Virtual reality in pediatric emergency department and burn unit: a scoping review of current applications

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Abstract

Virtual Reality (VR) represents an innovative and effective tool for reducing pain and anxiety in children undergoing painful procedures in pediatric emergency departments and burn units. VR has the ability to modulate both the sensory and emotional components of pain by immersing children in a virtual world, effectively diverting their attention from the painful experience. Specifically, VR distraction competes for the patient's attentional resources, reducing their focus on the painful stimulus and, consequently, diminishing the perception of pain. The primary objective of this review was to assess and summarize the current knowledge regarding the use of VR for painful procedures in pediatric emergency and burn units by comparing and analyzing the existing literature. Of the 340 articles reviewed, 25 met the selection criteria and were included in the analysis. These studies examined the use of VR in venous procedures (such as venipuncture, cannulation, and blood sampling) as well as other procedures, including laceration repair and burn wound care. The findings indicated that 20 studies reported a reduction in pain scores, while 9 studies noted a reduction in anxiety scores. Additionally, three studies demonstrated a reduction in procedural time. Overall, the studies supported the efficacy, safety, and feasibility of VR in managing procedural pain and anxiety in pediatric settings. Furthermore, VR use contributed to a reduction in parental and medical stress levels, as well as a decrease in the time spent in the pediatric emergency room. Studies involving larger sample sizes may provide further evidence of VR's effectiveness across different procedures and age groups.

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Introduction

In recent years, Virtual Reality (VR) has emerged as an innovative and effective healthcare tool with potential applications in pediatric Emergency Departments (EDs), particularly for minor painful procedures such as venipuncture and suturing of wounds. VR is defined as an artificial environment experienced through sensory stimuli generated by a computer, where a user's actions partially influence the events within the environment.[1] Depending on the level of immersion, VR is classified into non-immersive (using a computer screen or tablet), semi-immersive (with a large 3D screen), and fully immersive (featuring a head-mounted display that enables interaction through multiple sensory channels).[2] Children are transported into a three-dimensional (3D) world that is more engaging than traditional cartoons or video games, providing a distraction from the real world. They can interact with virtual objects by using a joystick or mouse or feel more or less "present" in the virtual environment through head-sensitive or hand-motion tracking devices.[3,4] The increasing use of VR in the ED is attributed to its ability to distract and its non-pharmacological mechanisms that effectively reduce pain and anxiety. Several neurobiological theories have been proposed to explain how VR exerts its effects.[5] According to the Gate Control Theory, pain perception is modulated by interactions between various neurons, with nociceptive signals regulated by a gate control system located in the dorsal horn of the spinal cord. Whether the gate opens or closes deter-

mines whether pain signals are transmitted to the brain, influenced by sensory, cognitive, and emotional factors.[6-11] Attention plays a critical role in pain perception, as processing pain signals in the brain require focused attention.[12] Therefore, a painful stimulus may be perceived as less intense when attention is diverted to other stimuli. It is hypothesized that VR distraction competes for limited attentional resources, limiting the patient's ability to focus on external cues related to the real environment and the painful stimulus. This results in a distraction that reduces the brain's focus on pain.[5,6,10] It is well established that approximately 80% of children visiting the emergency department undergo painful diagnostic or therapeutic procedures.[8] Additionally, unanticipated painful procedures can increase hospital-related distress and anxiety, leading to unpleasant experiences and negative long-term effects, such as heightened anxiety, altered pain perception, behavioral changes, and post-traumatic stress disorder.[8] Reducing pain and anxiety is a critical aspect of appropriate pediatric care in the ED, and VR offers a promising, non-invasive, and easy-to-use tool that can be employed alongside or as an alternative to conventional methods.

The primary objective of this systematic review is to assess and summarize the current knowledge regarding the use of VR for managing painful procedures in pediatric emergency departments and burn units by comparing and analyzing the existing evidence in the literature.

Materials and Methods

Data sources

We examined the electronic bibliographic databases PubMed and the Cochrane Library from their inception to February 2024. The search was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and was limited to English-language papers focused on VR in pediatric ED. To be considered eligible for inclusion in the review, studies had to meet the following criteria: i) participants aged over 1 year and under 18 years; ii) children who underwent minor procedures (such as venous procedures, surgical sutures, and foreign body removal) in ED and burn centers; iii) children in stable, non-critical condition who were conscious throughout the procedure; iv) studies that evaluated outcomes using pain and anxiety assessment scales. We excluded the following: i) non-English language papers; ii) studies in which the VR modality was not specified; and iii) studies not conducted in ED or burn units. The key terms used for the database search included: 'virtual reality' and 'pediatric emergency department'; 'virtual reality' and 'children'; 'virtual reality' and 'procedure'; 'virtual reality' and 'distraction'; 'virtual reality' and 'pain'; 'virtual reality' and 'anxiety'; 'virtual reality' and 'analgesia'; 'virtual reality' and 'venipuncture'; 'virtual reality' and 'cannulation'; 'virtual reality' and 'intravenous insertion'; 'virtual reality' and 'wound closure'; 'virtual reality' and 'laceration'; 'virtual reality' and 'burn'; and 'virtual reality' and 'foreign body removal.' The abstracts of the papers were assessed by two reviewers (IC and GF), who strictly applied the inclusion/exclusion criteria to determine eligibility for full review. Each paper meeting the eligibility criteria was further reviewed and analyzed in full text by both authors (IC and GF), with any discrepancies resolved through discussion.

Study selection

Overall, we identified 340 records through database searching. As the first step, we excluded 50 articles in non-English language, 10 records whose related articles were not available, 5 articles concerning ongoing trials, and 200 duplicated papers. As the second step, we eliminated 40 records by evaluating only title and abstract because they did not match the inclusive criteria we mentioned before. Of the remaining 35 studies, we excluded 10 through a further discussion among authors regarding the reliability of data. Thus, 25 selected articles were included in the review.

The detailed selection of literature is shown in Figure 1.

A wide and extensive summary of results is shown in *Supplementary materials, Table 1*.

Data extraction

The data extracted from each eligible study included the following: study population sample, mean age, gender distribution, study design, type of VR intervention, medical procedures performed, pain and anxiety scales used, and the primary outcomes investigated. The results encompassed studies that examined the use of VR in venous procedures, laceration repair, and wound care. In this review, we analyzed the current literature on the use of VR technology for minor procedures in pediatric ED and burn units. Given the nature of the review, ethical approval was not required.

Results

The selected studies, conducted between 2008 and 2023, included 23 randomized controlled trials and 2 observational studies, involving a total of 2,003 children, of whom 1,045 were male and 921 were female. One study did not report gender distribution. A total of 998 children (50%) were exposed to VR interventions. In most studies, VR was compared with standard treatments, which varied according to the local protocols of the participating hospitals. These standard treatments included medication (such as paracetamol and topical anesthetics), parental comfort measures, and traditional distraction techniques like music, books, television programs, iPads, and smartphones. The majority of the studies (15 [60%]) examined the use of VR in venous procedures, while 7 studies (28%) focused on burn wound care, and 2 studies (8%) addressed wounds requiring sutures. One study (4%) explored VR use during clinical visits, and another study (4%) investigated its application in the removal of foreign bodies. Pain assessments were conducted using a range of validated pain scales, depending on the age of the participants. These included the Faces Pain Scale-Revised (FPS-R) (6/25 studies), the Face, Legs, Activity, Cry, and Consolability (FLACC) scale (6/25 studies), Visual Analog Scales (VAS) (7/25 studies), the Wong-Baker FACES Pain Rating Scale (WBFPRS) (6/25 studies), the Verbal Numerical Rating Scale (VNRS) (2/25 studies), the Graphic Rating Scale (GRS) (1/25 studies), the Adolescent Pediatric Pain Tool (APPT) (1/25 studies), the Child Fear Scale (CFS) (7/25 studies), the Color Analog Scale (CAS) (1/25 studies), and the Child–Adult Medical Procedure Interaction Scale-Short Form (CAMPIS-SF) (1/25 studies). In addition to pain scales, some studies also used anxiety scales, including the Spielberger State-Trait Anxiety Inventory for Children (STAI-CH) (2/25 studies), the Venham Situational Anxiety (VSA) score (1/25 studies), the Revised Children's Anxiety and Depression Scale (RCADS) (1/25 studies), the Chinese version of the State Anxiety Scale for Children (CSAS-C) (1/25 studies), the Child Anxiety Meter-State (CAM-S) (4/25 studies), the Children's Emotional Manifestation Scale (CEMS) (2/25 studies), and Likert-type anxiety scales (1/25 studies). The results

indicated that 20 studies reported a statistically significant reduction in pain scores, while 9 studies showed a statistically significant reduction in anxiety scores. Additionally, 3 studies demonstrated a statistically significant reduction in procedural time.

Discussion

Our review of the current literature demonstrates that VR represents a promising and innovative approach for managing pain during minor procedures in pediatric ED. Numerous studies have established the positive role of VR in various pediatric settings, including its effectiveness as a distraction tool for pain and anxiety management, as well as its potential in rehabilitation programs.[5,13-16] The most recent studies particularly highlight the application of VR in pediatric ED, where children are often exposed to stressful and potentially traumatic experiences. These stressors can negatively impact both anxiety levels and pain tolerance, which in turn may affect the success rate and duration of medical interventions.[17] Traditional passive distraction techniques have been widely utilized in pediatric ED due to their accessibility, low cost, and ease of implementation, with no age restrictions. Common methods include deep breathing, guided imagery, music, the use of iPads and smartphones, television programs, books, progressive muscle relaxation, and cutaneous stimulation. These methods have been shown to provide effective control of pain and anxiety symptoms in many cases.[8] However, these traditional techniques, while beneficial, are generally considered passive forms of distraction, where the patient plays a more passive role in the experience. In contrast, the recent integration of immersive and active VR has

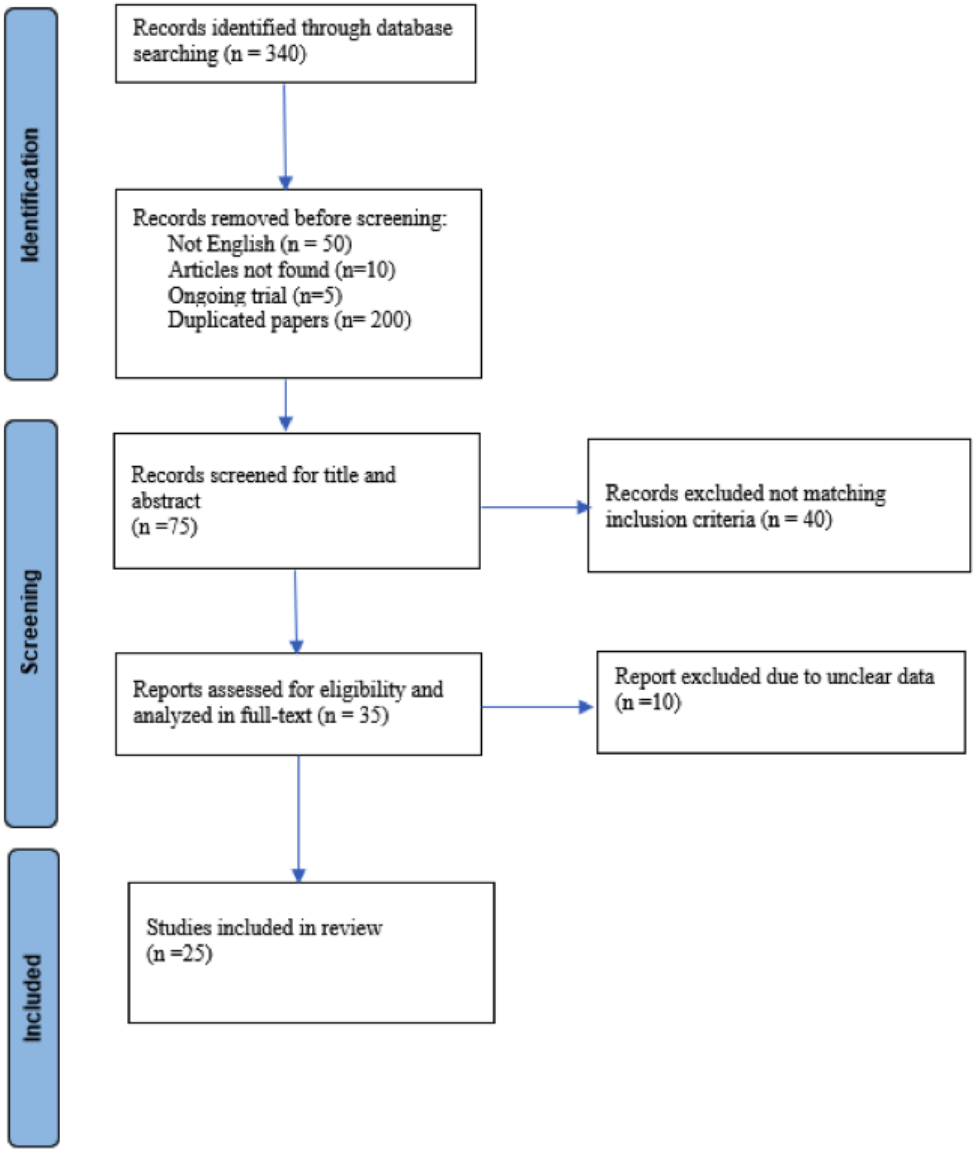

Figure 1. Detailed summary of the literature search.

shown promising results in the management of pain and anxiety. In immersive VR, patients are transported into a fully interactive and engaging virtual world, where they perform tasks or explore environments that divert their attention away from the painful or anxiety-provoking procedure. This active engagement has been suggested to be more effective in pain and anxiety control during key medical procedures in the ED compared to traditional passive methods. The active involvement of the patient in VR not only enhances the level of distraction but also fosters a sense of control, which may be particularly beneficial for managing the psychological components of pain. Therefore, the application of VR in pediatric ED offers a novel and potentially more effective alternative to traditional distraction techniques, particularly for more invasive or stressful procedures. The primary procedure investigated in most studies was venous interventions, which are among the most common and distressing procedures in the pediatric ED and a leading cause of pain in the hospital setting.[4,18-32] Procedural pain and anxiety can have both short- and long-term consequences for patients, increasing the time and resources required to perform the procedure, while also diminishing the satisfaction of both parents and healthcare professionals.[29] Standard strategies, such as the use of topical local anesthetics or cooling agents, are often insufficient, as they primarily address nociception without addressing the psychological component of anxiety.[19] Goldman *et al.* conducted a randomized clinical trial in children with a mean age of 10.1 years to assess the effect of VR combined with oral analgesia or topical anesthetics during intravenous catheterization. They found a modest reduction in post-procedural pain in the VR group, as well as higher parental satisfaction.[18] Similarly, Chan *et al.* observed that in children with a mean age of 8.2 years who received topical local anesthetics before intravenous cannula insertion, the control group (using traditional distraction techniques) showed no significant change in pain from baseline. In contrast, VR significantly reduced pain, with the Faces Pain Scale-Revised (FPS-R) score increasing by an average of 10% in the control group but decreasing by 31% in the VR group.[19] Chen *et al.* reported a reduction in both pain and fear scores in the VR group, not only in children (pain score 3.35±2.38 *vs.* 4.35±2.95; fear score 1.32±1.19 *vs.* 1.78±1.40) but also in their caregivers (pain score 3.26±2.37 *vs.* 3.29±2.70; fear score 1.35±1.23 *vs.* 2.03±1.36), with a strong correlation between the pain and fear levels reported by both children and their primary caregivers.[21] Additionally, Osmanlliu *et al.* found that children who underwent VR interventions reported lower pain recall 24 hours after the procedure, suggesting that VR may have a beneficial impact on how children remember the painful experience.[23] The effect of VR on anxiety was assessed in most of the included studies. While Yıldırım *et al.* found no significant difference in pre-procedural emotional appearance scores or procedure-related pain and anxiety scores, VR had a more pronounced positive effect on anxiety in studies by Wong *et al.* and Chan *et al.*[19,29,32] Furthermore, Gerçeker *et al.* documented increased anxiety levels in children who did not receive VR.[19,22,29] In Goldman *et al.* clinical trial, anxiety levels following IV placement were similar in both the VR and non-VR groups; however, satisfaction with anxiety management was significantly higher in the VR group.[18] Children undergoing intravenous procedures often exhibit reactive pain behaviors such as crying, screaming, body contortions, and muscle rigidity, requiring additional time and effort from parents and medical personnel for comfort or coercion. This results in longer procedures and more attempts at successful IV insertion.[33] Knight *et al.* found that children using VR exhibited fewer reactive pain behaviors than those in the traditional distraction group, while Canares *et al.* reported higher patient coping in the VR group (patient coping score: 0.70 in the control group *vs.* 0.88 in the VR group, p=0.046).[20,24] Several studies found that VR interventions were associated with a shorter duration of venous procedures. Chen *et al.* documented, in children with a mean age of 9.13 years, a shorter time required for intravenous injections in case of VR application (53.5±19.0 seconds *vs.* 61.3±25.8 seconds, p=0.046) according to Wong *et al.* who also showed a shorter length of venipuncture procedure in the VR group (4.43 minutes *vs.* 6.56 minutes) in children with a mean age of 7.21 years.[29] On the other hand, Schlechter *et al.* found similar first-attempt IV success rates between the groups and a similar number of IV attempts. However, they noted a shorter median time to successful IV placement in the VR group (78 s *vs.* 104 s). Similarly, Litwin *et al.* reported no significant difference in the duration of IV insertions between the VR and control groups (mean = 4.0 min [SD 3.7] in the VR group *vs.* mean = 4.1 min [SD 4.0] in the control group, p=0.91), with 9.7% of IV insertions unsuccessful on the first attempt in the VR group, compared to 18.5% in the control group.[27] Maybe this difference is correlated to the higher age of children in the latter trials, with a mean age of 11.3 and 12.5 years, respectively.

Laceration repair, a common reason for pediatric visits to ED, can cause significant procedural pain and anxiety in children. While procedural pain can be managed with topical and injectable agents, controlling anxiety during suturing remains more challenging. Fewer studies have investigated the use of VR in laceration repair procedures. Nemetski *et al.* demonstrated that the use of an immersive VR game could reduce anxiety both at the start of the procedure and at various points throughout, including during local lidocaine injection. This effect was partly attributed to the fully immersive nature of VR, which diverted children's attention, so they were unaware of the procedure.[34] Although Goldman *et al.* found no significant difference in post-procedural pain and anxiety scores, children rated the VR experience more positively compared to other options (*e.g.*, books, TV, games, iPads, and parental comfort). This suggests that VR may be a valuable addition to the ED setting. In fact, 93% of physicians in the Nemetski *et al.* trial reported that VR helped them successfully complete the laceration repair.[34,35]

In this review, we also explored the use of VR in burn wound care, which, while not typically conducted in ED, is a common procedure in burn centers.[36-42] VR has shown great potential in burn debridement and care, serving as an innovative adjunct to pharmacological analgesia. Acute procedural pain during burn wound care can be difficult to manage, even with pre-medication using traditional pharmacologic analgesics such as opioids.[36] Hoffman *et al.* documented that VR, when used in conjunction with standard pre-procedure pharmacologic analgesia, resulted in significantly lower pain intensity (mean worst pain ratings for the no VR group = 7.46 vs. 5.54 in the VR group) and lower overall pain (no VR=4.29 *vs.* 1.68 for the VR group) both in younger and older children.[36] Similarly, Alrimy *et al.*, in children treated with paracetamol, found that VR significantly reduced pain during burn wound care by 40% and anxiety by 34%, compared to pharmacologic treatment alone.[41] Xiang *et al.* compared passive and active virtual reality with standard care, showing lower reported overall pain in the active VR (VAS score, 24.9 *vs.* 47.1 in the standard care group) and a lower worst pain score in active VR than passive VR (VAS score, 27.4 *vs.* 47.9).[37] Jeffs *et al.* conducted a similar trial in older children, with a mean age of 13.5 years, documenting that the VR group experienced less pain during wound care than either the passive distraction or standard care groups.[42] These results agreed with the cognitive-affective model of pain, suggesting that active VR is more efficacious than passive VR because it requires a heav-

ier attention load on a person's cognitive system. As demonstrated for venous procedures, Kipping *et al.* documented a lower median time of 10 minutes for dressing application in the VR group compared to the control group.[39]

In summary, VR operates through distraction techniques that reduce the patient's perception of pain. By diverting the patient's attention, afferent pain signals in the spinal cord are often inhibited, preventing many of these signals from reaching pain-processing areas in the brain, such as the primary sensory cortex, which remains less active under distraction.[15,33,43] The underlying mechanism of VR in reducing pain, rather than just anxiety, is based on the limited attentional capacity of humans. Pain demands attention, and if part of that attention is redirected, the patient's response to pain signals can be delayed. However, VR does not block pain signals directly; instead, it influences pain perception and signaling both directly and indirectly by engaging attention, emotion, concentration, memory, and other sensory modalities[15,16,43]. In this context, VR should be tailored to the individual, allowing patients to select topics or applications that align with their personal interests and hobbies. Personal differences in interests and skills can influence which distractor is most effective for a particular person. For instance, asking someone who experiences pain and has a history of struggling with mathematics to do mental arithmetic as a distraction is unlikely to work, unlike someone who enjoys solving math puzzles in their free time.[43] The use of VR is particularly effective in pediatric patients, as children exhibit a higher level of imagination and engage in "magical thinking," which results in both greater anticipatory anxiety and distress, as well as more profound immersion in the virtual environment.[15,33,43] Consequently, VR tends to be more effective in younger patients, as evidenced by several studies. For instance, Clerc *et al.* observed that VR was more effective for children aged 6 to 8 years compared to those aged 13 to 16 years.[44] This discrepancy may be attributed to the greater cognitive reserve and awareness in older children, which could lead to less effective pain distraction. Other factors influencing the response to VR include the patient's prior experiences with procedures, such as venipuncture, as well as cultural factors that may shape their perception of what constitutes a pleasurable VR experience.[15,33,44] The impact of VR on neuronal pathways and regions has been confirmed in recent years, as shown by some neuroimaging research reported in *Supplementary materials, Table 2*, despite the lack of studies in children. Studies using positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) have identified various neuroanatomical areas that consistently show metabolic activity during thermal nociceptive stimulation, especially when participants report experiencing pain. The most reliably activated regions include the Anterior Cingulate Cortex (ACC), the insula, the thalamus, and both the primary (SS1) and secondary (SS2) somatosensory cortices, which are collectively known as the "pain matrix."[45] Recent studies utilizing VR have demonstrated its effectiveness in decreasing the activation of these neuronal regions, thereby reducing the perception of pain. For example, Hoffman *et al.* correlated VR analgesia with neuroimaging studies using fMRI, demonstrating that the brain areas metabolically active during pain stimuli are the same areas where VR application leads to reductions in pain-related brain activity.[46] They observed that the decrease in pain-related brain activity was clinically associated with lower subjective pain ratings, providing further evidence that VR distraction significantly reduces pain experienced by subjects. Moreover, VR affects not only the sensory aspects of pain but also the emotional components.[46,47] They also investigated the different impacts of pharmacological and non-pharmacological treatment on the modulation of pain and the association with specific regional reductions in metabolic brain activity. They conducted a comparison of clinical and neuroimaging data in subjects undergoing painful thermal stimulation under four conditions: no analgesia, target-controlled opioid administration alone, VR distraction alone, and a combination of opioid and VR distraction.[45] The results revealed a correlation between self-reported analgesia and brain activity. Specifically, opioid administration alone led to a significant reduction in subjective pain and pain-related brain activity in the insula and thalamus. VR alone also significantly alleviated both worst pain and pain unpleasantness, with notable reductions in pain-related brain activity in the insula, thalamus, and SS2. Furthermore, the combination of opioids and VR distraction provided a more substantial reduction in pain reports compared to opioids alone across all subjective pain measures.[45] Moreover, focusing on the role of multisensory input and the analgesic effects of VR, a study by Hoffman *et al.* demonstrated an enhanced analgesic response to thermal pain, as measured by subjective pain ratings, when the audio, visual, and interactive elements of the VR experience were fully optimized (*e.g.*, highly immersive VR).[48] This effect was compared to conditions involving lower levels of sensory stimulation and user interaction (*e.g.*, low-resolution video display, no sound, and no user interaction). The greater analgesic effect was linked to higher reports of "presence" (the sensation of being immersed in the virtual environment), suggesting that simple video stimulation without high-resolution, wide-field-of-view head-mounted displays, 3D sound, head tracking, or user interaction results in a weaker sense of immersion in the virtual world, leading to less effective pain distraction than when using highly immersive VR.[48,49]

Based on the available data, our review illustrates how VR can be a valuable and reliable tool to integrate into clinical practice in the pediatric emergency department. It significantly impacts the management of pain and procedural anxiety in children, enhances parental satisfaction, and contributes to time and resource savings for both medical and nursing staff. As reported in our review, VR contributes to the overall reduction of healthcare expenses by reducing the dependence on costly pharmaceutical treatments, lowering the number of hospital visits and time of procedures, and accelerating recovery times. Thus, by enhancing patient outcomes and decreasing the chances of readmissions, VR helps hospitals make better use of resources and increase efficiency, leading to notable cost savings.[50-53] Additionally, VR-based training programs for healthcare providers enable simulation-based education, decreasing the need for costly in-person training sessions and lowering the chances of mistakes during actual procedures. This approach not only improves healthcare delivery efficiency but also reduces training costs.[54-56] Thus, the adoption of VR in healthcare settings offers the dual benefits of improving patient care quality while significantly lowering operational costs, making it a promising tool for increasing healthcare system effectiveness.

Limitations

The main limitations of our review include the heterogeneity of study designs, the small sample sizes of some randomized controlled trials, the variability in the types of VR interventions used, and the differences in standard protocols based on individual hospital policies.

Conclusions

This review demonstrates that VR is a feasible, innovative, and

effective tool for reducing pain and anxiety in pediatric patients undergoing painful procedures in the ED. VR can modulate both the sensory and emotional aspects of pain processing by immersing children in a virtual environment, diverting their attention from the pain experience. This is due to the limited attentional resources of the brain; when the brain focuses on tasks that require concentration, the perception of pain is diminished. Distraction through VR can be achieved in a timely and effective manner, not only alleviating the patient's negative emotions but also reducing stress for both parents and medical staff, ultimately shortening the time spent in the ED. Studies involving larger sample sizes and exploring further applications in diverse clinical settings could provide additional evidence on the effectiveness of VR, facilitating its global adoption in pediatric care.

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Online supplementary materials
Table 1. Studies that evaluated VR in ED medical procedures and burn units.
Table 2. Studies of VR and functional neuroimaging.