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While still in its infancy, AR has already proven beneficial for educational training and intraoperative MISS applications. We believe that with continued research and advancement of this technology, AR is poised to become a dominant player within the fundamentals of surgical education and MISS operative technique [1).

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Augmented reality devices on the market show promising clinical outcomes in preoperative training and intraoperative use. Three prominent systems were: XVision, HoloLens, and ImmersiveTouch.

Perin et al. conducted a study involving 92 residents and attending neurosurgeons from different European Centres; each participant had to perform a virtual task, namely the placement of an external ventricular drain (EVD) at a neurosurgical simulator (ImmersiveTouch). The number of attempts needed to reach the ventricles and the accuracy in positioning the catheter were assessed.

Data suggests a positive correlation between subjects who placed more EVDs in the previous year and those who get better scores at the simulator (p = .008) (fewer attempts and better surgical accuracy). The number of attempts to reach the ventricle was also analyzed; senior residents needed fewer attempts (mean = 2.26; SD = 1.11) than junior residents (mean = 3.12; SD = 1.05) (p = .007) and staff neurosurgeons (mean = 2.89, SD = 1.23). Scoring results were compared by using the Fisher's test, for the analysis of the variances, and the Student's T-test. Surprisingly, having a wider surgical experience overall does not correlate with the best performance at the simulator.

The performance of an EVD placement on a simulator correlates with the density of the neurosurgical experience for that specific task performed in the OR, suggesting that simulators are able to differentiate neurosurgeons according to their surgical ability. Namely, this suggests that the simulation performance reflects the surgeons' consistency in placing EVDs in the last year [2)]

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 the 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 [3)].

A real-time sensory haptic feedback virtual reality aneurysm clipping simulator was developed using the ImmersiveTouch platform. A prototype middle cerebral artery aneurysm simulation was created from a computed tomographic angiogram. Aneurysm and vessel volume deformation and haptic feedback are provided in a 3-dimensional immersive virtual reality environment. Intraoperative aneurysm rupture was also simulated. Seventeen neurosurgery residents from 3 residency programs tested the simulator and provided feedback on its usefulness and resemblance to real aneurysm clipping surgery.

Residents thought that the simulation would be useful in preparing for real-life surgery. About two-thirds of the residents thought that the 3-dimensional immersive anatomic details provided a close resemblance to real operative anatomy and accurate guidance for deciding surgical approaches. They thought the simulation was useful for preoperative surgical rehearsal and neurosurgical training. A third of the residents thought that the technology in its current form provided realistic haptic feedback for aneurysm surgery.

Neurosurgical residents thought that the novel immersive VR simulator is helpful in their training, especially because they do not get a chance to perform aneurysm clippings until late in their residency programs [4)].

Twenty junior medical students participated in the study and were randomized into two groups. Subjects in Group A participated in virtual simulation training using the ImmersiveTouch simulator

(ImmersiveTouch, Inc., Chicago, IL, USA) that required differentiating the firmness of virtual spheres using tactile and kinesthetic sensation via haptic technology. Subjects in Group B did not undergo any training. With their visual fields obscured, subjects in both groups were then evaluated on their ability to use the suction and bipolar instruments to find six elastothane objects with areas ranging from 1.5 to 3.5 cm2 embedded in a urethane foam brain cavity model while relying on tactile and kinesthetic sensation only.

Results: A total of 73.3% of the subjects in Group A (simulation training) were able to find the brain cavity objects in comparison to 53.3% of the subjects in Group B (no training) ($P = 0.0183$). There was a statistically significant difference in the total number of Group A subjects able to find smaller brain cavity objects (size ≤ 2.5 cm2) compared to that in Group B (72.5 vs. 40%, $P = 0.0032$). On the other hand, no significant difference in the number of subjects able to detect larger objects (size ≧ 3 cm2) was found between Groups A and B (75 vs. 80%, $P = 0.7747$).

Virtual computer-based simulators with integrated haptic technology may improve tactile discrimination required for the microsurgical technique [5].

Twenty-six senior medical students anonymously participated and were randomized into two groups (A = no simulation; B = simulation). Both groups were given 15 minutes to place two pedicle screws in a sawbones model. Students in Group A underwent traditional visual/verbal instruction whereas students in Group B underwent training on pedicle screw placement in the ImmersiveTouch simulator. The students in both groups then placed two pedicle screws each in a lumbar sawbones models that underwent triplanar thin slice computerized tomography and subsequent analysis based on coronal entry point, axial and sagittal deviations, length error, and pedicle breach. The average number of errors per screw was calculated for each group. Semi-parametric regression analysis for clustered data was used with generalized estimating equations accommodating a negative binomial distribution to determine any statistical difference of significance.

Results: A total of 52 pedicle screws were analyzed. The reduction in the average number of errors per screw after a single session of simulation training was 53.7% ($P = 0.0067$). The average number of errors per screw in the simulation group was 0.96 versus 2.08 in the non-simulation group. The simulation group outperformed the non-simulation group in all variables measured. The three most benefited measured variables were length error (86.7%), coronal error (71.4%), and pedicle breach (66.7%).

Conclusions: Computer-based simulation appears to be a valuable teaching tool for non-experts in a highly technical procedural task such as pedicle screw placement that involves sequential learning, depth perception, and understanding triplanar anatomy [6]

Gasco et al. used the ImmersiveTouch simulation platform (ImmersiveTouch, Inc., Chicago, Illinois, USA) in two U.S. Accreditation Council for Graduate Medical Education-accredited neurosurgical training programs: the University of Chicago and the University of Texas Medical Branch. A total of 54 trainees participated in the study, which consisted of 14 residents (group A), 20 senior medical students who were neurosurgery candidates (group B), and 20 junior medical students (group C). The participants performed a simulation task that established bipolar hemostasis in a virtual brain cavity and provided qualitative feedback regarding perceived benefits in eye-hand coordination, depth perception, and potential to assist in improving operating skills.

Results: The perceived ability of the simulator to positively influence skills judged by the three groups: group A, residents; group B, senior medical students; and group C, junior medical students was, respectively, 86%, 100%, and 100% for eye-hand coordination; 86%, 100%, and 95% for depth perception; and 79%, 100%, and 100% for surgical skills in the operating room. From all groups, 96.2% found the simulation somewhat or very useful to improve eye-hand coordination, and 94% considered it beneficial to improve depth perception and operating room skills.

This simulation module may be suitable for resident training, as well as for the development of career interest and skill acquisition; however, validation for this type of simulation needs to be further developed [7].

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