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REVIEW ARTICLE

Virtual reality simulation in orthopaedic surgical training during periods of restricted clinical hours: a systematic review

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Abstract

Background: The public health response to the coronavirus pandemic has imposed limitations on orthopaedic surgeons' scheduled care practice, with a consequential reduction in training time for residents within the specialty. A potentially viable option for maintenance of operative competency is the use of virtual reality (VR) surgical simulation. This review looks at the effectiveness of VR as a pedagogical method of learning for orthopaedic trainees. **Question:** Can VR be a viable method of learning and skill retention for orthopaedic trainees during periods of reduced operative time? **Methods:** A systematic search using Google Scholar, EMBASE and PubMed was conducted in July 2020. **Results:** Following the PRISMA guidelines, the initial search revealed 779 studies. Thirty-five full-text articles were analysed by two reviewers and a final total of 29 articles were included in this review. The levels of evidence ranged from one to four with variable quality. A thematic analysis revealed three broad categories: quality and validity of VR teaching simulations studies (n = 8); learning curves and subject performance papers (n = 14); usefulness of VR simulators in orthopaedics reviews (n = 7). **Conclusion:** We demonstrated that VR has the capacity to help trainees maintain their technical skills, enhance their precision and retain rudimentary competency during this pandemic. Additional developments are necessary to ensure its safety as a training tool. Although there are limited orthopaedic-specific VR simulators, surgical trainees can benefit from VR-based training when paired with other forms of orthopaedic education, such as cadaveric laboratories and simulation suites.

Keywords: *virtual reality; orthopaedic training; simulations; COVID-19*

Introduction

A number of pedagogical methods have been described in the formalization of surgical training and acquisition of operative skills, including Peyton's four-step approach and the Halstedian technique.[1–3] These methods have a prerequisite of exposure to theatre and are predicated mainly on the actual operative caseload experienced by the trainee. The development of operative skills through experience in the operating room remains the primary mode of teaching, but with current guidelines in place, surgical trainees are forced to engage in distance learning. During the COVID-19 pandemic, orthopaedic surgeons have been obliged to postpone elective surgeries and to review their standard clinical schedules. With a reduction in theatre time, different pedological approaches have been explored,[4] virtual reality (VR)-based training in particular. In this review, we define VR as an interactive, computer-generated, simulated surgical procedure or skill acquisition programme.

VR has accompanied the continuing development of new technologies and surgical simulation devices. It allows trainees to remotely learn and augment their skills via virtual operative settings. Evidence on augmented surgical training with VR programmes has been well documented in various areas of surgery. Arroyo-Berezowsky et al.[5] suggested specific orthopaedic educational goals that incorporate VR; they found it to be an accessible and safe method for trainees to learn new skills. Spicer at al.[6] demonstrated VR to be a viable adjunct to traditional methods of teaching neurosurgical techniques, providing the technology continues to advance. Kim et al.[7] established the potential of VR in plastic surgery, notably in surgical training, navigation and planning.

Surgery is a physically technical field that requires its practitioners to engage in live scenarios to enhance and maintain their skills.[8] The use of VR, online teaching seminars, surgical walkthroughs, at-home training,[4,9–12] etc. appear to offer an educational and demonstrative avenue during these unique times. The question this review poses is whether VR is a viable method of learning and skill retention for surgical trainees during periods of restricted clinical hours. This systematic review looks at the efficacy of VR in orthopaedic surgical training to assess its potential benefits during this period of isolation. These results could also prove to be useful in a post-pandemic environment. An informal review of amendments that other institutions have put in place to combat this educational crisis was also carried out.

Method

Study eligibility

Articles were chosen initially based on titles and abstracts. These articles were reviewed by one author and duplicates and unavailable full texts were removed. Two authors then analysed each article based on the following criteria.

The inclusion criteria were as follows: (1) literature in English language; (2) level of evidence ranging between one and four based on the Oxford Centre for Evidence-Based Medicine 2011 Levels of Evidence;[13] (3) VR used in all areas of orthopaedic surgery; (4) studies involving experienced and inexperienced orthopaedic surgeons; and (5) articles that included a segment on the usefulness of VR in orthopaedic surgery.

The exclusion criteria were as follows: (1) non-English articles; (2) articles focusing solely on augmented reality; (3) articles focusing exclusively on specialities other than orthopaedic surgery; (4) articles with only medical students as participants; (5) articles for which the full text was not available.

Educational commentaries on current orthopaedic teaching practices during the COVID-19 pandemic are mentioned in the review for references to current practices, not for secondary data.

Search strategy

This review began in July 2020 and it followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[14] The PRISMA flowchart is illustrated in Fig. 1. The Embase, Google Scholar and PubMed databases were searched using a combination of the following keywords: [virtual reality], [orthopaedic] [residents] and [covid].

Data extraction

Eligible articles were reviewed by two authors. A total of 29 articles were included in this review. Rayyan,[15] a web app for systematic reviews, was used to aid in the selection. Summaries of each article used are given in Tables 1–3.

Bias assessment

Critical appraisal tools were used to assess each article's relevance and quality of results. Tools used included the Cochrane Risk of Bias assessment tool[16] and the Joanna Briggs Institute Critical Appraisal checklists.[17]

Results

The search strategy yielded 779 results: 52 from Embase, 646 from Google Scholar, 79 from PubMed and two from other sources (colleague recommendations). On initial screening, after removal of duplicates and studies for which full text was not available, 35 articles remained: 16 studies from Embase, 14 from Google Scholar, four from PubMed, and one from other sources. These 35 articles were reviewed by two authors, and 29 articles were considered to meet the requirements for inclusion (Fig. 1).

Thematic analysis

Three broad themes were identified during the analysis of the literature on the use of VR in orthopaedic training. The first theme covers quality and validity of VR teaching simulations. Eight studies[18–25] covered this area of research (Table 1). The second theme discusses learning curves and changes in performance using these simulations. A total of 14 papers[26–39] investigated this theme (Table 2). The third theme reports on reviews of orthopaedic VR simulators and evidence of their usefulness in orthopaedic training. Seven papers[40–46] analyse this topic (Table 3).

Quality and validity of VR teaching simulations

Studies have developed and/or studied VR simulations and their validity in areas of arthroscopy and arthroplasty in orthopaedic surgery. Vankipuram et al.[18] designed and demonstrated the validity and performance of a VR drilling simulator. The construct validity of the TraumaVision (Swemac Orthopaedics, Linkoping, Sweden) simulator was established by Akhtar et al.[19] Stunt et al.[20] and Martin et al.[21] compared and verified the face and construct validity of shoulder and knee arthroscopic VR simulators; Bartlett et al.[24] demonstrated the face validity of a VR hip arthroscopy simulator. In spinal surgery, Shi et al.[23] found that the validity of the VR system they analysed was more accurate than conventional teaching methods. It was found to be a favourable alternative to traditional pedicle screw placement training. Gupta et al.[22,25] developed a VR system for less

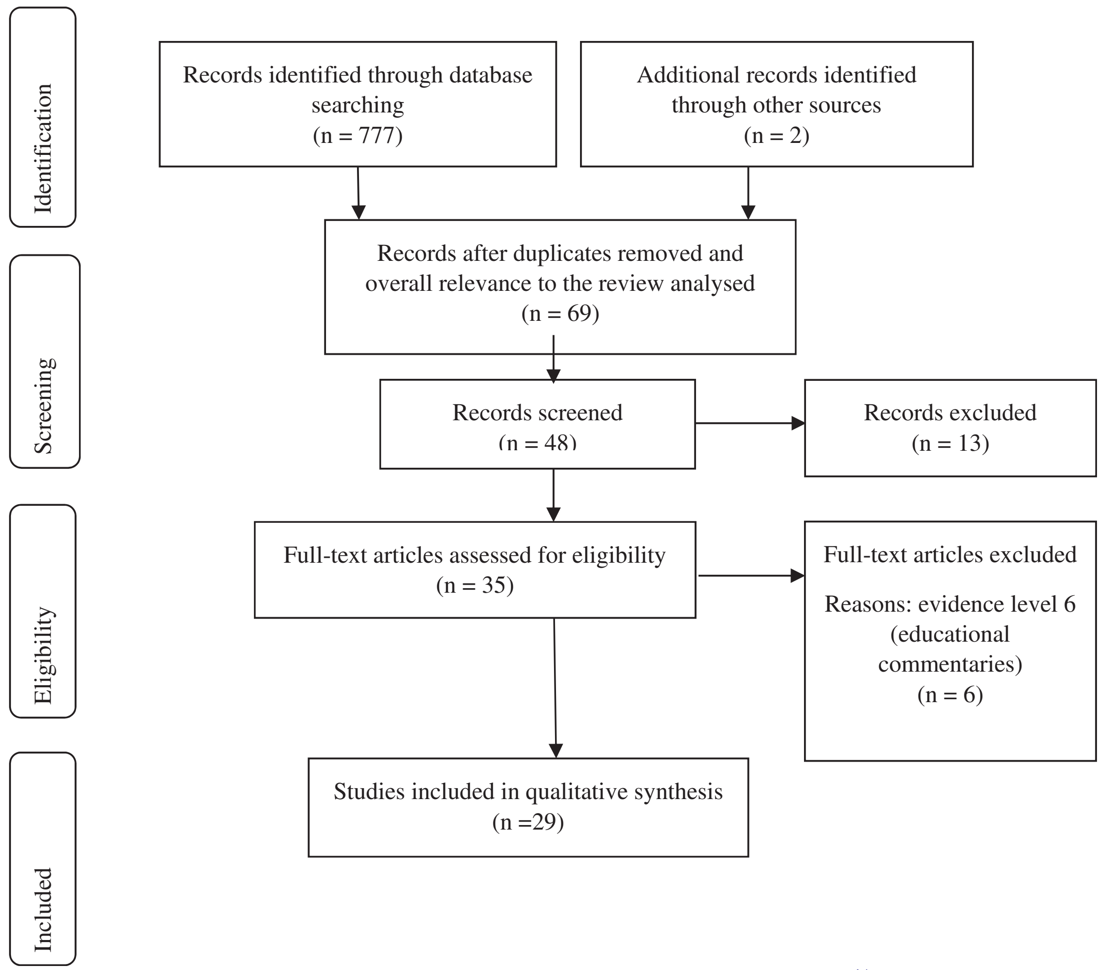

Figure 1. Flowchart of the selection process using the template document in the PRIMSA statement[14]

invasive stabilization system plating surgery, which is used in the repair of fractured femurs. The system was enhanced two years later[25] and its validity was established.

Learning curves and subject performance

Subject abilities were tested in various areas of orthopaedic surgery, ranging from basic skills such as drilling, to more complex procedures such as total joint arthroplasty. Pedersen et al.[27] found VR simulation-based examinations to be a valuable adjunct in assessing trainees in performing hip screws/nails. A pass/fail standard was discriminated between trainees and experts. Gustafsson et al.[33] found a pass/fail standard score of 92% and established the learning curves of novices and experts. They also noted the importance of constant simulation-based training to a predefined standard in order to reap the true benefits of VR training. Both articles demonstrate a valid basic skill test, that has the potential to be utilized before trainees participate in live surgery with real patients.

Waterman et al.[29] verified a transfer of skills from shoulder arthroscopy VR simulation to surgical skills in theatre. Residents who had VR-based training in Yari et al.,[32] made significant improvements in knee and shoulder arthroscopic surgical skills. Subjects in Gomoll et al.[26] who had previously been tested using VR simulation 3 years previously, showed a significant improvement in their performance 3 years later. This further confirmed the use of VR simulation to evaluate surgical skills.[26] They and Dammerer et al.[30] recommend VR be used as a tool for teaching and improvement of technical surgical skills, mainly in anatomy and hand-eye coordination.

Studies with similar study designs agree on the advantages of VR in improving technical skills.[34,38,39] Rahm et al.[31] noted that VR-based training appears useful to learn camera handling, basic anatomy and triangulation with instruments. Notably with more challenging and precise procedures, such as pedicle screw placement, Xin et al.[39] found a significant difference in success rate between

Table 1. Quality and validity of virtual reality teaching simulations

Reference	Aim(s)	Total no. of participants	Participant characteristics	Sample design	Conclusion
Vankipuram et al., 2010[18]	Measure the validity of the simulator using various tests. Test its ability to differentiate between experts and novices	33	Orthopaedic surgeons; experts and residents; novices	Controlled laboratory study	The multi-tiered testing strategy showed that the simulator was able to produce a learning effect that transfers to real-world drilling. It was also able to differentiate between experts and novices
Akhtar et al., 2015[19]	Evaluated the construct validity of a new VR trauma simulator for performing dynamic hip screw (DHS) fixation of a trochanteric femoral fracture	30	Orthopaedic residents	Non-randomized controlled trial	Proved construct validity of a haptic VR DHS trauma simulator. Results showed that the surgeons who performed this procedure regularly also performed best on the simulator. The detailed level of objective feedback provided by the simulator is unavailable in the operating theatre and provides precise guidance on areas for improvement
Stunt et al., 2016[20]	Demonstrate face and construct validity of the (practice Arthroscopic Surgical Skills for perfect Operative real-life Treatment) PASSPORT simulator	31	Orthopaedic surgeons (residents and experts); researchers	Non-randomized controlled trial	The simulator showed construct and face validity, and its physical nature offered adequate haptic feedback during training. This indicates that it has potential to evolve as a valuable training modality
Martin et al., 2016[21]	Assess face validity of three available VR simulators	30	Orthopaedic residents; medical students; αrthroscopy-trained staff	Single blinded randomized controlled trial	ArthroS has the highest overall face validity of the three current arthroscopic VR simulators. However, only external appearance for ArthroS reached statistical significance when compared with the other simulators. Each simulator had satisfactory intra-articular quality
Cecil et al., 2017[22]	Propose that virtual reality-based simulations can be used to educate and train surgical residents in target surgical processes	20	Orthopaedic surgeons (experts and residents); medical students	Controlled laboratory study	Most participants showed significant improvements in their understanding of the Less Invasive Stabilization System (LISS) plating surgical process after interacting and learning using the simulator
Shi et al., 2018[23]	Assess the validity of a virtual surgical training system on lumbar pedicle screw placement for residents	10	Orthopaedic residents (inexperienced in pedicle screw implantation)	Single blinded randomized controlled trial	The virtual surgery simulation with greater accuracy is superior to the traditional teaching methods in surgical training of pedicle screw placement and can be used as a promising alternative for training of neurosurgical procedures
Bartlett et al., 2019[24]	To test the face validity of the hip diagnostics module of a virtual reality hip arthroscopy simulator	50	Orthopaedic surgeons (experts and residents); faculty members	Controlled laboratory study	This VR hip arthroscopy simulator was demonstrated to have a sufficient level of realism, thus establishing its face validity. These results suggest this simulator has sufficient realism for use in the acquisition of basic arthroscopic skills and supports its use in orthopaedics surgical training
Gupta et al., 2019[25]	Discuss the adoption of information-centric systems engineering (ICSE) principles to design a cyber-human systems-based simulator framework to train orthopaedic surgery medical residents using haptic and immersive virtual reality platforms	64	Orthopaedic residents; medical students	Controlled laboratory study	Most participants showed significant improvements in their understanding of the LISS plating surgical process after interacting and learning using the training simulators

Table 2: Learning curves and subject performance

Reference	Aim(s)	Total no. of participants	Participant characteristics	Sample design	Conclusion
Gomoll et al., 2008[26]	Prove that participants will show an improved performance on simulator retesting 3 years after an initial baseline evaluation	10	Orthopaedic surgeons (with limited to no shoulder arthroscopic experience)	Controlled laboratory study	Participants significantly improved their performance on simulator retesting 3 years after initial evaluation
Pedersen et al., 2014[27]	Develop a reliable and valid test with credible pass/fail standards	20	20 physicians (10 untrained novices and 10 experienced orthopaedic surgeons)	Single blinded non-randomized controlled trial	The simulation-based test was reliable and valid in the setting, and the pass/fail standard could discriminate between novices and experienced surgeons
Camp et al., 2016[28]	Assess the efficacy of cadaveric skills laboratories and virtual reality simulator training methods, compare their rates of improvement, and provide economic value data to programmes seeking to implement such technologies	45	Orthopaedic residents	Prospective randomized controlled trial	Cadaveric skills laboratories improved residents' performance of knee arthroscopy compared with that of matched controls. Residents practicing on cadaveric specimens improved twice as fast as those utilizing a high-fidelity simulator
Waterman et al., 2016[29]	Simulation training would improve residents' basic arthroscopic performance and safety	22	Orthopaedic residents	Single blinded, prospective randomized control trial	Established transfer validity for an arthroscopic shoulder simulator model. Additional simulation training improved technical performance and patient safety measures among residents compared with a standard teaching curriculum
Dammerer et al., 2018[30]	Analyse learning curves of medical students and orthopaedic resident surgeons using a virtual knee arthroscopy simulator	19	Orthopaedic residents; medical students	Controlled laboratory study	Demonstrated the usefulness of the arthroscopy training simulator as an important tool for improving surgical and arthroscopic skills in orthopaedic resident surgeons and medical students
Rahm et al., 2018[31]	Tested the efficacy of a standardized, competency-based training protocol on a validated virtual reality-based knee and shoulder arthroscopy simulator	25	Orthopaedic surgeons (experts and residents)	Descriptive laboratory study	This sort of training method appears useful to learn the handling of the camera, basic anatomy and triangulation with instruments
Yari et al., 2018[32]	Determine the utility of the ArthroS arthroscopic simulator for orthopaedic trainees based on their level of training	18	Orthopaedic residents	Descriptive laboratory study	Residents training on a virtual arthroscopic simulator made significant improvements in both knee and shoulder arthroscopic surgery skills
Gustafsson et al., 2019[33]	Determine the characteristics of learning curves for novices and experts and establish a pass/fail mastery learning standard for junior trainees	46	Orthopaedic surgeons (first year residents and consultants)	Controlled laboratory study	Training time to reach plateau varied widely and it is paramount that simulation-based training continues to a predefined standard instead of ending after a fixed number of attempts or amount of time
Hooper et al., 2019[34]	Does the use of VR simulation improve postgraduate year (PGY)-1 orthopaedic residents' performance in cadaver total hip arthroplasty and its beneficial effects on specific aspects of surgical skills or knowledge	14	Orthopaedic residents	Blinded randomized controlled trial	VR simulation improves PGY-1 resident surgical skills but has no significant effect on medical knowledge. The most significant improvement was seen in technical skills
Rölfing et al., 2019[35]	Investigate the role of failure in repeated practice of virtual reality (VR) simulation of hip fracture surgery on cognitive load (CL)	42	Orthopaedic residents	Controlled laboratory study	Reducing CL through instructional design and handling of participant frustration might improve the learning outcome of simulation training programmes
Lohre et al., 2020[36]	Determine the validity and efficacy of immersive VR training in orthopaedic resident education	26	Orthopaedic surgeons (experts and residents)	Blinded, randomized controlled trial	Immersive VR demonstrated substantially improved translational technical and non-technical skill acquisition over traditional learning in senior orthopaedic residents
Walbron et al., 2020[37]	This study of residents' initial performance was performed to determine which factors predisposed residents for success in demonstrating the best arthroscopic skills	116	Orthopaedic residents (1st year)	Prospective, comparative, non-randomized study	This study shows a significant difference in skills regarding spatial recognition and triangulation related to gender at the beginning of specialization training
Walbron et al., 2020[38]	The primary aim was to compare various arthroscopy learning techniques after 6 months of training	107	Orthopaedic residents (1st year)	Prospective, comparative, non-randomized study	The residents who participated in the VR arthroscopy simulator training programme for 6 months had better results when performing practical exercises and standard arthroscopy tasks. Their final performance indicated technical mastery that the other residents had not achieved
Xin et al., 2020[39]	To verify whether the pedicle screw placement (PSP) skills of young surgeons receiving immersive virtual reality surgical simulator (IVRSS) training could be improved effectively and whether the IVRSS-PSP training mode could produce a real clinical value in clinical surgery	24	Orthopaedic surgeons (attendings <1 year)	Randomized double-blind controlled trial	Demonstrated that IVRSS-PSP was helpful to improve the success rate of PSP for young surgeons and may provide valuable reference for PSP training of young surgeons. Study also showed a promising potential of the VR technology in surgical simulation training

Table 3. Evidence of the usefulness of VR simulators in orthopaedics

Reference	Aim(s)	Total no. of participants	Participant characteristics	Sample design	Conclusion
Mabrey et al., 2010[40]	(1) How has VR worked for other surgical specialties; (2) what VR solutions are available for orthopaedics; and (3) should VR simulation become part of the orthopaedic curriculum?	N/A	N/A	Literature review	VR simulators are readily available for shoulder and knee arthroscopy but not as well incorporated into training curricula. Orthopaedic training programmes should take advantage of the commercially available VR simulators for orthopaedic procedures
Vaughan et al., 2016[41]	Present existing virtual reality-based training simulators for hip, knee and other orthopaedic surgery, including elective and trauma surgical procedures	N/A	N/A	Systematic review	Few training simulators are available for hip replacement, yet more advanced virtual reality is being used for other procedures such as hip trauma and drilling. This suggests there is a gap in the market for a new high-fidelity hip replacement and resurfacing training simulator
Pfandler et al., 2017[42]	Examine the existing research on VR-based simulators in spinal procedures. Assess the quality of current studies evaluating VR-based training in spinal surgery	N/A	N/A	Systematic review	Higher-quality studies with patient-related outcome measures are needed. To establish further adaptation of VR-based simulators in spinal surgery, future evaluations need to improve the study quality, apply long-term study designs, and examine non-technical skills, as well as multidisciplinary team training
Bartlett et al., 2018[43]	To assess the current evidence relating to the benefits of virtual reality (VR) simulation in orthopaedic surgical training, and to identify areas of future research	N/A	N/A	Systematic review	Evidence supporting the usefulness of VR simulation in other forms of orthopaedic surgery is lacking. Further studies of validity and usefulness should be combined with robust analyses of the cost efficiency of validated simulators to justify the financial investment required for their use in orthopaedic training
Fritz et al., 2019[44]	A review of surgical training programmes and their methods of training	N/A	N/A	Literature review	VR simulators have a training programme already implemented, which allows the trainee to perform the procedures with or without supervision by a trainer. They enable the training of complex procedures such as rotator cuff reconstruction
Hedman et al., 2020[45]	For a growing number of minimally invasive and technically challenging orthopaedic procedures, there is a movement to improve surgical skills training outside the operating room because of, e.g. patient safety concerns. Surgical simulation is a powerful tool that can help meet these training demands	N/A	N/A	Literature review	When used appropriately, extended simulation training can be a highly effective additional training tool in the development and maintenance of technical skills and combatting skills decay, considering motivation and flow. This is relevant also for temporarily non-performing orthopaedic surgeons during a crisis affecting the organization of health care such as the COVID-19 pandemic
Negrillo-Cárdenas et al., 2020[46]	Analysis of the impact of virtual and augmented reality to bone fracture healing, detailing each task from diagnosis to rehabilitation	N/A	N/A	Systematic review	We have noted that virtual reality is an appropriate technology to assist in pre-surgical tasks, mainly focusing on visualization in training systems. It also represents an excellent choice to treat several conditions or perform rehabilitation exercises

trainees who had undergone VR-based training and those who did not. Lohre et al.[36] was the only study that demonstrated an improvement in translational technical and non-technical skills acquisition with VR-based training compared with traditional learning in senior orthopaedic residents.

Conversely, Camp et al.[28] found that residents who trained on cadaveric specimens improved twice as fast as those who had VR-based training, for diagnostic knee arthroscopies. Rolfing et al.[35] noted participant frustration to be a barrier for simulation training programmes. Nevertheless, a cost analysis showed VR simulation to be more cost-effective if utilized properly.

Evidence of the usefulness of VR simulators in orthopaedics

Pfandler et al.[42] and Bartlett et al.[43] presented the benefits of VR-based training in improving technical skills and knowledge of surgical trainees. However, they noted a need for more high-quality randomized controlled trials, testing VR-based training's effectiveness in surgical performance. Fritz et al.[44] noted a key advantage of VR-based training where trainees can perform procedures and receive feedback such as precision, error rates and accuracy, without supervision by a senior. Mabrey et al.[40] addressed the challenges of implementing surgical simulators in orthopaedic training; particularly, that the current simulators address a limited range of surgical skills. To implement them in a training curriculum, a "universal platform" with a variety of procedures would be favoured. Negrillo-Cárdenas et al.[46] reported that VR-based training was useful for pre-surgical tasks, especially aiding in visualization. Vaughan et al.[41] found that numerous VR simulators were targeted to hip trauma procedures, in contrast to the few hip arthroplasty simulators at the time (2015). Walbron et al.[37] used VR simulation to determine which factors predisposed residents for success in demonstrating the best arthroscopic skills. They found their male residents had better spatial recognition and triangulation skills. They proposed introducing VR-based training earlier in training schemes to combat this discrepancy. One article mentioned the usefulness of VR-based training during the COVID-19 pandemic. Hedman et al.[45] observed its usefulness in skill retention and maintenance, especially for orthopaedic surgeons who are not operating temporarily.

Discussion

There is increasing evidence of the potential VR has as an adjunct method of training for orthopaedic surgical trainees. The evidence of its effects in orthopaedic training is broad; from constructing and testing the validity of simulators to examining whether these skills are transferable in the theatre. The results are promising, although some of the studies were of lower quality than others and potentially biased.

Shortcomings of VR training

Our review discovered that training with cadaveric specimens surpassed VR-based training twofold. Camp et al.[28] found that residents who trained using cadaveric specimens improved their arthroscopy skills twice as fast as those practising with VR-based simulation. Both groups practiced for 4 hours with their respective methods, but the cadaveric group was explicitly asked to develop their arthroscopic skills. This group also received simple instructions from a senior resident, i.e. mentoring, whereas the VR-trained group did not. The beneficial role of mentoring in improving surgery simulations scores was observed in a study by Lee et al.[47]. These points could account for the time discrepancy found in the study by Camp et al.[28] Nevertheless, trainees do not necessarily have to learn as quickly as possible but rather safely and accurately.

In addition, Hooper et al.[34] found that VR-based training had no significant effect on the medical knowledge of their residents. This indicated that VR simulations, although effective in the setting of novice learning,[48] still lack an element of training that real anatomic specimens seem to provide. Mainly, our review revealed a dearth of evidence of the usefulness of VR in orthopaedic surgical training compared with other specialities.[49] Among the limited orthopaedic VR simulators, there appears to be a lack of various staple orthopaedic procedures; notably hip replacements.[41]

Benefits of VR training

The shortcomings of VR exposed the disparity of the usefulness of VR in orthopaedics; despite this, our review included multiple studies that had designed their own VR orthopaedic simulators. The creators involved in these training environments included expert orthopaedic surgeons who have insight on the needs of orthopaedic trainees to improve their surgical skills. Despite the novelty of these innovations, their validity was proven. These studies display a constructive attempt to fill the gap of the usefulness of VR-based training in orthopaedics. Only six articles included in this review had received some form of funding, i.e. doctoral grants or national grants. No articles disclosed funding directly linking them to the VR manufacturers used in their articles, suggesting funding bias to be a low possibility.

We found VR to aid in maintaining[45] and improving technical surgical skills.[34,42,43] This was observed to be beneficial during periods of restricted clinical hours.[45] Fritz et al.[44]

demonstrated the benefits of technological feedback from VR simulators. Boyle et al.[48] reinforced this point and noted significant improvement in surgical skills, especially in the setting of novice training, regardless of supervised feedback. We also found possible substitutes for the gaps in training. McKechnie et al.[11] provided a succinct overview of the technologies available for surgical trainees to use domestically. They offered three computer-based platforms for orthopaedics: Ortho Oracle (International Business Machines Corporation Watson, London and Wales), AO Surgery Reference (AO Foundation, Switzerland) and the VR option in Fundamental Surgery (Fundamental VR, London). Ortho Oracle offers live and recorded videos on almost all subspecialties of orthopaedic surgery; AO Surgery Reference is a valuable resource for the management of numerous types of fractures. Overall, VR offers trainees the opportunity to practice their surgical skills at their own convenience. With the added ability to train at home, the work-life balance for orthopaedic trainees could be strengthened. Additional time to train may also result in a learning curve that is not as steep when starting to operate on live patients.

Changes during the pandemic

Other institutions have adapted to this pandemic by introducing online teaching seminars, cadaveric simulations, at-home training, etc. They also considered how to integrate VR into their traditional teaching models during this pandemic. Plancher et al.[4] noted its advantages of being more portable and more easily accessible than cadaveric training, allowing surgical trainees to practice distanced learning. Stambough et al.[9] acknowledged that the post-COVID-19 environment will likely lead to an emphasis on VR advancement but mentions that it is lacking the necessary visual and tactile feedback needed to practise safe surgery. Davey et al.[12] comments on the overnight changes the pandemic brought in the importance of orthopaedic training methods. Especially, how platforms that were previously believed supplementary quickly became crucial in response to the unprecedented COVID-19 pandemic.[11] Overall, these institutions agreed on two aspects: the necessity of more high-quality VR-based training trials and the need for developments to ensure VR is a safe form of teaching.

VR-based training appears to provide a safe environment for orthopaedic surgical skill education. With or without guidance from experts, it allows for repeatability and reproducibility within a setting that minimizes risk to patients. Several articles acknowledge the necessity of repeatability in VR. We found that to gain its full benefits, trainees must practice regularly to match/overtake a standard score. Camp et al.[28] determined for their VR simulation to be more cost-effective than cadaveric training, residents must practice at least 300 hours annually. The COVID-19 pandemic has provided orthopaedic residents with more free time for training on these simulations, therefore gaining from their educational value. Although there are limited orthopaedic-specific VR simulators, surgical trainees still benefit when VR is paired with other forms of orthopaedic training, primarily in improving technical surgical skills.

Limitations

Only three online databases were used for this review, resulting in evidence selection bias. No unpublished papers were found/included, which may have provided a more well-rounded outcome, leading to publication bias. The number of participants in each study varied ranging from ten to 116, with only six studies including 50 or more participants. The studies also included residents at different levels of training, mainly from the USA. As there is a significant difference in orthopaedic training between the USA and other countries, this limitation must also be considered.

Conclusion

VR simulation appears to be a favourable adjunct to training, both in times of a pandemic when the access to theatre is limited, and with restrictions to working hours. Therefore, it can act as an accelerator of development of surgical skills. We observed that it serves as an appreciated pedological adjunct in orthopaedic education and we have shown it has the capacity to help trainees maintain their technical skills, enhance their precision and retain rudimentary competency. It can provide the ability to practice and repeat procedures with less radiation exposure. Additional advancements still need to be made to ensure its safety as a training tool. Despite this, we anticipate that in time and with the input of expert surgeons, experienced technicians and software developers, VR simulations will eventually be a key part of orthopaedic training.

Conflict of interests

None declared.

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