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CHRONIC PAIN MEDICINE (O VISWANATH, SECTION EDITOR)

Telehealth and Virtual Reality Technologies in Chronic Pain Management: A Narrative Review

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Abstract

Purpose of Review This review provides medical practitioners with an overview of the present and emergent roles of telehealth and associated virtual reality (VR) applications in chronic pain (CP) management, particularly in the post-COVID-19 healthcare landscape.

Recent Findings Accumulated evidence points to the efficacy of now well-established telehealth modalities, such as videoconferencing, short messaging service (SMS), and mobile health (mHealth) applications in complementing remote CP care. More recently, and although still in early phases of clinical implementation, a wide range of VR-based interventions have demonstrated potential for improving the asynchronous remote management of CP. Additionally, VR-associated technologies at the leading edge of science and engineering, such as VR-assisted biofeedback, haptic technology, high-definition three-dimensional (HD3D) conferencing, VR-enabled interactions in a Metaverse, and the use of wearable monitoring devices, herald a new era for remote, synchronous patient-physician interactions. These advancements hold the potential to facilitate remote physical examinations, personalized remote care, and innovative interventions such as ultra-realistic biofeedback. Despite the promise of VR-associated technologies, several limitations remain, including the paucity of robust long-term effectiveness data, heterogeneity of reported pain-related outcomes, challenges with scalability and insurance coverage, and demographic-specific barriers to patient acceptability. Future research efforts should be directed toward mitigating these limitations to facilitate the integration of telehealth-associated VR into the conventional management of CP.

Summary Despite ongoing barriers to widespread adoption, recent evidence suggests that VR-based interventions hold an increasing potential to complement and enhance the remote delivery of CP care.

Keywords Telemedicine · Persistent pain · Biofeedback · Haptics · Precision medicine · Remote care · Wearable devices

Introduction

Chronic pain (CP), commonly defined as pain persisting or recurring for over three months [1], is a prevalent and debilitating condition affecting approximately 1 in 5 adults [2]. These individuals report significant challenges, including difficulty in performing basic daily activities [3], increased symptoms of depression and anxiety [4], limited participation in social activities [5], and increased absenteeism from work [6] when compared to individuals without CP. The economic impact of CP is substantial. Over 2 decades ago, annual costs attributed to CP in the USA, including direct medical expenses, disability programs, and loss of productivity, were estimated between $560 and $635 billion per year [6] with costs consistently rising since [7, 8].

The known public health toll of CP and the difficulty addressing its growing prevalence can be attributed partly to the complexity of its management. The multifaceted nature of pain as conceptualized by the biopsychosocial model of pain, along with its poorly understood pathogenesis in many cases, demands multimodal and highly specialized care [9, 10]. Consequently, the treatment of CP is resource-intensive and often inaccessible to marginalized, vulnerable

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populations. Particularly affected are women, the elderly, those in poverty, publicly insured individuals, and rural residents, who tend to report a higher incidence of chronic and high-impact pain [11]. Accessibility concerns are further compounded by additional sociodemographic barriers, including geographic distance from medical facilities, housing instability, lower education levels, lack of insurance coverage for therapies, and limited caregiver support [12, 13].

Against this backdrop of the substantial societal and individual burden of CP, the complexity of current therapeutic approaches, and the various obstacles to accessing effective treatment, telehealth stands out as a key component in the contemporary management of CP [14]. Particularly since the onset of the COVID-19 pandemic, telehealth has offered patients experiencing CP new possibilities for remote assessment, treatment, and ongoing support. Since then, rapidly evolving technological innovations in mobile health (mHealth) and virtual reality (VR) have enhanced the scope and effectiveness of remote healthcare services. These innovations promise revolutionary advances in the remote therapeutics of CP. Here, we provide medical practitioners with an overview of the current and imminent role of telehealth and associated VR-based interventions in managing CP.

Telehealth in Chronic Pain

The onset of the COVID-19 pandemic dramatically accelerated the adoption of telemedicine in CP management. With the closure of ambulatory units and the suspension of non-urgent in-person consultations, leading pain societies endorsed the swift integration of telehealth into standard care protocols [15, 16]. Early survey-based studies indicated that by late 2020, 90% of surveyed patients were using telehealth to meet their CP care needs [17]. By July 2021, preliminary estimates indicated that telehealth visits accounted for 13 to 17% of total healthcare visits, a 38-fold increase from pre-pandemic levels [18]. Following this widespread adoption, healthcare systems providing CP care rapidly refined telemedicine practices to appropriately discern which patients needed in-person visits while providing comprehensive remote support [19, 20]. These innovative solutions in multidisciplinary care pathways cemented telemedicine as a cornerstone of CP management strategies in the modern healthcare landscape [21].

The extent to which telehealth will be integrated into CP management in a post-COVID-19 era remains uncertain. However, a considerable portion of CP patients continue to experience limitations in mobility and daily functioning, along with multiple comorbidities, which necessitate regular consultations with various specialists [22, 23]. These continued challenges, combined with the growing adoption of remote healthcare services in part due to their potential for improving treatment adherence [24] and reducing costs [13, 25], enhancing provider productivity [26], and facilitating multidisciplinary approaches [27], suggest that telehealth may continue to be an integral part of CP management. Indeed, recent estimates from FAIR Health, an independent non-profit organization managing a large national database of private and Medicare claims, indicate that telehealth claims comprised approximately 4.0 to 7.5% of all health claims in August 2023 [28]. These estimates are consistent with those from August 2020 (between 4.3 and 8.43%) [28] and up from an average of approximately 0.1% in 2019 [29].

Telehealth-Associated Technologies

Videoconferencing

Perhaps the best-known and most widely used modality of telehealth applications is the synchronous delivery of services through videoconferencing. Platforms such as Doximity, Cisco Webex, and Microsoft Teams now commonly support the delivery of numerous CP services, including follow-up appointments for interval and post-procedure assessments, medication management, triaging of cases by advanced practice providers, psychiatric consultations and psychotherapy, pain education sessions, and physical therapy guidance. Randomized controlled trials (RCTs) have demonstrated the efficacy of a number of these interventions delivered through videoconferencing [30]. A recent systematic review concluded that interventions incorporating videoconferencing were superior to conventional management alone for patients with CP secondary to cancer [31]. A meta-analysis of 14 RCTs suggested that videoconferencing-based rehabilitation leads to decreases in pain intensity, depressive symptoms, and pain catastrophizing among patients with fibromyalgia, a relatively common CP condition [32]. Moreover, systematic reviews have concluded that remotely delivered psychological therapies may contribute to small improvements in pain intensity as well as substantial improvements in quality of life in both the pediatric [33] and adult [34, 35] CP populations. For example, it was demonstrated early on that video-based acceptance and commitment therapy (ACT) is as effective as in-person therapy in improving pain interference, quality of life, and activity levels among patients with CP [36]. Videoconferencing also supports the delivery of synchronous peer-to-peer support groups, a modality often preferred to asynchronous or chat-based alternatives [37]. For example, among patients with musculoskeletal CP, support groups and group therapy are determined to be convenient, accessible, and perceived to enhance self-accountability [38].

It is important to note that the success of the migration of some CP services to the videoconference format is also reflected by high satisfaction levels among patients and providers [39–41]. When technological challenges and limited digital literacy are not a concern or if they are addressed [42], patients utilizing telehealth-supported services often report increased confidence and empowerment [39, 42]. A large, nationally representative survey of American households determined that by the end of 2020, nearly 86% of individuals considered their telehealth visits good or better than in-person visits, a result that was consistent across a variety of sociodemographic strata [43]. A number of subpopulations suffering from CP, including veterans [25], individuals with cancer [40], and patients with substantial chronic comorbidities [35], all report high levels of satisfaction with telehealth-delivered interventions. Unsurprisingly, satisfaction levels associated with telehealth in the general population decrease significantly when people experience delayed medical care for serious health concerns [43]. Similar levels of satisfaction have been observed among physicians [44]. The number of physicians selecting "telehealth" as a skill in an annual Doximity survey doubled from 20% in 2019 to 40% in 2020 [45], reflecting increased familiarity and acceptance of telehealth modalities.

Short Message Service (SMS)

Text messaging or short message service (SMS) is the most prevalent form of electronic communication in the USA, with approximately 5.5 billion daily messages sent [46]. Its widespread use, not contingent on internet access, reaches virtually all mobile phone owners, representing 97% of the US population [47]. The ease of use and familiarity of text messaging are especially advantageous among populations with limited digital literacy. Older adults, who account for the overwhelming majority of CP patients [48], often cite SMS as a preferred tool to seek short forms of validation and social support relating to their pain experience [49]. Despite a relative paucity of recent research into interventions based exclusively on SMS in favor of more modern technologies, accumulated evidence points to their effectiveness in improving patient adherence, acceptance, and satisfaction in post-operative pain management [46]. In the CP realm, an SMS-only intervention in which non-oncologic CP patients received supportive messages twice daily was determined to reduce pain interference and improve positive affect [50]. More recently, SMS-based platforms are being studied to aid CP patients during opioid tapering [51] and for supporting self-management strategies among patients with bladder pain syndrome [52]. Contrasting its limited standalone use in CP management, SMS has been widely incorporated into numerous telehealth modalities in recent years through wifi-based text messaging. When coupled with mobile applications and videoconferencing, SMS serves a wide range of functions, including providing appointment reminders, facilitating consistent communication with healthcare providers, and serving as a tool to check in with patients during periods of prolonged inactivity [34, 53].

Mobile Device–Based Interventions

Mobile health (mHealth) refers to the practice of medicine and public health facilitated by mobile devices, such as mobile phones, tablet computers, personal digital assistants, and their supporting wireless infrastructure [54]. Mobile applications, or mobile apps, are the cornerstone of mHealth and are widely utilized among patients with CP, with a total of 508 pain management applications identified as of August 2022 [55]. mHealth applications can be divided into 3 broad categories according to their goal in CP management [56, 57]: (1) patient education, (2) monitoring of symptoms and medication use, and (3) delivery of treatment or self-management skills.

Perhaps unsurprisingly, educational apps for CP have demonstrated excellent efficacy in RCTs [58]. For instance, an application offering educational content about the pathophysiology of knee osteoarthritis led to enhanced physical function and quality of life when compared to patients only receiving conventional care [59]. Adding a mobile application providing guidance for postural re-education to standard treatment of chronic neck pain led to an average of two-point reductions in the visual analog scale (VAS) of pain intensity [60]. Mobile applications focusing on identifying alleviating and exacerbating factors, patient education, and community forums have been determined effective in improving pediatric CP outcomes [61]. Examples of mobile applications used to monitor symptoms and medication use that have shown promise in RCTs are abundant [62]. They include an application to alarm healthcare providers when undesired self-reported pain outcomes are identified in patients with musculoskeletal CP [63] and a point-of-care tool capable of detecting facial micro-expressions indicative of pain in patients with dementia [64]. Examples of applications directly delivering treatment with good results in RCTs include a home-based strengthening exercise program for patients with knee osteoarthritis leading to a 47% reduction in pain as measured by the numerical rating scale (NRS) [65] and a physical activity platform for chronic neck pain leading to an average reduction of 1.5 points in the VAS of pain intensity [66].

A notable use case for mHealth applications in CP management is supporting clinical decision-making associated with opioid prescribing [67]. The Collaborative Health Outcomes Information Registry (CHOIR) is a sophisticated electronic platform with multiple functions in research and clinical care [68]. Patients can remotely access CHOIR using their own devices and complete online assessments capturing a wide range of data, including physical, psychological, and social dimensions of their pain experience. This information can then be used to both inform clinical decision-making and facilitate quality improvement and research efforts [69]. Among an unlimited number of applications, this software platform can be deployed to collect patient-reported symptoms during opioid tapering and, when paired with real-time clinical alerts, has the potential to guide personalized care in a timely fashion [70]. A second example of clinical decision-making supported by a mHealth application is the Safer Prescription of Opioids Tool (SPOT) [71]. This mobile application assists clinicians in validating their mathematical opioid conversions and has been demonstrated to lead to increased provider confidence in prescribing opioids. These examples illustrate the potential for mHealth to improve efficiency and safety in opioid-prescribing practices.

Systematic reviews of RCTs assessing the efficacy of mHealth interventions for CP patients have identified beneficial effects on pain intensity, quality of life, and functional disability [56, 57]. However, despite overall efficacy demonstrated in short-term outcomes, there exists significant variability in the quality of care offered by various applications currently available on the consumer market, which remains a concern and requires further evaluation [72]. Particularly within the domain of psychological care, many applications operate without the guidance of healthcare providers, and many of their recommendations have not undergone independent scientific validation [55]. Considering their broad accessibility and affordability, providers managing CP should consider including mobile applications as short-term add-ons to their treatment approach [57]. However, prescribers should exercise discernment in selecting alternatives that offer scientifically validated advice and are established as resulting in benefits among CP patients.

Virtual Reality

Virtual reality (VR) is a technology that creates a simulated environment using computer-generated sensory inputs. Users experience VR environments through head-mounted displays (HMD), specialized goggles, or images projected onto a screen, and interaction is made possible via hand-held devices (HHDs) and motion-tracking systems. While currently in the nascent stages of its clinical applications, VR is a rapidly evolving technology poised to play a significant role in enhancing the remote delivery of CP care.

VR extended beyond its origins in the entertainment industry and into pain management for the first time in 2000, when it was demonstrated that “SnowWorld,” a game in which players threw snowballs at animated characters, effectively reduced burn pain in adolescents [73] and adults [74]. Since then, multiple systematic reviews have identified the positive effects of VR-mediated therapies for CP on a wide range of variables, including pain intensity, quality of life, daily functioning, mobility, and psychological outcomes [75, 76, 77•]. The most recent of such reviews identified 46 studies of VR-based interventions in CP, including 19 RCTs [75]. In 78% of these RCTs, the intervention was associated with improved pain-related outcomes.

The mechanisms by which VR-based interventions might effectively treat pain include distraction, focus shifting, and skill-building [78]. These mechanisms build on each other and can be understood as lying in a continuum that progresses in the amount of conscious agency that the patient has when regulating the pain response [78]. VR-mediated distraction analgesia diverts attention from pain processing by engaging sensory and cognitive resources toward an immersive virtual environment [79]. Positive emotional stimuli can enhance distraction analgesia by further reducing negative affect, a strong detrimental modulator of the pain experience [80]. Focus shifting represents the next step in the engagement ladder and describes improved redirection away from pain processing when users interact with the VR environment by systematically shifting their attention between virtual objects [78]. Skill-building, in turn, involves empowering patients to develop abilities that aid in autonomously regulating their response to painful stimuli [78]. Beyond supporting these beneficial neurocognitive changes, VR might help treat CP by directly improving motion function endpoints directly related to pain outcomes, such as range of motion, isokinetic strength, and static muscular endurance [81, 82].

In the realm of VR applications, an important distinction is made between immersive and non-immersive formats [77•]. Immersion is defined as the capacity to isolate users from real-world stimuli [75]. Achieving high degrees of immersion requires high-fidelity graphics, high graphic resolution, directional audio, and an expansive field of view that emulates natural human vision [83].

Non-immersive Virtual Reality

Although it remains an arbitrary binary distinction in a continuum of immersivity, non-immersive VR interventions are generally defined as those not using HMD and rather utilizing two-dimensional displays [84]. Categories of non-immersive, VR-based interventions for CP include exergames (or video games that integrate physical activity into their gameplay), the use of an avatar or exoskeleton, and non-gamified virtual images projected on a screen [77, 85].

Several applications of exergames that do not rely on HMDs have yielded promising results [85]. For instance, a 4-week intervention using a VR shooting game controlled with trunk movements was superior to conventional care for athletes with persistent low back pain, reducing pain intensity by 7 VAS points and pain-related fear by 65% on the

17-item Tampa scale for kinesiophobia at a 6-month follow-up [86]. Another intervention focusing on neuropathic CP patients achieved an overall reduction of 37% in pain intensity as measured by the VAS and the McGill pain scale. The system provided visual and auditory feedback while patients attempted to grasp and transfer virtual targets with the non-affected arm to generate a 3D mirrored illusion of pain-free movement in the affected arm [87].

Among other use cases, deploying avatars or exoskeletons in non-immersive VR environments has been determined beneficial in physical rehabilitation for chronic low back pain (CLBP) [75]. Compared to conventional care, superior improvements in pain and rehabilitation performance have been identified when patients connected to a motion tracker system receive immediate audiovisual feedback from a screen-projected virtual representation of their body while performing trunk flexibility exercises [88] and moving a gamified avatar with pelvic motions during pelvic tilt exercises [89].

Virtual interactive images projected on a screen represent the most commonly used non-immersive modality [77•]. Mirrored feedback interventions (or the use of distorted mirrored images of the patient's body) that are not gamified fall into this category, many of which have proven effective in treating CP syndromes [76]. For instance, patients with burning mouth syndrome report a 32% average reduction in burning pain when observing a live, slightly delayed virtual mirror image of themselves created by a VR system using a high-speed camera and software to manipulate the shape and color of their face and tongue [90]. A similar concept had been tested earlier on patients with complex regional pain syndrome (CRPS), this time changing the size and transparency of images of their affected limb, with substantial improvements in pain intensity [91].

Immersive Virtual Reality

Modalities used in immersive VR include the use of VR games, mindfulness-based interventions, practical exercises, and visual illusions [77•]. VR games identified in this review range from an airplane controlled by head movements [92] to games involving all 4 limbs, such as grasping and stomping on fruit [93]. Notable applications of VR-guided gamified interventions have been specifically designed for patients with various limitations in utilizing all 4 limbs due to various medical conditions. For example, for patients with intractable phantom limb pain, a VR system used a HMD to project live video of the patient with a virtual limb added [94]. This virtual limb is controlled by electromyography (EMG) signals from the patient's stump to interact in a gaming environment in which the patient steers a racing car. More recently, a VR system was developed to simulate walking for patients with complete paraplegia and neuropathic pain following a spinal cord injury [95]. The system translates arm movements into virtual leg movements using hand-held devices (HHDs) with built-in accelerometers and, through a HMD, allows patients to immerse themselves and interact with a gamified virtual world.

VR-based mindfulness-based applications represent excellent examples of skill-building interventions and often involve high-definition virtual environments featuring therapeutic narrations, relaxing audiovisual content, guided breathing exercises, and prompts for meditation [96–98]. Another noteworthy skill-building strategy is the inclusion of practical exercises in immersive virtual environments, in which patients perform tasks representative of daily activities or physical exercises that they previously struggled to perform. Examples include using a simulated kitchen environment for patients with upper limb CRPS [99] and the simulation of simple bicycling motions for patients with phantom limb pain [100]. Lastly, immersive VR-based therapies have used visual illusions to treat CP [77•]. A notable example is the use of a VR-induced visual illusion to enhance spinal cord stimulation (SCS) for chronic leg pain [101]. The system achieved an average of 44% reduction in VAS scores by first merging real-time video of the participant's body with a pre-recorded 3D environment to provide immersive feedback and then illuminating the avatar's legs in the video to match the tactile sensations experienced by the participant during SCS.

Virtual Reality–Assisted Biofeedback

A notable emergent application of VR in CP management is supporting biofeedback therapy. Biofeedback is a technique that teaches individuals to consciously control bodily functions that are otherwise automatic, such as heart rate and muscle tension, using real-time data from monitoring devices. Biofeedback without the use of VR has been studied extensively in the treatment of CP [102]. Examples of physiological signals tracked in biofeedback therapies for CP include heart rate variability (HRV) [103] and electroencephalography (EEG) signals [104], both of which can be fed back to the patient as a direct representation (i.e., numerical value or spectrogram) or as a transformed auditory, visual, or tactile signal. VR holds promise in enhancing biofeedback, given that physiological signals can be transformed into a much richer sensorial experience. This combination technique has been successfully used as an add-on for anxiety treatment [105] and post-stroke rehabilitation [106] and is being actively investigated for acute post-surgical pain [107, 108].

Though the literature on VR-based biofeedback for CP remains scarce, notable examples stand out. For instance, a VR system employing visual biofeedback successfully mirrored diaphragmatic breathing by responding to breath depth in real time, which led to improvements in pain and mood in CP patients [96]. A recent randomized controlled pilot study demonstrated that regular use of a portable VR-assisted HRV biofeedback system was linked to a 65% decrease in the frequency of analgesic medication use among chronic migraine patients [109]. In another earlier application of VR-assisted biofeedback in chronic migraine headaches, reductions in the galvanic skin response (GSR) in pediatric patients were used to alter pre-obtained virtual images of their pain expressions into calm ones, teaching them to associate relaxation with positive, pain-free self-representations [110]. Lastly, in a VR-biofeedback system termed the Virtual Meditative Walk, GSR sensors are used to adjust the virtual environment's weather in response to the patient's arousal levels, clearing fog with reductions in GSR and thickening it during heightened arousal [111]. This intuitive visual representation of the arousal response was determined to be effective for reducing pain intensity among patients with CP.

High-Definition 3D (HD3D) Conferencing and Virtual Reality–Enabled Interactions in a Metaverse

As demonstrated by this review, VR technologies hold promise for revolutionizing telehealth in CP management, given their potential for creating effective therapeutic environments even in the absence of direct patient-provider contact. As such, for the totality of VR-based interventions reviewed above, their clinical impact will likely take the form of asynchronous, self-guided adjuvant interventions. However, and very importantly, VR offers the potential for enhanced, real-time patient-physician remote communication within a virtual space. In their simplest iterations, these interactions would occur in a virtual setting that deploys advanced 3D graphics and auditory elements to more accurately simulate an in-person medical consultation, a process sometimes described as high-definition 3D (HD3D) conferencing [112]. Recent and rapidly evolving technological advancements are paving the way for interactions within a more sophisticated virtual environment commonly described as a Metaverse. A Metaverse is a collective and fully immersive virtual space, created by the integration of digital and augmented realities, in which users can interact through avatars or high-fidelity representations of themselves [113]. HD3D conferencing applications and interactions within a Metaverse are poised to become a fundamental aspect of human communication in the foreseeable future. Indeed, companies such as Meta are already showcasing advanced stages of HD3D conferencing outside of the clinical and academic realms, as evidenced by their recent facilitation of the first-ever podcast interview in a high-fidelity VR environment [114]. The integration of real-time remote interactions in ultra-realistic virtual spaces into medical practice appears to be an inevitable progression of this technology [115–117].

Haptic Technology

Though current iterations of HD3D conferencing offer the potential to enhance patient-physician remote interactions, it currently falls short in allowing comprehensive physical exams, a crucial component of in-person consultations. This gap might be bridged by the addition of haptics, or the simulation of the sense of touch, a feature currently integrated in a select number of VR applications. This simulated sense of touch is, at present, primarily achieved by applying forces or vibrations to the user. However, there is growing research into touchless ultrasonic stimulation as a promising, less-invasive alternative [118]. Although a substantial amount of research and development is still required, haptic technology has already been demonstrated to enhance CP treatment by providing additional sensory distraction that increases immersivity [119]. Additionally, tactile feedback may improve phantom limb pain by reducing incongruences between motor commands and sensory feedback [120]. If remotely controlled by a physician, haptic technology could eventually aid in examining CP patients by facilitating palpation, muscle tone and strength assessment, and cutaneous sensation evaluation. Future advancements in VR-associated hardware, such as additional remote auscultation and ultrasonography capabilities, could further establish HD3D technology in clinical settings.

A cutting-edge development in haptics with potential applications in CP is the use of haptic bioholograms. This innovation involves holograms that can either respond to physiological signals or are designed as realistic 3D models of biological tissues [121], the latter of which are currently gaining traction in medical training [122, 123]. Haptic bioholograms offer the potential for integrating both ultra-realistic biofeedback and patient interactions with modified virtual self-representations—2 approaches identified by our review as holding great promise in improving CP symptoms—into synchronous practice. Advancements in haptics will need to be accompanied by the development of thoughtful guidelines that ensure patient autonomy and respect for their privacy in a manner that does not differ from current cultural and legal frameworks associated with in-person interactions.

Wearable Monitoring Devices

Additionally, the prospect of VR-based interventions that can be precisely tailored to the individual should be further explored. Such customization could be facilitated by wearable monitoring devices (e.g., vital sign monitors, gait analysis devices, portable EEG recorders, pupillometers, and photoplethysmography) that collect real-time data during VR tasks. These objective metrics can complement subjective or self-reported information not only in observational research but also in clinical settings, where physicians may utilize these data to guide future therapeutic steps.

As explored above, devices such as accelerometers, GSR sensors, and EMG units are currently an integral part of the inner workings of VR applications in CP. However, the full potential of these sensors lies in utilizing data that they can collect to inform clinical decision-making recursively. Although further comprehensive research is needed, initial progress is being made in that direction. For example, a system using HMD accelerometers and wrist wearables to track movement and electrodermal activity during VR tasks recently demonstrated potential for utilizing body movement as a disease monitoring biomarker in patients with CLBP [124]. Utilizing pupillometers already integrated within various HMDs for tracking eye movements presents a particularly promising avenue. This promise is predicated on the identification of eye movements as potential biomarkers of the pain response [125], in addition to their correlation with VR immersivity and interactivity [126].

Limitations and Future Directions

While substantial research is required for the clinical integration of the advanced VR-based applications discussed in preceding sections, immediate challenges also exist for simpler VR-based interventions that are closer to widespread clinical adoption despite encouraging preliminary data supporting their use. The long-term analgesic effects of VR-based interventions remain poorly investigated, with limited research revealing only modest benefits [75]. Future research should focus on RCTs with larger sample sizes and extended follow-up periods, prioritizing skill-building interventions that can provide the patient with strategies applicable outside of the constraints of the VR headset. Moreover, given the heterogeneity of outcomes currently reported in the literature [75, 76, 77•], future research would benefit from standardizing protocols for the evaluation of VR-based interventions in CP. Such protocols should consider integrating physiological markers such as EEG signals and stress response biomarkers alongside self-reported measures to assess efficacy [78]. Additionally, more convincing placebos are needed to better establish the potential role of VR in remote CP management [127]

Furthermore, patients' reservations regarding VR-powered interventions might limit their broader acceptability. Some patients have reported difficulty with adherence due to cybersickness [128], and others have hesitated to engage with VR for fear that it would reproduce their pain [129]. Older adults are more likely to find VR-based interventions invasive and confusing [94]. Better understanding these demographic-specific reservations is essential for customizing treatments. A further limitation to consider is the acceptance and integration of VR within the healthcare system, including its adoption by providers. Perceived lack of VR-related experience or knowledge, appropriate patients, time and support to learn, and availability of rooms or VR systems are apprehensions commonly cited by clinicians [130].

Scalability poses a further challenge. The balance between cost and effectiveness, particularly for more immersive and sensor-rich technologies, is still not well-defined [75]. High costs are often perceived to be a barrier for both providers and patients [130]. Lastly, despite the growing affordability and improved quality of portable VR systems, the path to widespread clinical use remains uncertain. Lack of insurance reimbursement to compensate for VR costs and inadequate hospital Information Technology infrastructure are two important systemic barriers [130]. Extensive adoption that can benefit remote areas of the country will likely require initial prioritization of standalone HMDs that do not require complex installations as well as data privacy frameworks that can safely accommodate emerging remote healthcare delivery technologies. Public investment through initiatives similar to the Healthcare Connect Fund Program and the Distance Learning & Telemedicine Grants and the expansion of public insurance coverage to include VR-based applications proven to be safe and efficacious in CP management will be essential for realizing significant advances in accessibility.

Conclusion

This review highlights the expanding role of telehealth and related VR applications in CP management within the post-COVID-19 healthcare landscape. VR-based interventions in early stages of clinical adoption have demonstrated potential for enhancing the asynchronous delivery of adjunctive CP therapy, while emerging VR technologies promise to fuel a new era in remote, synchronous interactions between patients and providers. These technologies hold the potential to facilitate remote physical examinations, support innovative therapies such as ultra-realistic biofeedback, and enable personalized remote CP care. Despite promising advances in telehealth-related VR applications, future efforts should address current limitations, such as the need for long-term effectiveness data, heterogeneity of reported outcomes, scalability concerns, the challenge of insurance coverage, and demographic-specific barriers to patient acceptability, in order to fully integrate these technologies into mainstream CP care.

Author Contribution IHC, AT, SM, and CLR conceptualized the original idea. IHC, AT, and SM conducted the literature review and drafted the first draft of the manuscript. All authors provided critical reviews and edited subsequent versions of the manuscript. All authors read and approved the final version of the manuscript.

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

Compliance with Ethical Standards

Conflict of Interest Author IHC receives consulting fees from Layer Health. AT, SM, and ARD are co-founders and equity holders of AugMend Health. ML is an Associate Partner at MEDA Angels and Vice President of Operations at AMXRAAS. RT receives consulting fees from Abbott and Medtronic. AS 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 is an equity owner and advisor for AugMend Health.

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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