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Virtual Reality in Orthopedic Surgery Training

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Abstract: One emerging technology with the potential to improve and further transform the field of orthopaedic surgery is virtual reality (VR). VR has been explored and used in many different specialties with clinical applications, such as psychiatric therapy, pain management, rehabilitation, and traumatic brain injury. Recent studies have suggested that the use of VR during the training of orthopaedic surgery residents produces similar or improved surgical performance by residents. This is an area where VR can provide a tremendous benefit to the field of orthopaedic surgery, as it offers a safe and accessible complement to orthopaedic surgical training outside of the operating room (OR) and without involving patients directly. This review will elucidate the current state of virtual reality use in the training of orthopaedic surgeons and highlight key benefits and challenges in its application as a training resource.

Keywords: virtual reality, orthopaedic, surgery, medical education, training

Introduction

Technological advances continue to improve and transform the field of medicine and patient care. One emerging technology is virtual reality (VR). VR is a technology that uses 3-dimensional imaging and databases to create a simulate, interactive environment, typically using a head-mounted display. VR has been explored in many different specialties with clinical applications, such as psychiatric therapy, pain management, rehabilitation, and traumatic brain injury.¹⁻⁵ This technology has the potential for a wide range of uses in orthopaedic surgery, such as surgical training, pre-operative planning, and intra-operative navigation.

Currently, VR is predominantly utilized by orthopaedic surgeons for pre-operative planning and training.⁶ There is considerable variability among orthopaedic surgery residency programs in the frequency of use and applications of VR in training residents.⁷ The literature is also limited regarding the exposure to VR training exercises orthopaedic surgery residents receive nationally. Current applications of VR in resident training include arthroscopic simulators, fully immersive operative simulations (eg, trauma management, arthroplasty), bone drilling haptic simulators, and reconstruction simulations.^{6,8-11}

Studies exploring VR use have been limited in the past due to infrequent utilization and incomplete development of the technology. However, adoption has accelerated with continued development and more studies have investigated its use during the last decade. Recent studies have suggested that the use of VR during the training of orthopaedic surgery residents improves surgical performance.^{7,9,10,12} This is an area where VR can provide a tremendous benefit to the field of orthopaedic surgery as it offers a safe and accessible complement to orthopaedic surgical training outside of the operating room (OR) without involving patients directly.¹³ Additionally, VR

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simulation may prove especially valuable in the development of arthroscopic skill where the nature of arthroscopic surgery can make it more difficult for residents to develop from assisting and observation alone.¹⁴ Furthermore, the use of VR has been positively received by residents and associated with increased comfort in perceived operating skills.^{14,15} Recent primary studies referenced in this study are summarized in Table 1.

As discussions around developing a standardized orthopaedic surgical skills curriculum continue, it is important to continue exploring the efficacy of VR in education,

challenges in its use, barriers to its adoption, and its safety in surgical training.^{6,16} Overarching advantages and disadvantages of the use of VR simulators in orthopaedic training are summarized in Table 2. This review will elucidate the current state of virtual reality use in the training of orthopaedic surgeons and highlight key benefits and challenges in its application as a training resource.

Virtual Reality Technology Overview

Virtual reality is a technology capable of producing a simulation that allows users to become immersed in

Table 1 Summary of Referenced Primary Studies Evaluating the Use of Virtual Reality Simulation in Orthopaedic Surgery Training Published Within Five Years

Study	Population	Methods	Outcomes
Logishetty et al, 2019 ⁸	24 surgical trainees naïve to anterior approach total hip arthroplasty	1:1 randomization with 12 trainees completing conventional preparation and 12 trainees completing a six-week immersive VR training using headsets and a VR-enabled operating room	VR trainees outperformed conventional trainees requiring less guidance and instructor intervention, completing more key steps, more accurately handling instruments, and finishing in less overall time in a procedure-based assessment
Walbron et al, 2020 ²²	107 first-year residents learning arthroscopy	Non-random assignment to one of three groups: conventional training only (Group A, 76 residents); conventional training with a single, non-VR supplemental session (Group B, 17 residents); conventional training with 10 hours of VR training (Group C, 14 residents)	VR-trained residents (Group C) outperformed both other groups in procedure time and measures of accuracy and instrument handling in two procedure-based assessments
Khanduja et al, 2017 ²³	10 residents who had completed <250 hip arthroscopies each and 9 faculty who had completed >250 hip arthroscopies each	All participants completed a procedure-based assessment that measured procedure time, soft tissue and bone collisions, and instrument handling	Faculty outperformed residents showing a correlation between experience in hip arthroscopy and performance in the simulator supporting the construct validity of the simulator and its potential to assist in the development of basic arthroscopic skills
Hooper et al, 2019 ³⁴	14 first-year residents who had completed one cadaver total hip arthroplasty	1:1 randomization with 7 trainees completing conventional preparation and 7 trainees completing conventional preparation and two virtual total hip arthroplasties before completing their second cadaver total hip arthroplasty	VR-trained residents outperformed the conventionally trained residents in all steps of the Ottawa Surgical Competency Operating Room Evaluation in the second cadaver total hip arthroplasty
Lohre et al, 2020 ³⁶	16 senior residents and 7 faculty	1:1 randomization with 8 residents and 3 faculty completing conventional preparation and 8 residents and 4 faculty completing a single immersive VR training using headsets and a VR-enabled operating room	VR-trained participants outperformed the conventionally trained participants in mean time and instrument handling while within groups experience correlated to greater simulator performance supporting the construct validity of the simulator and its potential to assist in the development of basic arthroscopic skills

Table 2 Advantages and Disadvantages of Virtual Reality in Teaching Orthopaedic Procedures

Advantages	Disadvantages
Potential benefit to patient safety and ethical acceptability	Nascent technology with imperfect fidelity
Opportunity to assess trainee competence in a consistent and reproducible manner	Expensive to implement
Low-risk environment in which trainees can practice at any time	Limited evidence regarding optimal implementation within residency training
Predictable availability regardless of external factors	Limited to certain procedures
Emerging evidence of construct validity and transferability of simulator skills	Current simulators only focus on developing technical skill and do not incorporate interaction with the rest of the intraoperative team

and interact with a three-dimensional, computer-generated multisensory environment.¹⁷ It typically involves the use of a head-mounted display placing the user inside the experience, thus making the environment and experience feel realistic. VR simulators also characteristically involve the use of handheld devices capable of allowing users to experience force-feedback haptic technology, including visual and physical feedback. These handheld devices are able to be tracked and their movement measured with incredible accuracy, up to the submillimeter.¹⁸ Beyond the hardware, VR also offers valuable software advantages specific to surgical training, such as automatically measuring and assessing performance through the use of advanced analytics and algorithms. Currently, VR simulators are used in a variety of industries, such as the training of aviation pilots, first responders for disaster preparation, and the military.

Virtual Reality Training in Arthroscopic Surgery

Arthroscopy has been a particularly challenging skill to train residents on with less opportunity for “hands on” learning. Consequently, many of the studies investigating the use of VR in orthopaedic surgical training have focused on its impact on arthroscopic surgical skills.¹⁹ Various resources exist to supplement OR experiences for residents, including cadaveric models, sawbone models, low-fidelity simulators, and high-fidelity simulators,

including VR.¹⁹ Arthroscopic simulators, such as the Knee arthroscopy surgical trainer (KAST) developed by the AAOS and the Symbionix Arthromentor, are capable of providing haptic feedback of simulated cartilage and tendon and mimic surgical tools.⁶ Simulators using VR also offer three-dimensional views of anatomy, can simulate realistic events such as bleeding, and also offer recording and analysis on performance.²⁰ Consequently, VR simulations offer unique advantages in comparison to more traditional simulators and to other methods of education.

While many simulators exist, the fully immersive VR systems have had the most demonstrated evidence of improvement in surgical skills.²¹ In a study of 107 first-year residents investigating the effect of VR training on arthroscopy skills, Walbron et al found that after 6 months of VR training, there was significant improvement in surgical performance such as camera alignment, camera path, camera path length, and grasper path length.²² However, evidence of translation of these results into real-life skills in the OR is imperative. A study investigating the reliability and validity of the Arthromentor simulator found that there are significant differences in time and operative accuracy between novice and expert groups with two operative tasks, supporting its construct validity.²³ This finding is promising as it supports the viability of incorporating VR training simulators into residency curriculums. In another multicenter, randomized, blinded study assessing the efficacy of the ArthroSim VR arthroscopic knee simulator, Cannon et al found that residents trained on the VR simulator performed significantly better in the operating room compared to the control group based on the authors’ procedural checklist ($p = 0.031$) and including probing skills ($p = 0.016$).²⁴ This is noteworthy as it demonstrates transfer validity, meaning that skills acquired through simulations transfer to applicable skills in the OR. Another meta-analysis studying the utility of arthroscopic simulators in transferring skills learned on the model to the OR found that simulator training can improve basic diagnostic arthroscopy skills in a human joint.¹⁹ Additional studies have also further supported the transfer validity of VR arthroscopic training, including improvement in performance on cadaveric models following VR training.^{25–28} It has also been suggested that training with VR arthroscopic simulators can improve time to completion of diagnostic shoulder arthroscopy.²⁹ Therefore, VR may be a viable option to use as a supplemental training tool to improve arthroscopic skills among orthopaedic residents in the OR setting.

The frequency of use of VR training among residency programs vary. In a survey study conducted in 2015 of orthopaedic residency program directors, sports medicine faculty, and orthopaedic residents, Koehler et al found that only 9.8% of programs utilized VR as an arthroscopic training resource.³⁰ Furthermore, programs vary in the type of simulator available at their institution given the higher cost associated with higher fidelity simulators.³¹ For example, just one high fidelity arthroscopic simulator can cost as high as \$10,000.¹⁷ It is therefore important to continue to explore the efficacy and value VR training adds to resident education to justify the high cost of the technology. There is also variation in the timing and amount of exposure orthopaedic residents have to VR training.¹⁷ Most orthopaedic surgery residencies incorporate some form of laboratory-based surgical skills training into the intern year curriculum, with some including VR training. However, the exposure to VR training is often limited to that short period during the first year of training. Studies have revealed how there is increased benefit in the use of VR training tools later in residency when compared to at the start of their training.¹⁷ Given the potential VR training encompasses in improving more technical surgical skills in residents, it is worth considering integrating further VR exposure later into residents' training.

The Expanding Scope of Virtual Reality Simulation

The use of VR in surgical education extends beyond arthroscopic simulators. As VR technology continues to advance, so too has its scope - encompassing more areas in orthopaedic surgery such as arthroplasty, fracture management, bone drilling, open procedures, and others.^{8,11,32} With this expansion in scope, VR offers residency programs a valuable tool at enhancing key surgical skills for orthopaedic residents, such as intramedullary nail placement, pedicle screw placement, hemiarthroplasty, and fixation of pelvic fractures.³³⁻³⁵ Studies investigating the efficacy of VR in open procedures have also revealed that its utilization is an effective educational tool.^{10,33-35} In a multicenter, blinded, randomized control trial investigating the efficacy and validity of immersive VR training in orthopaedic resident education, Lohre et al found that immersive VR demonstrated improved translational technical and nontechnical skills acquisition over traditional learning in senior orthopaedic residents.³⁶ Participants in the study utilized a head-mounted display and haptic

controllers in a virtual OR and performed an open glenoid exposure. Another randomized control trial conducted by Logishetty et al observing 24 surgical residents found that VR-trained residents performed a hemiarthroplasty at a higher level than the control cohort as assessed by 2 independent hip surgeons.⁸ The authors found VR-trained surgeons completed 33% more key steps than controls, were 12° more accurate in component orientation, and were 18% faster.⁸ In a stratified, randomized control trial comparing 22 orthopaedic surgery residents' performance on a virtual ulnar surgical fixation simulator to performance on a sawbones simulator, LeBlanc et al found that both simulators distinguished between differing experience levels, demonstrating construct validity.¹⁰

Given the increasing scope and potential VR offers as a surgical training tool, it may be a particularly useful and effective educational tool. As health-care systems and residency programs continue to deal with the transition to more virtual and remote learning environments, VR can fill the gap left from less frequent in-person activities and patient exposure.³⁷ Furthermore, VR offers a solution to patient safety concerns, as it provides trainees access to a variety of techniques that may accurately simulate real-life procedures while minimizing the risk to the patients.³⁸ It also allows the possibility for residents to practice and rehearse procedures without a limit on the number of times they can do so, and with less ethical concerns and need for supervision.

Barriers to the Implementation of Virtual Reality in Surgical Training

The incorporation of VR into surgical training is not without its unique challenges and cost. As previously discussed, there are many different options and types of VR simulators available on the market. It is difficult to draw conclusions on VR simulators across all brands and types, and consequently it is important to understand and be aware of the specific VR simulator being considered. Furthermore, the cost of a simulator is considerably higher than an alternative lower fidelity simulator or educational tool. As an example, the cost of one fracture reduction model using a sawbone kit can cost around \$455 compared to the cost of the Arthromentor Symbionix's cost of > \$10,000.^{39,40} For many programs, this significant expense may either be unfeasible or not perceived to be valuable enough. Therefore, further research into the efficacy, reliability, and cost-benefit analysis of VR in resident

education should be done to aid in residency program leadership decision making. More studies validating the translation of VR acquired skills to real world surgical skills need to be conducted.

Satisfaction and Impression of Virtual Reality Among Trainees

Despite accelerating research and development, studies of virtual reality surgical simulators have yet to rigorously assess trainee satisfaction and impressions. Only two studies included in this literature review focused on this topic. A survey of 142 orthopedic surgeons in 2005 found the majority expected virtual reality simulators to be useful adjuncts to surgical training.¹³ However, only four (3%) had used a virtual reality simulator at the time of the survey.¹³ In 2018, a survey of 57 osteopathic orthopedic surgery residents demonstrated the increasing adoption of VR simulators with 26 respondents (46%) having access to a VR simulator.¹⁵ Impressions continued to be generally positive and are underscored by statements from 53 respondents (93%) that they were not comfortable when they performed their first arthroscopic procedure and 36 respondents (63%) who indicated it took over 20 arthroscopic procedures before they felt comfortable conducting such a procedure independently.¹⁵ Of these respondents, 34 (60%) believed skills learned on a simulator would transfer directly into the OR and 33 (58%) stated that all orthopedic residencies should offer access to VR simulators.¹⁵ The opportunity to practice procedures in a low consequence environment and at any time has been shown to improve performance in the operating room.¹⁹ Though this effect has not been fully characterized, it is possible that the increase in familiarity and confidence that VR simulators may provide trainees contributes to this effect. This may be particularly important in programs with low patient volume. While VR simulators continue to require further development and implementation, surveyed trainees generally considered VR simulators to be useful additions to their training resources. Further study of trainee impressions and satisfaction is critical to the effective implementation of VR simulators as part of a surgical skills laboratory and a residency program.

Conclusion

Virtual reality is an emerging technology that has recently increased in use in orthopaedic surgery. While there are

many current and potential applications of virtual reality, one particularly beneficial use is in surgical training in orthopaedic surgery. Studies have demonstrated a benefit to using virtual reality as a training tool, including in areas such as arthroscopy, arthroplasty, and trauma. Trainees have responded positively to the growing adoption of virtual reality simulators with the majority stating that all residency programs should offer access to such simulators and that the simulators enable the development of skills immediately transferable to the operating room. However, this technology can be costly and difficult to incorporate into educational curriculums, and consequently further evaluation of the efficacy and value of this technology is needed. In the current state of the technology and given its growing adoption as a training aid, virtual reality simulators are best implemented as supplemental resources secondary to real-world experience in the operating room rather than a panacea. Future studies should explore the effective implementation of VR simulators in orthopaedic training by assessing cost and other factors relevant to adoption and implementation, transferability of skills developed in a simulator to the operating room, and the potential for VR to simulate procedures beyond arthroscopy.

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Disclosure

None of the authors report any conflict of interest related to this study.

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