Impact of Virtual and Augmented Reality on Quality of Medical Education During the COVID-19 Pandemic: A Systematic Review

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ABSTRACT

Background The COVID-19 pandemic and the subsequent mandatory social distancing led to widespread disruption of medical education. This contributed to the accelerated introduction of virtual reality (VR) and augmented reality (AR) technology in medical education.

Objective The objective of this quantitative narrative synthesis review is to summarize the recent quantitative evidence on the impact of VR and AR on medical education.

Methods A literature search for articles published between March 11, 2020 and January 31, 2022 was conducted using the following electronic databases: Embase, PubMed, MEDLINE, CINAHL, PsycINFO, AMED, EMCARE, BNI, and HMIC. Data on trainee confidence, skill transfer, information retention, and overall experience were extracted.

Results The literature search generated 448 results, of which 13 met the eligibility criteria. The studies reported positive outcomes in trainee confidence and self-reported knowledge enhancement. Additionally, studies identified significant improvement in the time required to complete surgical procedures in those trained on VR (mean procedure time 97.62±35.59) compared to traditional methods (mean procedure time 121.34±12.17). However, participants also reported technical and physical challenges with the equipment (26%, 23 of 87).

Conclusions Based on the studies reviewed, immersive technologies offer the greatest benefit in surgical skills teaching and as a replacement for lecture- and online-based learning. The review identified gaps that could be areas for future research.

Introduction

Immersive technology is a term used to depict 2 main types of alternate realities: virtual reality (VR) and augmented reality (AR). Both immerse the user in a fully or partially simulated environment. VR is a computer simulation that allows users to fully immerse and interact with an artificial environment.[1] On the other hand, AR is an interactive technology that superimposes holographic content onto the user's actual environment.[2] In medical education, immersive technologies are a means through which a mentor can provide knowledge or skills to a mentee either in-person or from a remote location.[3,4] This is achieved through technological communication devices such as head-mounted devices, commonly known as smart glasses.[5,6]

Since the onset of the COVID-19 pandemic, the use of immersive technologies in medical education has been adopted by a number of specialities and used to demonstrate anatomy and provide bedside teaching.[7-9] The purpose of immersive technologies was to minimize disruption to medical education caused by the restriction on face-to-face teaching and hospital training.[7,10,11] This review builds on previous publications exploring the use of immersive and telemedical technologies in medicine and surgery.[2,6,12-25] Previous work has demonstrated promise with respect to feasibility and usability despite technical limitations such as difficulties operating the technology.[2,6,12,15-18,20-24] VR and AR provided a unique and interactive learning experience while protecting patients and health care providers from COVID-19.[12-14] Therefore, this technology represented a pragmatic way to tackle the restrictions imposed on medical education during the global pandemic.[12] We believe this is important because COVID-19 has the potential to continue to disrupt learning, encouraging medical educators to consider and adopt new teaching methods.[12]

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Editor's Note: The online version of this article contains search term strategies, quality appraisal data of included studies using the MMAT, and a PRISMA flow diagram of included studies.

Aims

The objective of this quantitative narrative synthesis review is to summarize the recent quantitative

TABLE 1
List of Inclusion and Exclusion Criteria

Refinements	Inclusion Criteria	Exclusion Criteria
Year	Published between March 11, 2020 and January 31, 2022	Published before March 11, 2020 Studies conducted before March 11, 2020 regardless of the publication date
Source format	Primary research Full text available	Books, expert opinions, commentary, editorials, online/news report, reviews, conference abstract, pre-prints Abstracts without accompanying full text Duplicate records
Language	English	Non-English
Intervention	Use of one of the following in an educational setting: ▪ Virtual reality ▪ Augmented reality ▪ Mixed reality	Digital and virtual teaching Online lectures Video conferencing technology
Participants	Medical students Medical trainees Medical educators	
Outcomes	Quantitative data pertaining to trainee confidence, skill transfer, information retention, and overall experience following the use of immersive technologies in medical education	

evidence on the impact of virtual and augmented reality on medical education with a focus on identifying areas of greatest and least benefit to trainees. The research question is: How has the implementation of VR or AR impacted medical education during the COVID-19 pandemic? This review focuses on evidence relating to surgical-, clinical-, and anatomy-based learning.

Methods

Design

This review is a quantitative narrative synthesis review. To ensure complete reporting, the 2020 Preferred Reporting Issues for Systemic Reviews and Meta-Analyses (PRISMA) statement was followed in the conduct of this review.[26] The protocol for this review was registered through submission to PROSPERO on July 25, 2022. This review did not require review or approval by the ethics committee.

Search Strategy and Study Selection

A search of the literature was conducted on January 31, 2022, using the following electronic databases: Embase, PubMed, Cochrane reviews, MEDLINE, CINAHL, PsycINFO, AMED, EMCARE, BNI, and HMIC. Medical Subject Headings were combined by Boolean operators (AND, OR, and NOT) to generate the search terms (online supplementary data). Articles underwent a 2-stage selection process: first title and abstract screening followed by full-text screening. Two independent reviewers conducted the search and screening process.

Eligibility Criteria

Articles that satisfied the inclusion and exclusion criteria outlined in TABLE 1 were included in the study. All studies conducted between March 11, 2020 and January 31, 2022 with evidence reporting the impact of immersive technologies on medical education during the COVID-19 pandemic were included. Studies conducted before March 11, 2020 regardless of the publication date were excluded. Primary research written in English describing one or more of VR, AR, or mixed reality were included. Finally, only studies examining the impact of immersive technologies on medical students, medical trainees, and medical educators were included. Studies on other technologies (such as videoconferencing and online teaching), duplicate articles, books, expert opinions, commentaries, editorials, online/news reports, reviews, conference abstracts, and preprints were excluded.

Data Extraction

Each selected article underwent data extraction conducted in a standardized form by 2 reviewers. The following data were extracted into a Microsoft Excel spreadsheet: details of publication, participant characteristics, sample size, setting, intervention, study design, data type, and results as well as quantitative data on medical education, specifically, results on trainee confidence, skill transfer, information retention, and overall experience.

Critical Appraisal

Two independent reviewers methodically appraised the quality of the included studies using the Mixed Methods Appraisal Tool (MMAT) criteria.[27] Results of the quality assessment are presented as online supplementary data. No adaptations were made to the MMAT criteria.[27] No studies were excluded on the basis of their quality. Articles were selected based on their overall quality rather than specific criteria.

Evidence Synthesis

Statistical analysis (ie, meta-analysis) was not conducted, for requisite effect sizes from the primary research studies were not available. The primary analysis was in the form of a quantitative narrative synthesis. A narrative synthesis was the preferred method of data analysis due to the lack of data to calculate standardized effect sizes and significant heterogenicity among the included studies. The 4 stages of the narrative synthesis are (1) the development of a theory on how the intervention works; (2) development of a preliminary synthesis; (3) exploration of relationships within the data; and (4) assessment of the robustness of the synthesis.[28] Data synthesis was led by one reviewer. Results of the included studies were quantitatively analyzed and presented. Tables were used to summarize study findings. An effect direction plot was used to provide a visual summary of the various study outcomes.[29-31]

Results

Search Results

Details on the literature search and screening processes are illustrated in the online supplementary data. The literature search yielded 448 citations. After removing duplicate articles, 250 were screened at the title/abstract stage, of which 40 were screened at the full-text stage. Twenty-seven studies were excluded at the full-text stage, and the remaining 13 studies met the predefined criteria and were included in the article.[3,4,7,11,32-40]

Study Characteristics

A summary of the general characteristics of included studies are outlined in TABLE 2. Included studies were published between March 11, 2020 and January 31, 2022. Most were conducted in the United States (n=8). The remaining 5 studies were conducted in the United Kingdom (n=2), Italy (n=1), Germany (n=1), and Turkey (n=1). The studies included quantitative descriptive studies (n=8), randomized control trials (n=3), mixed methods study (n=1), and a quantitative non-randomized study (n=1). Sample sizes ranged from 5 to 88 participants with a mean sample size of 31. Immersive interventions included surgical, medical, and anatomical applications, with medical (n=6) and surgical (n=6) being the most common, followed by anatomical (n=2). Technologies differed between studies: 9 studies used VR, 7 used smart glasses, 1 used mixed reality (hybrid of VR and AR), and none used AR only. Quantitative data on the impact of immersive technologies on medical education were reported in all 13 articles.

Critical Appraisal

The MMAT criteria were used to critically appraise the 13 studies included in the systematic review. All studies stated a clear research question or study aim and collected relevant data that addressed the research question. However, 2 studies had a risk of nonresponse bias due to an attrition rate of 20% or more.[3,33] In addition, all quantitative descriptive studies did not meet the criteria for sampling strategy because none outlined and justified the sampling procedure.[3,4,7,11,33,35,36,38] Both are required to meet the criteria. Another study did not show evidence of an appropriate measure of the outcome.[35] Meanwhile, the appropriateness of the statistical analysis was unknown in 5 studies since they did not state or justify the type of statistical analysis conducted.[4,7,35,36,38]

Furthermore, all 3 randomized control studies carried a risk of bias because they did not meet the criteria for blinding assessors.[32,34,39] In addition, the criteria for appropriate randomization was unknown because the randomization process was not clearly stated in all 3 trials. Finally, the mixed methods study did not show any risk of bias or features of low quality.[37] TABLE 2 shows the detailed quality appraisal of all studies included.

Evidence Synthesis

Overview of Results: There was significant variation between the measured outcomes of the 13 studies. TABLE 3 shows a summary of the study outcomes. The effect direction plot outlines a summary of the variable outcomes assessed within each study (TABLE 4). Eleven out of 11 studies reported a positive overall experience, 2 of 13 studies did not report on overall experience, 2 of 4 studies reported significant improvement while 2 of 4 studies reported no significant improvement in knowledge/understanding, 3 of 3 studies reported significant

TABLE 2
Summary of Included Studies Evaluating the Impact of Immersive Technology on the Quality of Medical Education

Author, Year	Country	Study Design	N	Application	Study Setting
Young et al, 2021[3]	United States	Quantitative descriptive study	88	Medicine	VR + smart glasses A physician using smart glasses to share VR cases of hospitalized infants with respiratory distress
Simone et al, 2021[4]	Italy	Quantitative descriptive study	5	Surgery	Mixed reality in laparoscopic and open surgery Mixed reality used in right adrenal carcinoma surgery and gastrectomy surgery
Atli et al, 2021[11]	United States	Quantitative descriptive study	12	Surgery	Yearlong VR neurosurgical course
Bala et al, 2021[7]	United Kingdom	Quantitative descriptive study	11	Medicine	VR + smart glasses Medical students participated in a teaching ward round involving HoloLens 2 technology.
Sommer et al, 2021[32]	Germany	Prospective 2-arm randomized control trial	60	Surgery	VR training (intervention group) In the training group, training consisted of 48 different VR simulator tasks. Trainees were assessed before and after curriculum training which lasted 9 days. Control group participants were assessed on day 1 and day 9 without complete curriculum training.
Papalois et al, 2021[33]	United Kingdom	Quantitative descriptive study	15	Surgery and anatomy	VR curriculum focusing on surgical anatomy and decision-making
Huri et al, 2021[34]	Turkey	Randomized control trial	34	Surgery	VR simulators compared to cadaveric dissection for surgical education Participants assigned to either simulator training or cadaver dissection Followed by a test performed on shoulder arthroscopic simulator
Ike et al, 2021[35]	United States	Quantitative descriptive study	48	Surgery	Smart glasses in surgical skills training
Baker et al, 2021[36]	United States	Quantitative descriptive study	22	Medicine	Smart glasses in the emergency department An emergency physician was deployed into the emergency department while wearing smart glasses to give medical students onsite virtual shadowing.
Herbst et al, 2021[37]	United States	Mixed methods study	14	Medicine	VR-based behavioral health anticipatory guidance curriculum for pediatric residents
Ralston et al, 2021[38]	United States	Quantitative descriptive study	6	Medicine	VR in pediatric cardiac critical care simulation
Chan et al, 2021[39]	United States	Randomized control trial	39	Anatomy	Smart glasses in anatomy education Compares 360° videos (smart glasses) to 2D videos on engagement in anatomy education
Behmadi et al, 2022[40]	United States	Quantitative non-randomized study	44	Medicine	VR teaching in emergency medicine VR was compared to lecture-based teaching in emergency medicine

Abbreviation: VR, virtual reality.

TABLE 3
Summary of Study Outcomes and Results

Author, Year	Outcomes	Results
Young et al, 2021[3]	The outcomes measured were based on student evaluation of the VR experience.	Results showed that 78% of participants reported that VR captured their senses, and 73% were completely dedicated to the virtual experience. Eighty percent of participants reported that VR was more effective than reading and equally or more effective than didactic teaching. However, 80% of participants reported that VR was less effective than bedside teaching.
Simone et al, 2021[4]	The primary outcome measured was the feasibility of using mixed reality technology for real-time remote monitoring of doctors under training during surgery.	Results showed a positive evaluation of smart glasses in various aspects including real-time interaction during surgery (average score 7.5/10), degree of focus (average score 9/10), degree of attention (average score 9/10), feedback (average score 9/10), and overall experience (average score 8.5/10).
Atli et al, 2021[11]	The primary outcome measured was the self-reported student confidence following a yearlong VR neurosurgical course. The secondary outcome measured was participants' subjective experiences.	Results showed that students reported overall greater competency confidence levels on all topics following the VR course. VR helped in gaining a deeper understanding (100% of participants [12 of 12]) and greater information retention (92% of participants [11 of 12]) of neuroanatomy and neurosurgery.
Bala et al, 2021[7]	The primary outcome measured was participants' subjective experiences following a mixed reality teaching ward round.	Results showed that 100% (11 of 11) of participants agreed that VR enabled access to learning opportunities that were otherwise inaccessible to students; 82% (9 of 12) of students agreed or strongly agreed that they were able to interact and ask questions during the virtual ward round; and 100% (11 of 11) of participants found the experience enjoyable.
Sommer et al, 2021[32]	The primary outcome measured was of evidence of improvement following a 9-day VR training curriculum.	Results showed significant improvements in the training group in both surgical performances, as well as completion times in 5 of the 7 analyzed parameters. This study provided evidence that VR training could be helpful in surgical training programs in light of the COVID-19 pandemic.
Papalois et al, 2021[33]	The primary outcome measured was the confidence in knowledge of anatomy before and after the VR curriculum.	Results showed that 73% of participants agreed or strongly agreed that they achieved a better understanding of surgical anatomy and the rationale behind each procedural step. This was reflected by a significant increase in the median knowledge scores. One hundred percent of subject matter experts (n=5) and 93.4% of participants agreed or strongly agreed that virtual mentorship would be useful for future surgical training. Further, 87% of participants agreed or strongly agreed that the VR curriculum improved their understanding of the operative steps and critical decision-making points.
Huri et al, 2021[34]	The hypothesis tested was whether VR simulators could replace cadaveric dissection.	Results showed that the intervention group (those who trained on the VR simulators) completed the task in a statistically significant shorter period of time. The intervention group also had statistically significantly less scratching of humeral cartilage. However, there was no statistically significant difference in safety scores between the intervention and control groups.
Ike et al, 2021[35]	The primary outcome measured was the self-reported confidence in basic wound closure.	Results showed significant improvement in confidence following the session using smart glass technology (mean pre-session confidence=4.7/10, mean post-session confidence=8.1/10). Further, the quality of teaching (average score 9.6/10) and the content/relevance (average score 9.5/10) of the teaching was highly rated.

TABLE 3
Summary of Study Outcomes and Results (continued)

Author, Year	Outcomes	Results
Baker et al, 2021[36]	The primary outcome measured was participants' subjective experiences following a remote emergency department clinical experience for medical students.	Results showed that 100% (22 of 22) of participants agreed or strongly agreed that it was a good overall experience with educational value.
Herbst et al, 2021[37]	The primary outcome measured was the usability of a VR-based behavioral health anticipatory guidance curriculum for pediatric residents.	Results showed that residents reported high degrees of immersion, spatial presence, and cognitive involvement. One hundred percent of (14 of 14) residents agreed or strongly agreed that they could devote their whole attention to the VR experience; 86% (12 of 14) of residents agreed or strongly agreed that the VR presentation activated their thinking; and 79% (11 of 14) participants agreed or strongly agreed that it seemed as though the residents took part in the action of the simulation. However, 50% (7 of 14) of residents disagreed or strongly disagreed that they felt they could do things with objects in the virtual presentation.
Ralston et al, 2021[38]	The primary outcome measured was participants' subjective experiences following VR training in simulated pediatric cardiac critical care clinical scenarios.	Results showed that participants found the VR experience enjoyable (100% [6 of 6] agreed or strongly agreed) and realistic (67% [4 of 6] agreed or strongly agreed), with most participants agreeing that it has enhanced their experience (83% [5 of 6] agreed or strongly agreed).
Chan et al, 2021[39]	The primary outcomes measured were based on participants' engagement during anatomy education.	Results showed that the group using 360-degree videos had statistically significant higher engagement throughout the 8-minute anatomy video compared to the 2-dimensional group. Participants using 360-degree video reported that it was more practical and interesting compared to the 2-dimensional group. There was no significant difference in perceived ease of learning. The effectiveness of these technologies to enhance knowledge was not evaluated.
Behmadi et al, 2022[40]	The primary outcome measured was the rate of learning measured by the participants' test scores at the end of the VR-based emergency medicine course.	Results showed that scores from the virtual simulation were slightly higher but not statistically significant. Satisfaction was significantly higher in virtual simulation. Overall results advocated that VR simulation can improve knowledge but is not more effective than traditional methods.

Abbreviation: VR, virtual reality.

improvement in trainee confidence, 3 of 3 studies reported significant improvement in surgical skills, 6 of 6 studies reported positive students' enjoyment/attention, and 3 of 3 studies reported on limitations of immersive technologies.

Trainee Confidence: Three studies reported on trainee confidence following the VR training.[11,33,35] One study showed statistically significant improvement in self-reported confidence in all 10 parameters, such as identifying gross brain structures (pre-course average 3.64±2.10; post-course average 7.42±1.00; $P<.0001$) and performing neurological examinations (pre-course average 4.21±1.89; post-course average 7.92±1.24; $P<.0001$).[11] Another study showed improvement in self-reported trainee confidence following VR training on basic wound closure.[35] Finally, one study showed an increase in the median knowledge confidence scores before and after VR curriculum on surgical anatomy.[33] The knowledge confidence score was self-reported and analyzed by a Wilcoxon signed rank test.[33]

Skill Transfer: Three studies reported on the impact of VR training on surgical skills.[11,32,34] One study found that immersive technologies demonstrated significant ($P<.05$) improvement in surgical completion times (mean procedure time 97.62±35.59) compared to those training on cadavers (mean procedure time 121.34±12.17).[34] Other outcomes measured, such as surgical safety scores, showed no statistical improvement ($P=.19$), meaning the surgical practice was not made safer by implementing VR technology (VR group mean 19.93±0.38, cadaver

TABLE 4
Effect Direction Plot of a Summary of Outcomes

Author, Reference	Quality of Medical Education					
	Enjoyment/ Attention	Confidence	Surgical Skills	Knowledge/ Understanding	Limitations	Overall Experience
Young et al[3]	↑↑ 2				↑↑ 9	↑↑ 6
Simone et al[4]	↑ 4					↑ 16
Atli et al[11]		↑ 10	↑ 1	↑ 3		↑ 2
Bala et al[7]	↑ 1				↑ 1	↑ 3
Sommer et al[32]			↑↑ 5			
Papalois et al[33]		↑ 1		↑ 2		↑ 1
Huri et al[34]			↑ 2			
Ike et al[35]		↑ 1				↑ 4
Baker et al[36]						↑ 1
Herbst et al[37]	↑ 1				↑ 1	↑ 1
Ralston et al[38]	↑ 1					↑ 4
Chan et al[39]	↑ 1			<>		↑ 2
Behmadi et al[40]				<>		↑ 1

Note: Arrows represents positive (↑) or negative (↓) statistically significant associations. The subscript represents the number of statistically significant outcomes reported. One arrow represents a sample size <50, 2 arrows represent a sample size of ≥ 50. <> represents non-significant outcomes.

group mean 19.56±0.51).[34] In the study, surgical safety was assessed in terms of damage to adjacent tissue including glenoid and humeral cartilage.[34]

Finally, one study measured surgical performance and surgical task completion times in 7 parameters.[32] The surgical parameters assessed were grouped into camera navigation skills (n=3) and surgical performance of cholecystectomy dissection (n=4).[32] The result showed significant improvement in 5 of the 7 surgical parameters assessed.[32] Finally, one study reported that 8 of 12 (66%) participants agreed that the VR training helped retain the surgical skills and techniques learnt during the VR curriculum.[11] The surgical skills taught were not specified.[11]

Information Retention: Four studies reported on information retention and subject understanding following VR training.[11,33,39,40] Two studies reported significant improvement in knowledge and understanding, while 2 studies reported no significant improvement. One study reported that 93.4% of participants strongly agreed or agreed that their knowledge of surgical anatomy had improved after the VR session.[33] The study concluded that the module improved participants' understanding of operative steps and critical decision-making points.[33] Another study reported that VR helped gain a deeper understanding (100% [12 of 12] of participants) and greater information retention (92% [11 of 12] of participants) of neuroanatomy and neurosurgery.[11]

One study measured the rate of learning and found that test scores of the VR simulation group were slightly higher (mean 17.32±1.83) but not statistically significant compared to the control group (mean 16.67±1.82) that received lecture-based learning.[40] Despite this, the intervention group showed statistically significant greater satisfaction (mean 3.36±0.31) compared to lecture-based teaching (mean 4.10±0.20).[40] Based on the findings, the study concluded that VR could improve knowledge, but is not more effective than lecture-based learning.[40] The assessments tested participants on simple triage and rapid transport after it was taught through lectures or VR.[40]

The final study compared 360-degree immersive video to 2D video.[39] The primary outcome measured was engagement in anatomy education.[39] The study showed that 360-degree videos had statistically significant higher engagement in the 6th (2D mean 66.5, SD 14.4; 360-degree mean 88.7, SD 8.3; $P<.0001$) and 8th minute (2D mean 58.0, SD 19.1; 360-degree mean 87.1, SD 9.9; $P<.0001$).[39] However, there was no significant difference in perceived ease of learning.[39]

Overall Experience: Trainee experience was the most commonly reported outcome. Eleven studies reported on overall experience, while 2 studies did not. Results showed that participants gave positive feedback in terms of enjoyment, attentiveness, and the realistic experience of VR and AR technology.[3,7,36,38] Participants reported high degrees of immersion and cognitive involvement, where 100% (14 of 14) and 86% (12 of 14) of residents agreed or strongly agreed that they could devote their whole attention to the VR experience and that VR captured their senses, respectively.[37] Additionally, 82% (9 of 11) of participants stated that they were able to interact and ask questions during virtual ward rounds.[7] The same study also commented on the accessibility of teaching that would otherwise be inaccessible during the COVID-19 pandemic.[7]

Three studies commented on how realistic the experience was.[3,37,38] Two studies showed that only 40% (35 of 87) of participants and 50% (7 of 14) of participants felt physically present in the environment, whereas one study reported that 67% (4 of 6) of participants found VR to be realistic.[3,37,38] Evidence for this was variable and depended on the clinical scenario. Finally, one study showed that 80% (70 of 87) of participants found VR to be less effective than bedside teaching, which was deemed invaluable by most participants.[3]

Discussion

Immersive technologies have been shown to increase confidence, skill, and knowledge of trainees.[1,11,32-35,41] VR also provides a safe environment for new trainees to practice surgical skills without risk to patients.[32,34] However, the technology has challenges including high initial costs and difficulties in operating communication devices such as VR headsets.[1,3,7,15,37,41] Furthermore, concerns over safety and privacy relating to patient anonymity and confidentiality have caused cautious adoption among physicians.[16-18] These shortcomings have been highlighted in recently published primary research articles, which have advocated the need for continuous development of immersive technologies.[1,3,7,15,37] This narrative synthesis identified similar technical and physical challenges with the equipment, further complementing the aforementioned findings.[3,7,37] In light of this, researchers proposed video conferencing and online lectures as suitable alternatives.[21] However, this form of education also has limitations, namely difficulty teaching clinical skills, as well as having lower participant satisfaction ratings compared to VR teaching.[1,3,21]

Reviews similar to ours have evaluated the use of immersive technologies in surgery.[5,20,42] These reviews demonstrated that participants trained with immersive technologies showed significantly improved surgical efficiency when compared to traditional teaching methods.[5,20,42] Similarly, this review showed positive outcomes in terms of knowledge acquisition and self-reported confidence following VR training.[11,32-35] This review also identified significant improvement in the time required to complete surgical procedures for those trained on VR compared to traditional methods.[32,34] However, where previous reviews reported improved surgical outcomes, this review showed no significant difference between VR and cadaveric training on surgical safety.[34]

Previous reviews have also reported non-educational benefits of immersive technologies, such as their role in limiting the exposure of patients, health care providers, and medical students to COVID-19.[12,41] This proved to be particularly useful in vulnerable groups such as cancer patients where the use of technological innovation helped limit travel to high-risk areas such as hospital premises.[12] Moreover, the use of AR led to improved decision-making and quality of patient care.[41] These findings were consistent across the literature.[12,15,20,41,42] However, despite reported improvement in patient care and infection prevention, our review identified shortcomings in patient interaction, which impacted self-reported quality of medical education.[3,4,20]

Our findings both complement and challenge existing literature. However, where recent reviews studied the general use of various immersive technologies in medicine, this review exclusively examined the impact of VR and AR on medical education during the period of the COVID-19 pandemic. The aim of this narrative synthesis was to build on the efforts of the review published by Xu et al that examined the use of immersive technologies in medical education up to 2020.[15] Given the rapid adoption of technological innovations and the volume of published research on immersive technologies during the pandemic, it was useful to reevaluate the subject.

Limitations

Four limitations have been identified in this systematic review. First, studies had small sample sizes, which may not be wholly representative of the study population. Second, the selected studies were highly variable in terms of the methodology, sampling, and comparators, making it difficult to group them and identify themes. Third, some studies published in 2021 did not specify when the study was conducted. Consequently, it is possible that these studies could include some pre-pandemic data; however, we ensured that only studies that took place during the pandemic were included. Finally, one study declared a conflict of interest, and 2 studies did not comment on conflicts of interest.

Recommendations

This review identified the gaps and variations in the existing literature, which informs future research in this area. Most notably, objective evidence on knowledge enhancement and surgical outcomes following VR or AR training was underreported, and available evidence was mostly self-reported by participants. Both knowledge enhancement and surgical outcomes are considered accurate predictors of the quality of education. Therefore, further primary research with standardized effect evaluating the knowledge enhancement, and surgical outcomes following VR or AR training would allow statistical analysis (ie, meta-analysis) to be conducted. Moreover, there was a wide variation in the outcomes measured across the studies, and a more consistent approach would allow for more generalizability and comparison. Further research is also required to determine whether immersive technologies would be a cost-effective addition to medical education. Our recommendations to developers would be to improve the useability of the technology as this was the main barrier to adoption.

Conclusions

Our narrative synthesis review demonstrates that immersive technologies are beneficial to learning surgical skills during a period of reduced training opportunities. Compared to didactic teaching methods, such as lecture-based, online, 2D video, and reading, immersive technologies were found to encourage student learning and increase trainee confidence. However, gaps in the literature, such as limited evidence on the effectiveness of immersive technologies on knowledge enhancement and surgical outcomes, make it difficult to draw robust conclusions.

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