj (ed.), *Comprehensive Healthcare Simulation: Neurosurgery*,
Comprehensive Healthcare Simulation, https://doi.org/10.1007/978-3-319-75583-0_12

curriculum for posterior cervical decompression, including laminectomy and foraminotomy exercises, and demonstrated improved posttest didactic and technical scores [7]. Additionally, the CNS Simulation Committee developed a simulation model for durotomy and cerebrospinal fluid leak repair both within the lumbar spine [8] and cervical spine [9].

Simulated endovascular procedures have similarly been studied. A 2-h resident simulator-based course on diagnostic cerebral angiography available at two CNS annual meetings showed significant improvement in posttest-written assessment and practical skill scores [10]. Additionally, another small, pilot study assessed technical skills in performing a diagnostic cerebral angiogram on the Simbionix ® ANGIO Mentor ™ system, and participants improved procedure and fluoroscopy time over five attempts [11]. A study of VR-based simulation for endovascular aneurysm repair, also using Simbionix ® ANGIO Mentor ™, demonstrated faster procedural times, better device sizing, and fewer complications after training with the simulator [12]. Furthermore, simulated carotid artery stenting improved procedural and overall fluoroscopy times, as well as successful cannulation of the common carotid artery and sizing and deployment of embolic protection device [13]. A longitudinal analysis of participants over 30 days with five participants showed overall performance improvement in diagnostic cerebral angiogram, embolectomy, and coil embolization, as measured by total procedure time, fluoroscopy time, contrast dose, packing densities, number of coils used, and number of stent-retriever passes [14].

Many simulated cranial procedures have also been designed, from ventriculostomy placement to cerebral aneurysm clipping and brain tumor resection. The CNS Simulation Committee implemented a trauma module at two annual meetings, including ventriculostomy and craniotomy procedures; participants performing ventriculostomies demonstrated improved burr hole placement, catheter location, and procedure completion time [15], and those participating in craniotomies for traumatic brain injury bettered their incision planning, burr hole placement, and craniotomy size [16]. Similarly, utilizing the ImmersiveTouch ®, neurosurgical residents improved their ability to perform ventriculostomy, with an increase in successful first-pass attempts [17]; in using a novel mixed-reality simulator, residents placed ventriculostomy catheters more accurately and in less time after practicing with the device [18]. VR simulators have also implemented in vascular procedural training; for instance, using the ImmersiveTouch ® virtual reality platform with real-time sensory haptic feedback to rehearse cerebral aneurysm clipping, neurosurgical residents reported usefulness of the simulation in preparing for surgery [19]. An application of the NeuroTouch ® VR simulator for practicing the endoscopic endonasal transsphenoidal approach has also been developed [20], and a study on simulated practice of endoscopic endonasal procedures using this platform showed improved operative performance among residents [21]. Several additional studies have also examined the NeuroTouch ® platform in simulated brain tumor resection [22–24]. The National Research Council of Canada published their conceptual framework for a simulation-based curriculum utilizing the NeuroTouch ®, which developed five standardized training modules for technical skill acquisition in neurosurgical oncology, including ventriculostomy, endoscopic nasal navigation, tumor debulking, hemostasis, and microdissection [25].

Skills Development and Performance Metrics

Advocates of the incorporation of virtual reality simulation into neurosurgical education argue that VR simulators strengthen cognitive task processing, technical skills, and understanding of operative and neuroanatomy [4]. Advancing technology has become increasingly realistic as the VR platforms have become both more immersive and interactive, adding haptic feedback to visual and audio cues. Simulators such as Simbionix ® ANGIO Mentor ™, NeuroTouch ®, and ImmersiveTouch ® include tactile feedback to represent the force required of the user to perform a particular task with a specific instrument and to replicate the texture of the tissue. Better visualization of operative anatomy improves understanding of relationship between key structures; current technology, including the Surgical Theater ®, allows cut-throughs and specific tissue selection to view the neuroanatomy, including patient-specific imaging data and reconstructions, which may prove useful not only in the study of the pertinent structures but also in the design of surgical approaches.

VR simulators offer longitudinal tracking of learning and improvement among objective performance assessments, which represents another advantage of simulator-based training within neurosurgical residency. Further, simulator-based curriculums can be incrementally designed, providing increasing number of tasks with growing complexity and layering of possible complications. The NeuroTouch ® platform provides reports on specific computer-generated metrics, which derived 13 performance metrics and categorized into tier 1, tier 2, or tier 3 [23]. Tier 1 metrics aim to evaluate safety and quality and include volume of tumor and brain resected as well as blood loss. Tier 2 metrics assess motor skills, such as instrument tip path length, time taken to resect the brain tumor, pedal activation frequency, and sum of applied forces. Advanced tier 2 and tier 3 metrics measure complex motor and cognitive bimanual skills interactions, including sum of forces applied to different tumor regions, instrument tips average separation distance, efficiency index, simulated aspirator path length index, coordination index, and simulated ultrasonic aspirator bimanual forces ratios [23, 24, 26]. These metrics have further been studied to assess proficiency among varying level of experience, from novice to expert, which enabled the authors to establish goal benchmarks for neurosurgical residents [27].

In several published studies, a variety of VR simulator platforms appropriately discriminate among level of expertise, which further enhances their utility in neurosurgical education and competency assessment. Seventy-one residents participated in a study of the simulation-based training in percutaneous trigeminal rhizotomy using the ImmersiveTouch ®; as PGY level increased, the distance from ideal entry point decreased, as well as the distance from the target, and more senior residents had better final scores [28]. Another study assessing performance in brain tumor resection on the NeuroTouch ® device with eight different lesions varying in color, stiffness, and border complexity successfully differentiated from novice and expert participants [23]. Using the Simbionix ® ANGIO Mentor ™ to assess performance in carotid artery stenting, a study of 33 participants in 82 simulated procedures appropriately discriminated between operator experience with metrics of fluoroscopy time, incomplete coverage of the lesion by the stent, and coverage of the lesion with devices other than a 0.014-in. wire prior to filter deployment [29].

Limitations of Simulation in Training

Although VR simulation provides many advantages in neurosurgical training and certainly enhances graduate medical education, it does not replace hands-on experience of live, real-time operating. The simulated procedures are not perfectly realistic, but haptic and visual feedback have improved drastically over recent years. The cases are also not truly three-dimensional; however, with the advancement of holographic technologies, such as the Microsoft HoloLens, this limitation may be short-lived. Furthermore, current simulators are generally not patient-specific, which limits their utility in operative planning and practice; however, recent technological advancements, including newer iterations of Surgical Theater ®, may incorporate patient-specific details, allowing for improved preoperative anatomical visualization. Furthermore, although the benefits of VR-based simulators in neurosurgical education may be easily recognized, the literature on these technologies and on educational curriculums based on them is limited to small studies and affected by publication bias. Larger studies to validate VR simulators in neurosurgical education are required.

To date, only one publication illustrates the cost and financial feasibility of including simulation in neurosurgical training. To quantify the total costs and benefits of incorporating simulation-based curricula remains a challenging task. Gasco et al. discuss the development of a simulation program for neurosurgical residents at the University of Texas Galveston [30]. Within this study, 180 procedures among six residents were analyzed, and both junior and senior residents self-reported improvement in performing procedures following simulations. This simulation program included cadaver simulations, physical simulators, and computer-based platforms and cost $341,978.00 initially with $27,876.36 annually afterward, although industry collaboration defrayed expenses through academic grants and equipment rentals. In this study, costs comprehensively included materials, equipment, space, and operating room time, which do not necessarily translate from one program to another, depending on the resources available and the specific program contents of the simulation curriculum (i.e., strictly computer-based versus cadaver and physical simulators).

Conclusion and Future Directions

Although simulations are not formally included in neurosurgical training across residency programs, one might easily imagine the incorporation of VR-simulated case scenarios into board examinations. Many studies are ongoing to confirm the validity of VR simulators in a variety of neurosurgical procedures and among trainees, and as these simulators continue to improve, an expansion of their use in graduate medical education becomes more likely. As imaging quality improves, computing power expands, and simulation software advances, the application of VR simulators in neurosurgery will similarly grow, especially as patient-specific data may be incorporated into future procedure simulations. Currently, VR simulators provide an avenue for basic procedural skill acquisition among residents. In the future, as support from national professional societies and industry spreads and new technologies emerge, simulators will become more affordable, readily available, and effective adjuncts to neurosurgical education.

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