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ALTERNATIVE TREATMENTS FOR PAIN MEDICINE (C ROBINSON, SECTION EDITOR)

Virtual Reality in Acute and Chronic Pain Medicine: An Updated Review

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Abstract

Purpose of Review This review critically analyzes the recent literature on virtual reality's (VR) use in acute and chronic pain management, offering insights into its efficacy, applications, and limitations.

Recent Findings Recent studies, including meta-analyses and randomized controlled trials, have demonstrated VR's effectiveness in reducing pain intensity in various acute pain scenarios, such as procedural/acute pain and in chronic pain conditions. The role of factors such as immersion and presence in enhancing VR's efficacy has been emphasized. Further benefits have been identified in the use of VR for assessment as well as symptom gathering through conversational avatars. However, studies are limited, and strong conclusions will require further investigation.

Summary VR is emerging as a promising non-pharmacological intervention in pain management for acute and chronic pain. However, its long-term efficacy, particularly in chronic pain management, remains an area requiring further research. Key findings highlight that VR programs vary in efficacy depending on the specificity of the origin of pain.

Keywords Virtual reality · Chronic pain · Acute pain · Pain management · Immersive technology · Digital therapeutics

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Introduction

The International Association for the Study of Pain defines pain as an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage [1]. Acute pain, serving as a physiological signal of actual or potential tissue damage, arises from injuries or disease and is expected to subside upon the healing of its underlying cause. When pain outlasts the expected tissue healing period, persisting beyond 3 months and leading to significant emotional distress and/or functional disability, it is considered chronic [2, 3].

The immediate sensation of acute pain can evolve to trigger behavioral responses aimed at minimizing injury or avoiding further harm. Although evolutionarily advantageous and ontogenically useful in promoting survival, acute pain is by definition an unpleasant experience and can, in many cases, be significantly debilitating. Inadequately managed acute pain contributes to a range of physiological derangements, including poor cough and ventilation mechanics, increased sympathetic activity, increased inflammation and reduced immune function, and impaired wound healing, among many others [4, 5]. Moreover, poorly controlled acute pain contributes to increased healthcare expenses through longer hospital stays, resource utilization, and potential development of chronic pain [5]. Thus, adequate management of acute pain necessitates diverse and effective management strategies.

Chronic pain, in contrast to acute pain, represents a persistent condition extending for at least 3 months [1, 3]. While acute pain is in many circumstances an evolutionarily advantageous physiological mechanism, chronic pain is by definition maladaptive, reflecting changes in the nervous system that perpetuate pain even after the initial injury or noxious stimulus has resolved [6, 7]. The development of chronic pain is frequently associated with the insufficient or inappropriate management of acute pain, highlighting the critical importance of effective acute pain control in preventing this transition [8, 9]. Chronic pain is characterized not only by its duration but also by its multifaceted impact on the individual's physical, psychological, and social well-being [8–11]. This condition can lead to significant functional impairment, reduced quality of life, and substantial financial burden [12]. Thus, treating chronic pain is an important, albeit resource-intensive endeavor.

Significant advancements in non-pharmacologic, minimally invasive techniques have recently transformed the landscape of pain management [13–15]. Within this context, extended reality (XR) has emerged as a pioneering and versatile modality capable of enhancing the relief of both acute and chronic pain through its broad range of applications. This narrative review provides an overview of recent XR-based applications in pain medicine, focusing on select studies conducted between 2020 and 2023, with the aim of shedding light on XR's emerging role in pain management.

The Realm of Extended Reality: Definitions and Developments

VR is a computer-generated simulation of a three-dimensional (3D) environment which supplants the user's real-world surroundings and can be interacted with in a seemingly natural manner. Augmented reality (AR) overlays digital elements such as images, sounds, or other data onto the real environment, thereby enriching the user's perception of reality. Distinct from VR, AR enhances rather than replaces the physical world, enabling users to engage with both virtual and actual elements simultaneously. Mixed reality (MR) applications combine virtual and augmented realities. Of note, the term extended reality (XR) includes VR, AR, and MR applications (see Table 1, 2, and 3 for definitions and Fig. 1).

Technological Evolution in Human Computer Interaction (HCI)

The history of XR, particularly VR and AR, is deeply intertwined with the evolution of human computer interaction (HCI). The advancement from text-based commands to intuitive graphical user interfaces (GUIs) made technology more accessible and user-friendly [16]. Touchscreen technology further revolutionized HCI by allowing for direct manipulation of digital elements, setting the stage for more interactive interfaces. These advancements in HCI have progressively enhanced user engagement, paving the way for the creation of more complex and realistic virtual environments [16]. The development of XR technologies is marked by continuous innovations, from Ivan Sutherland's "Sword of Damocles," the first VR head-mounted display (HMD) system, to contemporary VR and AR applications [17]. This evolution has introduced novel ways for users to interact with digital environments, culminating in transformative experiences offered by XR. Modern XR systems offer high-resolution displays, accurate motion tracking, and advanced interactive capabilities, providing users with increasingly realistic and immersive experiences. The shift to intuitive, user-centered interfaces has been a critical factor in the growth of XR, increasingly democratizing access to immersive technologies and paving the way for their widespread adoption.

Table 1 Definitions of extended reality terms and concepts

Human–computer interaction (HCI)	Extended reality (XR)	Virtual reality (VR)	Augmented reality (AR)
An interdisciplinary field focusing on the design, evaluation, and implementation of interactive computing systems for human use. It integrates knowledge from computer science, design, psychology, and sociology to enhance the usability and user experience of technology, aiming to create interfaces that are intuitive, efficient, and adaptable to human needs	An all-encompassing term that includes a spectrum of immersive technologies such as virtual reality (VR), augmented reality (AR), and mixed reality (MR). These technologies collectively extend or alter human perception by integrating digital information with the physical environment, offering new possibilities for interaction, visualization, and experiencing virtual content	A technology that creates a completely virtual environment, immersing users in a digital world that replaces their physical surroundings. This environment can simulate real-world settings or create entirely fantastical scenarios, typically accessed through VR headsets or specialized rooms, providing sensory experiences such as sight, sound, and sometimes touch	Superimposes digital information – such as images, sounds, or other data – onto the real world, enhancing one's perception of reality. Unlike VR, AR does not replace the physical world but rather augments it, allowing users to interact with both virtual and real-world elements simultaneously, often through devices like smartphones or AR glasses
Mixed reality (MR)	**Biofeedback**	**Behavioral realism**	**Immersion**
An advanced form of AR that not only overlays but also anchors virtual objects to the real world, allowing for interactions that are perceptually realistic and contextually relevant. MR technology blends the physical and digital worlds in a way that these environments can coexist and interact in real-time, providing a more integrated and immersive experience	A technique that trains individuals to improve their health and performance by using signals from their own bodies. It involves measuring physiological indicators such as heart rate, muscle tension, and brainwave patterns, providing real-time feedback to help individuals recognize and modify their physiological responses to stress, pain, or other conditions	Refers to the extent to which behaviors in a virtual environment accurately mimic those in the real world. This concept is crucial in fields like virtual reality and simulation, where the goal is to create experiences that are convincingly lifelike, enhancing the user's engagement and the effectiveness of training or therapeutic interventions	Refers to the degree of sensory and psychological engagement experienced by a user. A highly immersive environment captivates the user's senses, making them feel as if they are truly part of the virtual world. This can be achieved through advanced graphics, sound, interactive elements, and responsive interfaces that seamlessly integrate with the user's actions and perceptions

Table 2 Types of extended reality head mounted displays

Occulus series	Vive series	Varjo series	Hololens series
Oculus Quest 1, Oculus Quest 2, and Oculus Quest Pro have revolutionized XR with standalone, wireless headsets that offer impressive room-scale tracking, intuitive hand controllers, passthrough cameras, and seamless hand tracking. The Oculus Series, known for its user-friendly interface and affordability, is widely used in gaming and education but sometimes criticized for its dependency on Facebook accounts	The Vive series, including the original HTC Vive, HTC Vive Pro, and HTC Vive Cosmos, has significantly contributed to the XR landscape. These headsets offer high-quality VR experiences with precise tracking, ergonomic design, and a wide range of compatible accessories. The open ecosystem has allowed for the development of innovative applications and games. The Vive Series, with its superior tracking and high-quality display, excels in professional training and architectural visualization, though it can be costly and requires a spacious setup	Varjo's XR-3 headset stands out in the XR domain with its exceptionally high-resolution mixed reality capabilities. The XR-3 offers stunning visual fidelity, enabling users to seamlessly blend the digital and real worlds. It promotes further eye-tracking capabilities with physiological benefits. Varjo Series stands out in industrial design and flight simulation due to its unparalleled resolution and realism, but its high price and heavy hardware make it less accessible for casual users	Hololens Series, a leader in mixed reality, is pivotal in medical training and remote assistance, offering hands-free operation and spatial awareness, but is hindered by a limited field of view and high cost
Magic leap series	**Apple series**	**Sony series**	**Pico series**
Magic leap series, known for its lightweight design and innovative spatial computing, is ideal for creative industries and healthcare, but faces challenges with content limitations and high expectations	Apple series, though not yet released as of my last update, is anticipated to impact various sectors with Apple's ecosystem integration, potentially facing challenges in market penetration against established players	Sony series, popular in the gaming sector, offers a seamless integration with PlayStation consoles but is often seen as less versatile for non-gaming applications	Pico Series, with its focus on business applications and affordability, is making strides in education and training, though it may not match the high-end performance of its competitors

Table 3 Extended reality additional hardware and sensors

Motion sensors	Handheld controllers	Audio components	Lidar sensors and camera sensors
Motion sensors in XR are critical for capturing and translating a user's physical movements into the virtual environment. They detect and track head, limb, and body movements, enabling a natural and intuitive interaction within the XR space. These sensors ensure that the virtual environment responds accurately and in real-time to the user's actions, enhancing the sense of presence and immersion	Handheld controllers in XR environments act as extensions of the user's hands, allowing them to interact with the virtual world in a more intuitive and natural manner. These controllers are equipped with buttons, joysticks, and sometimes motion sensors, enabling users to grab, manipulate, and engage with virtual objects or control their virtual avatar, thereby enhancing the interactive experience	Audio components in XR are essential for creating a fully immersive experience. They deliver spatial audio that adjusts to the user's movements and interactions, enhancing the realism of the virtual environment. Accurate audio cues provide directional and environmental context, contributing to a more engaging and believable XR experience	Lidar and camera sensors play a pivotal role in XR by providing advanced spatial awareness and depth perception. These sensors facilitate accurate hand and eye tracking and enable the seamless integration of real-world objects into the virtual environment. This enhances user interaction and immersion, making the XR experience more realistic and responsive
Haptic feedback	**Wearable exosuits**	**Infrared sensors**	**Wearables**
Haptic feedback in XR offers tactile sensations that simulate the texture, resistance, and impact of virtual objects. This technology, through devices like controllers, gloves, or vests, provides users with physical sensations that correspond to their virtual interactions, significantly enhancing the realism and immersiveness of the XR experience	Wearable exosuits in XR are advanced garments equipped with sensors and actuators that provide physical feedback and resistance. They are designed to replicate the sensation of touch, force, and weight, offering a more comprehensive and realistic physical experience in the virtual environment. This technology greatly enhances the immersive aspect of XR by simulating real-world physical interactions	Infrared sensors in XR are utilized for precise tracking of user movements and positioning. These sensors detect infrared light emitted or reflected from the user or the environment, enabling accurate spatial mapping and gesture recognition. This technology is key in creating responsive and interactive XR experiences, allowing the virtual environment to adapt seamlessly to the user's actions	Wearables in XR, such as smart glasses, gloves, and wristbands, serve as interactive devices that enhance the user's engagement with the virtual environment. These wearables can track movements, provide haptic feedback, display information, and even monitor physiological responses, contributing to a more integrated and personalized XR experience. They bridge the gap between the user and the digital world, offering new dimensions of interaction and immersion

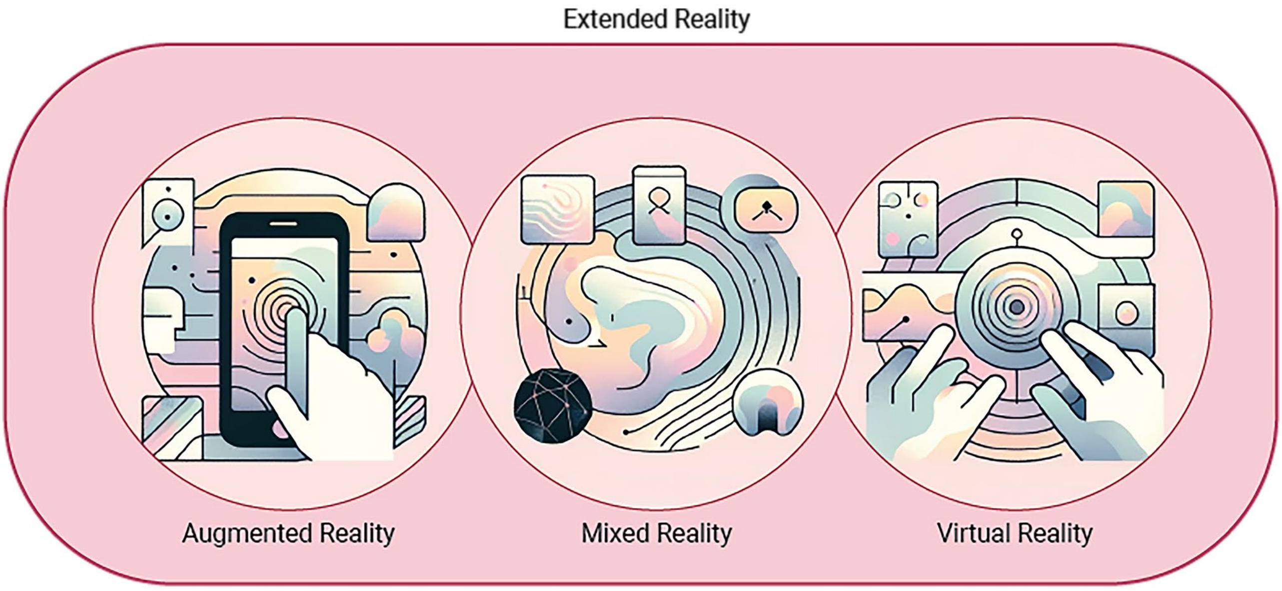

Fig. 1 Extended reality nomenclature and concepts

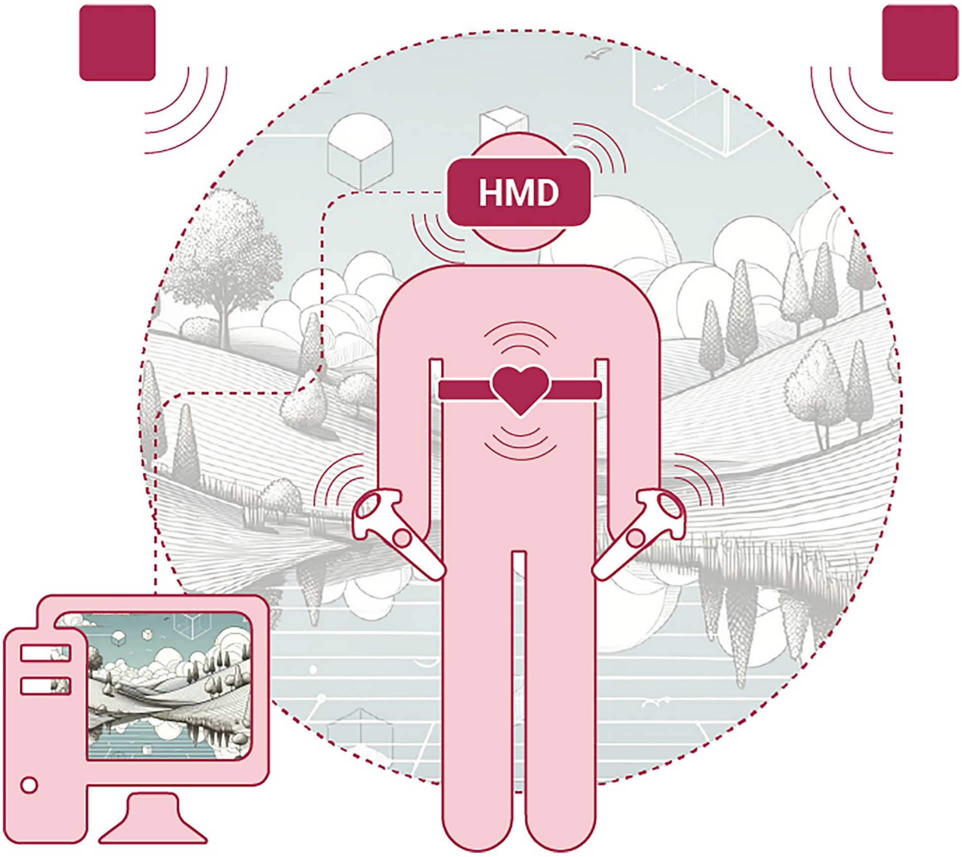

Fig. 2 Diagrammatic representation of head mounted display (HMD) and hardware needed for XR

Technological Principles Behind VR and AR

The core of VR and AR technologies lies in creating immersive 3D environments through HMDs which rely on stereoscopic display, or the use of slightly different angles of the same scene, to simulate natural human depth perception (Fig. 2). HMDs have evolved to include integrated or external motion sensors for VR immersion as well as accurate digital overlays and depth perception systems for AR. Haptic feedback and refined spatial audio are integral components of current iterations, allowing for more accurate simulations of natural human touch and sound perception, respectively. Additional improvements in image-rendering engines and motion tracking systems now support increasingly realistic and interactive experiences (Fig. 3).

Fig. 3 Depiction of a mindfulness and assessment environment with an avatar. Reproduced with permission from AugMend Health

In the realm of XR applications, the qualitative characteristics of behavioral realism and immersion are fundamental in enriching user experience. Immersion, achieved through sophisticated graphics, spatial audio, and interactive elements, deepens the user's sensory engagement, creating a more compelling sense of real presence within the virtual environment. Behavioral realism, which measures how closely interactions and behaviors within an XR environment mimic those in the real world, increases participant engagement in therapeutic or training interventions in which accurate replication of real-life scenarios is fundamental. The addition of biofeedback, or responsiveness to real-time physiological data, such as heart rate, electrophysiological signals, or breathing patterns, further enhances user engagement by allowing for personalized interactions with the virtual or augmented environment.

Extended Reality Applications in Pain Management

In the realm of medicine, VR and AR support a wide range of applications. AR has been leveraged to simulate operating room environments for surgical training and enhance learning experiences for physicians and patients. Meanwhile, VR has been extensively used for immersive therapies in several conditions, ranging from spinal cord injuries to pain management [18–25]. The use of VR in acute pain management, such as during burn wound care, dental procedures, and labor, has been shown to facilitate rapid reductions in pain intensity [26–28]. In chronic pain management, VR often goes beyond immediate relief, serving as a longstanding therapeutic tool by offering techniques for relaxation, physical rehabilitation, cognitive behavioral therapy, and pain education [29]. This dual capability of VR, encompassing strategies for both immediate pain relief and enduring pain management, highlights its promise in contributing to the future landscape of pain management.

Mechanism of Action

The utility of XR applications in medicine is a direct result of their capability to interface with and engage human perception [30]. By stimulating the visual, auditory, and haptic senses, these technologies create immersive experiences that significantly modulate the user's attention, thoughts, and emotions [16, 29]. In pain management, specifically, XR facilitates therapeutic neurocognitive and psychological states through distraction, focus-shifting, and skill-building [31]. These mechanisms form a continuum, reflecting a progression in the patient's active role in managing pain [31]. VR-mediated distraction analgesia involves shifting sensory and cognitive focus away from pain processing toward an immersive virtual world [32, 33]. VR is thus particularly suited to provide analgesia during painful medical interventions for the awake patient or in periods of sharp, fleeting pain such as during labor and post-surgical recovery [34]. Attention modulation, or focus shifting, further refines this approach by encouraging users to systematically alter their focus within the VR environment, aiding in more effectively diverting attention from both acute and chronic pain [31, 35]. For chronic pain, the emphasis shifts to skill-building, which empowers patients to develop and refine self-regulatory techniques for managing their pain over the long term [31, 36]. In addition to facilitating these neurocognitive adaptations, VR also offers therapeutic benefits for chronic pain by directly improving physical function endpoints closely related to pain relief, such as enhancing range of motion, building isokinetic strength, and bolstering static muscular endurance [37, 38].

Although the detailed neurobiological mechanisms of XR's effects on pain still require further exploration, it has been hypothesized that immersive XR experiences might lead to disruption of maladaptive corticothalamic pathways involved in pathologic pain processing [39]. For example, a fully immersive simulation of gait biomechanics was determined to increase thalamic gamma-aminobutyric acid (GABA) levels in patients with spinal cord injuries (SCI) and increase activity in cortical regions involved in sensorimotor execution and control in patients with spinal cord injuries (SCI) [40]. A VR meditative intervention for patients with opioid use disorder (OUD) experiencing pain was associated with decreases in task-related postcentral gyrus (PCG) activation, a key area of the pain neuromatrix [41]. XR-facilitated experiences may exert their therapeutic effects by modulating additional brain regions implicated in the brain's descending pain-control system known to be regulated by attention, emotion, and memory, including the periaqueductal gray (PAG) and the anterior cingulate cortex (ACC) [42–44].

XR Applications in Acute Pain

The effectiveness of VR in helping manage acute pain has been supported through numerous clinical trials across a wide range of conditions and clinical settings (Table 4).

Labor and Delivery

In a randomized controlled trial (RCT) studying 40 women in labor, the VR treatment arm witnessed an average decrease of 0.52 in the visual analog score (VAS) versus an increase of 0.58 ($p = 0.03$) in the control arm [27]. Additionally, the control arm experienced a higher average maternal

Table 4 Studies using virtual reality for acute pain conditions

Author (year)	Study design	Study goals	N	Study group	VR programs (treatment)	Comparator (control)	Results	Conclusions
Wong et al.(2021) [27]	RCT	To evaluate the effectiveness of VR in reducing pain in laboring women	40	Laboring women experiencing pain	Labor-specific VR program with visualization of a blossoming tree, ocean waves, campfire, and meditative auditory guidance. (up to 30 min using a labor-specific VR program)	No additional intervention for the control group	The control group experienced a pain increase of 0.58, while the VR group saw a reduction of 0.52 ($p=0.03$). 23.8% of VR participants achieved a clinically important pain reduction, compared to 0% in control ($p=0.049$). Postintervention heart rate was higher in the control arm (86.8 vs. 76.3, $p=0.01$). Analysis showed VR led to a 28% reduction in pain score ($p=0.01$). Control subjects used more positioning changes (73.7% vs. 23.8%, $p=0.002$). Other secondary outcomes showed no significant differences	VR was effective in reducing pain in laboring women compared to no intervention, suggesting its utility as a non-pharmacological pain management tool in labor

Table 4 (continued)

Author (year)	Study design	Study goals	N	Study group	VR programs (treatment)	Comparator (control)	Results	Conclusions
Momenyan et al. (2020) [48]	RCT	To evaluate immersive VR analgesia's impact on cognitive, affective, and sensory components of pain, anxiety, and nausea during un-medicated labor	52	Laboring women in un-medicated childbirth	360-degree video of nature scenes (beach and peaceful landscapes) with accompanying natural sounds, delivered via a head-mounted display and noise reduction headphones. Two 10-min interventions were delivered	Control group received usual care without VR over two 10-min interventions	Significant reduction in cognitive pain during the first stage of labor in VR group ($p = 0.013$), and sensory pain significantly decreased in the first stage ($p = 0.033$). Anxiety levels were significantly lower in VR group ($p < 0.05$)	Immersive VR is an effective non-pharmacological method to reduce pain and anxiety during childbirth, demonstrating potential as a beneficial intervention in labor without major side effects
Gür and Apay (2020) [45]	5 arm double-blind RCT	To investigate the effects of cognitive behavioral techniques using virtual reality on birth pain	273	Pregnant women in labor	VR for displaying videos of newborn photographs with classical music, newborn photographs only, an introductory film of Turkey, classical music only. Intervention implemented for 10 min	The control group received routine hospital care	Significant reduction in VAS and VRS scores in groups A (newborn photographs with music) and B (newborn photograph album) compared to control. Groups A and B showed significant reductions in birth pain ($p < 0.05$). The mean VAS posttest scores were 4.98 ± 1.69 for Group A and 4.96 ± 1.72 for Group B	Cognitive-behavioral techniques with VR, particularly videos of newborn photographs with classical music and newborn photograph albums, were effective in reducing labor pain

Table 4 (continued)

Author (year)	Study design	Study goals	N	Study group	VR programs (treatment)	Comparator (control)	Results	Conclusions
Hoag et al. (2022) [57]	Single-site crossover RCT	To assess the impact of guided imagery and VR on procedural pain and anxiety during unsedated procedures	50	Patients aged 8 to 25, undergoing unsedated procedures such as venipuncture, port access, or central-line dressing changes	KindVR Aqua, a VR game that runs over 15 min, providing an interactive audio and visual underwater experience	The control was a 2D audiovisual guided imaging similar to the VR condition and equivalent duration	Postintervention anxiety scores decreased by 10 points in the VR group and 6 points in the iPad group (STAI), with no significant differences in pain scores (VAS) ($p = 0.953$) and respiratory rates ($p = 0.776$). The mean difference in anxiety scores between groups was 4 points (95% CI = 0.44 to 7.6). A trend toward a lower heart rate was observed in the VR group, with a 3-point reduction ($p = 0.061$)	The study concluded that VR is as effective as GI in managing procedural pain and distress in pediatric patients. VR appears to be more beneficial for children with high pain catastrophizing, while GI is more suitable for those with high trait anxiety
Gold et al. (2021) [52]	RCT	To determine whether a VR intervention decreases pain and anxiety among patients undergoing PIVC placement compared with standard care in the pediatric setting	107	Children and young adult patients undergoing peripheral intravenous catheter (PIVC) placement	Two different VR headsets were used based on age groups—Samsung Gear VR for patients aged 13–21 years and Merge VR for patients aged 10–12 years. Both groups played a multisensory VR game (Bear Blast; AppliedVR)	The control group received simple distraction techniques and numbing cream	Patients who received the VR intervention had significantly lower mean post-PIVC anxiety and pain scores across various reporting methods (patient-reported, caregiver-reported, and clinician-reported), with (p values ranging from < 0.001 to 0.04)	The VR intervention significantly decreased pain and anxiety among patients undergoing PIVC placement in the pediatric setting

Table 4 (continued)

Author (year)	Study design	Study goals	N	Study group	VR programs (treatment)	Comparator (control)	Results	Conclusions
Goldman and Behboudi (2021) [49]	RCT	To assess the effectiveness of VR in reducing pain and anxiety in pediatric population in the emergency department	66	Pediatric patients needing intravenous catheterization	VOX + Z3 3D VR Headset with a roller coaster simulation app	Control group received standard of care including distraction tools and support by a child life specialist	The time of procedure was shorter in the VR group (median 5 min) compared to the control group (median 7 min), but not statistically significant. Pain scores were lower in the VR group both before and after the procedure, but differences were not statistically significant. However, satisfaction from anxiety management was significantly higher in the VR group ($p < 0.007$). Children in the VR group reported more fun ($p < 0.024$)	VR is effective as a distraction tool in the emergency department setting for children undergoing intravenous catheterization, increasing satisfaction from anxiety management and perceived fun during the procedure

Table 4 (continued)

Author (year)	Study design	Study goals	N	Study group	VR programs (treatment)	Comparator (control)	Results	Conclusions
Yıldırım and Gerceker (2023) [51]	RCT	To evaluate the effectiveness of VR in improving first-attempt intravenous insertion success and in reducing procedure-related pain	15	Pediatric patients undergoing intravenous insertion in the pediatric emergency department	The study used an Oculus Rift VR with Samsung Galaxy S7 mobile phone for the VR group. The VR experience included three virtual environments suitable for children: roller coaster, mine craft, ocean rift	The control group received no distraction device but engaged in conversation with questions such as age, grade, favorite friend, and preferred sports	Mean DIVA scores were 2.0 to 2.3 in all groups, with difficult IV access (DIVA > _4 points) in 39.2% VR, 42% Buzzy, and 46.9% control groups. First-attempt IV success rates were similar (VR = 47.2%, Buzzy = 50%, control = 46.9%). IV insertion duration averaged 10.5 min in VR, 11.3 min in Buzzy, and 9.9 min in control. Emotional appearance, pain, and anxiety levels pre- and post-procedure were comparable across groups	The use of VR during intravenous insertion did not significantly improve the first-attempt IV insertion success or reduce procedure-related pain and anxiety. However, these technologies may decrease procedure-related fear in children. The study highlights that simpler distraction methods are also effective

Table 4 (continued)

Author (year)	**Study design**	**Study goals**	**N**	**Study group**	**VR programs (treatment)**	**Comparator (control)**	**Results**	**Conclusions**
Wong and Choi (2023) [53]	RCT	To examine the effects of VR on reducing pain, anxiety, and stress experienced by pediatric patients undergoing venipuncture	149	Pediatric patients aged 4 to 12, undergoing venipuncture	The VR group received headsets for age-specific scenarios about venipuncture. It featured a cartoon character, DD, and provided distraction and information, with screen zooming and body movements for visual stimulation. Patients watched these scenarios before and during venipuncture, with medical staff aligning real-time procedures with the VR script. The intervention could be stopped for discomfort	The control received standard care and a reassuring explanation of the procedure	The VR group reported significantly less pain ($\beta = -0.78$; 95% CI, -1.21 to -0.35; $p < .001$) and anxiety ($\beta = -0.41$; 95% CI, -0.76 to -0.05; $p = .03$) post-intervention. Healthcare professional satisfaction was higher in the VR group (mean score 34.5 ± 4.5) than in the control group (mean score 32.9 ± 4.0; $p = .03$). The venipuncture procedure was shorter in the VR group (mean duration 4.43 ± 3.47 min) compared to the control (mean duration 6.56 ± 7.39 min; $p = .03$)	The VR intervention effectively reduced pain and anxiety in children undergoing venipuncture. It also resulted in shorter procedure times and higher staff satisfaction compared to standard care. The study highlighted the potential of C10VR as an effective nonpharmacological intervention for pediatric patients undergoing needle-related procedures

Table 4 (continued)

Author (year)	**Study design**	**Study goals**	**N**	**Study group**	**VR programs (treatment)**	**Comparator (control)**	**Results**	**Conclusions**
Wong et al. (2021) [129]	Open-label RCT	To determine whether virtual reality distraction intervention can alleviate pain and anxiety and reduce the length of the procedure	108	Pediatric cancer patients aged 6 to 17 years, scheduled to receive peripheral intravenous cannulation (PIC)	The VR intervention, offered alongside standard care, started 5 min before and continued during the procedure. VR content, including animated videos, was selected. Four VR videos, mostly cartoons, were provided, with two from "Minions" chosen for their visual and auditory appeal, free availability, and minimal head movement requirement	The control received standard care with no additional intervention	Pain levels post-PIC increased from 1.11 to 4.00 in the control group and 0.74 to 1.94 in the VR group, with VR showing a smaller increase (mean difference = −1.69, $p = .007$). Anxiety reduction was greater in VR (from 20.4 to 14.8) than control (from 19.9 to 17.8) with a mean difference of −3.50 ($p < .001$). PIC duration was shorter in VR (2.70 ± 0.74 min) versus control (3.41 ± 2.13 min). No VR side effects were reported	The study concluded that VR is a beneficial distraction intervention for alleviating physical and psychological sufferings among pediatric cancer patients undergoing PIC. It can be considered an adjunctive treatment to manage pain and anxiety, thereby facilitating PIC insertion by healthcare providers

Table 4 (continued)

Author (year)	Study design	Study goals	N	Study group	VR programs (treatment)	Comparator (control)	Results	Conclusions
Butt et al. (2022) [50]	Single blinded RCT	To assess the effectiveness of VR-based mindfulness intervention in reducing situational anxiety	110	Pediatric patients in emergency department aged 13–17 years with acute pain	Take-Pause an immersive mindfulness-based VR program where patients experience a calming VR journey, syncing their breathing with a virtual character to manage stress and anxiety for a duration of 5 min	Passive intervention iPad group had access to age appropriate gaming applications for 5 min	The VR group showed a 10-point improvement in anxiety scores compared to a 6-point improvement in the iPad group ($p < 0.001$; 95% confidence interval = 0.44 to 7.6). No significant differences were observed in pain score reduction ($p = 0.953$) and respiratory rates ($p = 0.776$), but a trend towards a lower heart rate with a 3-point reduction was noted ($p = 0.061$)	The mindfulness-based VR intervention was more effective than passive distraction techniques (iPad games) in reducing short-term anxiety in pediatric patients with moderately painful conditions in the emergency department

Table 4 (continued)

Author (year)	Study design	Study goals	N	Study group	VR programs (treatment)	Comparator (control)	Results	Conclusions
Taylor et al. (2021) [54]	Prospective non-RCT	To assess the feasibility of using VR as an alternative to sedation or general anesthesia (GA)	31	Pediatric patients undergoing minor surgical procedures, specifically hormone pellet procedures	Patients used a Samsung Gear VR headset with custom VR experiences developed by the institution and a customized version of the commercial application DreamFlight. The VR experiences were designed to increase cognitive load and decrease anxiety during procedures	The control group (historic controls) underwent similar procedures without VR, receiving conventional sedation, GA, or local anesthesia alone	Patients using VR reported maximum pain during the procedure as 3.5 out of 10, with mean post-procedure pain scores of 0.4 out of 10. No significant difference in mean post-procedure pain scores was found between the VR and non-VR groups. The procedures were completed without GA, sedation, or IV placement. Recovery times were significantly shorter for VR patients (18 vs 65 min)	VR distraction was a feasible and favorable alternative to sedation or GA in pediatric patients undergoing minor surgical procedures. All patients completed their procedures without sedation, GA, or IV placement, with most displaying only non-interfering behaviors and significantly shorter recovery times

Table 4 (continued)

Author (year)	Study design	Study goals	N	Study group	VR programs (treatment)	Comparator (control)	Results	Conclusions
Deo et al. (2020) [61]	Parallel group prospective RCT	To evaluate the effectiveness of VR as a distraction technique in managing acute pain and anxiety during outpatient hysteroscopy	40	Adults undergoing outpatient hysteroscopy	An 8-min "Forest of Serenity" video, a calming rainforest simulation narrated by Sir David Attenborough, with minimal movement and head-tracking interaction. The video replayed for procedures over 8 min, and patients could stop or remove the headset at will	Control only received standard care procedures. Additional procedures were performed for both groups as needed. Intracervical anesthetic was used as needed	Women in the VR group experienced less average pain (score 6.0 vs. 3.7, mean difference 2.3, 95% CI 0.61–3.99, $p = 0.009$) and less anxiety (score 5.45 vs. 3.3, mean difference 2.15, 95% CI 0.38–3.92, $p = 0.02$) compared to standard care. VR was feasible in 90% of cases and preferred by all participants in the VR group for future procedures, versus 15% in standard care preferring general anesthesia	Overall, VR effectively reduced pain and anxiety during procedures. Gynecologists and nurses found VR helpful in most cases. Interviews revealed VR provided relaxation and distraction from pain, though some patients reported discomfort or nausea with the headset

Table 4 (continued)

Author (year)	Study design	Study goals	N	Study group	VR programs (treatment)	Comparator (control)	Results	Conclusions
Roxburgh et al. (2021) [60]	Observational study	To assess the feasibility and effectiveness of VR in patients undergoing catheter ablation of atrial fibrillation (AF) under conscious sedation	48	Patients undergoing AF ablation	Five minutes of cardiac coherence breathing, followed by immersion in one of five 3D scenarios with music therapy and gamification. Patients interacted with the virtual environment to distract from pain. The analgesia protocol included 1 g IV paracetamol, 20 mg IV nefopam, 1 mg IV midazolam, and 3 mg IV morphine before the procedure, with additional 1 mg morphine boluses upon request	Patients using VR for AF ablation were compared to a prior cohort receiving routine AF cryoablation with standard analgesia	The mean perceived pain assessed with VAS and was lower in the VR group (3.5) compared to the control group (4.3; $p=0.004$). Comfort was higher in the VR group (7.5 vs. 6.8; $p=.03$). Morphine consumption and complications were not significantly different between the groups	VR was associated with a reduction in the perception of pain and improved patient experience during AF ablation procedures, although it did not result in reduced opioid consumption. The study supports the potential of VR as an adjunct in clinical practice for pain management during AF ablation
Peuchot et al. (2021) [63]	Prospective cohort study	To explore the interest of VR distraction during total knee arthroplasty (TKA)	20	Adults undergoing TKA surgery for primary osteoarthritis	HyponVR® headset, offering five different 3D computer-simulated scenarios: tropical beach, diving, astral travel, undergrowth, snowy landscape	The control group received no VR and routine standard care protocol	No significant difference in patient anxiety as measured by the STAI Y-1 score between the two groups (95% CI -7 to 10 $p=0.71$). VR Group experienced decreased sedation and intra-operative adverse events like hypotension and oxygen requirement ($p<0.0001$, $p=0.015$, $p=0.0054$), with a significant increase in comfort score ($p=0.002$). Patient satisfaction showed no difference	The study concluded that while VR did not significantly alter patient anxiety during TKA under spinal anesthesia, it was effective in reducing sedation requirements and intra-operative adverse events, and increased post-operative comfort

Table 4 (continued)

Author (year)	Study design	Study goals	N	Study group	VR programs (treatment)	Comparator (control)	Results	Conclusions
Lahti et al. (2020) [28]	RCT	To study if a short-term VR intervention reduced preoperative dental anxiety	277	Adults attending a primary dental care clinic, likely with varying levels of dental anxiety	The VR intervention consisted of a 1- to 3.5-min 360° immersive video in a peaceful virtual landscape, supplemented with audio features for relaxation	The control group remained seated for 3 min without the VR intervention	VR relaxation (VRR) group experienced greater decreases in total and anticipatory dental anxiety than the Treatment As Usual (TAU) group (total MDAS: $\beta = -0.75$, $p < .001$; anticipatory: $\beta = -0.43$, $p < .001$). In the VRR group, women showed a larger decrease in total MDAS score ($\beta = -1.08$, $p < 0.001$) and treatment-related anxiety ($\beta = -0.597$, $p = .011$), while anticipatory anxiety decreased in both men ($\beta = -0.217$, $p < 0.026$) and women ($\beta = -0.498$, $p < 0.001$)	A brief usage of VRR proves to be feasible and effective in lowering preoperative dental anxiety in public dental care environments. No pain scores were measured

Abbreviations: *DIVA* difficult intravenous access score, *VAS* visual analogue scale, *VRS* verbal rating scale, *VR* virtual reality, heart rate (86.8/min) postintervention compared to the VR arm (76.3/min, $p=0.01$). A double-blind, RCT investigating VR-delivered cognitive behavioral techniques for patients in the active labor phase reported significant reduction in pain intensity as measured by the VAS and the Verbal Rating Scale (VRS) [45]. The study included 5 groups: A (VR videos of newborn photographs with classical music), B (VR video of newborn photograph album), C (introductory film regarding Turkey), D (only classical music), and E (routine hospital care). While all techniques led to average reductions in labor pain, the VR groups A and B were more effective than the other assessed interventions, with Groups A and B reporting average reductions of 21.94% and 22.26% in VAS and 33.33% and 31.82% in VRS scores, respectively. These findings suggest that the effectiveness of VR in pain management may critically depend on the specific content provided and its interplay with the user's psychological state.

Additional insights emerge from evidence suggesting that VR interventions in labor and delivery may be more effective in addressing specific dimensions of pain [46, 47]. An RCT assessing VR-delivered analgesia via the Pain Inventory, a validated pain intensity and quality questionnaire, identified reductions in the cognitive and sensory dimensions, but not in the affective dimension of pain [48]. The intervention consisted of an immersive 360-degree environment featuring a serene beach and was associated with reductions of 5.83% and 6.43% in the cognitive and sensory aspects of pain, respectively. These findings underscore the nuanced efficacy of VR in the context of labor and delivery, hinting at its capacity for selective mitigation of specific acute pain dimensions.

Acute Perioperative Pain

Research on VR applications for periprocedural acute pain in the pediatric population has revealed beneficial effects on psychological endpoints associated with pain, although results on its efficacy in pain intensity have been mixed. For example, providing pediatric patients with a VR application featuring a roller coaster simulation during intravenous catheter placement increased satisfaction from anxiety management when compared to standard two-dimensional distraction methods [49]. Similarly, a mindfulness-based VR intervention resulted in superior improvements in short-term anxiety as measured by the Spielberger State-Trait Anxiety Inventory compared to conventional distraction methods among pediatric patients waiting in the emergency department [50]. Of note, although both interventions led to greater reductions in average pain intensity endpoints compared to traditional methods, neither reached statistical significance [49, 50]. Along these lines, a three-arm RCT comparing VR, cold vibrations, and conventional management identified no differences in pain intensity reduction among pediatric patients undergoing peripheral IV catheterization [51]. A fourth study in this population, testing a multisensory VR intervention during peripheral IV catheter placement, yielded statistically significant reductions in pain intensity when compared to conventional distraction methods, amounting to average patient-reported reductions of 1.34 points in pain intensity as measured by the Faces Pain Scale–Revised (FPS-R) [52]. Similarly, a VR application providing distraction and procedural information to pediatric patients undergoing venipuncture procedures was found to lead to moderate reductions in FPS-R scores [53] Intraprocedural VR-enabled distraction has also been associated with shorter recovery times when compared to standard of care for pediatric patients undergoing minor surgical procedures without sedation [54].

The observed variability in pain intensity outcomes for VR interventions in pediatric perioperative pain may partly stem from differential responses to VR depending on individual patient characteristics [55, 56•, 57]. Notably, among pediatric patients with high pain catastrophizing baseline tendencies, VR was associated with less nervousness about pain during procedures than was GI [57]. Additionally, it was determined that patients with sickle cell disease experienced greater reductions in procedural anxiety with VR than with GI [57].

In the adult population, numerous VR applications have been tested intraoperatively during procedures that do not require general anesthesia [58, 59]. A recent RCT revealed that patients assigned to VR-supported 3D environments with elements of music therapy and gamification reported lower average VAS scores during atrial fibrillation ablation procedures when compared to patients in the control group (3.5 vs 4.3; $p=0.004$) [60]. Another notable recent intervention is a VR-supported immersive and interactive 8-min video called "Forest of Serenity," which simulated a peaceful rainforest and a lake with animated wildlife, among patients undergoing outpatient hysteroscopy [61]. This intervention was associated with greater reductions in VAS scores (6.0 vs. 3.7, $p=0.009$) among women undergoing outpatient hysteroscopies when compared to standard of care. A recent example of XR in the adult intraoperative setting is the use of a VR-based application that featured relaxing virtual environments during total knee arthroplasty (TKA) under spinal anesthesia [62]. A small preliminary study ($n=20$) of VR in this setting not only found an average reduction in post-operative VAS scores of 2.2 points, but was also associated with fewer intraoperative adverse events [63]. Furthermore, fewer patients in the VR group required sedation (20% vs 100%) or experienced hypotensive events (10% vs 60%) compared to the control group.

While VR-based interventions delivered intraoperatively contribute to improved pain outcomes in the immediate postoperative period [64], VR can also support the delivery of postoperative care in painful procedures [65]. When VR-enabled distraction is coupled with pharmacologic analgesia during wound dressing changes following a hemorrhoidectomy, it has been associated with significant reductions in acute pain when compared to pharmacologic analgesia alone [66]. Similar effects on acute pain intensity have been identified when using VR during wound dressing changes among patients with burn injuries [67] and postoperatively following the drainage of perianal abscesses [68].

Acute Pain Associated with Dental Procedures

VR-based interventions in dental periprocedural care stand out, given their demonstrated effectiveness in reducing pain intensity while positively affecting psychological endpoints that modulate the pain experience, including procedural anxiety and fear [69]. An RCT comparing VR-based distraction against tell-show-do (TSD) behavioral techniques during pediatric dental procedures identified decreases in pain intensity as measured by the Wong Baker FACES Pain Rating Scale (WBFS), procedural fear as measured by the Children's Fear Survey Schedule-Dental Subscale (CFSS-DS), and procedural time in the VR arm [70]. Perhaps unsurprisingly, a vast majority of child participants involved in numerous RCTs stated that they prefer VR to the alternative [71]. Another study revealed that even brief VR sessions can significantly reduce dental anxiety among adults prior to operations in a primary dental care setting [28]. Of note, the effectiveness of VR-based interventions in reducing pain intensity may be restricted to a limited set of dental procedures, as one RCT demonstrated a reduction in pain intensity during rubber dam placement but not during local anesthesia administration [72].

Acute Pain in Special Populations

VR has shown promise in addressing acute pain in specific populations with particular pain management requirements [73–75]. For example, an RCT observed that veterans assigned to explore immersive VR environments to cope with acute pain and anxiety experienced a significant decline in pain intensity as measured by the Defense and Veterans Pain Rating Scale (DVPRS) [76]. On average, participants experienced a 1.2-point (12%) decline in pain intensity and a 92% reduction in anxiety levels, as measured by a scale developed by the Western North Carolina Veterans Affairs Health Care System (WNC VA HCS). Additionally, emerging evidence suggests that patients with chronic kidney disease on hemodialysis may benefit from VR-based interventions for acute pain management needs [77]. Lastly, a clinical trial is underway to assess whether the use of a VR-based application during venous fistula punctures, which are notably unpleasant procedures, is associated with decreased acute pain intensity scores [78].

Extended Reality Applications in Chronic Pain

Building on XR's success in helping manage acute pain, several studies provide evidence of its promise as an effective non-invasive and non-pharmacological approach to help address the complex challenges of chronic pain, thereby providing a potential pathway for improving patient outcomes, particularly quality of life [79] (Table 5).

Chronic Low Back Pain

Perhaps owing to its high prevalence and substantial public health burden [80], the most extensively studied condition in the realm of XR applications for chronic pain is chronic low back pain (CLBP). In a trial involving 1067 participants, RelieVRx was demonstrated to be more effective than a sham treatment in alleviating chronic low-back pain, with reductions of 2.0 points on the NRS reported [81]. Similar effects on pain intensity were reported by an RCT studying EaseVRx, an immersive application supporting CBT, mindfulness interventions, and pain neuroscience education [82].

A range of VR applications may improve secondary outcomes that directly impact patients' pain experiences and prognoses. A 3-arm RCT using a VR-based digital therapeutic system for pain (DTxP) that provided psychological therapy demonstrated superiority compared to both a sham placebo and standard of care alternatives in improving kinesophobia [83]. An RCT using a VR-based 8-week training program resulted not only to reductions in symptoms of CLBP, but also to an average decrease in risk of falls in women > 65 years of age [84]. A pilot RCT ($n = 41$) utilizing a 4-week VR behavioral therapy-based pain management intervention revealed that fewer patients utilized opioids at week 4 (28%) as compared to week 1 (47%), with no changes from week 1 to 4 observed in the control group [85]. Though preliminary, VR may play a future role in reducing opioid intake in chronic pain patients and may also lead to prognostic benefits specific to certain demographics.

Chronic Neck Pain

Similar to CLBP, chronic neck pain is a debilitating and prevalent condition in which VR has demonstrated success in improving pain-related prognostic factors [86]. However, without accounting for variability in protocols and interventions, the relative effects compared to controls on pain intensity are currently not as robust. An RCT determined that two immersive environments supported by Oculus Go VR headsets were superior to motor control neck exercises in improving pain pressure threshold, joint position sense error, and overall functional status among patients with chronic pain [87]. Furthermore, a second study investigating the effects

Table 5 Studies using virtual reality for chronic pain conditions: chronic lower back and neck pain, fibromyalgia, adult and pediatric cancer pain, pelvic pain/endometriosis

Author (year)	Study design	Study goals	N	Study group	VR programs (treatment)	Comparator (control)	Results	Conclusions
Eccleston, et al. (2022) [83]	Three-arm prospective double-blind RCT	To assess a novel automated, digital, psychological VR intervention for pain (DTxP)	42	Adults with CLBP and high fear of movement	An “embodied” VR intervention focusing on immersion, exploration, and experimentation to reduce fear of movement and reinjury. Sessions lasted 15 to 60 min, with 5 sessions per week, totaling 30 days over 6 to 8 weeks	Sham placebo comparator and open-label standard care. Similar duration as treatment	DTxP group had reduced TSK scores post-intervention ($p < 0.001$) and at 5-month follow-up ($p < 0.01$), and lower ODI scores post-treatment ($p = 0.05$)	DTxP VR intervention reduced fear of movement and pain intensity from baseline
Maddox et al. (2023) [130]	Double-blind RCT	To compare an 8-week self-administered in-home VR program (RelieVRx) to an active sham for improving pain intensity and pain interference	1067	Adults with nonmalignant CLBP	RelieVRx, VR program for CLBP, was administered for a 56-day treatment integrating skills like breathing, biofeedback, and mindfulness over 8 weeks, with daily sessions lasting 2–16 min featuring biodata-enabled interactive biofeedback	Sham VR program	RelieVRx was superior to Sham for pain intensity and pain interference reductions from pretreatment to day 56 (pain intensity (0.406 [0.170–0.642]) and interference (0.523 [0.285–0.760]) by day 56. Clinically meaningful reductions for RelieVRx were 2.0 points for pain intensity and 2.3 for interference	RelieVRx was effective in reducing pain intensity and pain interference
Garcia et al. (2021) [82]	Double-blind single-cohort remote RCT	To evaluate the effectiveness of a self-administered behavioral skills-based VR program	179	Adults with self-reported nonmalignant CLBP	Participants in the treatment group received EaseVRx, a 56-day VR program combining CBT, mindfulness, and pain neuroscience education. The program, averaging 6 min per session	Sham VR active control with nonimmersive 2D footage. Similar duration as treatment	EaseVRx superior to Sham VR in all primary outcomes ($p = 0.009$) with moderate clinical significance (Cohen d 0.40–0.49) and large effects in reducing pain and interference. Improved physical function and sleep disturbance ($p = 0.022$ and 0.013). No significant changes in pain psychology or opioid use, except for reduced analgesic use in EaseVRx ($p < .01$)	Eight-week program reduced pain intensity and related interference, showing clinically important effects, high engagement, and user satisfaction

Table 5 (continued)

Author (year)	Study design	Study goals	N	Study group	VR programs (treatment)	Comparator (control)	Results	Conclusions
Yalfani et al. (2022) [84]	RCT	To evaluate the effectiveness of an 8-week VR training (VRT) program in relieving pain, minimizing fall risk, and improving quality of life in elderly women with chronic low back pain	25	Adults with CLBP	VRT exercises with an HTC Vive system included games like Fisher and Boxing, positioned 1.5 to 2 m from the sensor, using safety ropes and gamepad straps for fall prevention. Sessions were capped at 30 min	Control group continued with their daily activities without interventions	There were improvements in the VRT group over controls post-intervention in pain intensity ($F = 117.002$, $p = 0.001$, ES = 0.84), fall risk reduction ($F = 18.14$, $p = 0.001$, ES = 0.45), physical health ($F = 30.84$, $p = 0.001$, ES = 0.58), mental health ($F = 15.52$, $p = 0.001$, ES = 0.42), and quality of life (QoL) ($F = 32.03$, $p = 0.001$, ES = 0.59).	The VRT program improved CLBP management, reduced pain, and increased daily living activities, enhancing movement accuracy and muscle strength proving a valid therapeutic intervention for elderly women
Groenveld et al. (2023) [85]	Open-label RCT	To investigate the effect of a self-administered behavioral therapy-based VR application on quality of life	41	Adults with CLBP	Reducept, a VR app for chronic pain management, based on the biopsychosocial pain model. 10 min sessions daily for 4 weeks at home, maximum of 30 min per session and 3 sessions per day	The control group was on waitlist and received no additional treatment or VR	No significant effect was observed for SF-12 physical (mean difference: 2.6; 95% CI: − 5.60 to 0.48) and mental scores (− 1.75; − 6.04 to 2.53) at 4 weeks. Significant improvements were noted in "worst pain score" (F [1, 91.425] = 33.3, $p < 0.001$) and "least pain score" (F [1, 30.069] = 11.5, $p = 0.002$), with three patients experiencing mild, temporary dizziness	The VR intervention did not significantly improve physical and mental function of patients with nonspecific CLBP. However, opioid use was halved in the VR group, and the app was found to positively affect daily pain experience
Darnall et al. (2020) [36]	RCT	To evaluate feasibility and satisfaction of the VR program and to assess its efficacy on pain intensity, interference with activity, pain, mood, sleep, and stress	97	Adults with nonmalignant CLBP or fibromyalgia	A self-administered 21-day skills-based VR program, including pain CBT, relaxation training, and mindfulness content. Sessions lasted 1 to 15 min each	Control group used an audio-only version of the VR program content	VR group showed significant improvement in pain indicators with effect sizes ranging from 0.71 to 0.94. Pain intensity reduced by 30%, activity interference by 37%, mood interference by 50%, sleep interference by 40.4%, and stress interference by 49.1%	The VR program was effective in reducing pain intensity and related interference, demonstrating higher efficacy and satisfaction compared to audio-only treatment

Table 5 (continued)

Author (year)	Study design	Study goals	N	Study group	VR programs (treatment)	Comparator (control)	Results	Conclusions
Polat et al. (2021) [131]	RCT	To investigate the effect of motion-controlled VR on pain, functionality, cardiopulmonary capacity, and quality of life	34	Fibromyalgia	VR exercises involved playing volleyball using the Microsoft Xbox Kinect system	The control condition performed cycling and conventional exercises without VR	After 4 weeks, VAS scores were reduced from 6.45 (± 1.41) to 4.85 (± 1.40) in the Conventional Training Group (CTG) and from 6.4 (± 1.4) to 4.25 (± 1.33) in the VRG, while EQ-5D-VAS scores rose from 49.5 (± 11.5) to 57.2 (±9.7) in CTG, and from 48 (± 10.8) to 65 (± 10.2) in VRG ($p<0.05$)	VR exercises combined with aerobic exercise increase cardiopulmonary capacity, reduced pain intensity, and increased quality of life in FMS patients. They also elevate patient satisfaction and may enhance compliance with exercise routines
Cetin et al. (2022) [87]	RCT	To explore the effects of 6-week VR treatment compared to motor control (MC) exercises on joint position sense error (JPSE), pain, and muscle performance in patients	41	Adults with chronic neck pain	VR treatment used two apps, "Ocean Rift" and "Gala 360," for the lack of VR cybersickness and allowance for neck movement. Treatment was in a calm environment with 360° chair movement	The MC group performed only motor control exercises	VR showed significant benefits in PPTs of C1/C2 and C5/C6 (Cohen's $d>0.8$, $p<0.05$), reduced JPSE (Cohen's $d>0.08$; mean difference -2.91 to -1.24), and functional limitation (Cohen's $d=0.7$, mean difference 8.27). However, no superiority was found in pain intensity, muscle performance, symptoms, HADS, or SF-36 (Cohen's $d<0.5$)	VR in addition to MC exercises was more effective than MC exercises alone in improving PPTs, JPSE, and functional limitation. The study suggests that VR can improve proprioception and decrease cervical articular pain pressure thresholds in CNP patients, as well as being effective in reducing functional limitations
Nusser et al. (2021) [132]	RCT	To evaluate the effects of neck-specific sensorimotor training using a VR device in patients with chronic neck pain	51	Adults with non-traumatic chronic neck pain	The VR Group (VRG) had a standard program plus 120 min of neck-specific sensorimotor training (NSST) using VR, divided into six 20-min sessions, where patients followed a moving globe in virtual space by head movements, guided by a VR system	The control group (CG) underwent a standard rehab program including various exercises and therapy, plus lectures from orthopedists and psychologists	VRG showed significant improvements in neck pain and headache relief, notably in reducing headaches at rest ($p=0.008$) and during motion ($p=0.023$). They also improved in cervical motion, especially in flexion and extension ($p=0.041$ and $p=0.007$)	VR-based neck-specific sensorimotor training within a standard rehabilitation program is feasible and beneficial for patients with non-traumatic chronic neck pain. It showed potential advantages in improving headaches, ACROM, and cervical extension compared to standard rehabilitation

Table 5 (continued)

Author (year)	Study design	Study goals	N	Study group	VR programs (treatment)	Comparator (control)	Results	Conclusions
Tejera et al. (2020) [88]	RCT	To compare the effects of VR versus exercise on pain intensity, conditioned pain modulation (CPM), temporal summation (TS), and functional and somatosensory outcomes	44	Adults with non-specific chronic neck pain	Using VR Vox Play glasses (330 g) with an LG Q6 smartphone, patients used two VR apps: "Fulldive VR" for neck tilts and "VR Ocean Aquarium 3D" for complex neck movements. Progression was from simple to advanced exercises, with decreasing physiotherapist aid. The 4-week intervention had two weekly sessions, structured in 3 sets of 10 reps with 30 s rests, followed up at baseline, immediately, 1 month, and 3 months post-intervention	The control group performed neck exercises	Significant differences were found for time ($F=16.40$, $p<0.01$, $\eta p^2=0.28$) and grouptime interaction in kinesiophobia ($F=3.89$, $p=0.01$, $\eta p^2=0.08$), with the VR group showing improvement at 3 months ($p<0.05$, $d=0.65$). Time factor showed significant effects for pain intensity, rotation ROM, Neck Disability Index, and other measures, but not for grouptime interaction. No significant differences were found for CPM, TS, right side PPT, and flexo-extension or lateral-flexion ROM	VR was more effective in reducing kinesiophobia at 3 months, with a near 10-point decrease in VR versus less than 4 points in exercise. However, it did not outperform exercise in improving pain intensity, ROM, neck disability, pain catastrophizing, fear-avoidance beliefs, or anxiety in chronic neck pain patients
Lutfi et al. (2023) [133]	RCT	To evaluate impact of single sessions of VR-delivered exercise and telehealth-delivered exercise on pain	22	Women with endometriosis-related pelvic pain	Various VR applications for a 10-min VR pain-distraction experience and 50 min of exercise	Control group continued with their daily activities without interventions	There was no significant difference ($p=0.45$) in pain scores between groups (VR, telehealth, control) after one session. However, a medium-to-large interaction effect ($\eta^2=0.10$) showed more favorable pain score changes in the telehealth (+ 10 ± 12 mm) and VR groups (+ 9 ± 24 mm) compared to control (+ 16 ± 12 mm)	The study indicates that a single session of self-managed VR exercise may be as effective as supervised telehealth exercise in immediately relieving pelvic pain in women with mild-to-moderate endometriosis
Merlot et al. (2022) [96]	RCT	To measure immediate and 4-h persisting effects of a single 20-min use of DTx (Endocare) on pain in women	45	Endometriosis-related pelvic pain	Endocare, developed for this study, is a medical VR software designed to alleviate pain in people with endometriosis. It provides a 20-min treatment combining auditory (alpha/theta binaural beats, nature sounds) and visual (bilateral alternative stimulations) therapies in a 3D VR environment	The control condition consisted of a 20-min phone-based 2D audio–video composition akin to Endocare with less stimuli	Endocare significantly reduced posttreatment pain more than the control group ($p<.01$), decreasing mean pain intensity from 6.0 (SD 1.31) to 4.5 (SD 1.71), compared to the control's decrease from 5.7 (SD 1.36) to 5.0 (SD 1.43). Endocare showed significant pain reduction up to 4 h post-treatment, notably at 15, 30, and 45 min ($P<.001$), with higher perceived pain relief of 28% (SD 2%) versus control's 15% (SD 1%)	Effective intervention for relieving endometriosis-related pelvic and perineal pain, potentially offering an alternative to hormonal treatment or surgery, especially for women seeking pregnancy. Effects were witnessed up to 4 h after intervention

Table 5 (continued)

Author (year)	Study design	Study goals	N	Study group	VR programs (treatment)	Comparator (control)	Results	Conclusions
Merlot et al. (2023) [97]	At Home RCT	To assess the effect of repeated at-home administrations of VR solution on pain in women	102	Endometriosis-related pelvic pain	Endocare, developed for this study, is a medical VR software designed to alleviate pain in people with endometriosis. It provides a 20-min treatment combining auditory (alpha/theta binaural beats, nature sounds) and visual (bilateral alternative stimulations) therapies in a 3D VR environment	The control condition consisted of a 20-min phone-based 2D audio–video composition akin to Endocare with less stimuli	Endocare's maximum pain reduction was 51.58% at day 2 (120 min post-treatment) versus 27.37% in the control at day 3 (180 min). Endocare was significantly more effective than sham on days 1 to 3 at various times (lowest $p = .04$). Mean perceived pain relief was also higher with Endocare, and no adverse events were reported	First effective unsupervised home use of a VR for endometriosis-related chronic pelvic pain. Reduced analgesic use and pain intensity
Semerci et al. (2021) [134]	RCT	To investigate the effect of VR on reported pain levels during venous port access	71	Pediatric cancer pain	The Piranha™ VR system has a rollercoaster video appropriate for the developmental level and age of the children	The control group received standard care without any specific nonpharmacological methods	The children in the VR group reported lower pain scores compared to the control group. The mean pain score was 5.02 ± 3.35 in the control group and 2.34 ± 3.27 in the VR group	VR is effective in reducing pain during venous port access in pediatric oncology patients
Hundert et al. (2022) [102]	RCT	To determine the feasibility of VR distraction for children with cancer undergoing subcutaneous port access	40	Pediatric cancer pain	The VR intervention used auditory and visual stimuli. A game which consisted of aiming rainbow balls at sea creatures as they explored an underwater environment insearch of treasure	The control group used an iPad as a distraction	While not statistically significant, more VR group participants indicated no pain (65% vs. 45%) and no distress (80% vs. 47%) during the procedure compared with the iPad group	VR is a feasible and acceptable intervention to reduce procedural pain during SCP access in pediatric oncology
Le Du et al. (2023) [103]	RCT	To evaluate the safety and efficacy of a novel VR therapy solution for distraction in the context of bone marrow biopsy	126	Adults with previously documented or suspected untreated malignant hemopathy requiring a bone marrow biopsy	The Bliss VR application, a type 1 medical device, ran on a smartphone with a GearVR head-mounted display. It included 4 VR environments: Nohara (countryside walk), Kaitei (seabed exploration), Uchuu (space walk), and Mori (forest walk). These environments were designed to induce relaxation and light sedation through passive contemplation	Control received a standard local anesthesia with one 20 mL dose of lidocaine at 10 mg/mL concentration. The equivalent biopsy was performed on the posterior iliac crest with a classic trocard and started at the same time as the VR group	The average pain intensity was 3.5 (SD ± 2.6) in the MEOPA group and 3.0 (SD ± 2.4) in the VR group, with no significant differences between the groups. One month after the procedure, the median residual pain was 0.0 for each group, and approximately one-quarter of patients retained a memory of pain experienced during the biopsy	The study concluded that pain intensity did not significantly differ between the VR and MEOPA arms during bone marrow biopsy. The VR-based distraction method was safe, well-tolerated, and highly appreciated by patients and caregivers, suggesting it could be an alternative treatment in cases of contraindication or intolerance to MEOPA

Table 5 (continued)

Author (year)	Study design	Study goals	N	Study group	VR programs (treatment)	Comparator (control)	Results	Conclusions
Burrai et al. (2023) [104]	Three-arm RCT	To assess the effects of immersive VR on anxiety, fatigue, and pain in people undergoing antiblastic therapy	74	Adult cancer patients undergoing intravenous antiblastic therapy	The VR content included 310 videos in nine categories such as Africa, hills, rivers, lakes, waterfalls, islands, deserts, beaches, mountains, sea, and submarines. The VR sessions were 30 min long and conducted during antiblastic therapy	The control group engaged in narrative medicine, expressing their illness experiences through writing during AT infusion, guided by nurses. The third group received standard care during AT, partaking in activities like reading or using smartphones, without specialized interventions	Anxiety levels significantly decreased for participants in the VR group (change of 6.24, $p < .001$). Fatigue levels decreased for participants in the VR group (change of 0.576, $p < .001$) but remained stable for those in narrative medicine and increased for those in standard care. Pain levels did not change significantly before and after the intervention for any group	Immersive VR was effective in reducing anxiety and fatigue in cancer patients undergoing antiblastic therapy, with high participant satisfaction and negligible cybersickness symptoms. However, it did not significantly impact pain levels
Basha et al. (2022) [135]	RCT	To compare the effects of Xbox Kinect training (VR) and resistance exercises training on lymphedema symptom severity, physical functioning, and QoL	60	Women with unilateral breast cancer–related lymphedema	In the Xbox Kinect group, participants engaged in VR exercises including the "Macarena" dance and other Kinect games such as darts, bowling, boxing, table tennis, fruit ninja, and beach volleyball, chosen based on the participant's performance level	The control group received complex decongestive physiotherapy, compression therapy, skin care, and specific exercises with a focus on joint mobilization and muscle stretching, complemented by breathing exercises and continuous bandaging during the regimen	Significant improvements in the Xbox Kinect group were observed in VAS (pain intensity), DASH scores, ROM of shoulder flexion, abduction, external rotation, bodily pain, general health, and vitality ($p < 0.001$). In contrast, the resistance exercise group showed significant improvements in physical functioning such as strength of shoulder flexion, abduction, external rotation, and handgrip strength	The Xbox Kinect provided significant improvements in pain intensity, shoulder ROM, and overall quality of life, suggesting its potential as an effective intervention in the clinical setting for managing breast cancer–related lymphedema without adversely the lymphedema

Table 5 (continued)

Author (year)	Study design	Study goals	N	Study group	VR programs (treatment)	Comparator (control)	Results	Conclusions
Feyzioglu et al. (2020) [107]	Prospective randomized controlled study	To investigate the potential effects of early postoperative VR therapy on pain, range of motion, muscle strength, functionality, and fear of movement in patients undergoing surgery	40	Female patients who had undergone breast cancer surgery with axillary dissection	Xbox 360 Kinect™ video game program was used in the KBRG. Games like Kinect Sports I (darts, bowling, boxing, beach volleyball, table tennis) and Fruit Ninja were played, requiring active upper extremity movements	Control received standardized physiotherapy group (SPTG)	Shoulder ROM, muscle strength, and hand grip strength were significantly improved in both groups, though no statistical differences were observed between groups. The mean increases in shoulder flexion and abduction were 52.0° and 63.82°, respectively, in the KBRG, and 49.2° and 61.58°, respectively, in the SPTG	VR training using Xbox Kinect™ was found to be as effective as standard physiotherapy in managing upper limb dysfunctions after breast cancer surgery. The study highlighted the potential of Xbox Kinect™ video games as more entertaining, low-cost, and motivating programs that could be added to standard physiotherapy, especially for patients with high levels of fear of movement or severe pain after breast cancer surgery
Park et al. (2023) [106]	RCT	To investigate the effect of hospital-home-linked rehabilitation therapy using an AR-based digital health care system in postoperative patients	100	Postoperative breast cancer patients	The AR-based UINCARE Home + rehabilitation system was used in the intervention group. It uses the Xbox One Kinect for Windows to track movement of the upper and lower extremities in three-dimensional space. Participants accessed prescribed daily exercises through the UINCARE Home + system, with exercises including warm-up, main workouts, and cool-down components	The control group received a brochure detailing the same exercise program used for the intervention group. The brochure included pictures and brief descriptions of each exercise	Both groups showed significant improvement in active and passive shoulder ROM (flexion, abduction) from baseline to 12 weeks ($p < 0.001$), with no significant differences between groups. Pain severity, functional outcomes, and quality of life also improved significantly over time in both groups ($p < 0.001$), without significant group differences	The study concluded that AR-based telerehabilitation improved shoulder ROM, functional outcomes, and quality of life in postoperative breast cancer patients. It can be considered a useful technology to encourage home exercise and complement hospital-based treatment for breast cancer patients

Table 5 (continued)

Author (year)	Study design	Study goals	N	Study group	VR programs (treatment)	Comparator (control)	Results	Conclusions
Chuan et al. (2023) [136]	RCT	To evaluate the feasibility, acceptability, recruitment rates, and risk of cybersickness of a bespoke virtual reality-delivered pain therapy software program	39	Adults with cancer-related neuropathic chronic pain	Custom VR software teaches pain self-efficacy with muscle relaxation and pain visualization, using computer avatars for 30-min sessions	Control arm patients watched a selection of short documentaries and videos in VR format from YouTube's VR	Demonstrated trends in reducing oral morphine equivalent daily dose (1 month: −8 mg, 3 months: −4 mg; vs. control: 0 mg, +15 mg), pain severity (−0.4, −0.8; vs. control +0.4, −0.3), and pain interference (−0.9, −1.8; vs. control −0.2, −0.3) at 1- and 3-month follow-ups. However, changes in opioid consumption and global quality of life were small and not statistically significant (opioid: intervention −8 mg, control 0 mg at 1 month; quality of life: intervention −5, control +3 at 1 month). The virtual reality pain therapy was feasible for cancer patients with neuropathic pain	The VR-delivered pain therapy program showed promise in managing cancer-related neuropathic pain, with potential benefits in pain reduction and acceptability, although no significant changes in clinical outcomes were observed
Austin et al. (2021) [90]	Randomized cross-over pilot trial	To determine whether a 3D HMD VR device results in significant reductions in neuropathic pain	16	Neuropathic pain following spinal cord injury	The Oculus Rift® headset was used to display a 3D VR experience called Nature Trek®. Participants used a handheld joystick to navigate a scenic meadow environment and interact with the 360° scene. The sessions were 15 min long and non-interactive to avoid cybersickness	Control group used a 2D screen application using the same virtual environment	Participants reported significantly lower pain intensity after 3D HMD VR compared to 2D screen application (1.9 ± 1.8 vs. 3.4 ± 1.6; $p < 0.0001$). The effect size for pain reduction using 3D HMD VR was 0.80, indicating a large effect	The study suggests that 3D HMD VR may provide neuropathic pain relief for people with spinal cord injury. Given the lack of cybersickness and ease of access, the study proposes that immersive VR could be a helpful adjunct to current pharmacotherapy for managing neuropathic spinal cord injury pain

Table 5 (continued)

Author (year)	Study design	Study goals	N	Study group	VR programs (treatment)	Comparator (control)	Results	Conclusions
Tran et al. (2022) [91]	Randomized cross-over study	To explore the effects of VR on neuropathic pain in people with spinal cord injury	17	Neuropathic pain following spinal cord injury	A 3D VR experience called Nature Trek® which includes nine nature environments with various animals and calming music. Participants used a hand-held joystick to navigate an alpine meadow environment in the VR	Within participant comparison of two interventions 1 VR and 1 2D screen against baseline measures	Significant reductions in pain ratings were observed from pre-task to interventions, with mean pain ratings decreasing from 4.9 pre-task to 1.9 post-3D VR intervention ($p < 0.001$). Significant EEG changes were noted in the frontal, central, and parietal regions during VR use, particularly in the 3D VR condition. In the frontal region, notable changes occurred in delta, theta, alpha, and gamma frequencies. The study found significant fractal dimension differences in the central and parietal regions between eyes-open and VR tasks. An artificial neural network model classified 3D VR against other conditions with 80.3% accuracy	VR interventions could be viable alternative therapeutic interventions for neuropathic pain in individuals with SCI

Studies not discussed in the manuscript were cited in the table

Abbreviations**:** *ACROM* active cervical range of motion, *CLBP* chronic low back pain, *CBT* cognitive behavioral therapy, *HADS* Hospital Anxiety and Depression Scale, *MEOPA* mixture of nitrous oxide/oxygen, *ODI* Oswestry Disability Index, *RCT* randomized controlled trial, *ROM* range of motion, *SF-36* 36-Item Short Form Health Survey, *TSK* Tampa Scale of Kinesiophobia of two VR mobile applications was determined to be more effective than exercise alone in reducing kinesophobia [88]. However, both of the aforementioned studies reported no differences on pain intensity between the experimental and control group [87, 88].

Spinal Cord Injury

VR has emerged as a promising intervention in the management of pain for patients with spinal cord injuries (SCIs), offering immersive environments capable of facilitating simulations of gait biomechanics for patients with quadriplegia [89]. Regarding outcomes specific to pain, two recent RCTs concluded that Nature Trek, a 3D immersive VR experience supported by the Oculus Rift HMD, was superior to a 2D screen-based VR application in reducing the intensity of SCI-related neuropathic pain [90, 91]. Moreover, the most recent of these studies observed electroencephalography (EEG) changes unique to the more immersive 3D experience, although more data are needed to assess whether these EEG changes are reliable biomarkers of VR interventions in SCI [91].

Endometriosis

Endometriosis, characterized by the presence of endometrial-like tissue outside of the uterus, often leads to chronic pelvic pain, a cardinal symptom affecting approximately 75% of those diagnosed [92, 93]. This severe, debilitating pain can significantly impair quality of life and poses a persistent challenge in both diagnosis and management [94, 95]. Notably, two recent RCTs comparing Endocare, a 20-min program offering a combination of auditory and visual procedures through a 3D VR environment, to a 2D equivalent counterpart found superior pain intensity reductions in the experimental group [96, 97]. These findings suggest a promising potential of immersive VR technologies in enhancing pain management strategies for endometriosis, warranting further exploration through larger clinical studies.

Cancer Pain

Cancer pain, often resulting from the disease process itself or as a side effect of treatments such as chemotherapy, radiation, or surgery, adversely affects quality of life [98]. Moreover, undertreated cancer pain may increase morbidity and mortality [99]. The combination of VR and conventional therapies may be beneficial in alleviating pain and anxiety as witnessed in the adult and pediatric in-patient population when undergoing painful procedures or antineoplastic therapies [100, 101]. In line with these findings, recent RCTs have demonstrated VR's efficacy in helping alleviate pain intensity among children with cancer undergoing subcutaneous port needle insertions [102]. In the adult population, recent studies have yielded improvements in pain intensity among patients with malignant hemopathies undergoing bone marrow biopsies [103] and patients undergoing antiblastic therapy [104].

XR has also been explored as a tool to support patients with cancer in their long-term recovery from surgeries [105]. In a comparative analysis, postoperative patients with breast cancer engaging in a daily physical exercise program delivered through an AR-based home rehabilitation system demonstrated greater enhancements in shoulder range of motion and quality of life compared to those who received the same program via traditional paper-based methods [106]. Conversely, a smaller RCT on the same population found that while a VR-based intervention was not superior to standard physiotherapy in improving shoulder range of motion (ROM) and strength, it was more effective in diminishing pain-related fear [107]. Notably, both of these XR applications were supported by the Xbox One Kinect platform, a relatively low-cost alternative to more sophisticated XR platforms, highlighting the potential for certain XR interventions to become cost-effective and accessible solution in postoperative rehabilitation and recovery for cancer patients.

Limitations of Using XR in Pain Management

Cybersickness in VR

Cybersickness, akin to motion sickness, presents a challenge particularly for the patient in acute pain, who may already be administered medications that may induce nausea, such as opioids. The prevailing theory attributes cybersickness to a sensory mismatch arising from a discrepancy between actual physical movement and the perceived motion experienced in a VR environment [108]. The utilization of VR, particularly its immersive forms, has been associated with the onset of symptoms such as nausea, disorientation, and headaches, factors which could deter patients from opting for VR-based interventions [109, 110]. Studies indicate a notable incidence of these symptoms, with reports suggesting that as many as 80% of participants engaging in immersive VR experiences may suffer from cybersickness [111, 112]. Notably, a disparity in the susceptibility to cybersickness has been observed across age groups. Research employing the Fast Motion Sickness Scale (FMS) revealed a significantly higher impact on individuals aged 40–59 compared to those aged 19–39 (FMS scores: 7.76 vs 4.28, $p = 0.001$) [112]. In response to these challenges, recent methods have been utilized to mitigate cybersickness. Technological advancements in VR hardware have significantly contributed to reducing cybersickness [113].

Cybersickness, which was a notable issue in older generation HMDs, has seen a dramatic improvement with newer hardware. These modern HMDs account for depth of field and field of vision in their rendering of environments, along with improved refresh rates of visual content, which have been proven to improve cybersickness [113]. Moreover, the design of the VR environment itself plays a crucial role in reducing cybersickness, as indicated by recent research [114]. Thoughtful and user-centric design, which takes into account the user's physical and cognitive experiences within the virtual space, can significantly diminish the occurrence of cybersickness, making VR more accessible and comfortable for a wider range of users [114]. An additional study investigated the potential of transcranial oscillatory stimulation of the vestibular cortex as a method to reduce the frequency-dependent symptoms of cybersickness in VR. The findings from this study indicate that targeted neurostimulation can effectively alleviate the sensory mismatch leading to cybersickness, offering a promising avenue for enhancing the comfort and feasibility of VR interventions, especially in sensitive populations [115].

Challenges in Study Designs

VR research in chronic pain management often faces methodological shortcoming such as small sample sizes and limited follow-up periods. These limitations have largely impeded a robust evaluation of the long-term effectiveness of VR in treating chronic pain specifically [83]. The lack of standardized VR-specific outcome measures and the heterogeneity of VR-based interventions make synthesizing findings a challenging endeavor [116]. The paucity of the use of control conditions that more closely resemble the immersive 3D experience, such as high-fidelity 2D environment or a non-immersive 3D experience, has been identified as a barrier to accurately estimating the relative efficacy of newer VR interventions [117].

Relative Lack of Data on AR in Pain Management

In the field of pain management, there exists a notable disparity in the volume and depth of research data between VR and AR applications. This discrepancy is particularly pronounced when considering the unique capabilities of AR, such as overlaying digital information onto the physical environment, which could offer distinct advantages in pain treatment scenarios. However, the current literature on AR in pain management is limited, both in terms of the number of studies and the scope of their findings [118]. This lack of extensive research on AR not only hinders the full exploration of its therapeutic possibilities but also limits the development of evidence-based guidelines for its application in clinical settings for pain management.

XR Content and User Experience

The specific nature and rendering quality of XR content significantly affects its therapeutic effectiveness. The analysis of XR experiences in mental health and chronic pain management studies underscores the critical need for personalization [119]. The effectiveness of XR is enhanced when tailored to individual psychological profiles, addressing specific symptoms and triggers [120]. VR interventions for chronic pain have been determined to result in notable improvements in pain, functioning, and mobility, with the greatest benefits observed in programs customized to individual patient needs [121]. Additionally, the efficacy of VR in pain management may be contingent upon the engagement quality of the VR content. Suboptimal or unengaging VR experiences may fail to provide the necessary distraction from pain [85]. Research has demonstrated varying degrees of pain reduction associated with VR interventions, with the effectiveness partly attributed to differences in the nature and interactivity of VR content [122]. Specifically, "active VR," which involves user interaction and navigation within the virtual environment, has demonstrated higher analgesic effectiveness compared to "passive VR" [122]. This suggests that the type and degree of user interaction within VR play a critical role in determining its therapeutic efficacy in pain management.

Furthermore, the heterogeneity of VR content employed in various studies explored in this review highlights the intricacies involved in evaluating the overall effectiveness of VR in pain management. Although VR interventions are generally found to be more effective than non-VR counterparts, the wide array of VR applications used in studies complicates direct efficacy comparisons across different studies. Despite these challenges, both laboratory and clinical research consistently demonstrate VR's capacity to reduce pain intensity, underscoring its potential utility as a pain management tool [122].

Ethical and Safety Concerns

Ethical and safety concerns in clinical VR applications are crucial, particularly when addressing vulnerable populations, such as children and the elderly. Tailoring VR experiences to individual needs and ensuring responsible usage in complex psychiatric conditions are critical steps in enhancing safety and mitigating potential harm to the patient [123, 124]. Alongside these considerations, it is imperative to acknowledge the contraindications of VR in certain populations. VR interventions may not be suitable for individuals with conditions that predispose them to adverse reactions, such as severe motion sickness or epilepsy. This necessitates rigorous screening processes and informed consent protocols, especially when dealing with vulnerable groups who might be at increased risk [125]. Moreover, the development of comprehensive ethical frameworks and robust safety protocols for VR therapy across medical disciplines is essential to prioritize and maintain patient well-being [126]. For populations where VR is contraindicated, alternative therapeutic approaches should be considered to ensure safety and effectiveness. This highlights the need for ongoing research into the comprehensive assessment of VR contraindications and the development of inclusive therapeutic strategies that accommodate the diverse needs of all patients [125].

Future Directions

Further research in the application of XR for pain management should prioritize the customization of XR content specific to various pain conditions and settings and the integration of XR with advanced data processing systems powered by artificial intelligence (AI). In XR for chronic pain specifically, emphasis should be placed on assessing long-term effects, prioritizing skill-building applications, and standardizing protocols for the evaluation of pain-related outcomes [81]. Moreover, research endeavors should focus on elucidating the neurobiological mechanisms of VR analgesia, developing personalized interventions, and overcoming technological barriers to cost-effective implementation. The confluence of AI and telemedicine in VR applications presents a prospective landscape in which such interventions are not only personalized and scalable but also broadly accessible [127, 128•]. This advancement holds significant promise for transforming pain management, particularly in settings with limited resources, in which conventional methods face constraints.

Conclusion

VR holds considerable potential as a pain management tool uniquely capable of distracting, educating, and therapeutically engaging patients. Despite existing challenges, its benefits in augmenting pain management practices are evident and recent studies continue to support its use. With ongoing technological advancements and evolving research, VR is set to become a fundamental component of pain management protocols, effectively complementing traditional pain therapies. As research progresses, the integration of VR into routine pain management practice promises new insights and breakthroughs in patient care, potentially transforming how acute and chronic pain is managed in clinical settings.

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Data Availability No datasets were generated or analysed during the current study.

Compliance with Ethical Standards

Conflict of Interest SM and AT: cofounders of Augmend Health. IHC: receives consulting fees from Layer Health. RT: receives consulting fees from Abbott and Medtronic. SA: provided consulting and teaching services for Allergan/Abbvie, Eli Lilly and Company, Impel NeuroPharma, Linpharma, Lundbeck, Satsuma, Percept, Pfizer, Teva, and Theranica. MES: serves as a research consultant to Modoscript and was a member of an Advisory Committee for Syneos Health. CLR and MEM: consultant and equity holder in Augmend Health. CLR and AA: section editor at Current Pain and Headache Reports.AK: editor-in-chief at Current Pain and Headache Reports.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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