The utility of virtual reality and augmented reality in spine surgery

Joon S. Yoo, Dillon S. Patel, Nadia M. Hrynewycz, Thomas S. Brundage, Kern Singh

Department of Orthopaedic Surgery, Rush University Medical Center, Chicago, IL, USA

Contributions: (I) Conception and design: JS Yoo, DS Patel, K Singh; (II) Administrative support: NM Hrynewycz, TS Brundage; (III) Provision of study materials or patients: NM Hrynewycz, TS Brundage; (IV) Collection and assembly of data: NM Hrynewycz, TS Brundage; (V) Data analysis and interpretation: JS Yoo, DS Patel, K Singh; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Kern Singh, MD. Professor, Department of Orthopaedic Surgery, Rush University Medical Center, 1611 W. Harrison St., Suite #300, Chicago, IL 60612, USA. Email: kern.singh@rushortho.com.

Abstract: As the number of advances in surgical techniques increases, it becomes increasingly important to assess and research the technology regarding spine surgery techniques in order to increase surgical accuracy, decrease overall length of surgery, and minimize overall radiation exposure. Currently, augmented reality and virtual reality have shown promising results in regard to their applicability beyond their current functions. At present, VR has been generally applied to a teaching and preparatory role, while AR has been utilized in surgical settings. As such, the following review attempts to provide an overview of both virtual reality and augmented reality, followed by a discussion of their current applications and future direction.

Keywords: Virtual reality (VR); augmented reality (AR); simulation; training; navigation

Submitted Jun 12, 2019. Accepted for publication Jun 17, 2019.
doi: 10.21037/atm.2019.06.38
View this article at: http://dx.doi.org/10.21037/atm.2019.06.38

Introduction & background

In recent years, technological systems such as virtual reality (VR) and augmented reality (AR) have become more heavily researched. However, the application of such simulation systems remains in infancy. At present, there are three principal types of simulation systems that have been documented in the literature: (I) virtual reality, where the entire simulation is virtual; (II) mixed reality, which is a combination of virtual and physical components; and (III) augmented reality, in which case a virtual component is superimposed onto a physical reality. Recently, augmented reality, in the form of a heads-up display, has been primarily employed and studied in the cervical spine (1), thoracic spine (2), lumbar spine (3), deformity (4), kyphoplasty, and vertebroplasty (5), and biopsy (6). This is contrasted with VR that has more often been used in an educational and preparational capacity, allowing medical students, residents, and surgeons to practice procedures in a controlled environment, eschewing the risk of serious error.

Though there is an overall paucity in the literature regarding the true applicability of these aforementioned technological advances, there are a number of studies demonstrating the potential for these tools to be applicable to the spine surgery practice. Not only do these tools offer the advantage of increasing surgical accuracy, they also have the potential benefit of reducing ionizing radiation exposure and improving clinical outcomes that must be weighed against cost and workflow concerns.

Methodology

Studies published in the literature regarding virtual reality and augmented reality in the context of spine surgery were identified. Article types including retrospective cohort studies, prospective studies, and randomized controlled trials (RCT) were searched using PubMed, MEDLINE, and the Cochrane Library. Relevant keywords that were used included “virtual reality”, “augmented reality”, “spine surgery”, “education”, “training”, “simulation”, “imaging”, “guidance” and “pedicle screw placement”. Though English articles were exclusively considered, studies were not additionally excluded on the parameters of publication date and/or country of origin. Articles considered for this review were identified by relevant search criteria including title, keywords, abstract, and full-text.

AR in spine surgery

Pedicle screw placement

AR can be defined as the superimposition of a virtual environment on the real world, offering an enhanced view of reality through the use of computer-generated digital images. Spine surgeons may find utility in AR through wearable heads up displays and projection of images on real world surroundings inside the operating room. One promising avenue in which AR can provide valuable intraoperative assistance to the spine surgeon is during pedicle screw fixation. The current standard for pedicle screw placement during spinal has room for improvement. In an overarching study of 4,790 pedicle screws, 5.1% breaches were reported, representing an alarming amount that requires urgent attention (7). AR allows surgeons to not move their field of vision from the patient during a procedure and instead maintain their gaze while assessing the relevant trajectories and anatomy. Despite this form of simulation system being relatively untired, the interesting amount of potential has preempted a push for the assessment of its surgical accuracy and safety *in vivo*.

Given that pedicle screw breaches have an inherent potential to be dangerous, Abe *et al.* attempted to assess the safety and effectiveness of AR in spine models *in vivo* with a patient population undergoing percutaneous vertebroplasty (8,9). The authors found an average error of the needle insertion angle to be 2.09 degrees in the axial plane and 1.98 degrees in the sagittal plane with no pedicle breaches noted (8,9). In addition, Emi-Terander *et al.* investigated AR in a cadaveric model instead of a virtual patient and showed that AR was able to increase both accuracy and efficiency with thoracic pedicle screws, which are smaller than in the lumbar spine, making them inherently more difficult to place appropriately (10). It is important to note that a hybrid operating room was set up in which a flat detector C-arm with intraoperative imaging capabilities, optical cameras for AR navigation, and patient motion tracking were employed (10). The additional benefits of this design was the fact that fluoroscopy was not used, sparing radiation exposure, and real time operating guidance was able to increase the overall screw accuracy (10). In addition, Luciano *et al.* employed AR as a training tool, in which 51 residents and fellows placed virtual screws into virtual patients and demonstrated that trainees benefited from AR technology (2). Specifically, this study used an *Immersive Touch* technology, which is a workstation that includes an electromagnetic head-tracking systems, AR, and haptic feedback (2).

A number of other studies have assessed the applicability of AR to lumbar spine pedicle screw placement. Gibby *et al.* made use of a head-mounted display AR with superimposed CT to insert percutaneous pedicle screws on a silicone sawbone model. The authors determined that 97% of needles were placed into pedicles (3). Furthermore, Ma *et al.* conferred a unique AR surgical navigation system employed on a sheep cadaver that was entirely based on ultrasound assisted registration for pedicle screw placement (11). With the combination of ultrasound, AR, and CT, followed by an intrinsic videography overlay device, pedicle screws were placed and deemed both effective and accurate (11). The findings determined from the aforementioned studies were further substantiated by a ground-breaking 2018 paper in which Elmi-Terander *et al.* used a prospective clinical trial of 20 patients for spinal fixation and reported an overall thoracic pedicle screw accuracy level of 94.1%. This demonstrated that a high level of accuracy could be obtained through the use of AR in pedicle screw placement (12).

Cervical spine

In addition to the growing body of evidence related to the use of AR in the context of pedicle screw placement, AR is now being discussed in the realms of cervical spine. In fact, the first cervical spine AR application was unveiled in 2018 where AR was used in combination with navigation to allow for necessary anatomical landmarks to be projected onto the surgeon's visualized microscopic view (13). This investigation referenced patients that were undergoing minimally invasive anterior cervical discectomy and fusion and posterior cervical laminotomy and foraminotomy (13). The authors concluded that AR was helpful in both surgeries, thus providing credence to a wider implementation of AR (13).

Deformity

Spinal deformity is another subspeciality of spine surgery that can benefit from the advances of AR. Due to the inherent 3-dimensional nature, paired with high complication rates and aberrations from normal anatomy, spinal deformity surgeries are difficult to perform. Kosterhon *et al.* employed AR to visualize resection planes of an intraoperative osteotomy in a live patient to determine if it could help increase accuracy and patient safety (4). The study utilized a heads-up display in the virtual resection planes made visible through the microscope eyepieces in combination with Brainlab navigation systems (4). Ultimately, the authors concluded that the surgeon benefitted from the heads-up display and was able to turn the display off if it was ever found to be too distracting (4).

VR in spine surgery

VR training mechanisms

VR has been well-established as a learning and training tool that allows surgeons and trainees alike to improve surgical technique while avoiding the possibility of making a mistake on a live patient. In a study of medical students who were practicing lumbar pedicle placements, potential advantages of VR in contrast to traditional methods of learning were explored (14). In this study, one group utilized traditional visual and verbal instructions, while the other group made use of an "ImmersiveTouch" VR simulator (14). The authors determined that the simulation group outperformed the traditional learning group in all variables including trajectory, depth of screw error, and breach. The results were attributed to the sequential learning, enhanced depth perception, and increased 3-dimensional anatomical understanding (14). Shi *et al.* performed a randomized study, using VR in the form of a surgical training simulator, that was specifically targeted to resident and fellow learning (15). The authors of this study also grouped participants into two cohorts in which one group made use of "traditional" methods while the other group made use of VR (15). The study determined that residents and fellows significantly benefited from VR usage in regard to accuracy of pedicle placement, which was increased in the VR group as compared to the group utilizing traditional learning methods (15).

Gottschalk *et al.* provided further credence to the applicability of VR through a blinded, randomized controlled trial that examined whether VR helped residents improve lateral mass screw insertion in the cervical spine of cadavers and sawbones (16). The authors determined that residents significantly improved when previously trained with VR (16). Though popularized as a tool exclusively for medical students, residents, fellows, Halic *et al.* determined that the use of VR and AR in a VICON optical motion tracking system allowed five attending-level physicians to actively learn cervical disc replacements (CDR) more easily (17).

Conclusions

Currently, AR and VR serve various promising functions in the realm of spine surgery, but these simulation systems remain in infancy. Though the potential of simulation systems cannot be discounted, few prospective and randomized control trials are currently available in the literature. Given that AR and VR in spine surgery are growing at such a rapid pace, further research and collaboration will be necessary to ensure that these simulation systems continue to improve and expand in their applications to spine surgery.

Acknowledgments

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

References

1. Umebayashi D, Yamamoto Y, Nakajima Y, et al. Augmented Reality Visualization–guided Microscopic Spine Surgery. J Am Acad Orthop Surg Glob Res Rev 2018;2:e008.
2. Luciano CJ, Banerjee PP, Bellotte B, et al. Learning retention of thoracic pedicle screw placement using a high-resolution augmented reality simulator with haptic feedback. Neurosurgery 2011;69:ons14-9; discussion ons19.
3. Gibby JT, Swenson SA, Cvetko S, et al. Head-mounted display augmented reality to guide pedicle screw placement utilizing computed tomography. Int J Comput Assist Radiol Surg 2019;14:525-35.
4. Kosterhon M, Gutenberg A, Kantelhardt SR, et al. Navigation and Image Injection for Control of Bone

Removal and Osteotomy Planes in Spine Surgery. Oper Neurosurg (Hagerstown) 2017;13:297-304.
5. Deib G, Johnson A, Unberath M, et al. Image guided percutaneous spine procedures using an optical see-through head mounted display: proof of concept and rationale. J Neurointerv Surg 2018;10:1187-91.
6. Fritz J, U-Thainual P, Ungi T, et al. Augmented reality visualization using image overlay technology for MR-guided interventions: cadaveric bone biopsy at 1.5 T. Invest Radiol 2013;48:464-70.
7. Lonstein JE, Denis F, Perra JH, et al. Complications associated with pedicle screws. J Bone Joint Surg Am 1999;81:1519-28.
8. Kirkman MA, Ahmed M, Albert AF, et al. The use of simulation in neurosurgical education and training. A systematic review. J Neurosurg 2014;121:228-46.
9. Abe Y, Sato S, Kato K, et al. A novel 3D guidance system using augmented reality for percutaneous vertebroplasty: technical note. J Neurosurg Spine 2013;19:492-501.
10. Elmi-Terander A, Nachabe R, Skulason H, et al. Feasibility and Accuracy of Thoracolumbar Minimally Invasive Pedicle Screw Placement With Augmented Reality Navigation Technology. Spine (Phila Pa 1976) 2018;43:1018-23.
11. Ma L, Zhao Z, Chen F, et al. Augmented reality surgical navigation with ultrasound-assisted registration for pedicle screw placement: a pilot study. Int J Comput Assist Radiol Surg 2017;12:2205-15.
12. Elmi-Terander A, Burström G, Nachabe R, et al. Pedicle Screw Placement Using Augmented Reality Surgical Navigation With Intraoperative 3D Imaging: A First In-Human Prospective Cohort Study. Spine (Phila Pa 1976) 2019;44:517-25.
13. Mascitelli JR, Schlachter L, Chartrain AG, et al. Navigation-Linked Heads-Up Display in Intracranial Surgery: Early Experience. Oper Neurosurg (Hagerstown) 2018;15:184-93.
14. Gasco J, Patel A, Ortega-Barnett J, et al. Virtual reality spine surgery simulation: an empirical study of its usefulness. Neurol Res 2014;36:968-73.
15. Shi J, Hou Y, Lin Y, et al. Role of Visuohaptic Surgical Training Simulator in Resident Education of Orthopedic Surgery. World Neurosurg 2018;111:e98-104.
16. Gottschalk MB, Yoon ST, Park DK, et al. Surgical training using three-dimensional simulation in placement of cervical lateral mass screws: a blinded randomized control trial. Spine J 2015;15:168-75.
17. Halic T, Kockara S, Bayrak C, et al. Mixed reality simulation of rasping procedure in artificial cervical disc replacement (ACDR) surgery. BMC Bioinformatics 2010;11 Suppl 6:S11.

Cite this article as: Yoo JS, Patel DS, Hrynewycz NM, Brundage TS, Singh K. The utility of virtual reality and augmented reality in spine surgery. Ann Transl Med 2019;7(Suppl 5):S171. doi: 10.21037/atm.2019.06.38

