Review

Current Clinical and Educational Uses of Immersive Reality in Anesthesia: Narrative Review

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Abstract

Background: The concept of immersive reality (IR), an umbrella term that encompasses virtual reality, augmented reality, and mixed reality, has been established within the health care realm as a potentially valuable tool with numerous applications in both medical education and patient care.

Objective: This review aimed to introduce anesthesiologists to the emerging and rapidly evolving literature on IR, its use in anesthesia education, and its transferability into the clinical context.

Methods: A review of the relevant literature was conducted using the PubMed database from inception to July 5, 2023. Additional references were identified from the reference lists of selected papers.

Results: A total of 51 papers related to the use of IR in anesthesia medical education (including both technical and nontechnical skills) and 63 papers related to applications in clinical practice (eg, preprocedure planning, patient education, and pain management) were included. We present evidence supporting the use of IR in the training and clinical practice of modern anesthesiologists.

Conclusions: IR is useful for a variety of applications in anesthesia medical education and has potential advantages over existing simulation approaches. Similarly, IR has demonstrated potential improvements in patient care across several clinical contexts relevant to practicing anesthesiologists. However, many applications remain in the early stages of development, and robust trials are urgently needed to confirm clinical or educational effectiveness and to assess mechanisms, educational validity, and cost-effectiveness.

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KEYWORDS

virtual reality; augmented reality; mixed reality; anesthesia; immersive reality; medical education; artificial intelligence

Introduction

Nomenclature and Definitions

The nomenclature surrounding immersive reality (IR) has evolved, and in this review, we provide some definitions to assist the reader. We use IR as an overarching term encompassing virtual reality (VR), augmented reality (AR), and mixed reality (MR), although other umbrella terms, such as extended reality, can also be found in the literature [1,2]. VR is any type of computer-generated immersive environment that users can interact with, including both 2D and 3D experiences. AR involves overlaying computer-generated elements on a real-world environment, and MR blends aspects of VR and AR [3,4], capturing both real-world and virtual elements in 3D and allowing for interaction across these realms [5].

IR experiences are often facilitated using a head-mounted display (HMD or headset), a piece of hardware worn on the face of the user, surrounding their field of view, with 1 or 2 small displays showing stereoscopic computer-generated imagery [6]. In this form of VR, users wearing an HMD can only perceive images of the virtually generated world displayed on the screens. This allows a user to experience a fully immersive, computer-generated 3D environment and interact with objects using handheld controllers or a set of virtual hands that mimic their own. More recently, with advances in consumer-level hardware, many IR headsets allow users to physically walk around within a defined interactive VR environment. In contrast to VR headsets, AR and MR headsets allow the user to see the real world while immersed in an overlaid computer-generated environment within the field of view of the headset.

Consumer-level HMDs most commonly used for clinical and medical education purposes incorporate variable levels of functionality (Table 1). For example, different devices are capable of tracking various types of motion. Simple systems with 3 degrees of freedom can only detect rotation around a fixed point. Newer, more complex systems, with 6 degrees of freedom can detect rotation and position in 3D space.

Regarding HMDs, 3 degrees of freedom devices can only detect where you are looking (the rotation and tilt of your head) but not your position in space (ie, whether you move forward or backward, left or right, or crouch down). Devices with 6 degrees of freedom can detect all the abovementioned types of motion using either sensors built into the device itself or external sensors, such as tripod or wall-mounted hardware.

Table 1. Technical characteristics and practical considerations for commonly available immersive reality head-mounted displays (HMDs) used in anesthesia.

Device	Commercial availability	Additional component requirement	HMD degrees of freedom	Eye tracking	Hand tracking	Controller degrees of freedom	Example uses in anesthesia
Oculus Rift	Discontinued	Yes, computer desktop	6 (requires external sensors)	No	No	6	• VR[a] distraction [7,8] • Preprocedure education [9] • Immersive VR simulation [10-12]
Oculus Go	Discontinued	No	3	No	No	3	• VR distraction [13-15] • Preprocedure education [16] • Immersive VR simulation [17]
Oculus Quest	Discontinued	No	6	No	Yes	6	• N/A[b]
Oculus Quest 2	Yes	No	6	Yes, with third-party hardware	Yes	6	• N/A
Gear VR (Samsung)	Discontinued	No	3	No	No	3	• VR distraction [7,18-21] • Preprocedure relaxation [22]
Pico G2 4K	Yes	Yes, computer desktop	3	No	No	3	• VR distraction [23]
Pico Neo 3 Pro	Yes	Yes, computer desktop	6	Yes, with additional cost	No	6	• N/A
HTC Vive Pro	Discontinued	Yes, attachments	6	Yes, with third-party hardware	No	6	• Immersive VR simulation [17,24-26]
HTC Vive Pro 2	Yes	Yes, attachments	6	Yes, with third-party hardware	No	6	• —[c]
Valve Index	Yes	Yes, computer desktop	6	Yes, with 3rd party hardware	Yes, using controller	6	• N/A
Prism Pro (Mira)	Yes	Yes, mobile device	N/A	No	No	3	• N/A
PlayStation VR (Sony)	Yes	Yes, PlayStation 4 or PlayStation 5 console	6 (requires external sensors)	No	No	6	• VR distraction game [27]
Google Daydream	Discontinued	Yes, mobile device	3	No	No	3	• N/A
Hololens (Microsoft)	Discontinued	No	6	Yes	Yes	3	• AR[d] simulation [28]
Hololens 2 (Microsoft)	Yes	No	6	Yes	Yes	No controller	• N/A
Magic Leap 1	Discontinued	No	6	Yes	Yes	6	• AR simulation [29,30]
Magic Leap 2	Yes	No	6	Yes	Yes	6	• N/A
Apple Vision Pro	Yes	No	6	Yes	Yes	No controller	• N/A

[a] VR: virtual reality.

[b] N/A: not applicable.

[c] Data not available.

[d] AR: augmented reality.

Similar to headsets, VR controllers with 3 degrees of freedom have limited tracking ability, while newer controllers with 6 degrees of freedom allow a more naturalistic, full range of motion (eg, extending your controller in real life will be replicated in VR). Eye tracking refers to an extra set of lenses within the HMD, which tracks the movement of each eye. This allows the device to track where the user is looking and, in some cases, it allows interaction with the virtual environment through changes in gaze alone [31-33]. Hand tracking uses a front-facing camera on the HMD to track a user's hands and project them into the virtual environment, allowing users to interact with the virtual environment without the need for controllers.

Handheld devices (eg, cell phones and tablets) can also be used for AR, by observing digital images overlaid on the real world using the camera viewer. However, these devices offer limited functionality as they have only a small field of view and are not ergonomic, as they must be held up by the user.

The Spectrum of Immersion

Immersion is the ability of a system to create the sensation of "presence," the subjective feeling of existing in a computer-generated world [34]. This is created in computer-based simulations by providing sensory input, including visual, auditory, and tactile (ie, haptic feedback) stimuli. Placing an individual in an IR system with these stimuli creates the sensation of being physically present in a virtual environment. Advancements in computational processing power and associated decreases in the size of electronic components have led to lower costs and rising availability of consumer-level IR technologies. This increase in availability has been accompanied by a parallel increase in the adoption of virtual-based simulation in medicine and beyond [35].

Historically, 2D worlds, which lack the increased sense of presence provided by newer 3D immersion technology, have also been labeled immersive experiences. In the context of medicine, this has mainly been limited to medical education, where learners view a 2D screen with a virtual image of a simulated task to be practiced. Many examples of simple 2D simulation exist in surgical training [36,37] and anesthesia [38-42], where students view virtual anatomical images on a screen and use partial task trainers or practical tools (eg, endoscopes, bronchoscopes, and surgical instruments), which provide haptic feedback to practice their technical skills.

Affordable HMDs and 360° cameras developed in recent years have allowed educators to increase immersion in IR educational experiences. Instead of watching on a 2D screen, learners can now be immersed in 360° experiences using headsets to experience real or animated clinical environments. As reduced work hours for medical trainees has resulted in fewer clinical learning opportunities, IR has emerged as an alternative method to supplement traditional clinical curricula. In addition, during the global COVID-19 pandemic, where social distancing and remote learning presented challenges for clinical learning, IR enabled students and residents to continue participating in interactive training. However, the literature is just beginning to examine how IR modalities can most effectively be incorporated into clinical teaching curricula.

Another relevant component of teaching curricula is simulation-based training. Simulation is an educational technique that allows interactive, immersive activity by recreating all or part of a clinical experience without exposing patients to associated risks [43]. Historically, full-body manikin simulation has been proposed as an adjunct to clinical learning, complementing clinical experience. Simulation in medical education is a well-established pedagogical practice [44], providing a viable alternative to practice with actual patients, whereby medical trainees are afforded the opportunity to train until they reach a specific competency level. Simulation ranges from decontextualized bench models and VR-based environments to high-fidelity recreations of actual operating rooms [45]. Simulation can engage the trainee in the progressive accumulation of knowledge through deliberate practice, allowing for careful matching of the complexity of the learning environment to the trainees' current level of advancement [46]. Although simulation is widely used in medical education, it is often resource intensive, cost prohibitive [47] and requires learners to physically attend simulation centers. A survey of 154 anesthesiologists found that insufficient time and training opportunities were major barriers to taking part in simulation-based education, with 48% of respondents saying that they would be more likely to attend simulation-based courses if they were hosted at their own hospital [48].

Current advances in IR technology are addressing these limitations through the development of innovative, immersive experiences using cost-effective, consumer-level hardware capable of engaging trainees. A major advantage of IR over manikin-based simulation is increased accessibility, as learners can use the equipment on-site or access IR educational applications remotely. IR equipment can be set up in small spaces (eg, call rooms and conference rooms) with minimal time requirements so that the curricula can be delivered instantaneously in perioperative settings. In addition, although there are costs associated with developing IR applications, the end products can be made modular with the potential for both learning and assessment embedded within. IR curriculum delivery is highly cost-effective and can be easily scaled for additional learners with minimal expense, unlike manikin-based programs. These advantages may result in increased feasibility and reduced costs for IR-based simulation training, although this must still be verified using appropriate cost-benefit studies.

In addition to the use of IR simulation for education and training purposes, IR technologies are increasingly being used directly in patient care, both in patient-centric interventions (eg, as a distraction during painful procedures) and by health care providers (eg, real-time AR-image guidance). In this review, we discuss the theory underlying the use of IR technology in both medical education and clinical care as well as the evidence supporting specific examples relevant to practicing anesthesiologists.

Methods

Overview

This narrative review aimed to identify uses of IR relevant to practicing anesthesiologists. As such, we focused on perioperative applications and applications related to techniques in which anesthesiologists commonly take part (eg, fiber-optic intubation). Applications of IR focused on addressing pain or anxiety in instances where an anesthesiologist is not normally present (eg, burn wound dressing changes [49]) were excluded. Similarly, while a large amount of research has been done in the area of pediatric anesthesia, we chose to focus on IR applications relevant to those practicing in adult populations. IR applications in pediatric populations have been described elsewhere [50-52]. Finally, we focused on describing existing applications of IR in anesthesia, including up-to-date clinical protocols, while a review focused on theoretical and future applications has been recently published elsewhere [53].

Search Strategy

Relevant publications were identified using PubMed and search terms including “Virtual Reality” AND (“anesthesia” OR “Anaesthesia” OR “Anesthesiology” OR “Anaesthesiology”); “Augmented Reality” AND (“anesthesia” OR “Anaesthesia” OR “Anesthesiology” OR “Anaesthesiology”); vital AND signs AND monitoring AND anesthesia AND display; (“anesth*” OR “anaesthe*”) AND (virtual reality OR immersive reality OR augmented reality OR mixed reality OR 360 video) AND (simulation) AND (education) AND (technology) AND (pedagogy OR teaching); (“anesth*” OR “anaesthe*”) AND (virtual reality OR immersive reality OR augmented reality OR mixed reality OR 360 video) AND (simulation) AND (education) AND (pedagogy OR Teaching) AND (clinical medicine); (“anesth*” OR “anaesthe*”) AND (virtual reality OR immersive reality OR augmented reality OR mixed reality OR 360 video). The literature search included articles published from inception to the date of the search, July 5, 2023. Additional references were identified from the reference lists of the selected papers.

Results

Education Through Immersion: Current and Potential Uses in Medical Education

Overview

Virtual simulation can lead to better learning outcomes for various procedures. Improved health outcomes (eg, patient safety, reduction in costs, and morbidity) have also been reported after the use of computer-enhanced training [54]. Moreover, there are many cases where both technical [55-57] and nontechnical [11] skills acquired during virtual simulation–based training have proven transferrable to subsequent performance in clinical settings.

However, studies aiming to address IR-based educational tools have been heterogeneous in their design and validation, leading to mixed results. This is compounded by the fact that many IR frameworks are designed without using educational theory as a foundation [54,58]. Literature discussing the theory behind the use of immersive technology is limited. However, by taking a broader perspective and viewing the educational literature as a whole, one can begin to form a narrative supporting its use. For example, the learning theory of constructivism outlines that learning occurs by amalgamating previous knowledge and new information to create meaning from an educational activity [59-61]. Both accuracy and real-life relevance of a problem increase learner engagement, and meaningful learning occurs when learners actively interact with the environment through decision-making. IR content is well suited to these tasks as realistic, deeply immersive clinical scenarios can be created, allowing learners to interact with their environment and to have a safe space to make mistakes, free of consequences.

Similarly, medical education has evolved toward self-directed learning and case-based practice [62-64], including the involvement of learning theories, such as self-regulated learning (SRL). SRL is a process by which learners autonomously set goals, monitor their own performance, reflect on outcomes, and then repeat the process to attain desired goals, without an emphasis on instructor-led learning and feedback [65-70]. The versatility of IR learning environments lends itself well to incorporating important components of SRL. For instance, immersive environments based on SRL concepts could provide the learner with educational objectives, allowing them to practice clinical scenarios at their own pace with mechanisms incorporated into the software to assist with progressive difficulty, automatic evaluation, and improved learning.

Many applications in health care, especially those related to nontechnical skills, are still in prototype stages that lack an explicit pedagogical basis [5]. However, this does not imply that IR applications related to clinical decision-making should not be developed. Rather, we are at a critical stage where medical learning theory must inform future IR-based learning applications. Thus, robust research studies examining the effectiveness of these applications, beyond subjective assessments, are urgently needed [71].

IR solutions have the potential to be, and in some cases already are [72,73], effective teaching tools when based on a foundation of learning theory–based design. While this foundation is not always present in current IR-based medical education solutions, we attempted to highlight examples of how IR has been used in anesthesia-based medical education for both technical and procedural teaching and nontechnical skills.

Technical Skills

Traditionally, the most common use of IR in medical education has been to train technical and procedural skills. Training programs in laparoscopic, neurological, endovascular, and orthopedic surgery have led the development of IR with positive learning outcomes [74-77]. This could be considered counterintuitive, as a principal criticism of IR in medical education has been the lack of life-like haptic (the means whereby information is conveyed through touch) technology [78], which is thought to be needed to teach technical skills.

However, educators in heavily procedural medical specialties are faced with a conundrum. On the one hand, trainees require greater autonomy as exposure to clinical settings is reduced. On the other hand, learning technical skills from text alone or by merely watching the corresponding procedure being performed has shown mixed results [79]. IR allows learners to not only visualize procedural skills in the first person but also practice the steps needed for completion in an active manner, with or without haptic capabilities. The sense of touch has been simulated using joysticks, haptic gloves, and by attaching sensors to common medical tools (eg, syringes).

Existing IR simulators with relevance to anesthesia include simulators for teaching regional anesthesia techniques [39,80-82], bronchoscopy or intubation [40,41,57,83,84], and central vein insertion [85,86] (Table 2; Table S1 in Multimedia Appendix 1) [28,38-42,56,57,80-103]. Often these applications take the form of nonimmersive VR simulators where the trainee uses a clinical tool such as a fiber-optic bronchoscope on a physical model while receiving appropriate clinical feedback (eg, ultrasound or endoscopy images) through a 2D screen. Furthermore, several MR and AR simulators have been developed that combine physical anatomical models with live tracking of handheld tools (eg, ultrasound probes and syringes) translated onto a virtual 3D computer model mimicking real anatomy [80,101,104]. Thus, the user can see, in real time, how their actions performed on the model map onto the 3D virtual anatomy model. By combining physical anatomical models and tools with IR-simulated environments, these models can effectively simulate complex procedures such as vascular access [101,104] and regional anesthesia blocks [80]. In other instances, immersive 360° VR environments have been combined with existing manikin-based simulations to increase immersion and learner engagement [91].

Table 2. Immersive reality (IR) interventions for both technical and nontechnical skills in anesthesia education.

Educational application	Clinical skill
Technical skills	
IR intervention	
AR[a] or MR[b] simulator (nonimmersive)	• Nasogastric tube placement [96] • Central line insertion [85,86,101] • Intravenous insertion [90] • Epidural injection [80] • Transthoracic and transesophageal echocardiography [28] • Lumbar puncture [87] • CPR[c] [92]
VR[d] simulator (nonimmersive)	• Fiber-optic bronchoscopy and intubation [40,41,57,83,84,97,99,102] • Lung isolation [100] • Regional anesthesia [38,39] • Cystoscopy [94] • Ultrasonography [98] • Intravenous insertion [103] • Spinal cord stimulation [42]
VR simulator (immersive)	• Regional and spinal anesthesia [56,81] • CPR and ACLS[e] [17,88,89,91] • Ultrasound guided regional anesthesia [82] • Central line insertion [93]
Nontechnical skills (eg, clinical reasoning and communication)	
IR intervention	
Virtual simulator (nonimmersive)	• Recognition of clinical intraoperative events [105] • Stress response: clinical deterioration [106]
AR simulator	• Communication skills: ACLS scenario [29]
VR simulator (immersive)	• Airway crisis management [26] • Anesthesia crisis management and local anesthetic systemic toxicity [107] • Emergency medicine [108] • Operating room fire safety [10,24,30,109] • Operating room infection prevention [12] • Persuasion training (influenza vaccine hesitancy) [11] • Preparation for an epidural procedure [110] • ACLS team leadership [111] • Surgical unit virtual tour [112] • Therapeutic communication skills [113]
Multiuser VR simulator (immersive)	• Operating room communication [25]
MR simulator (virtual humans)	• Operating room communication [114] • Operating room conflict resolution [115]

[a] AR: augmented reality.

[b] MR: mixed reality.

[c] CPR: cardiopulmonary resuscitation.

[d] VR: virtual reality.

[e] ACLS: advanced cardiac life support.

Nontechnical Skills

IR simulations have also been adapted to teach important nontechnical skills, such as clinical reasoning, communication, and teamwork. These nontechnical skills are crucial to successful clinical encounters, and efficacious uptake of these skills is vital for reducing medical errors and enhancing patient safety. IR simulations can be used to strengthen these skills.

Immersive instructional 360° videos have been developed to teach clinical reasoning skills, allowing for more active learning by incorporating problem-solving elements into the immersive experience. For example, Masson et al [12] developed a 360°

simulation that teaches perioperative infection prevention techniques and allows the learner to make choices during key decision-making points, creating a more “active” observational learning process.

Active learning can also be achieved through computer-generated immersive simulations (Table 2; Table S2 in Multimedia Appendix 1) [10-12,17,24-26,29,30,105-109,111-115]. This is especially useful for teaching comparatively rare or complex clinical events with steep learning curves (eg, airway crisis scenarios). Using commercially available HMDs (Table 1) and tracking sensors, our group [116] (NCT04451590 and NCT04591041) and others [24,26,106,111,117] created simulated crisis scenarios that allowed learners to create objectives and manage patients who are critically ill in virtual operating rooms or trauma bays. Crucially, these IR simulations respond to learners’ decisions and provide feedback upon completion. These serve as self-contained simulation scenarios learners can use for deliberate practice to supplement their clinical experiences. Specific clinical scenarios relevant to anesthesiology that have been developed include response to an operating room fire [24,118], airway crisis scenarios (NCT04451590) [26,117], advanced cardiac life support [29,111], and operating room procedures for preventing surgical site infection [12] (Table 2; Table S2 in Multimedia Appendix 1). In addition to specific clinical scenarios, IR can be used to teach and practice “soft skills,” such as teamwork and patient communication. Real et al [11] developed a simulator that uses virtual standardized patients to teach health care providers persuasion techniques for supporting patients who are hesitant about vaccines. VR training translated directly to improved clinical communication, as demonstrated by reduced vaccine refusal rates in the 3 months following VR training relative to controls [11].

In another study by Cordar et al [115], virtual humans were used as an operating room team to model conflict resolution skills during critical operating room scenarios. They found that participants were positively influenced by the virtual humans demonstrating ideal conflict resolution techniques and, conversely, were negatively influenced when they modeled negative conflict resolution behavior. These findings demonstrate that IR can be an effective method to teach nontechnical skills, such as team training and communication [115].

We have discussed the theoretical foundation for the use of IR in medical education and specific applications related to anesthesia education for both technical and nontechnical skills. IR allows learners to actively experience the complex anatomy of patients and how they interact with medical tools in a safe, accessible environment. Similarly, IR using HMDs and 360° recordings, facilitated by advances in technology, offers the ability to develop important nontechnical skills. Further information regarding the key outcomes of studies supporting the use of IR in anesthesia medical education is provided in Tables S1 and S2 in Multimedia Appendix 1. Moving forward, it is important to conduct robust trials to assess the educational efficacy of IR, determine its simulator validity, and confirm its cost-effectiveness.

Clinical Uses of IR in Anesthesia

Overview

In addition to the educational applications described in the Education Through Immersion: Current and Potential Uses in Medical Education section, IR technologies are increasingly being used directly in patient care. These include patient-centered interventions, where patients are exposed to IR as an educational tool or as a distraction during painful procedures (Table 3; Table S3 in Multimedia Appendix 1) [7-9,13-16,18-23,27,32,119-144] as well as applications focused on health care providers, where IR technology and 3D visualizations are used to plan or guide clinical care (Table 4; Table S4 in Multimedia Appendix 1) [145-166]. In this Clinical Uses of IR in Anesthesia section, we discuss existing clinical uses of IR technology relevant to practicing anesthesiologists.

Table 3. Patient-based clinical applications of immersive reality (IR) in anesthesia.

Clinical application	Clinical scenario
Intraprocedure distraction	
IR intervention	
Immersive video	• Awake hand surgery [13,19,139] • Orthopedic surgery with regional anesthesia [7,8,138] • Ambulatory surgery [144] • Pregnancy termination [18] • Episiotomy repair [143] • Outpatient hysteroscopy [128] • Lipoma excision [133] • Cystoscopy [129] • Bone marrow aspiration [132] • Transcatheter aortic valve implantation [122] • Gastrointestinal endoscopy [126] • Endovascular aneurysm repair [130] • Breast biopsy [134]
Interactive environment	• Adductor canal catheter insertion [32] • Upper gastrointestinal endoscopy [141,142] • Cystoscopy [135] • Outpatient hysteroscopy [124] • Bone marrow biopsy [121] • Awake hand surgery [127]
Interactive game	• Lumbar puncture [27]
Guided breathing, hypnosis, or relaxation	• Hip or knee arthroplasty [23,125,136] • Upper limb surgery [14,15,123] • Atrial fibrillation ablation [137] • Epidural placement for labor [20] • Endoscopic urological surgery [21]
Preprocedure preparation	
IR intervention	
Operating room tour or procedural education	• Elective surgery with general anesthesia [16] • Elective cranial or spinal procedures [9] • Colorectal cancer surgery [140]
Relaxation	• Elective gynecological surgery [22] • Cardiac surgery [131] • Septorhinoplasty [119] • Gastrointestinal endoscopy [120]

Table 4. Applications of immersive reality (IR) focused on health care providers in clinical anesthesia practice.

Clinical application	Clinical scenario
Clinical data visualization and vital signs monitoring	
IR intervention	
AR[a]- or MR[b]-based HMD[c] or smart glasses	• Simulated operating room scenarios [163,165] • General surgery [166] • Nurse anesthetists anesthesia care [155] • Supervising anesthesiologist (simulated) [156,164]
VR[d] HMD	• Arterial blood gas monitoring [145]
Real-time procedure guidance	
IR intervention	
AR HMD overlay or projection	• Epidural and spinal anesthesia [153,157,161] • Simulated epidural and spinal anesthesia [147-149] • Simulated peripheral nerve block [160,162] • Simulated central venous catheterization [159] • Fine-needle aspiration [158] • Triage decision-making and mass casualty event [154] • Percutaneous rhizotomy [146]
Preprocedure planning	
IR intervention	
Immersive VR HMD	• Difficult airway intubation [150]
Nonimmersive VR simulation	• Regional anesthesia administration [152]
AR or MR HMD	• Awake craniotomy [151]

[a] AR: augmented reality.

[b] MR: mixed reality.

[c] HMD: head-mounted display.

[d] VR: virtual reality.

Clinical Data Visualization

AR-based HMDs allow users to see virtual data overlaid on the real world. For example, an anesthesiologist can view patient vital signs overlaid on the surgical field of view. Since 1995, researchers have been investigating the utility of AR-based HMDs in clinical anesthesia [166]. Several studies of anesthesiologists have reported advantages of using IR, including easier and faster recognition of clinical events [156,163,167] and the ability to spend more time focusing on the patient and the surgical field compared to vital sign monitors [168,169].

Liu et al [163] studied whether 12 anesthesiologists in a simulated environment would notice different events that occurred either on the patient monitor or in the operating room. The HMD did not interfere with participants' ability to detect clinical events and may have allowed participants to detect some events more quickly when they were physically constrained by the need to perform a concurrent clinical procedure [163]. Conversely, Sanderson et al [164] reported that IR displays did not improve the ability to detect clinical events relative to advanced auditory displays [170], and others reported that HMDs might make individuals less likely to detect unexpected clinical events [171]. Thus, further research is needed to confirm how to optimally use HMDs, best ergonomic visualization practices, and whether increased attention leads to improved patient outcomes.

Preanesthesia Planning and Real-Time Guidance

Anesthesiologists often use x-rays, computerized tomography (CT), magnetic resonance imaging (MRI), and ultrasound sonography data to evaluate and plan for complex cases [172]. This provides a foundation for planning the safe management of patients with difficult airways, complex comorbidities, or complex neuraxial anatomy for regional blocks.

The use of AR-based HMDs allows for images obtained via CT, MRI, or ultrasound sonography to be mapped directly onto a patient, offering a window into the patient's anatomy. In a surgical context, systems that generate 3D models of solid organs from CT data and overlay them onto the patient using AR enable precise planning of the optimal approach for abdominal procedures [173,174]. Similarly, our group used IR to augment real-life regional anesthesia procedures using AR holographic projections [175]. Here, live ultrasound scans are converted into holographic projections overlaid on a patient's anatomy to serve as a pathway for an operator's needle to follow. Holographic pathways create reliable needle trajectory guidance that has the potential to facilitate neuraxial block procedures, reducing unsuccessful attempts, needle repositioning, patient discomfort, hematomas, and failure. These studies, along with findings from simulation or phantom models [147-149], reflect the potential for IR systems in preanesthesia planning and procedure guidance, although further research is needed to confirm clinical findings [153].

Pain Management

IR applications have been widely studied with regard to their use as an adjunct to traditional anesthesia, analgesia, and anxiolytic techniques during painful or uncomfortable procedures [176-178]. These interventions come in many forms (eg, passive 360° videos, interactive games, guided breathing exercises, and hypnosis) and have been studied in diverse patient populations. IR applications of most relevance to anesthesiologists include distraction during minor surgery using local or regional anesthesia [7,14,15,19,125,136] as well as during epidural placement [20,123] and adductor canal catheter insertion [32] (Table 3; Table S3 in Multimedia Appendix 1).

IR is generally well received by patients and health care providers. However, studies have shown conflicting results regarding effectiveness. These contradictory findings can likely be explained by the considerable heterogeneity in study design (eg, the nature of control groups and outcome measures) and in the specific nature of the intervention (eg, passive 360° video vs interactive game) that impede useful comparisons between studies [179]. Thus, while the use of IR as a distraction technique during painful or stressful procedures is well reported [176,177], full-scale, adequately powered studies with appropriate controls are needed to confirm the effectiveness in specific patient populations.

Recent studies have shown that reductions in pain or anxiety can reduce or eliminate sedative requirements, for example, during an orthopedic surgery with spinal anesthesia [125,136] or adductor canal catheter insertion [32]. In a study of endoscopic urological surgery comparing VR distraction without sedation to sedation using intravenous midazolam, participants in the VR group required no rescue sedation and reported higher satisfaction and fewer respiratory adverse events. Despite these promising results, other recent studies have shown no difference in sedation use between IR and control groups [7,137]. Therefore, additional research is needed to clarify the observed effects and determine which populations are most likely to benefit.

Similarly, to optimize the utility of these interventions and better understand how and where they will be useful, further robust studies are needed to determine how IR is able to influence pain and anxiety. For example, are reductions in pain or anxiety the result of distraction via immersion in the virtual environment, due to the content of the intervention (eg, videos and guided relaxation), or due to the novelty of the experience itself? While distraction likely contributes to the analgesic effects of VR, some studies suggest that IR may reduce pain directly through inhibition of ascending pain pathways [180]. These findings have been verified using functional MRI studies, where reductions in brain activity secondary to pain stimuli have been demonstrated with the use of IR. Notably, improved immersion and image quality have been associated with higher levels of pain reduction [181].

Patient Preparation and Education

A significant proportion of patients experience anxiety before anesthesia and surgery, often triggered by fear of the unknown [182-184]. Importantly, preoperative anxiety is associated with negative patient outcomes, including increased intraoperative anesthetic requirements, increased postoperative pain, and longer recovery times [185-187]. IR offers the ability to reduce preoperative anxiety, either through immersive, guided relaxation exercises before the procedure [22] or by providing information that alleviates anxiety through exposure therapy [188,189]. In the latter case, immersive operating room tours can allow patients to witness the steps and processes leading up to the induction of anesthesia and continuing to the recovery room firsthand. While much of the research in this area focuses on pediatric populations [51,190-192], 2 randomized controlled trials have demonstrated reduced preoperative anxiety and higher patient satisfaction using VR relative to standard preoperative procedures in an adult population [9,140].

Overall, IR preprocedure preparation is well received by patients, and the creation of similar 360° content is relatively easy. This, therefore, makes for an accessible entry into IR for anesthesiologists looking to create content at low cost [193].

Further information regarding the key outcomes of studies supporting the use of IR in anesthesia-related patient care is provided in Tables S3 and S4 in Multimedia Appendix 1. However, further research is needed to assess whether these findings are reproducible and generalizable to additional patient populations.

Discussion

Future Applications: Practicality of the Technology and Culture Change

The continued development of low-cost, consumer-level IR technology is facilitating a shift in pedagogy from traditional 2D images and videos to learning through interactive IR environments. This is particularly important in medical education, where knowledge acquisition usually includes greater experiential, self-directed, and hands-on learning than in many other disciplines [4]. As described in this paper, IR technologies have already been used to educate trainees, prepare health care providers, and help patients. Over time, emerging technologies, such as multitouch displays, telepresence (an immersive meeting experience that offers high video and audio quality), 3D environments, natural language processing, and artificial intelligence (AI) software [194], have the potential to transform not only medical education and practice but also teaching and learning in general [195].

Expanding Current Use

The advances in technology discussed above in the Introduction section allow for higher fidelity, increased presence, and creation of new applications in the field of IR, but it is also important to consider how existing IR technologies can extend the impact and reach of experts in the field of anesthesia. For instance, IR can be used in conjunction with traditional or virtual simulations to facilitate feedback and decrease demands on facilitator time. For example, IR can assist with the initial prebriefing [196,197], wherein participants are oriented to objectives and frameworks for their upcoming experience by facilitating a "flipped classroom" experience [198]. In this case, learners are virtually oriented to the simulation center from home, reducing the time required of facilitators and the overall time spent at the simulation center, allowing more time for participation in the simulated scenarios upon their arrival.

Similarly, telesimulation and telementoring, whereby a skilled practitioner can remotely guide a less experienced colleague through a complex procedure, either for educational purposes [199-201] or in an emergency situation [202], have been successfully used in surgical contexts [199-202]. The most complex versions of these apparatuses allow for annotations and even the movements of surgical tools, manipulated by an instructor, to be projected onto the surgical field of view of a colleague using AR technology [200,203]. This provides a proof of concept for using this technology to extend anesthesia services and aid in training anesthesiologists in underserved and rural communities, where they often work in challenging, underresourced environments to serve populations with high needs. In Ontario, Canada, the government is paying attention to the needs of such populations, especially Indigenous populations [204], as they have higher mortality rates and poorer health outcomes compared to urban populations [205]. IR applications, including telementoring and IR simulation training delivered via remote technology, are tools that can be used to advance health care in these regions and bring it in line with urban centers.

One noteworthy strength of IR over other simulation strategies is the ability to readily reimmerse in a simulation. For example, during feedback stages, IR allows both the facilitator and learner to be reimmersed in the simulation scenario. This can trigger the same emotional cues as when the learner was managing the simulated crisis, heightening recall and potentially leading to more fruitful discussions. This would similarly apply to self-debriefing, where learners are able to visualize the scenario from their own perspective but without the cognitive and emotional burden of managing the case, facilitating focus on the decision-making cues. Finally, during interprofessional training, immersive 360° cameras can be oriented to provide the point of view of each participant (eg, a surgeon could use an HMD to be immersed in the anesthesiologist's point of view), potentially leading to a greater appreciation of one another's roles.

The importance of well-being in health care providers has gained greater attention in recent years and presents another area where IR may have utility. Emerging evidence suggests that IR interventions, such as guided relaxation, could also help reduce stress and burnout among health care practitioners both during training [206] and in high-stress situations, such as a pandemic [207,208]. Intriguingly, a recently published small study of 20 nurses has also provided preliminary evidence that the increased usability of VR patient education compared to traditional approaches may lead to improved health care provider satisfaction and reduced burnout scores [209]. While further studies are needed, this early evidence suggests potential indirect benefits of IR, which have not been fully characterized.

Incorporating Technological Advances

As technology advances, the ways we interact with it also evolve. Instead of interacting through touchscreens or hand controllers, we will be able to interact directly through hand motions and eye movement tracking. This may accelerate as promising design breakthroughs, such as transparent interfaces, are integrated into IR systems. AI is another emerging technology that can be incorporated into medical training and presents a potentially paradigm-shifting advancement. For instance, an early study using AI-based feedback has shown evidence for effectiveness in achieving learning goals [118]. In a simulated operating room fire scenario, this study showed a significant performance improvement when an AI-guided virtual trainer provided timely feedback to users in the virtual operating room.

Further technological advances will occur in the field of haptics. Basic haptic (touch simulation) feedback is already widely available at the consumer level through devices that provide vibration feedback (eg, video game controller "rumble packs" or mobile phone vibrations). Furthermore, pseudohaptics [210,211], where illusory haptic sensations are created using combinations of audio, visual, and kinesthetic cues, has also been used to convey various touch-based properties [212-214]. However, currently available consumer-level haptic devices cannot provide the high level of fidelity and range of motion required to simulate many tasks realistically [215], and high-fidelity haptic solutions are cumbersome, complex, and often cost prohibitive [216,217]. As consumer interest in haptics grows, haptic devices capable of providing force feedback beyond simple vibrations will become more widespread. Notably, integrating haptic feedback into IR enhances immersion by simulating sensations and has been used in medical simulations, including training and simulation of medical procedures, allowing trainees to practice realistic interactions in a safe environment.

Adopting new technological advances in IR systems benefits from the increasing availability of so-called maker spaces. These are collaborative workspaces that contain equipment such as laser cutters, computer numerical control machines, soldering irons, and 3D printers that can easily create innovative, customizable, and cost-effective learning tools. 3D printing, in particular, which is becoming widespread in part due to decreased cost, allows digitally designed objects to be replicated in the real world, facilitating the merger between IR and real physical form, albeit with some limitations [4]. In the context of anesthesia, this creates the potential for faithful recreations of anatomical features (eg, airway or spinal column) to be generated using imaging data for use in training or preprocedure planning [218,219].

Limitations

While the potential benefits of IR simulation are considerable, the potential downsides of IR technology must also be considered. This includes the presence of cybersickness (negative symptoms associated with immersion in a digital world, including feelings of nausea, dizziness, or headache), which can limit usefulness in both educational and clinical contexts [220,221]. The incidence of cybersickness resulting from the use of IR systems depends on many different factors (eg, frame rate, field of view, sex, and previous game playing experience) and ranges from common to very rare [222]. The heterogeneity of both IR technology and interventions studied likely contributes to this variability [220]. However, both practical factors, such as limiting exposure duration, and technological factors, such as improved latency and higher levels of immersion, are known to reduce cybersickness [177,220,223], with 1 recent review concluding that benefits outweigh risks, at least in some patient populations [221]. Further research is needed to identify factors that can reduce unwanted side effects, such as cybersickness, while preserving the many advantages of IR technology.

Furthermore, it must be acknowledged that potential costs associated with the initial implementation of IR technologies, especially in low-resource settings, could be a barrier and potentially exacerbate existing inequality in health care outcomes. Until recently, IR technology was expensive, cumbersome, and restricted to several large institutions and research centers. However, recent increases in computational processing power and the accompanying decrease in the size of electronic components have led to decreasing costs and rising availability of consumer-level technologies (Table 1). The introduction of freely available game engines and mobile devices (eg, tablets and smartphones) capable of reproducing education-worthy environments with adequate fidelity has made IR technology an exciting and emerging field [4]. Widely available low-cost options, such as Google Cardboard [224] and other smartphone-based IR headsets, are suitable for many of the most common clinical uses of IR, such as patient education and pain distraction [134,225,226]. This suggests that the implementation of IR technology does not need to be limited to high-resource settings.

However, further research is needed to identify potential barriers and secondary costs related to the implementation of IR programs in different settings. Similarly, if supported by evidence from continued research, wide adoption of IR technology facilitated by funding support in low-resource settings could have an important impact on reducing inequality and generating long-term cost savings.

From Virtual to Concrete: Are We There Yet?

Despite the great technological advancements made, particularly with respect to computational processing, it is important to consider the limitations of computer hardware with IR applications, particularly when using VR devices. More specifically, designers and developers of IR applications should consider the fidelity of their virtual environments, that is, the level to which a virtual environment resembles the real world it is meant to represent. It is not currently feasible to create a high-fidelity virtual simulation that includes all the senses (ie, input related to sight, sound, and touch). Furthermore, higher-fidelity environments require greater computer processing requirements, which may not be readily available to the average computer users.

Moreover, we must consider the high variability of users who may be susceptible to motion sickness and address accessibility issues, including those related to visual impairment and other disabilities. Finally, as IR technologies in health care are relatively new, it is essential to address ethical concerns. These include the potential short- and long-term effects of virtual environment exposure and HMD use on both patients and health care providers, as well as whether VR headsets should be classified as medical devices?

Conclusions

In this review, we have presented the theoretical basis and evidence supporting the use of IR in the training and clinical practice of modern anesthesiologists. For those interested in implementing IR technology into their own practice, many ready-made technologies exist (Table 1). The processes and techniques required to create and implement low-cost 360° videos and virtual environments using commercially available cameras and software have been described elsewhere [116,193].

Despite recent advancements and increasing interest in IR as a research field, many applications remain in the early stages of development. Robust trials are urgently needed to confirm its clinical and educational effectiveness and to assess its mechanism, educational validity, and cost-effectiveness. While the use of IR technologies may have practical applications in medical education and for a variety of clinical patient populations, it is important to ensure that enthusiasm for this new technology does not overtake available evidence and that all applications are guided by pedagogical theory and evidence-based practice. Thus, there is a unique opportunity to innovate in a promising area of research to show the validity of IR within the anesthesia specialty and demonstrate its ability to optimize learning and clinical delivery of care. Our group founded the University of Toronto’s Collaborative Human Immersive Interaction Laboratory to develop IR solutions for clinical research, medical training, and patient education. The Collaborative Human Immersive Interaction Laboratory also aims to scientifically validate IR as a tool to enhance patient care now and in the future.

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Authors' Contributions

AF and LK completed the literature search, constructed summary tables, and addressed reviewer comments. AF, LK, BK, CM, and FA were involved in drafting the initial version of the manuscript. EBRB, PG, and JW provided contributions during the editing and revision of the manuscript. All authors provided final approval of the initial and revised manuscript and agreed to be accountable for the published work.

Conflicts of Interest

None of the authors have any financial disclosures that would serve as a conflict in writing this paper. However, some of the immersive reality examples mentioned in this paper were developed in our research laboratory (FA).

Multimedia Appendix 1

Summary tables of educational and clinical applications of immersive reality in anesthesia.
[PDF File (Adobe PDF File), 535 KB-Multimedia Appendix 1]

References

1. Curran VR, Xu X, Aydin MY, Meruvia-Pastor O. Use of extended reality in medical education: an integrative review. Med Sci Educ. Feb 2023;33(1):275-286. [FREE Full text] [doi: 10.1007/s40670-022-01698-4] [Medline: 36569366]
2. Andrews C, Southworth MK, Silva JN, Silva JR. Extended reality in medical practice. Curr Treat Options Cardiovasc Med. Mar 30, 2019;21(4):18. [FREE Full text] [doi: 10.1007/s11936-019-0722-7] [Medline: 30929093]
3. Arnaldi B, Guitton P, Moreau G. Virtual Reality and Augmented Reality: Myths and Realities. Hoboken, NJ. John Wiley & Sons; 2018.
4. Birt J, Stromberga Z, Cowling M, Moro C. Mobile mixed reality for experiential learning and simulation in medical and health sciences education. Information. Jan 31, 2018;9(2):31. [doi: 10.3390/info9020031]
5. Zhu E, Hadadgar A, Masiello I, Zary N. Augmented reality in healthcare education: an integrative review. PeerJ. 2014;2:e469. [FREE Full text] [doi: 10.7717/peerj.469] [Medline: 25071992]
6. Kapralos B, Uribe-Quevedo A, Dubrowski A. Immersive technologies for medical education. In: Lee N, editor. Encyclopedia of Computer Graphics and Games. Cham, Switzerland. Springer; 2018.
7. Huang MY, Scharf S, Chan PY. Effects of immersive virtual reality therapy on intravenous patient-controlled sedation during orthopaedic surgery under regional anesthesia: a randomized controlled trial. PLoS One. Feb 24, 2020;15(2):e0229320. [FREE Full text] [doi: 10.1371/journal.pone.0229320] [Medline: 32092098]
8. Chan PY, Scharf S. Virtual reality as an adjunctive nonpharmacological sedative during orthopedic surgery under regional anesthesia: a pilot and feasibility study. Anesth Analg. Oct 2017;125(4):1200-1202. [doi: 10.1213/ANE.0000000000002169] [Medline: 28598921]
9. Bekelis K, Calnan D, Simmons N, MacKenzie TA, Kakoulides G. Effect of an immersive preoperative virtual reality experience on patient reported outcomes: a randomized controlled trial. Ann Surg. Jun 2017;265(6):1068-1073. [doi: 10.1097/SLA.0000000000002094] [Medline: 27906757]
10. Dorozhkin D, Olasky J, Jones DB, Schwaitzberg SD, Jones SB, Cao CG, et al. OR fire virtual training simulator: design and face validity. Surg Endosc. Sep 2017;31(9):3527-3533. [FREE Full text] [doi: 10.1007/s00464-016-5379-7] [Medline: 28039649]
11. Real FJ, DeBlasio D, Beck AF, Ollberding NJ, Davis D, Cruse B, et al. A virtual reality curriculum for pediatric residents decreases rates of influenza vaccine refusal. Acad Pediatr. 2017;17(4):431-435. [doi: 10.1016/j.acap.2017.01.010] [Medline: 28126612]
12. Masson C, Birgand G, Castro-Sánchez E, Eichel VM, Comte A, Terrisse H, et al. Is virtual reality effective to teach prevention of surgical site infections in the operating room? Study protocol for a randomised controlled multicentre trial entitled VIP Room study. BMJ Open. Jun 21, 2020;10(6):e037299. [FREE Full text] [doi: 10.1136/bmjopen-2020-037299] [Medline: 32565477]
13. Krish G, Immerman I, Kinjo S. Virtual reality may reduce anxiety and enhance surgical experience during wide-awake local anaesthesia no tourniquet surgery: a report of two cases. J Perioper Pract. Jun 2022;32(6):136-141. [doi: 10.1177/1750458920984048] [Medline: 34190639]
14. Alaterre C, Duceau B, Sung Tsai E, Zriouel S, Bonnet F, Lescot T, et al. Virtual Reality for PEripheral Regional Anesthesia (VR-PERLA Study). J Clin Med. Jan 13, 2020;9(1):215. [FREE Full text] [doi: 10.3390/jcm9010215] [Medline: 31941129]
15. Faruki A, Nguyen T, Proeschel S, Levy N, Yu J, Ip V, et al. Virtual reality as an adjunct to anesthesia in the operating room. Trials. Dec 27, 2019;20(1):782. [FREE Full text] [doi: 10.1186/s13063-019-3922-2] [Medline: 31882015]
16. Vogt L, Klasen M, Rossaint R, Goeretz U, Ebus P, Sopka S. Virtual reality tour to reduce perioperative anxiety in an operating setting before anesthesia: randomized clinical trial. J Med Internet Res. Sep 01, 2021;23(9):e28018. [FREE Full text] [doi: 10.2196/28018] [Medline: 34252034]

17. Semeraro F, Ristagno G, Giulini G, Kayal JS, Cavallo P, Farabegoli L, et al. Back to reality: a new blended pilot course of basic life support with virtual reality. Resuscitation. May 2019;138:18-19. [doi: 10.1016/j.resuscitation.2019.02.034] [Medline: 30844415]
18. Sridhar A, Shiliang Z, Woodson R, Kwan L. Non-pharmacological anxiety reduction with immersive virtual reality for first-trimester dilation and curettage: a pilot study. Eur J Contracept Reprod Health Care. Dec 2020;25(6):480-483. [doi: 10.1080/13625187.2020.1836146] [Medline: 33140989]
19. Hoxhallari E, Behr IJ, Bradshaw JS, Morkos MS, Haan PS, Schaefer MC, et al. Virtual reality improves the patient experience during wide-awake local anesthesia no tourniquet hand surgery: a single-blind, randomized, prospective study. Plast Reconstr Surg. Aug 2019;144(2):408-414. [doi: 10.1097/PRS.0000000000005831] [Medline: 31348351]
20. Kist M, Bekemeyer Z, Ralls L, Carvalho B, Rodriguez ST, Caruso TJ. Virtual reality successfully provides anxiolysis to laboring women undergoing epidural placement. J Clin Anesth. May 2020;61:109635. [doi: 10.1016/j.jclinane.2019.109635] [Medline: 31662229]
21. Moon JY, Shin J, Chung J, Ji SH, Ro S, Kim WH. Virtual reality distraction during endoscopic urologic surgery under spinal anesthesia: a randomized controlled trial. J Clin Med. Dec 20, 2018;8(1):2. [FREE Full text] [doi: 10.3390/jcm8010002] [Medline: 30577461]
22. Chan JJ, Yeam CT, Kee HM, Tan CW, Sultana R, Sia AT, et al. The use of pre-operative virtual reality to reduce anxiety in women undergoing gynecological surgeries: a prospective cohort study. BMC Anesthesiol. Oct 09, 2020;20(1):261. [FREE Full text] [doi: 10.1186/s12871-020-01177-6] [Medline: 33036555]
23. Ledford CK, VanWagner MJ, Sherman CE, Torp KD. Immersive virtual reality used as adjunct anesthesia for conversion total hip arthroplasty in a 100-year-old patient. Arthroplast Today. Aug 07, 2021;10:149-153. [FREE Full text] [doi: 10.1016/j.artd.2021.07.001] [Medline: 34401418]
24. Truong H, Qi D, Ryason A, Sullivan AM, Cudmore J, Alfred S, et al. Does your team know how to respond safely to an operating room fire? Outcomes of a virtual reality, AI-enhanced simulation training. Surg Endosc. May 2022;36(5):3059-3067. [FREE Full text] [doi: 10.1007/s00464-021-08602-y] [Medline: 34264400]
25. Chheang V, Fischer V, Buggenhagen H, Huber T, Huettl F, Kneist W, et al. Toward interprofessional team training for surgeons and anesthesiologists using virtual reality. Int J Comput Assist Radiol Surg. Dec 2020;15(12):2109-2118. [FREE Full text] [doi: 10.1007/s11548-020-02276-y] [Medline: 33083969]
26. Lerner D, Mohr S, Schild J, Göring M, Luiz T. An immersive multi-user virtual reality for emergency simulation training: usability study. JMIR Serious Games. Jul 31, 2020;8(3):e18822. [FREE Full text] [doi: 10.2196/18822] [Medline: 32735548]
27. Thomas JJ, Albietz J, Polaner D. Virtual reality for lumbar puncture in a morbidly obese patient with leukemia. Paediatr Anaesth. Nov 2018;28(11):1059-1060. [doi: 10.1111/pan.13505] [Medline: 30284748]
28. Mahmood F, Mahmood E, Dorfman RG, Mitchell J, Mahmood FU, Jones SB, et al. Augmented reality and ultrasound education: initial experience. J Cardiothorac Vasc Anesth. Jun 2018;32(3):1363-1367. [doi: 10.1053/j.jvca.2017.12.006] [Medline: 29452879]
29. Hess O, Qian J, Bruce J, Wang E, Rodriguez S, Haber N, et al. Communication skills training using remote augmented reality medical simulation: a feasibility and acceptability qualitative study. Med Sci Educ. Oct 2022;32(5):1005-1014. [FREE Full text] [doi: 10.1007/s40670-022-01598-7] [Medline: 35966166]
30. Wunder L, Gomez NA, Gonzalez JE, Mitzova-Vladinov G, Cacchione M, Mato J, et al. Fire in the operating room: use of mixed reality simulation with nurse anesthesia students. Informatics. Sep 30, 2020;7(4):40. [doi: 10.3390/informatics7040040]
31. Chan E, Hovenden M, Ramage E, Ling N, Pham JH, Rahim A, et al. Virtual reality for pediatric needle procedural pain: two randomized clinical trials. J Pediatr. Jun 2019;209:160-7.e4. [doi: 10.1016/j.jpeds.2019.02.034] [Medline: 31047650]
32. Pandya PG, Kim TE, Howard SK, Stary E, Leng JC, Hunter OO, et al. Virtual reality distraction decreases routine intravenous sedation and procedure-related pain during preoperative adductor canal catheter insertion: a retrospective study. Korean J Anesthesiol. Aug 2017;70(4):439-445. [FREE Full text] [doi: 10.4097/kjae.2017.70.4.439] [Medline: 28794840]
33. Qian K, Arichi T, Price A, Dall'Orso S, Eden J, Noh Y, et al. An eye tracking based virtual reality system for use inside magnetic resonance imaging systems. Sci Rep. Aug 11, 2021;11(1):16301. [FREE Full text] [doi: 10.1038/s41598-021-95634-y] [Medline: 34381099]
34. Smith SA, Mulligan NW. Immersion, presence, and episodic memory in virtual reality environments. Memory. Sep 2021;29(8):983-1005. [doi: 10.1080/09658211.2021.1953535] [Medline: 34294002]
35. Reznek M, Harter P, Krummel T. Virtual reality and simulation: training the future emergency physician. Acad Emerg Med. Jan 2002;9(1):78-87. [FREE Full text] [doi: 10.1111/j.1553-2712.2002.tb01172.x] [Medline: 11772675]
36. Nagendran M, Gurusamy KS, Aggarwal R, Loizidou M, Davidson BR. Virtual reality training for surgical trainees in laparoscopic surgery. Cochrane Database Syst Rev. Aug 27, 2013;2013(8):CD006575. [FREE Full text] [doi: 10.1002/14651858.CD006575.pub3] [Medline: 23980026]
37. Alaker M, Wynn GR, Arulampalam T. Virtual reality training in laparoscopic surgery: a systematic review and meta-analysis. Int J Surg. May 2016;29:85-94. [FREE Full text] [doi: 10.1016/j.ijsu.2016.03.034] [Medline: 26992652]
38. Grottke O, Ntouba A, Ullrich S, Liao W, Fried E, Prescher A, et al. Virtual reality-based simulator for training in regional anaesthesia. Br J Anaesth. Oct 2009;103(4):594-600. [FREE Full text] [doi: 10.1093/bja/aep224] [Medline: 19706630]

39. O'Sullivan O, Iohom G, O'Donnell BD, Shorten GD. The effect of simulation-based training on initial performance of ultrasound-guided axillary brachial plexus blockade in a clinical setting - a pilot study. BMC Anesthesiol. 2014;14:110. [FREE Full text] [doi: 10.1186/1471-2253-14-110] [Medline: 25844062]
40. Jiang B, Ju H, Zhao Y, Yao L, Feng Y. Comparison of the efficacy and efficiency of the use of virtual reality simulation with high-fidelity mannequins for simulation-based training of fiberoptic bronchoscope manipulation. Simul Healthc. Apr 2018;13(2):83-87. [doi: 10.1097/SIH.0000000000000299] [Medline: 29621098]
41. K Latif R, Bautista A, Duan X, Neamtu A, Wu D, Wadhwa A, et al. Teaching basic fiberoptic intubation skills in a simulator: initial learning and skills decay. J Anesth. Feb 2016;30(1):12-19. [doi: 10.1007/s00540-015-2091-z] [Medline: 26493397]
42. White WWJ, Jung MJ. Three-dimensional virtual reality spinal cord stimulator training improves trainee procedural confidence and performance. Neuromodulation. Oct 2023;26(7):1381-1386. [doi: 10.1016/j.neurom.2022.03.005] [Medline: 35570148]
43. Perkins GD. Simulation in resuscitation training. Resuscitation. May 2007;73(2):202-211. [doi: 10.1016/j.resuscitation.2007.01.005] [Medline: 17379380]
44. Reznick RK, MacRae H. Teaching surgical skills--changes in the wind. N Engl J Med. Dec 21, 2006;355(25):2664-2669. [doi: 10.1056/NEJMra054785] [Medline: 17182991]
45. Kneebone RL. Practice, rehearsal, and performance: an approach for simulation-based surgical and procedure training. JAMA. Sep 23, 2009;302(12):1336-1338. [doi: 10.1001/jama.2009.1392] [Medline: 19773572]
46. Guadagnoli M, Morin MP, Dubrowski A. The application of the challenge point framework in medical education. Med Educ. May 2012;46(5):447-453. [doi: 10.1111/j.1365-2923.2011.04210.x] [Medline: 22515752]
47. Zendejas B, Wang AT, Brydges R, Hamstra SJ, Cook DA. Cost: the missing outcome in simulation-based medical education research: a systematic review. Surgery. Feb 2013;153(2):160-176. [doi: 10.1016/j.surg.2012.06.025] [Medline: 22884087]
48. Savoldelli GL, Naik VN, Hamstra SJ, Morgan PJ. Barriers to use of simulation-based education. Can J Anaesth. Nov 2005;52(9):944-950. [doi: 10.1007/BF03022056] [Medline: 16251560]
49. Scapin S, Echevarría-Guanilo ME, Boeira Fuculo Junior PR, Gonçalves N, Rocha PK, Coimbra R. Virtual reality in the treatment of burn patients: a systematic review. Burns. Sep 2018;44(6):1403-1416. [doi: 10.1016/j.burns.2017.11.002] [Medline: 29395400]
50. Wang E, Thomas JJ, Rodriguez ST, Kennedy KM, Caruso TJ. Virtual reality for pediatric periprocedural care. Curr Opin Anaesthesiol. Jun 01, 2021;34(3):284-291. [doi: 10.1097/ACO.0000000000000983] [Medline: 33935176]
51. Eijlers R, Utens EM, Staals LM, de Nijs PF, Berghmans JM, Wijnen RM, et al. Systematic review and meta-analysis of virtual reality in pediatrics: effects on pain and anxiety. Anesth Analg. Nov 2019;129(5):1344-1353. [FREE Full text] [doi: 10.1213/ANE.0000000000004165] [Medline: 31136330]
52. Davila U, Price A. Past present and future of simulation in pediatrics. In: StatPearls [Internet]. Treasure Island, FL. StatPearls Publishing; 2023.
53. Alam F, Matava C. A new virtual world? The future of immersive environments in anesthesiology. Anesth Analg. Aug 01, 2022;135(2):230-238. [FREE Full text] [doi: 10.1213/ANE.0000000000006118] [Medline: 35839493]
54. Barsom EZ, Graafland M, Schijven MP. Systematic review on the effectiveness of augmented reality applications in medical training. Surg Endosc. Oct 2016;30(10):4174-4183. [FREE Full text] [doi: 10.1007/s00464-016-4800-6] [Medline: 26905573]
55. Seymour NE, Gallagher AG, Roman SA, O'Brien MK, Bansal VK, Andersen DK, et al. Virtual reality training improves operating room performance: results of a randomized, double-blinded study. Ann Surg. Oct 2002;236(4):458-63; discussion 463. [doi: 10.1097/00000658-200210000-00008] [Medline: 12368674]
56. Kulcsár Z, O'Mahony E, Lövquist E, Aboulafia A, Sabova D, Ghori K, et al. Preliminary evaluation of a virtual reality-based simulator for learning spinal anesthesia. J Clin Anesth. Mar 2013;25(2):98-105. [doi: 10.1016/j.jclinane.2012.06.015] [Medline: 23274077]
57. Wong DT, Mehta A, Singh KP, Leong SM, Ooi A, Niazi A, et al. The effect of virtual reality bronchoscopy simulator training on performance of bronchoscopic-guided intubation in patients: a randomised controlled trial. Eur J Anaesthesiol. Mar 2019;36(3):227-233. [doi: 10.1097/EJA.0000000000000890] [Medline: 30234669]
58. Jiang H, Vimalesvaran S, Wang JK, Lim KB, Mogali SR, Car LT. Virtual reality in medical students' education: scoping review. JMIR Med Educ. Feb 02, 2022;8(1):e34860. [FREE Full text] [doi: 10.2196/34860] [Medline: 35107421]
59. Jonassen DH, Duffy TM. Constructivism and the Technology of Instruction: A Conversation. Milton Park, UK. Taylor & Francis; 2013.
60. Whitman N. A review of constructivism: understanding and using a relatively new theory. Fam Med. Sep 1993;25(8):517-521. [Medline: 8405799]
61. Dennick R. Constructivism: reflections on twenty five years teaching the constructivist approach in medical education. Int J Med Educ. Jun 25, 2016;7:200-205. [FREE Full text] [doi: 10.5116/ijme.5763.de11] [Medline: 27344115]
62. Graffam B. Active learning in medical education: strategies for beginning implementation. Med Teach. Feb 2007;29(1):38-42. [doi: 10.1080/01421590601176398] [Medline: 17538832]
63. Spencer JA, Jordan RK. Learner centred approaches in medical education. BMJ. May 08, 1999;318(7193):1280-1283. [FREE Full text] [doi: 10.1136/bmj.318.7193.1280] [Medline: 10231266]

64. Barrows H. Problem‐based learning in medicine and beyond: a brief overview. New Dir Teach Learn. Aug 17, 2006;1996(68):3-12. [doi: 10.1002/tl.37219966804]
65. Brydges R, Butler D. A reflective analysis of medical education research on self-regulation in learning and practice. Med Educ. Jan 2012;46(1):71-79. [doi: 10.1111/j.1365-2923.2011.04100.x] [Medline: 22150198]
66. Rajabi S. Towards self-regulated learning in school curriculum. Procedia Soc Behav Sci. 2012;47:344-350. [doi: 10.1016/j.sbspro.2012.06.661]
67. Loyens SM, Magda J, Rikers RM. Self-directed learning in problem-based learning and its relationships with self-regulated learning. Educ Psychol Rev. Jul 22, 2008;20(4):411-427. [doi: 10.1007/s10648-008-9082-7]
68. Zimmerman BJ. Becoming a self-regulated learner: an overview. Theory Into Pract. May 2002;41(2):64-70. [doi: 10.1207/s15430421tip4102_2]
69. White CB, Gruppen LD, Fantone JC. Self-regulated learning in medical education. In: Swanwick T, editor. Understanding Medical Education: Evidence, Theory and Practice, Second Edition. Hoboken, NJ. John Wiley & Sons; 2013.
70. Brydges R, Nair P, Ma I, Shanks D, Hatala R. Directed self-regulated learning versus instructor-regulated learning in simulation training. Med Educ. Jul 2012;46(7):648-656. [doi: 10.1111/j.1365-2923.2012.04268.x] [Medline: 22691145]
71. Swanwick T, Forrest K, O'Brien BC. Understanding Medical Education: Evidence, Theory, and Practice. Hoboken, NJ. John Wiley & Sons; 2018:1.
72. Huang VW, Jones CB, Gomez ED. State of the art of virtual reality simulation in anesthesia. Int Anesthesiol Clin. 2020;58(4):31-35. [doi: 10.1097/AIA.0000000000000298] [Medline: 32815861]
73. Gerup J, Soerensen CB, Dieckmann P. Augmented reality and mixed reality for healthcare education beyond surgery: an integrative review. Int J Med Educ. Jan 18, 2020;11:1-18. [FREE Full text] [doi: 10.5116/ijme.5e01.eb1a] [Medline: 31955150]
74. Brunozzi D, Shakur SF, Kwasnicki A, Ismail R, Charbel FT, Alaraj A. Role of immersive touch simulation in neurosurgical training. In: Alaraj A, editor. Comprehensive Healthcare Simulation: Neurosurgery. Cham, Switzerland. Springer; 2018.
75. Rudarakanchana N, Van Herzeele I, Desender L, Cheshire NJ. Virtual reality simulation for the optimization of endovascular procedures: current perspectives. Vasc Health Risk Manag. 2015;11:195-202. [FREE Full text] [doi: 10.2147/VHRM.S46194] [Medline: 25792841]
76. Sugand K, Akhtar K, Khatri C, Cobb J, Gupte C. Training effect of a virtual reality haptics-enabled dynamic hip screw simulator. Acta Orthop. 2015;86(6):695-701. [FREE Full text] [doi: 10.3109/17453674.2015.1071111] [Medline: 26168925]
77. Aïm F, Lonjon G, Hannouche D, Nizard R. Effectiveness of virtual reality training in orthopaedic surgery. Arthroscopy. Jan 2016;32(1):224-232. [doi: 10.1016/j.arthro.2015.07.023] [Medline: 26412672]
78. Hannaford B, Okamura AM. Haptics. In: Siciliano B, Khatib O, editors. Springer Handbook of Robotics. Cham, Switzerland. Springer; 2016.
79. Li L, Yu F, Shi D, Shi J, Tian Z, Yang J, et al. Application of virtual reality technology in clinical medicine. Am J Transl Res. 2017;9(9):3867-3880. [FREE Full text] [Medline: 28979666]
80. Ameri G, Rankin A, Baxter JS, Moore J, Ganapathy S, Peters TM, et al. Development and evaluation of an augmented reality ultrasound guidance system for spinal anesthesia: preliminary results. Ultrasound Med Biol. Oct 2019;45(10):2736-2746. [doi: 10.1016/j.ultrasmedbio.2019.04.026] [Medline: 31281009]
81. Kim JY, Lee JS, Lee JH, Park YS, Cho J, Koh JC. Virtual reality simulator's effectiveness on the spine procedure education for trainee: a randomized controlled trial. Korean J Anesthesiol. Jun 2023;76(3):213-226. [FREE Full text] [doi: 10.4097/kja.22491] [Medline: 36323305]
82. Chuan A, Qian J, Bogdanovych A, Kumar A, McKendrick M, McLeod G. Design and validation of a virtual reality trainer for ultrasound-guided regional anaesthesia. Anaesthesia. Jun 2023;78(6):739-746. [FREE Full text] [doi: 10.1111/anae.16015] [Medline: 37010989]
83. De Oliveira GSJ, Glassenberg R, Chang R, Fitzgerald P, McCarthy RJ. Virtual airway simulation to improve dexterity among novices performing fibreoptic intubation. Anaesthesia. Oct 2013;68(10):1053-1058. [FREE Full text] [doi: 10.1111/anae.12379] [Medline: 23952805]
84. Cailleau L, Geeraerts T, Minville V, Fourcade O, Fernandez T, Bazin JE, et al. Is there a benefit for anesthesiologists of adding difficult airway scenarios for learning fiberoptic intubation skills using virtual reality training? A randomized controlled study. PLoS One. 2023;18(1):e0281016. [FREE Full text] [doi: 10.1371/journal.pone.0281016] [Medline: 36706107]
85. Sappenfield J, Grek S, Cooper LA, Lizdas DE, Lampotang S. Reduced complications of supraclavicular approach in simulated central venous access: applicability to military medicine. Mil Med. Mar 01, 2019;184(Suppl 1):329-334. [FREE Full text] [doi: 10.1093/milmed/usy381] [Medline: 30901427]
86. Rochlen LR, Levine R, Tait AR. First-person point-of-view-augmented reality for central line insertion training: a usability and feasibility study. Simul Healthc. Feb 2017;12(1):57-62. [FREE Full text] [doi: 10.1097/SIH.0000000000000185] [Medline: 27930431]
87. Huang X, Yan Z, Gong C, Zhou Z, Xu H, Qin C, et al. A mixed-reality stimulator for lumbar puncture training: a pilot study. BMC Med Educ. Mar 22, 2023;23(1):178. [FREE Full text] [doi: 10.1186/s12909-023-04173-9] [Medline: 36949483]

88. Peek JJ, Max SA, Bakhuis W, Huig IC, Rosalia RA, Sadeghi AH, et al. Virtual reality simulator versus conventional advanced life support training for cardiopulmonary resuscitation post-cardiac surgery: a randomized controlled trial. J Cardiovasc Dev Dis. Feb 04, 2023;10(2):67. [FREE Full text] [doi: 10.3390/jcdd10020067] [Medline: 36826563]
89. Moll-Khosrawi P, Falb A, Pinnschmidt H, Zöllner C, Issleib M. Virtual reality as a teaching method for resuscitation training in undergraduate first year medical students during COVID-19 pandemic: a randomised controlled trial. BMC Med Educ. Jun 22, 2022;22(1):483. [FREE Full text] [doi: 10.1186/s12909-022-03533-1] [Medline: 35733135]
90. Rochlen LR, Putnam E, Levine R, Tait AR. Mixed reality simulation for peripheral intravenous catheter placement training. BMC Med Educ. Dec 17, 2022;22(1):876. [FREE Full text] [doi: 10.1186/s12909-022-03946-y] [Medline: 36528576]
91. Issleib M, Kromer A, Pinnschmidt HO, Süss-Havemann C, Kubitz JC. Virtual reality as a teaching method for resuscitation training in undergraduate first year medical students: a randomized controlled trial. Scand J Trauma Resusc Emerg Med. Feb 01, 2021;29(1):27. [FREE Full text] [doi: 10.1186/s13049-021-00836-y] [Medline: 33526042]
92. Lee DK, Im CW, Jo YH, Chang T, Song JL, Luu C, et al. Comparison of extended reality and conventional methods of basic life support training: protocol for a multinational, pragmatic, noninferiority, randomised clinical trial (XR BLS trial). Trials. Dec 20, 2021;22(1):946. [FREE Full text] [doi: 10.1186/s13063-021-05908-z] [Medline: 34930418]
93. Mah E, Yu J, Deck M, Lyster K, Kawchuk J, Turnquist A, et al. Immersive video modeling versus traditional video modeling for teaching central venous catheter insertion to medical residents. Cureus. Mar 02, 2021;13(3):e13661. [FREE Full text] [doi: 10.7759/cureus.13661] [Medline: 33824812]
94. Bube S, Dagnaes-Hansen J, Mahmood O, Rohrsted M, Bjerrum F, Salling L, et al. Simulation-based training for flexible cystoscopy - a randomized trial comparing two approaches. Heliyon. Jan 2020;6(1):e03086. [FREE Full text] [doi: 10.1016/j.heliyon.2019.e03086] [Medline: 31922043]
95. Nas J, Thannhauser J, Vart P, van Geuns RJ, Muijsers HE, Mol JQ, et al. Effect of face-to-face vs virtual reality training on cardiopulmonary resuscitation quality: a randomized clinical trial. JAMA Cardiol. Mar 01, 2020;5(3):328-335. [FREE Full text] [doi: 10.1001/jamacardio.2019.4992] [Medline: 31734702]
96. Aebersold M, Voepel-Lewis T, Cherara L, Weber M, Khouri C, Levine R, et al. Interactive anatomy-augmented virtual simulation training. Clin Simul Nurs. Feb 2018;15:34-41. [FREE Full text] [doi: 10.1016/j.ecns.2017.09.008] [Medline: 29861797]
97. Casso G, Schoettker P, Savoldelli GL, Azzola A, Cassina T. Development and initial evaluation of a novel, ultraportable, virtual reality bronchoscopy simulator: the computer airway simulation system. Anesth Analg. Nov 2019;129(5):1258-1264. [FREE Full text] [doi: 10.1213/ANE.0000000000003316] [Medline: 29481426]
98. Jensen JK, Dyre L, Jørgensen ME, Andreasen LA, Tolsgaard MG. Simulation-based point-of-care ultrasound training: a matter of competency rather than volume. Acta Anaesthesiol Scand. Jul 2018;62(6):811-819. [doi: 10.1111/aas.13083] [Medline: 29392718]
99. Nilsson PM, Russell L, Ringsted C, Hertz P, Konge L. Simulation-based training in flexible fibreoptic intubation: a randomised study. Eur J Anaesthesiol. Sep 2015;32(9):609-614. [doi: 10.1097/EJA.0000000000000092] [Medline: 24809483]
100. Failor E, Bowdle A, Jelacic S, Togashi K. High-fidelity simulation of lung isolation with double-lumen endotracheal tubes and bronchial blockers in anesthesiology resident training. J Cardiothorac Vasc Anesth. Aug 2014;28(4):865-869. [doi: 10.1053/j.jvca.2013.07.015] [Medline: 24231196]
101. Robinson AR3, Gravenstein N, Cooper LA, Lizdas D, Luria I, Lampotang S. A mixed-reality part-task trainer for subclavian venous access. Simul Healthc. Feb 2014;9(1):56-64. [doi: 10.1097/SIH.0b013e31829b3fb3] [Medline: 24310163]
102. Goldmann K, Steinfeldt T. Acquisition of basic fiberoptic intubation skills with a virtual reality airway simulator. J Clin Anesth. May 2006;18(3):173-178. [doi: 10.1016/j.jclinane.2005.08.021] [Medline: 16731318]
103. Reznek MA, Rawn CL, Krummel TM. Evaluation of the educational effectiveness of a virtual reality intravenous insertion simulator. Acad Emerg Med. Nov 2002;9(11):1319-1325. [FREE Full text] [doi: 10.1111/j.1553-2712.2002.tb01594.x] [Medline: 12414488]
104. Sappenfield JW, Smith WB, Cooper LA, Lizdas D, Gonsalves DB, Gravenstein N, et al. Visualization improves supraclavicular access to the subclavian vein in a mixed reality simulator. Anesth Analg. Jul 2018;127(1):83-89. [FREE Full text] [doi: 10.1213/ANE.0000000000002572] [Medline: 29200069]
105. Erlinger LR, Bartlett A, Perez A. High-fidelity mannequin simulation versus virtual simulation for recognition of critical events by student registered nurse anesthetists. AANA J. Apr 2019;87(2):105-109. [Medline: 31587722]
106. Liaw SY, Sutini, Chua WL, Tan JZ, Levett-Jones T, Ashokka B, et al. Desktop virtual reality versus face-to-face simulation for team-training on stress levels and performance in clinical deterioration: a randomised controlled trial. J Gen Intern Med. Jan 2023;38(1):67-73. [FREE Full text] [doi: 10.1007/s11606-022-07557-7] [Medline: 35501626]
107. Abbas S, Chan V, Jin R, Kim E, Lorello G, Niazi A, et al. ESRA19-0614 Virtual reality simulation for teaching and assessment of anesthesia crisis management. Reg Anesth Pain Med. 2019;44:A262. [FREE Full text] [doi: 10.1136/rapm-2019-esraabs2019.480]
108. Knudsen MH, Breindahl N, Dalsgaard TS, Isbye D, Mølbak AG, Tiwald G, et al. Using virtual reality head-mounted displays to assess skills in emergency medicine: validity study. J Med Internet Res. Jun 06, 2023;25:e45210. [FREE Full text] [doi: 10.2196/45210] [Medline: 37279049]

109. Sankaranarayanan G, Wooley L, Hogg D, Dorozhkin D, Olasky J, Chauhan S, et al. Immersive virtual reality-based training improves response in a simulated operating room fire scenario. Surg Endosc. Aug 2018;32(8):3439-3449. [doi: 10.1007/s00464-018-6063-x] [Medline: 29372313]
110. Shewaga R, Uribe-Quevedo A, Kapralos B, Alam F. A comparison of seated and room-scale virtual reality in a serious game for epidural preparation. IEEE Trans Emerg Topics Comput. Jan 1, 2020;8(1):218-232. [doi: 10.1109/TETC.2017.2746085]
111. Katz D, Shah R, Kim E, Park C, Shah A, Levine A, et al. Utilization of a voice-based virtual reality advanced cardiac life support team leader refresher: prospective observational study. J Med Internet Res. Mar 12, 2020;22(3):e17425. [FREE Full text] [doi: 10.2196/17425] [Medline: 32163038]
112. Speidel R, Schneider A, Walter S, Grab-Kroll C, Oechsner W. Immersive medium for early clinical exposure - knowledge acquisition, spatial orientation and the unexpected role of annotation in 360° VR photos. GMS J Med Educ. 2023;40(1):Doc8. [FREE Full text] [doi: 10.3205/zma001590] [Medline: 36923314]
113. Hoek KB, van Velzen M, Sarton EY. Patient-embodied virtual reality as a learning tool for therapeutic communication skills among anaesthesiologists: a phenomenological study. Patient Educ Couns. Sep 2023;114:107789. [FREE Full text] [doi: 10.1016/j.pec.2023.107789] [Medline: 37230038]
114. Cordar A, Wendling A, White C, Lampotang S, Lok B. Repeat after me: using mixed reality humans to influence best communication practices. In: Proceedings of the IEEE Virtual Reality. 2017. Presented at: VR 2017; March 18-22, 2017; Los Angeles, CA. [doi: 10.1109/VR.2017.7892242]
115. Cordar A, Robb A, Wendling A, Lampotang S, White C, Lok B. Virtual role-models: using virtual humans to train best communication practices for healthcare teams. In: Proceedings of the 15th International Conference on Intelligent Virtual Agents. 2015. Presented at: IVA 2015; August 26-28, 2015; Delft, The Netherlands. [doi: 10.1007/978-3-319-21996-7_23]
116. Gupta S, Wilcocks K, Matava C, Wiegelmann J, Kaustov L, Alam F. Creating a successful virtual reality-based medical simulation environment: tutorial. JMIR Med Educ. Feb 14, 2023;9:e41090. [FREE Full text] [doi: 10.2196/41090] [Medline: 36787169]
117. Putnam EM, Rochlen LR, Alderink E, Augé J, Popov V, Levine R, et al. Virtual reality simulation for critical pediatric airway management training. J Clin Transl Res. Feb 25, 2021;7(1):93-99. [FREE Full text] [Medline: 34104812]
118. Truong H, Sullivan AM, Abu-Nuwar MR, Therrien S, Jones SB, Pawlowski J, et al. Operating room team training using simulation: hope or hype? Am J Surg. Dec 2021;222(6):1146-1153. [doi: 10.1016/j.amjsurg.2021.01.044] [Medline: 33933207]
119. Baytar AD, Bollucuo Lu K. Effect of virtual reality on preoperative anxiety in patients undergoing septorhinoplasty. Braz J Anesthesiol. 2023;73(2):159-164. [FREE Full text] [doi: 10.1016/j.bjane.2021.08.014] [Medline: 34562488]
120. Kim Y, Yoo SH, Chun J, Kim JH, Youn YH, Park H. Relieving anxiety through virtual reality prior to endoscopic procedures. Yonsei Med J. Feb 2023;64(2):117-122. [FREE Full text] [doi: 10.3349/ymj.2022.0319] [Medline: 36719019]
121. Le Du K, Septans AL, Maloisel F, Vanquaethem H, Schmitt A, Le Goff M, et al. A new option for pain prevention using a therapeutic virtual reality solution for bone marrow biopsy (REVEH Trial): open-label, randomized, multicenter, phase 3 study. J Med Internet Res. Feb 15, 2023;25:e38619. [FREE Full text] [doi: 10.2196/38619] [Medline: 36790852]
122. Lind A, Ahsan M, Totzeck M, Al-Rashid F, Haddad A, Dubler S, et al. Virtual reality-assisted distraction during transcatheter aortic valve implantation under local anaesthesia: a randomised study. Int J Cardiol. Sep 15, 2023;387:131130. [doi: 10.1016/j.ijcard.2023.131130] [Medline: 37355243]
123. Lopes K, Dessieux T, Rousseau C, Beloeil H. Virtual reality as a hypnotic tool in the management of anxiety during the performance of the axillary block. J Med Syst. Mar 01, 2023;47(1):31. [doi: 10.1007/s10916-023-01923-6] [Medline: 36856907]
124. Pelazas-Hernández JA, Varillas-Delgado D, González-Casado T, Cristóbal-Quevedo I, Alonso-Bermejo A, Ronchas-Martínez M, et al. The effect of virtual reality on the reduction of pain in women with an indication for outpatient diagnostic hysteroscopy: a randomized controlled trial. J Clin Med. May 24, 2023;12(11):3645. [FREE Full text] [doi: 10.3390/jcm12113645] [Medline: 37297840]
125. Barry KS, Nimma SR, Spaulding AC, Wilke BK, Torp KD, Ledford CK. Perioperative outcomes of immersive virtual reality as adjunct anesthesia in primary total hip and knee arthroplasty. Arthroplast Today. Dec 2022;18:84-88. [FREE Full text] [doi: 10.1016/j.artd.2022.09.015] [Medline: 36312886]
126. Boonreunya N, Nopawong E, Yongsiriwit K, Chirapongsathorn S. Virtual reality distraction during upper gastrointestinal endoscopy: a randomized controlled trial. J Gastroenterol Hepatol. May 2022;37(5):855-860. [doi: 10.1111/jgh.15786] [Medline: 35080055]
127. Faruki AA, Nguyen TB, Gasangwa DV, Levy N, Proeschel S, Yu J, et al. Virtual reality immersion compared to monitored anesthesia care for hand surgery: a randomized controlled trial. PLoS One. 2022;17(9):e0272030. [FREE Full text] [doi: 10.1371/journal.pone.0272030] [Medline: 36129891]
128. Fouks Y, Kern G, Cohen A, Reicher L, Shapira Z, Many A, et al. A virtual reality system for pain and anxiety management during outpatient hysteroscopy-a randomized control trial. Eur J Pain. Mar 23, 2022;26(3):600-609. [doi: 10.1002/ejp.1882] [Medline: 34748679]

129. Goergen DI, Freitas DM. Virtual reality as a distraction therapy during cystoscopy: a clinical trial. Rev Col Bras Cir. 2022;49:e20223138. [FREE Full text] [doi: 10.1590/0100-6991e-20223138-en] [Medline: 35584530]
130. Lame C, Mougin J, Postiglione TJ, Fabre D, Haulon S. Virtual reality to ease endovascular repair of thoracoabdominal aneurysms under local anesthesia. J Endovasc Ther. Apr 2023;30(2):312-315. [doi: 10.1177/15266028221079768] [Medline: 35184605]
131. Rousseaux F, Dardenne N, Massion PB, Ledoux D, Bicego A, Donneau AF, et al. Virtual reality and hypnosis for anxiety and pain management in intensive care units: a prospective randomised trial among cardiac surgery patients. Eur J Anaesthesiol. Jan 01, 2022;39(1):58-66. [FREE Full text] [doi: 10.1097/EJA.0000000000001633] [Medline: 34783683]
132. Soret L, Gendron N, Rivet N, Chocron R, Macraigne L, Clausse D, et al. Pain assessment using virtual reality facemask during bone marrow aspiration: prospective study including propensity-matched analysis. JMIR Serious Games. Oct 12, 2022;10(4):e33221. [FREE Full text] [doi: 10.2196/33221] [Medline: 36222814]
133. Bozdoğan Yeşilot S, Ciftci H, Yener MK. Using a virtual reality and communication intervention to reduce pain and anxiety in patients undergoing lipoma excision with local anesthesia: a randomized controlled trial. AORN J. May 2022;115(5):437-449. [doi: 10.1002/aorn.13665] [Medline: 35476192]
134. Karaman D, Taşdemir N. The effect of using virtual reality during breast biopsy on pain and anxiety: a randomized controlled trial. J Perianesth Nurs. Dec 2021;36(6):702-705. [doi: 10.1016/j.jopan.2021.04.007] [Medline: 34686402]
135. Łuczak M, Nowak Ł, Chorbińska J, Galik K, Kiełb P, Łaszkiewicz J, et al. Influence of virtual reality devices on pain and anxiety in patients undergoing cystoscopy performed under local anaesthesia. J Pers Med. Nov 16, 2021;11(11):1214. [FREE Full text] [doi: 10.3390/jpm11111214] [Medline: 34834565]
136. Peuchot H, Khakha R, Riera V, Ollivier M, Argenson JN. Intraoperative virtual reality distraction in TKA under spinal anesthesia: a preliminary study. Arch Orthop Trauma Surg. Dec 2021;141(12):2323-2328. [doi: 10.1007/s00402-021-04065-x] [Medline: 34292380]
137. Roxburgh T, Li A, Guenancia C, Pernollet P, Bouleti C, Alos B, et al. Virtual reality for sedation during atrial fibrillation ablation in clinical practice: observational study. J Med Internet Res. May 27, 2021;23(5):e26349. [FREE Full text] [doi: 10.2196/26349] [Medline: 34042589]
138. Tharion JG, Kale S. Patient satisfaction through an immersive experience using a mobile phone-based head-mounted display during arthroscopic knee surgery under spinal anesthesia: a randomized clinical trial. Anesth Analg. Oct 01, 2021;133(4):940-948. [doi: 10.1213/ANE.0000000000005666] [Medline: 34283040]
139. Touil N, Pavlopoulou A, Momeni M, Van Pee B, Barbier O, Sermeus L, et al. Evaluation of virtual reality combining music and a hypnosis session to reduce anxiety before hand surgery under axillary plexus block: a prospective study. Int J Clin Pract. Dec 2021;75(12):e15008. [doi: 10.1111/ijcp.15008] [Medline: 34811860]
140. Turrado V, Guzmán Y, Jiménez-Lillo J, Villegas E, de Lacy FB, Blanch J, et al. Exposure to virtual reality as a tool to reduce peri-operative anxiety in patients undergoing colorectal cancer surgery: a single-center prospective randomized clinical trial. Surg Endosc. Jul 2021;35(7):4042-4047. [doi: 10.1007/s00464-021-08407-z] [Medline: 33683433]
141. Mosso Vázquez JL, Wiederhold BK, Miller I, Wiederhold MD. Virtual reality assisted anaesthesia during upper gastrointestinal endoscopy: report of 115 cases. EMJ Innov. Jan 10, 2017;1(1):75-82. [doi: 10.33590/emjinnov/10314545]
142. Mosso JL, Wiederhold BK, Miller I, Lara DM, Wiederhold MD. Virtual Reality Assisted Anesthesia (VRAA) during upper gastrointestinal endoscopy: report of 115 cases— analysis of physiological responses. Surg Res Updates. 2017;5:1-11. [FREE Full text]
143. JahaniShoorab N, Ebrahimzadeh Zagami S, Nahvi A, Mazluom SR, Golmakani N, Talebi M, et al. The effect of virtual reality on pain in primiparity women during episiotomy repair: a randomize clinical trial. Iran J Med Sci. May 2015;40(3):219-224. [FREE Full text] [Medline: 25999621]
144. Mosso JL, Gorini A, De La Cerda G, Obrador T, Almazan A, Mosso D, et al. Virtual reality on mobile phones to reduce anxiety in outpatient surgery. Stud Health Technol Inform. 2009;142:195-200. [Medline: 19377147]
145. Bergauer L, Akbas S, Braun J, Ganter MT, Meybohm P, Hottenrott S, et al. Visual blood, visualisation of blood gas analysis in virtual reality, leads to more correct diagnoses: a computer-based, multicentre, simulation study. Bioengineering (Basel). Mar 08, 2023;10(3):340. [FREE Full text] [doi: 10.3390/bioengineering10030340] [Medline: 36978731]
146. Berger A, Choudhry OJ, Kondziolka D. Augmented reality-assisted percutaneous rhizotomy for trigeminal neuralgia. Oper Neurosurg (Hagerstown). Jun 01, 2023;24(6):665-669. [doi: 10.1227/ons.0000000000000661] [Medline: 36815787]
147. Hayasaka T, Kawano K, Onodera Y, Suzuki H, Nakane M, Kanoto M, et al. Comparison of accuracy between augmented reality/mixed reality techniques and conventional techniques for epidural anesthesia using a practice phantom model kit. BMC Anesthesiol. May 20, 2023;23(1):171. [FREE Full text] [doi: 10.1186/s12871-023-02133-w] [Medline: 37210521]
148. Jun EK, Lim S, Seo J, Lee KH, Lee JH, Lee D, et al. Augmented reality-assisted navigation system for transforaminal epidural injection. J Pain Res. Mar 17, 2023;16:921-931. [FREE Full text] [doi: 10.2147/JPR.S400955] [Medline: 36960464]
149. Reinacher PC, Cimniak A, Demerath T, Schallner N. Usage of augmented reality for interventional neuraxial procedures: a phantom-based study. Eur J Anaesthesiol. Feb 01, 2023;40(2):121-129. [FREE Full text] [doi: 10.1097/EJA.0000000000001755] [Medline: 36121289]
150. Iliff HA, Ahmad I, Evans S, Ingham J, Rees G, Woodford C. Using virtual reality for difficult airway management planning. Anaesth Rep. Jul 05, 2022;10(2):e12175. [FREE Full text] [doi: 10.1002/anr3.12175] [Medline: 35813404]

151. Moon RD, Barua NU. Usability of mixed reality in awake craniotomy planning. Br J Neurosurg. Oct 2024;38(5):1139-1143. [doi: 10.1080/02688697.2022.2152429] [Medline: 36537230]
152. Seong H, Yun D, Yoon KS, Kwak JS, Koh JC. Development of pre-procedure virtual simulation for challenging interventional procedures: an experimental study with clinical application. Korean J Pain. Oct 01, 2022;35(4):403-412. [FREE Full text] [doi: 10.3344/kjp.2022.35.4.403] [Medline: 36175339]
153. Tanwani J, Alam F, Matava C, Choi S, McHardy P, Singer O, et al. Development of a head-mounted holographic needle guidance system for enhanced ultrasound-guided neuraxial anesthesia: system development and observational evaluation. JMIR Form Res. Jun 23, 2022;6(6):e36931. [FREE Full text] [doi: 10.2196/36931] [Medline: 35737430]
154. Follmann A, Ruhl A, Gösch M, Felzen M, Rossaint R, Czaplik M. Augmented reality for guideline presentation in medicine: randomized crossover simulation trial for technically assisted decision-making. JMIR Mhealth Uhealth. Oct 18, 2021;9(10):e17472. [FREE Full text] [doi: 10.2196/17472] [Medline: 34661548]
155. Romare C, Enlöf P, Anderberg P, Jildenstål P, Sanmartin Berglund J, Skär L. Nurse anesthetists' experiences using smart glasses to monitor patients' vital signs during anesthesia care: a qualitative study. PLoS One. Apr 21, 2021;16(4):e0250122. [FREE Full text] [doi: 10.1371/journal.pone.0250122] [Medline: 33882100]
156. Schlosser PD, Grundgeiger T, Sanderson PM, Happel O. An exploratory clinical evaluation of a head-worn display based multiple-patient monitoring application: impact on supervising anesthesiologists' situation awareness. J Clin Monit Comput. Dec 2019;33(6):1119-1127. [doi: 10.1007/s10877-019-00265-4] [Medline: 30721389]
157. Hetherington J, Lessoway V, Gunka V, Abolmaesumi P, Rohling R. SLIDE: automatic spine level identification system using a deep convolutional neural network. Int J Comput Assist Radiol Surg. Jul 2017;12(7):1189-1198. [doi: 10.1007/s11548-017-1575-8] [Medline: 28361323]
158. Kaneko N, Tsunoda M, Mitsuhashi M, Okubo K, Takeshima T, Sehara Y, et al. Ultrasound-guided fine-needle aspiration in the neck region using an optical see-through head-mounted display: a randomized controlled trial. J Ultrasound Med. Oct 2017;36(10):2071-2077. [doi: 10.1002/jum.14237] [Medline: 28504313]
159. Kaneko N, Sato M, Takeshima T, Sehara Y, Watanabe E. Ultrasound-guided central venous catheterization using an optical see-through head-mounted display: a pilot study. J Clin Ultrasound. Oct 2016;44(8):487-491. [doi: 10.1002/jcu.22374] [Medline: 27297681]
160. Przkora R, McGrady W, Vasilopoulos T, Gravenstein N, Solanki D. Evaluation of the head-mounted display for ultrasound-guided peripheral nerve blocks in simulated regional anesthesia. Pain Med. Nov 2015;16(11):2192-2194. [doi: 10.1111/pme.12765] [Medline: 25930716]
161. Ashab HA, Lessoway VA, Khallaghi S, Cheng A, Rohling R, Abolmaesumi P. AREA: an augmented reality system for epidural anaesthesia. Annu Int Conf IEEE Eng Med Biol Soc. 2012;2012:2659-2663. [doi: 10.1109/EMBC.2012.6346511] [Medline: 23366472]
162. Udani AD, Harrison TK, Howard SK, Kim TE, Brock-Utne JG, Gaba DM, et al. Preliminary study of ergonomic behavior during simulated ultrasound-guided regional anesthesia using a head-mounted display. J Ultrasound Med. Aug 2012;31(8):1277-1280. [doi: 10.7863/jum.2012.31.8.1277] [Medline: 22837293]
163. Liu D, Jenkins SA, Sanderson PM, Watson MO, Leane T, Kruys A, et al. Monitoring with head-mounted displays: performance and safety in a full-scale simulator and part-task trainer. Anesth Analg. Oct 2009;109(4):1135-1146. [doi: 10.1213/ANE.0b013e3181b5a200] [Medline: 19762741]
164. Sanderson PM, Watson MO, Russell WJ, Jenkins S, Liu D, Green N, et al. Advanced auditory displays and head-mounted displays: advantages and disadvantages for monitoring by the distracted anesthesiologist. Anesth Analg. Jun 2008;106(6):1787-1797. [doi: 10.1213/ane.0b013e31817325cb] [Medline: 18499611]
165. Ormerod DF, Ross B, Naluai-Cecchini A. Use of an augmented reality display of patient monitoring data to enhance anesthesiologists' response to abnormal clinical events. Stud Health Technol Inform. 2003;94:248-250. [Medline: 15455902]
166. Block FEJ, Yablok DO, McDonald JS. Clinical evaluation of the 'head-up' display of anesthesia data. Preliminary communication. Int J Clin Monit Comput. Feb 1995;12(1):21-24. [doi: 10.1007/BF01142442] [Medline: 7782663]
167. Platt MJ. Heads up display. Br J Anaesth. Apr 2004;92(4):602-603. [FREE Full text] [doi: 10.1093/bja/aeh534] [Medline: 15013967]
168. Liu D, Jenkins SA, Sanderson PM, Fabian P, Russell WJ. Monitoring with head-mounted displays in general anesthesia: a clinical evaluation in the operating room. Anesth Analg. Apr 01, 2010;110(4):1032-1038. [doi: 10.1213/ANE.0b013e3181d3e647] [Medline: 20357147]
169. Ormerod DF, Ross B, Naluai-Cecchini A. Use of a see-through head-worn display of patient monitoring data to enhance anesthesiologists' response to abnormal clinical events. In: Proceedings of the Sixth International Symposium on Wearable Computers. 2002. Presented at: ISWC 2002; October 10, 2002; Seattle, WA. [doi: 10.1109/iswc.2002.1167229]
170. Sanderson P. The multimodal world of medical monitoring displays. Appl Ergon. Jul 2006;37(4):501-512. [doi: 10.1016/j.apergo.2006.04.022] [Medline: 16759627]
171. Krupenia S, Sanderson PM. Does a head-mounted display worsen inattentional blindness? Proc Hum Factors Ergon Soc Annu Meet. Oct 01, 2006;50(16):1638-1642. [doi: 10.1177/154193120605001626]
172. Liu SS, Ngeow JE, Yadeau JT. Ultrasound-guided regional anesthesia and analgesia: a qualitative systematic review. Reg Anesth Pain Med. 2009;34(1):47-59. [doi: 10.1097/AAP.0b013e3181933ec3] [Medline: 19258988]

173. Cartucho J, Shapira D, Ashrafian H, Giannarou S. Multimodal mixed reality visualisation for intraoperative surgical guidance. Int J Comput Assist Radiol Surg. May 2020;15(5):819-826. [FREE Full text] [doi: 10.1007/s11548-020-02165-4] [Medline: 32333360]
174. Wen R, Chng CB, Chui CK. Augmented reality guidance with multimodality imaging data and depth-perceived interaction for robot-assisted surgery. Robotics. May 24, 2017;6(2):13. [doi: 10.3390/robotics6020013]
175. Wiegelmann J, Choi S, McHardy PG, Matava C, Singer O, Kaustov L, et al. Randomized control trial of a holographic needle guidance technique for thoracic epidural placement. Reg Anesth Pain Med. Dec 02, 2024;49(12):861-866. [doi: 10.1136/rapm-2023-104703] [Medline: 38212048]
176. Mallari B, Spaeth EK, Goh H, Boyd BS. Virtual reality as an analgesic for acute and chronic pain in adults: a systematic review and meta-analysis. J Pain Res. Jul 03, 2019;12:2053-2085. [FREE Full text] [doi: 10.2147/JPR.S200498] [Medline: 31308733]
177. Chuan A, Zhou JJ, Hou RM, Stevens CJ, Bogdanovych A. Virtual reality for acute and chronic pain management in adult patients: a narrative review. Anaesthesia. May 2021;76(5):695-704. [FREE Full text] [doi: 10.1111/anae.15202] [Medline: 32720308]
178. Privorotskiy A, Garcia VA, Babbitt LE, Choi JE, Cata JP. Augmented reality in anesthesia, pain medicine and critical care: a narrative review. J Clin Monit Comput. Feb 2022;36(1):33-39. [doi: 10.1007/s10877-021-00705-0] [Medline: 33864581]
179. Small C, Laycock H. Are we near to making virtual reality the new reality in pain medicine? Anaesthesia. May 2021;76(5):590-593. [FREE Full text] [doi: 10.1111/anae.15252] [Medline: 32918754]
180. Hoffman HG, Richards TL, Van Oostrom T, Coda BA, Jensen MP, Blough DK, et al. The analgesic effects of opioids and immersive virtual reality distraction: evidence from subjective and functional brain imaging assessments. Anesth Analg. Dec 2007;105(6):1776-83, table of contents. [doi: 10.1213/01.ane.0000270205.45146.db] [Medline: 18042882]
181. Hoffman HG, Seibel EJ, Richards TL, Furness TA, Patterson DR, Sharar SR. Virtual reality helmet display quality influences the magnitude of virtual reality analgesia. J Pain. Nov 2006;7(11):843-850. [FREE Full text] [doi: 10.1016/j.jpain.2006.04.006] [Medline: 17074626]
182. Wollin SR, Plummer JL, Owen H, Hawkins RM, Materazzo F, Morrison V. Anxiety in children having elective surgery. J Pediatr Nurs. Apr 2004;19(2):128-132. [doi: 10.1016/s0882-5963(03)00146-5] [Medline: 15077211]
183. Kain ZN, Mayes LC, Caldwell-Andrews AA, Karas DE, McClain BC. Preoperative anxiety, postoperative pain, and behavioral recovery in young children undergoing surgery. Pediatrics. Aug 2006;118(2):651-658. [doi: 10.1542/peds.2005-2920] [Medline: 16882820]
184. Ayyadhah Alanazi A. Reducing anxiety in preoperative patients: a systematic review. Br J Nurs. Apr 2014;23(7):387-393. [doi: 10.12968/bjon.2014.23.7.387] [Medline: 24732993]
185. Munafò MR, Stevenson J. Anxiety and surgical recovery. Reinterpreting the literature. J Psychosom Res. Oct 2001;51(4):589-596. [doi: 10.1016/s0022-3999(01)00258-6] [Medline: 11595247]
186. Kagan I, Bar-Tal Y. The effect of preoperative uncertainty and anxiety on short-term recovery after elective arthroplasty. J Clin Nurs. Mar 2008;17(5):576-583. [doi: 10.1111/j.1365-2702.2007.01968.x] [Medline: 18093119]
187. Maranets I, Kain ZN. Preoperative anxiety and intraoperative anesthetic requirements. Anesth Analg. Dec 1999;89(6):1346-1351. [doi: 10.1097/00000539-199912000-00003] [Medline: 10589606]
188. Manyande A, Cyna AM, Yip P, Chooi C, Middleton P. Non-pharmacological interventions for assisting the induction of anaesthesia in children. Cochrane Database Syst Rev. Jul 14, 2015;2015(7):CD006447. [FREE Full text] [doi: 10.1002/14651858.CD006447.pub3] [Medline: 26171895]
189. Ryu JH, Park SJ, Park JW, Kim JW, Yoo HJ, Kim TW, et al. Randomized clinical trial of immersive virtual reality tour of the operating theatre in children before anaesthesia. Br J Surg. Nov 2017;104(12):1628-1633. [doi: 10.1002/bjs.10684] [Medline: 28975600]
190. Galvez J, Eisenhower M, England W, Wartman E, Simpao A, Rehman M, et al. An interactive virtual reality tour for adolescents receiving proton radiation therapy: proof-of-concept study. JMIR Perioper Med. Mar 05, 2019;2(1):e11259. [FREE Full text] [doi: 10.2196/11259] [Medline: 33393932]
191. Ryu JH, Park JW, Nahm FS, Jeon YT, Oh AH, Lee HJ, et al. The effect of gamification through a virtual reality on preoperative anxiety in pediatric patients undergoing general anesthesia: a prospective, randomized, and controlled trial. J Clin Med. Sep 17, 2018;7(9):284. [FREE Full text] [doi: 10.3390/jcm7090284] [Medline: 30227602]
192. Park JW, Nahm FS, Kim JH, Jeon YT, Ryu JH, Han SH. The effect of mirroring display of virtual reality tour of the operating theatre on preoperative anxiety: a randomized controlled trial. IEEE J Biomed Health Inform. Jan 11, 2019;23(6):2655-2660. [doi: 10.1109/jbhi.2019.2892485]
193. O'Sullivan B, Alam F, Matava C. Creating low-cost 360-degree virtual reality videos for hospitals: a technical paper on the dos and don'ts. J Med Internet Res. Jul 16, 2018;20(7):e239. [FREE Full text] [doi: 10.2196/jmir.9596] [Medline: 30012545]
194. Mergen M, Junga A, Risse B, Valkov D, Graf N, Marschall B. Immersive training of clinical decision making with AI driven virtual patients - a new VR platform called medical tr.AI.ning. GMS J Med Educ. Apr 17, 2023;40(2):Doc18. [FREE Full text] [doi: 10.3205/zma001600] [Medline: 37361242]
195. Huff G, Saxberg B. Full immersion 2025: how will 10-year-olds learn? Educ Next. 2009;9(3):79.

196. Stephenson E, Poore J. Tips for conducting the pre-brief for a simulation. J Contin Educ Nurs. Aug 01, 2016;47(8):353-355. [FREE Full text] [doi: 10.3928/00220124-20160715-05] [Medline: 27467309]
197. Sharoff L. Simulation: pre-briefing preparation, clinical judgment and reflection. What is the connection? J Contemp Med. Jun 2015;5(2):88-101. [doi: 10.16899/ctd.49922]
198. Dong C, Szarek JL, Reed T. The flipped classroom and simulation: a primer for simulation educators. Med Sci Educ. Dec 03, 2020;30(4):1627-1632. [FREE Full text] [doi: 10.1007/s40670-020-01041-9] [Medline: 34457830]
199. Nickel F, Cizmic A, Chand M. Telestration and augmented reality in minimally invasive surgery: an invaluable tool in the age of COVID-19 for remote proctoring and telementoring. JAMA Surg. Feb 01, 2022;157(2):169-170. [doi: 10.1001/jamasurg.2021.3604] [Medline: 34705030]
200. Liu P, Li C, Xiao C, Zhang Z, Ma J, Gao J, et al. A wearable augmented reality navigation system for surgical telementoring based on Microsoft Hololens. Ann Biomed Eng. Jan 2021;49(1):287-298. [doi: 10.1007/s10439-020-02538-5] [Medline: 32504141]
201. Rojas-Muñoz E, Cabrera ME, Lin C, Andersen D, Popescu V, Anderson K, et al. The system for telementoring with augmented reality (STAR): a head-mounted display to improve surgical coaching and confidence in remote areas. Surgery. Apr 2020;167(4):724-731. [doi: 10.1016/j.surg.2019.11.008] [Medline: 31916990]
202. Rojas-Muñoz E, Andersen D, Cabrera ME, Popescu V, Marley S, Zarzaur B, et al. Augmented reality as a medium for improved telementoring. Mil Med. Mar 01, 2019;184(Suppl 1):57-64. [doi: 10.1093/milmed/usy300] [Medline: 30901394]
203. Shabir D, Abdurahiman N, Padhan J, Trinh M, Balakrishnan S, Kurer M, et al. Towards development of a tele-mentoring framework for minimally invasive surgeries. Int J Med Robot. Oct 2021;17(5):e2305. [doi: 10.1002/rcs.2305] [Medline: 34256415]
204. Martin D, Miller AP, Quesnel-Vallée A, Caron NR, Vissandjée B, Marchildon GP. Canada's universal health-care system: achieving its potential. Lancet. Apr 28, 2018;391(10131):1718-1735. [FREE Full text] [doi: 10.1016/S0140-6736(18)30181-8] [Medline: 29483027]
205. Meit M, Knudson A, Gilbert T, Yu AT, Tanenbaum E, Ormson E, et al. The 2014 update of the rural-urban chartbook. Rural Health Reform Policy Research Center. Oct 2014. URL: https://ruralhealth.und.edu/projects/health-reform-policy-research-center/pdf/2014-rural-urban-chartbook-update.pdf [accessed 2025-02-17]
206. Weitzman RE, Wong K, Worrall DM, Park C, McKee S, Tufts RE, et al. Incorporating virtual reality to improve otolaryngology resident wellness: one institution's experience. Laryngoscope. Sep 2021;131(9):1972-1976. [doi: 10.1002/lary.29529] [Medline: 33764531]
207. Ferrer Costa J, Moran N, Garcia Marti C, Colmenares Hernandez LJ, Radu Ciorba Ciorba F, Ciudad MJ. Immediate impact of an 8-week virtual reality educational program on burnout and work engagement among health care professionals: pre-post pilot study. JMIR XR Spatial Comput. 2024;1:e55678. [doi: 10.2196/55678]
208. Croghan IT, Hurt RT, Aakre CA, Fokken SC, Fischer KM, Lindeen SA, et al. Virtual reality for health care professionals during a pandemic: a pilot program. J Prim Care Community Health. 2022;13:21501319221086716. [FREE Full text] [doi: 10.1177/21501319221086716] [Medline: 35352605]
209. Kim J, Kim D, Oh SH, Kwon H. Virtual reality for preoperative patient education: impact on satisfaction, usability, and burnout from the perspective of new nurses. World J Clin Cases. Oct 06, 2024;12(28):6204-6216. [FREE Full text] [doi: 10.12998/wjcc.v12.i28.6204] [Medline: 39371559]
210. Adolph KE, Hoch JE. Motor development: embodied, embedded, enculturated, and enabling. Annu Rev Psychol. Jan 04, 2019;70:141-164. [FREE Full text] [doi: 10.1146/annurev-psych-010418-102836] [Medline: 30256718]
211. Ujitoko Y, Ban Y. Survey of pseudo-haptics: haptic feedback design and application proposals. IEEE Trans Haptics. Oct 1, 2021;14(4):699-711. [doi: 10.1109/toh.2021.3077619]
212. Argelaguet F, Hoyet L, Trico M, Lecuyer A. The role of interaction in virtual embodiment: effects of the virtual hand representation. In: Proceedings of the IEEE Virtual Reality. 2016. Presented at: VR 2016; March 19-23, 2016; Greenville, SC. [doi: 10.1109/vr.2016.7504682]
213. Yu R, Bowman DA. Pseudo-haptic display of mass and mass distribution during object rotation in virtual reality. IEEE Trans Visual Comput Graphics. May 2020;26(5):2094-2103. [doi: 10.1109/tvcg.2020.2973056]
214. Pacchierotti C, Prattichizzo D, Kuchenbecker KJ. Cutaneous feedback of fingertip deformation and vibration for palpation in robotic surgery. IEEE Trans Biomed Eng. Feb 2016;63(2):278-287. [doi: 10.1109/TBME.2015.2455932] [Medline: 26186763]
215. D'Abbraccio J, Massari L, Prasanna S, Baldini L, Sorgini F, Airò Farulla G, et al. Haptic glove and platform with gestural control for neuromorphic tactile sensory feedback in medical telepresence. Sensors (Basel). Feb 03, 2019;19(3):641. [FREE Full text] [doi: 10.3390/s19030641] [Medline: 30717482]
216. Junput B, Wei X, Jamone L. Feel it on your fingers: dataglove with vibrotactile feedback for virtual reality and telerobotics. In: Proceedings of the 20th Annual Conference on Towards Autonomous Robotic Systems. 2019. Presented at: TAROS 2019; July 3-5, 2019; London, UK. [doi: 10.1007/978-3-030-23807-0_31]
217. Panariello D, Caporaso T, Grazioso S, Di Gironim G, Lanzotti A, Knopp S, et al. Using the KUKA LBR iiwa robot as haptic device for virtual reality training of hip replacement surgery. In: Proceedings of the 2019 Third IEEE International

Conference on Robotic Computing. 2019. Presented at: IRC 2019; February 25-27, 2019; Naples, Italy. [doi: 10.1109/irc.2019.00094]
218. Shaylor R, Verenkin V, Golden E, Matot I. The use of three-dimensional printing and virtual reality to develop a personalised airway plan in a 7.5-year-old child: a case report. Eur J Anaesthesiol. Jun 2020;37(6):512-515. [doi: 10.1097/EJA.0000000000001184] [Medline: 32379152]
219. Han M, Portnova AA, Lester M, Johnson M. A do-it-yourself 3D-printed thoracic spine model for anesthesia resident simulation. PLoS One. Mar 11, 2020;15(3):e0228665. [FREE Full text] [doi: 10.1371/journal.pone.0228665] [Medline: 32160198]
220. Weech S, Kenny S, Barnett-Cowan M. Presence and cybersickness in virtual reality are negatively related: a review. Front Psychol. 2019;10:158. [FREE Full text] [doi: 10.3389/fpsyg.2019.00158] [Medline: 30778320]
221. Drazich BF, McPherson R, Gorman EF, Chan T, Teleb J, Galik E, et al. In too deep? A systematic literature review of fully-immersive virtual reality and cybersickness among older adults. J Am Geriatr Soc. Dec 2023;71(12):3906-3915. [doi: 10.1111/jgs.18553] [Medline: 37560978]
222. Jensen L, Konradsen F. A review of the use of virtual reality head-mounted displays in education and training. Educ Inf Technol. Nov 25, 2017;23(4):1515-1529. [doi: 10.1007/s10639-017-9676-0]
223. Martirosov S, Bureš M, Zítka T. Cyber sickness in low-immersive, semi-immersive, and fully immersive virtual reality. Virtual Real. 2022;26(1):15-32. [FREE Full text] [doi: 10.1007/s10055-021-00507-4] [Medline: 34025203]
224. Google Cardboard. Google. URL: https://arvr.google.com/cardboard/ [accessed 2024-11-06]
225. Patel P, Ivanov D, Bhatt S, Mastorakos G, Birckhead B, Khera N, et al. Low-cost virtual reality headsets reduce perceived pain in healthy adults: a multicenter randomized crossover trial. Games Health J. Apr 2020;9(2):129-136. [doi: 10.1089/g4h.2019.0052] [Medline: 31804853]
226. Pandrangi VC, Gaston B, Appelbaum NP, Albuquerque FCJ, Levy MM, Larson RA. The application of virtual reality in patient education. Ann Vasc Surg. Aug 2019;59:184-189. [doi: 10.1016/j.avsg.2019.01.015] [Medline: 31009725]

Abbreviations

AI: artificial intelligence
AR: augmented reality
CT: computerized tomography
HMD: head-mounted display
IR: immersive reality
MR: mixed reality
MRI: magnetic resonance imaging
SRL: self-regulated learning
VR: virtual reality

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