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Recent Applications of Virtual Reality for the Management of Pain in Burn and Pediatric Patients

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Abstract

Purpose of Review Virtual reality, via integration of immersive visual and auditory modalities, offers an innovative approach to pain management. The purpose of this review is to investigate the clinical application of virutal reality as an adjunct analgesic to standard of care, particularly in pediatric and burn patients.

Recent Findings Although relatively new, virtual reality has been successfully implemented in a wide range of clinical scenarios for educational, diagnostic, and therapeutic purposes. Most recent literature supports the use of this adjunct analgesic in reducing pain intensity for pediatric and burn patients undergoing acute, painful procedures.

Summary This summative review demonstrates the efficacy of virtual reality in altering pain perception by decreasing pain and increasing functionality among pediatric and burn patients. However, large, multi-center randomized controlled trials are still warranted to generalize these findings to more diverse patient demographics and medical scenarios.

Keywords Virtual reality · Pediatrics · Children · Burn · Adjunct analgesia

Abbreviations

VR	Virtual reality
SOC	Standard of care
HMD	Head mounted display
ICU	Intensive care unit
IV	Intravenous
RCT	Randomized control trial
VAS	Visual analog scale

Introduction

Virtual reality (VR) is a technology that synthesizes a computer-generated world to provide immersive experiences. Although originally intended for gaming purposes, it has recently developed applications outside of entertainment [1]. Though VR equipment can vary significantly, it typically consists of a headset and goggles attached to a phone or computer to enable users to immerse themselves into simulated 3D worlds. This experience can affect perceptions and emotional responses [2]. Like VR, pain is strongly associated with perception and emotional response to a stimulus. Therefore, there has been an increased interest in manipulating VR to alter the pain response.

While opioid medications remain among the mainstay of both acute and chronic pain management, patient distraction from painful stimuli may also be therapeutic given that pain is a somatic *and* psychological response. In an effort to divert patient attention from such stimuli, a holistic approach, involving the mental and physical facets of pain, must be adopted. VR provides a powerful means of achieving that approach by incorporating visual and auditory modalities [1]. Unlike pharmacologic agents that block transmission of nociceptive signals, VR disrupts the pain pathway through attention, emotion, and memory [1].

Because the application of VR in medicine is a relatively new concept, data on its efficacy is still evolving. Nonetheless over the last several years, numerous studies have supported an association between VR and pain relief in vulnerable populations [3–6]. The purpose of this literature review is to evaluate the available data on the efficacy of VR in minimizing

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pain among burn and pediatric patient populations. Currently, the treatment of pain in these patient populations largely relies on opioid administration. However, opioids may not be the ideal treatment. With numerous side effects and increasing tolerance and dependence on opioids, clinicians are continuing to investigate additional modalities [7••]. VR may potentially develop a crucial role in multimodal pain control, and recent literature supports its positive effects as a non-pharmacologic, adjunctive analgesic tool [8].

Evolution of VR and Applications in Medicine

Although studies on the integration of VR into medicine have been present for nearly three decades, VR has only recently gained popularity among clinicians. Initially limited by cost and portability, VR is now undergoing a surge of new developments; with the emergence of mobile, high-performance computers, head-mounted displays, and enhanced graphics processing units, VR equipment is more affordable and portable. Furthermore, the advent of sensors to track hand positions and movements in real-time has expanded the horizons of VR, allowing for its widespread application to various aspects of medicine [9].

Therapeutic VR has emerged as an effective, non-pharmacological treatment modality for pain. By diverting a patient's attention from painful treatment procedures towards an entertaining virtual environment, it is possible to reduce the patient's discomfort and anxiety. VR distraction treatments can reduce self-reported unpleasantness, time spent thinking about pain, and levels of worst pain experienced [10, 11, 12••]. Reductions in patient-reported pain and anxiety scores when using VR have been demonstrated in a wide variety of clinical settings. These include laboring women on obstetrics units, post-cardiac procedure patients, and post-surgical patients in the intensive care unit (ICU) [13–15].

There has also been increased use of VR-based therapies beyond pain management. VR has been effectively used as a part of multimodal symptom management for cancer patients in addressing pain reduction, cancer-related fatigue, anxiety, depression, and cognitive dysfunction. In a meta-analysis performed by Zeng et al. investigating VR-based interventions in relieving cancer symptoms, VR use had an overall positive effect on reducing symptoms of anxiety, depression, fatigue, and pain. Statistically significant reductions were demonstrated with anxiety and fatigue. Although a statistically significant difference in cognitive function was not detected, there was a positive trend in the VR group in verbal memory and processing speed [16].

Furthermore, VR has been widely studied as a tool for pre-surgical planning. The use of VR for surgical planning has been demonstrated in plastic and orthopedic surgery, whereby surgeons created VR models of surgical sites and simulated planned procedure [14]. This interactive 3D environment lends itself particularly well to congenital heart disease. VR can be used to generate patient-specific heart models for anatomical assessment in neonates and young infants. Ong et al. demonstrated this novel use of VR with controller-based, interactive capabilities that allowed viewers to interact with 3D models of the complex intra- and extra-cardiac anatomy found in congenital heart disease [14]. In another study, Ong et al. successfully performed 3D segmentation of a complex pseudo-aneurysm in the distal cervical segment of the right internal carotid artery and projected this into VR [17]. These studies demonstrate the practicality of VR for pre-procedural planning.

VR may also have a unique, developing role as an educational tool for residents and medical students. One such example is for practicing laparoscopic surgery. Simulators are able to incorporate VR, allowing trainees to visualize a virtual rendering of many different procedures. Studies have shown that trainees who use VR simulators in their surgical curriculum have shorter times to completion of their learning tasks (defined here as the sequence of steps in a procedure) compared with their counterparts who did not use VR [18, 19]. Jensen et al. used a VR simulator (LapSim) to introduce participants to the procedural aspects of completing a right upper lobe lobectomy. Participants then performed two lobectomies on the simulator with 5-min breaks between attempts. Many of the simulator metrics demonstrated a significant difference between experienced and novice surgeons [20]. This suggests that VR may potentially be used to train and assess trainee competence across various types of surgery. Current literature supports the use of VR across a range of clinical applications, but there is particularly strong evidence for the use of VR in burn and pediatric pain management.

VR for Pain Management in Pediatric Patients

There is growing evidence to support VR as an adjunct analgesic in the pediatric population, particularly among children undergoing intravenous (IV) catheter placement and phlebotomy. These procedures are a source of great anxiety and pain for children. Chan et al. performed a randomized control trial (RCT) where pediatric patients were assigned to either a VR group involving immersive interaction with an underwater world or a standard of care (SOC) group involving caregivers distracting children with books and toys. The primary outcome was the reported change in pain score as measured by the Faces Pain Scale, a scoring system used to characterize pain based on facial expressions. Patients presenting to an outpatient center for venipuncture or IV placement had their baseline pain evaluated. While both groups experienced increases in pain, the VR group experienced less of an increase, with a 130% increase in baseline pain as compared to 190% increase in the SOC group [3].

Another study by Gold et al. similarly examined pediatric pain in response to venous cannulation. In this study, children were randomized to either a SOC group with television-led distraction or a VR group. The primary outcome was pain during the procedure, as measured by the visual analog scale (VAS). Results showed that children in the VR group experienced significantly less pain than the SOC group, 1.31 versus 1.93, respectively. Secondary outcomes also demonstrated a significant reduction in VAS anxiety scores among the VR group, 1.90 in the VR group compared to 2.48 in the SOC group [7••]. A quasi-experimental design by Piskorz et al. provided similarly favorable results for the use of VR in pediatric phlebotomy, further supporting the notion that VR can play a significant role in pain reduction for pediatric patients undergoing IV placement and venipuncture procedures [4].

There have also been several studies examining the potential role of VR in reducing perceived pain during pediatric dental procedures. In a study by Niharika et al., pediatric patients undergoing pulp therapy (similar to a root canal) for primary molars were randomized into one of two groups. Group 1 underwent two treatment sessions, the first session was with VR and the second session without it. Group 2 underwent two sessions as well, but treatment modalities were performed in reverse order. Pain scores were measured by the Faces Pain Rating Scale. In Group 1, children reported an average pain score of 2.56 during the first session (treatment with VR) and reported an average pain score of 5.22 in the second session (treatment without VR), demonstrating a statistically significant decrease in pain during their VR session. Group 2 replicated similar results, with a score of 5.44 in their first session (treatment without VR), and a score of 2.33 in their second session (treatment with VR). The results of this study support the use of VR during pediatric dental procedures for pain relief [21]. A subsequent RCT by Shetty et al. also examined the effect of VR on children undergoing pulp therapy. Anxiety and pain scores were evaluated between a VR group and SOC group; the results showed a statistically significant decrease in both anxiety and pain scores with the use of VR [8]. The results of these reported studies support the use of VR as a non-pharmacological modality for pain reduction in not only simple pediatric procedures such as venipuncture but also more invasive procedures.

VR may additionally be a useful tool in the pediatric perioperative setting. Eijlers et al. conducted an RCT to investigate the impact of VR in reducing pediatric anxiety and pain during induction of anesthesia and post-operative management. This study randomized patients into a VR or control group. The VR group participated in a VR session prior to procedure, where perioperative experience was simulated for the child. The control group underwent standard preoperative routine without VR. The study did not find statistically significant differences in pain or anxiety between the two groups. However, when data was analyzed by type of surgery, there was a significant reduction in post-operative analgesia requirements for children in the VR group who had adenoidectomy and/or tonsillectomy. Only 55% of patients in the VR group requested post-operative analgesia as compared to the 95% in the control group requested it. This study defined rescue analgesia as requirement of any post-operative pain medications, typically morphine. While the findings do not prove VR reduces post-operative opioid requirements, they do suggest that VR may play an integral role in managing pain and anxiety during perioperative care [22••]. VR may also be useful in reducing post-operative opioid use; however, this is yet to be investigated. Results from the most recent studies (Table 1) support the use of VR in pediatric acute and procedural pain.

VR for Pain Management in Burn Patients

It has long been established that burn patients experience particularly severe and excruciating pain. This pain is exacerbated during dressing changes and debridement procedures as well as physical therapy sessions, and opioid analgesics can be of limited use [23]. In the past few years, VR has been successfully utilized to decrease pain for hospitalized burn patients. A study by Hoffman et al. demonstrated reduced pain-related brain activity on fMRI brain scans while using VR equipment. Burn patients also reported 35–50% reductions in procedural pain when immersed in a distracting VR environment [24]. Along with these findings, a randomized, crossover study conducted by McSherry et al. on 18 burn patients demonstrated decreased opioid requirements during wound dressing procedures. Total opioid administration with VR usage was significantly less than with no VR, 17.9 ± 6.0 and 29.2 ± 4.5 mcg/kg fentanyl, respectively [5].

VR may also have a role in functional improvement for burn patients. A prospective, randomized, single-blind study by Joo et al. compared a VR-based rehabilitation to a conventional rehabilitation plan for 57 patients with burned hands. Hand function was evaluated before and after rehabilitation. Patients in the VR-based group demonstrated significantly higher scores in Jebsen-Taylor hand function test for picking up small objects, Michigan Hand Outcomes Questionnaire for hand function, functional activities of daily living, work, pain, aesthetics, and patient satisfaction [25].

VR has additionally been utilized to reduce pain in pediatric burn patients during wound cleaning. Hoffman et al. tested whether immersive VR could serve as an adjunctive non-opioid analgesic for children with > 10% total body surface area burn injuries. The study examined 48 pediatric burn subjects' pain responses to wound cleaning with and without VR. Those in the VR study group were immersed in SnowWorld,

Table 1 Recent significant VR pain studies in the pediatric population

Study	*N*	Sex (M/F)	Age range (years)	Study design	Intervention	Treatment length (mins)	Outcomes
Chan et al. (2019)	252	141/111	4–11	RCT, no blinding	Distraction with books and toys versus immersive interaction with underwater VR world	No VR: 4.55–9; VR: 5.06–7.08	Among pediatric patients undergoing venipuncture or IV cannulation, participants in the VR group had reduced pain perception.
Gold et al. (2018)	143	71/72	10–21	RCT, no blinding	Phlebotomist verbal preparation, low-volume cartoon movie versus aforementioned with immersive VR involving firing cannons	No VR: 5; VR: ~ 5*	Among pediatric patients undergoing venipuncture, participants in the VR group had lower pain and anxiety scores.
Piskorz et al. (2018)	38	20/18	Median age 11	RCT	Playing a VR game based on multiple object tracking versus no distraction	*	Among pediatric patients undergoing venipuncture, participants in the VR group had lower pain and stress scores.
Puppala et al. (2018)	36	18/18	4–8	Single-blind crossover RCT	Alternating pulp dental sessions with and without the use of VR	No VR: 45; VR: 45*	During dental procedures, pediatric patients in the VR arm had significant decreases in pain perception and anxiety scores.
Eijlers et al. (2019)	191	101/90	4–12	Single-blind, block RCT	Standard pain medication and parental reassurance versus aforementioned with immersive VR involving rendition of operative course	*	Among children undergoing elective day surgery, participants in the VR arm did not have reduced anxiety, pain, emergence delirium or parental anxiety; however, after more painful surgery, the VR arm required significantly less rescue analgesia.

*Actual duration of treatments unspecified or variable

an interactive 3D snowy canyon, during portions of wound care. All subjects then provided responses as “worst pain” ratings, using Graphic Rating scales. The mean “worst pain” without VR was 8.52 as compared to 5.10 with the use of VR. This pattern of lower pain scores with VR usage was demonstrated across multiple sessions [6]. Similarly, VR combined with standard pharmacological treatment resulted in reduced pain during hydrotherapy procedures for children with burn wound injuries [26].

A meta-analysis by Luo et al. assessed the efficacy of adjunctive VR for procedural pain management in burn patients. This meta-analysis examined 13 RCTs with a total of 362 patients who underwent 627 burn dressing changes or physical therapy sessions. Results from the study demonstrated that the use of VR significantly reduced pain intensity, time spent thinking about pain, unpleasantness; furthermore, VR was rated as more fun compared to groups using solely pharmacological analgesics. Among nine studies meeting inclusion criteria for the meta-analysis, the mean difference for pain intensity was 2.28 for dressing changes and 1.78 for physical therapy. Subgroup analysis did not reveal differences in pain scores based on age. However, it did show differences in VR presence and realism ratings, which were rated significantly higher among minors as compared to adults in one of the RCTs [27]. The data from this meta-analysis strongly supports the use of VR as an analgesic adjunct in burn patients undergoing dressing changes or physical therapy.

Scapin et al. analyzed data from 34 studies conducted across multiple countries, including 23 RCTs, which examined the use of VR in the treatment of burn patients. The results of this review similarly support the clinical application of VR for burn patients. Burn patients demonstrated increased enjoyment along with decreased pain, anxiety, and stress during dressing changes, physical rehabilitation, and physiotherapy [28]. In addition, several studies included in this review demonstrated an overall faster wound epithelization study groups using VR. One of these studies also demonstrated a minimum reduction of 2 days in epithelization for the VR group when compared to children undergoing conventional treatment. The authors of this study theorized that differences

Table 2 Recent significant VR pain studies in the burn population

Study	*N*	Sex (M/F)	Age range (years)	Study design	Intervention	Treatment length (mins)	Outcomes
McSherry et al. (2018)	18	13/5	20–73	Within-subject crossover RCT	Standard pain medication versus aforementioned with immersive VR involving throwing snowballs at objects (known as SnowWorld)	No VR: 30.7 ± 15.1; VR: 29.9 ± 15.1	During painful wound care procedures, adults in the VR arm had significantly less opiate requirements; however, pain scores were similar treatment (VR) and control (SOC) arms.
Joo et al. (2020)	57	54/3	≥ 18	Single-blind, RCT	Standard pain medication, physical therapy, burn rehabilitation massage therapy versus aforementioned with immersive VR involving targeted hand movements	No VR: 60; VR: 60*	Among adult hand-burn patients, participants undergoing VR-based rehabilitation had better scores on pain, ADL, work and satisfaction scales.
Hoffman et al. (2019)	48	34/14	6–17	Blocked RCT	Standard pain medications and alternating sessions with and without VR involving snowy canyons	No VR: 6.56; VR: 12.89	Among pediatric burn patients, participants in the VR group had significant reductions in severe pain and increases in satisfaction on day 1.
Khadra et al. (2020)	38	27/11	0.5–6	Within-subject crossover RCT	Two equivalent segments of hydrotherapy completed with and without projector-based hybrid VR distraction (both sessions with standard pain medications)	No VR: 21.1; VR: 23.6	Among pediatrics undergoing hydrotherapy procedures for burn wound injuries, participants in the VR group had significant pain reduction compared to SOC.
Brown et al. (2015)	75	44/31	4–13	RCT and retrospective cohort	Standard preparation and distraction (such as videos, books, toys, television, and parental soothing) versus Ditto intervention (computerized multimodal device delivering the procedural preparation in the waiting room) and distraction intervention during wound care procedures	*	VR proved to be highly cost-effectiveness against SOC for the significant benefits gained in pediatric burn patients.

*Actual duration of treatments unspecified or variable

in tissue recovery were due to reduced stress within the VR group [29].

As VR gains recognition for burn patients in both pain reduction and increasing functionality, it is important to understand its utility and perception when being used in a clinical setting (Table 2). A qualitative study by Furness et al. looked at the perception and usability of VR technology among five patients and three nurses at a single burn unit in the UK. The patients were involved in three observed dressing changes: one with an active VR scenario, one with a passive VR scenario, and one with no VR. Following the study, participants gave qualitative feedback. Overall, VR was found to be acceptable, feasible, and welcome by patients and staff nurses. Patients and nurses were particularly impressed with how well VR worked for distraction and anxiety reduction. Furthermore, nursing staff acknowledged a desire to be involved with future funded research. Based on qualitative feedback, both nurses and patients strongly felt that active VR was usable and desirable within clinical environments for burn patients [30].

Future Considerations

Although VR has proven effective in minimizing acute procedural pain, its role in chronic pain remains unclear. This is largely due to its unknown mechanism of action. Proposed mechanisms range from simple distraction to more complex processes involving sensory overload via simultaneous stimulation of visual and auditory cortices. With these notions, several studies have attempted to investigate the utility of VR in chronic pain conditions. Most are limited by small sample size and lack of long-term implications [31]. Despite these challenges, VR has been successfully incorporated into several pain management strategies, resulting in pain relief for several chronic pain syndromes including subacromial impingement syndrome ($n = 30$), fibromyalgia ($n = 6$), chronic migraines ($n = 32$), and phantom limb pain ($n = 14$) [32–35].

One promising study by Ortiz-Catalan et al. examined the use of VR on phantom limb pain. Participants were enrolled into 12 VR sessions, consisting of electrodes attached to the affected limbs. With myoelectric pattern recognition, the electrodes could predict movement and enable participants to have control over the virtual limbs. Participants then engaged in VR racing games with the car being manipulated by the electrode-bearing phantom limbs. At the end of the treatment period, there was a 47% decrease in pain distribution and 51% decrease for pain rating index. These authors also reported an 81% decrease in the intake of chronic pain medications for two out of four patients on long-term pharmacotherapy in this study [35]. Despite the significant findings, this study too is limited by a small sample size ($n = 14$). The overall evidence suggests that VR may have a role in reducing chronic pain, but larger RCTs are necessary to generalize these findings.

VR may also reduce opioid burden, but the current data has been controversial [5]. Although unlikely to eliminate opioid burden entirely, VR may elicit a clinically significant reduction. In addition, it is possible that the use of VR for opioid reduction is limited to specific types of pain within particular patient populations. Spiegel et al. conducted a prospective, randomized trial assessing the effects of VR in hospitalized adult patients with different types of somatic and visceral pain stemming from oncologic, orthopedic, gastrointestinal, and neurological conditions. Results showed that VR was most effective in reducing severe pain. However, the study did not analyze reductions in pain by etiology. Thus, it is necessary to compare the impact of VR usage across different types of pain as well as varying levels of pain [12••].

A large barrier to executing high-powered studies and implementing VR is patient refusal. Spiegel et al. assessed 591 participants for inclusion, but 171 of those participants declined to participate, with one of the primarily cited reasons being skepticism [12••]. This emphasizes the need for patient education and information on VR as a clinical tool moving forward. Investigating the limitations that thwart the widespread application of VR can ultimately pave the way to reducing the opioid burden and adopting a new modality into "multimodal" anesthesia [36].

Conclusions

The experience of pain is multi-faceted and current evidence suggests that this experience can be significantly modified by using VR. VR is a unique, non-pharmacological analgesic adjunct, which can be used in almost all patient populations with minimal to no adverse side effects. As per the meta-analysis by Luo et al., the main side effect related to VR usage reported among eleven of the included studies was nausea. Furthermore, the reported nausea was noted to be mild at worst, and may also have been due to concurrent administration of opioids, of which nausea is a known side effect [27]. Brief dizziness has also been previously reported, but resolved soon after removal of VR gear [12••]. In contrast to many analgesic pharmacological agents such as opioids, VR has virtually no contraindications to its use in clinical medicine other than patient refusal.

VR has been proven to be an effective analgesic adjunct, particularly in the pediatric and burn patient populations. However, it still remains unclear how to best optimize the VR software and user experience to bring about the greatest reduction in patient-experienced pain. Studies have linked greater degrees of VR immersion to greater levels of pain reduction and higher pain thresholds [37, 38]. Hoffman et al. additionally demonstrated that higher quality VR technology resulted in greater degrees of reported immersion. Given that greater immersion results in greater pain reduction, it can be expected and has also been shown that active VR (where patients are required to interact with the environment) reduces pain to greater degrees than passive VR (where patients simply observe their environment) [38]. However, to date, there is no evidence suggesting that any single active VR scenario is superior to another. In addition, multiple active scenarios of differing lengths would have to be trialed and factors of the VR environment correlating to immersion would have to be reviewed. Additionally, the ideal time of VR implementation relative to pain stimuli has yet to be closely examined. By studying these elements, the patient VR experience can be further optimized.

Ideally, with the growing evidence supporting VR and its wide applicability in medicine, every institution would be able to obtain the highest quality VR technology. However, given inevitable budget constraints, cost-benefit analysis will be necessary to determine the optimal VR hardware and software affordable for each institution. Cost is currently a significant consideration for clinical providers and may represent a significant barrier to the ubiquity of VR in clinical medicine. However, as technology inevitably becomes more advanced, VR equipment should continue to become more affordable. Along with this, it is likely that the role of VR technology in clinical practice will continue expanding along with the magnitude of VR's already-established pain reduction effects. Pain management is a constantly evolving field, and VR use has many promising results backed by significant data. If we can continue to apply this technology to patients in pain, then there exists the possibility of more efficient pain control as well as decreased anxiety related to pain in the future.

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Michael Montuori: This author aided in manuscript preparation.

Yuriy Trimba: This author aided in manuscript preparation.

Nicole Maldari: This author aided in manuscript preparation.

Divya Patel: This author aided in manuscript preparation.

Qian Cece Chen: This author aided in manuscript preparation and conceived the review study.

Compliance with Ethical Standards

Conflict of Interest None.

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•• Of major importance

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