

Virtual Reality for Pediatric Postoperative Pain Management: Exploring Methods and Efficacy

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Abstract

Background: Ineffective postoperative pain management is associated with several negative consequences, including increased morbidity, impaired physical function and quality of life, delayed recovery, prolonged opioid use during and after hospitalization, and increased healthcare costs. Traditional pain management therapies, including pharmacological interventions, have several drawbacks, particularly in children, with growing concerns over long-term opioid abuse. Virtual reality (VR) has emerged as a promising non-pharmacological intervention for pain management in various clinical settings. VR technology immerses individuals in computer-generated environments, providing them with multisensory experiences that can distract and engage their attention, ultimately reducing their perception of pain.

Objective: The objective of our study was to address the major concepts related to VR, the use of VR in differing clinical situations, various VR-based therapy methods, and the practicality of VR to alleviate pain, as well as several key findings to date and future directions.

Methods: Articles from database inception through January 2023 were searched in PubMed, EMBASE, PsycINFO, and CINAHL electronic database. Search terms included "virtual reality", "video games", "pediatrics" and keywords included "VR" and "postoperative pain". The review included randomized clinical trials, observational studies, cohort studies, and case-control studies evaluating VR interventions for postoperative pain management in pediatric populations.

Results: Eight studies were analyzed, including 6 randomized controlled trials and 2 prospective pilot studies. Studies investigated various VR modalities: distraction therapy (VR-D), exposure therapy (VR-E), guided relaxation (VR-GR), and biofeedback (VR-BF). VR interventions demonstrated significant reductions in pre- and post-operative anxiety and fear scores, with superior pain control compared to traditional distraction methods. One large trial found no significant impact on anxiety or emergence delirium but showed clinically important reduction in rescue analgesia following more painful surgeries. Common limitations included lack of standardization in VR session timing, potential self-reporting bias, and varying control group designs.

Conclusions: This systematic review suggests that VR is a promising emerging non-pharmacological intervention for perioperative pain management in pediatric patients. Future studies should standardize perioperative and postoperative protocols to investigate optimal timing and frequency of VR use, as well as investigate long term outcomes.

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Original Manuscript

Title: Virtual Reality for Pediatric Postoperative Pain Management: Exploring Methods and Efficacy

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Abstract

Ineffective postoperative pain management affects more than 25% of hospitalized children, leading to increased morbidity, impaired physical function, delayed recovery, prolonged opioid use, and heightened healthcare costs. Traditional pharmacological interventions have limitations, particularly given growing concerns over long-term opioid use in pediatric populations. Virtual reality (VR) has emerged as a promising non-pharmacological intervention for pediatric pain management, offering immersive, multisensory experiences that can effectively distract and engage patients' attention away from pain sensations. This viewpoint examines the current evidence and prospects for VR as a component of pediatric multimodal pain management strategies. Several VR modalities have shown potential for reducing pain and anxiety in pediatric populations, including distraction-based VR therapy (VR-D), exposure-based VR therapy (VR-E), guided relaxation-based VR therapy (VR-GR), and biofeedback-based VR therapy (VR-BF). The neurobiological underpinnings of VR's analgesic effects involve multiple mechanisms: the gate control theory explains how intense multisensory VR inputs compete with pain signal transmission, while the attention-modulation pathways involving the anterior cingulate cortex and periaqueductal gray work alongside emotional regulation pathways through amygdala connections to reduce pain perception. Recent studies involving various pediatric surgical populations have demonstrated VR's potential to reduce postoperative pain intensity, pain unpleasantness, anxiety, and in some cases, the need for rescue analgesia. However, VR's analgesic effects appear to be transient, typically lasting 15-30 minutes, which suggests the need for optimization in timing and frequency of VR sessions. Implementation challenges include cost considerations, technological access disparities, logistical requirements for safe use and storage, and staff training needs. As hospitals and healthcare systems continue to explore non-pharmacological pain management strategies, VR represents a promising adjunct to traditional approaches, potentially reducing reliance on opioid medications while improving patient experience and outcomes. Throughout this review, we address the major concepts related to VR, the use of VR in differing clinical situations, various VR-based therapy methods, and the practicality of VR to alleviate pain, as well as several key findings to date and future directions.

Keywords: Virtual reality, pediatrics, pain management, analgesia, post-operative

Introduction

It has been estimated that more than 25% of hospitalized children have moderate to severe pain because of insufficient pain assessment and management techniques.[1–4] Ineffective postoperative pain management is associated with a number of negative consequences, including increased morbidity, impaired physical function and quality of life, delayed recovery, prolonged opioid use during and after hospitalization, and increased healthcare costs.[4] A significant amount of effort has been placed on the use of multimodal analgesia to improve these outcomes. Despite these efforts, pediatric postoperative pain remains difficult to treat, increasing the risk of persistent postoperative and chronic pain in this population.[5,6] Various studies have reported persistent pain after surgery (PPAS) in many different pediatric surgical populations.[7–9] Pain following surgery can persist for days to weeks, and even months, leading to time away from school, decreased quality of life, and prolonged physical and emotional disability.[10,11] Furthermore, PPAS is a critical concern when discussing persistent opioid use after surgery.[6] This emphasizes the importance of proper pain management in pediatric patients with the optimization of postoperative analgesia and a decrease in the administration of opioid medications.

Traditional pain management therapies, including pharmacological interventions, may have limitations, particularly in children. Because of growing concerns over long-term opioid abuse among children and adolescents, alternative approaches to alleviate postoperative pain have garnered increasing interest.[6,10] In response to the opioid crisis and the need to address fear, anxiety, and the risks associated with narcotic overuse, there has been a push to identify novel and multimodal approaches to pain and anxiety control in pediatric patients undergoing surgery, aiming to reduce dependence on opioids and facilitating a rapid and effective recovery.[12,13]

VR Modalities

Virtual reality (VR) has emerged as a promising non-pharmacological intervention for pain management in various clinical settings. VR technology immerses individuals in computer-generated environments, providing them with multisensory experiences that can distract and

engage their attention, ultimately reducing their perception of pain.[14] Various types of VR technologies have been used to treat pain and anxiety, such as distraction-based VR therapy (VR-D), exposure-based VR therapy (VR-E), guided relaxation-based VR therapy (VR-GR), and biofeedback-based VR therapy (VR-BF). Distraction-based VR therapy (VR-D) uses interactive games or simulations to redirect attention away from pain, with programs ranging from simple exploration games to complex interactive environments. Exposure-based VR therapy (VR-E) creates realistic pre-operative environments to familiarize patients with medical procedures, often using age-appropriate graphics and interactive elements. Guided relaxation-based VR therapy (VR-GR) incorporates meditation and breathing exercises within immersive natural environments, while biofeedback-based VR therapy (VR-BF) integrates physiological monitoring with virtual environments that respond to the patient's vital signs. The selection of specific VR modalities depends on factors such as the patient's age, procedure type, and therapeutic goals. Each of these VR modalities have been studied in various patient populations.[15–19]

VR's neurobiological mechanisms

The effectiveness of VR in pain management stems from its ability to modulate pain processing through multiple neurobiological mechanisms. The fundamental mechanism involves the gate control theory of pain, where intense multisensory inputs from VR environments compete with and inhibit pain signal transmission.[20] VR operates through two key neural pathways: an attention-modulation pathway involving the anterior cingulate cortex and periaqueductal gray, and an emotional modulation pathway through amygdala connections that can reduce pain facilitation. [21,22] Functional neuroimaging studies have provided direct evidence for these mechanisms, demonstrating reduced activity in pain-processing brain regions during VR immersion, along with increased activation in areas associated with attention and emotional regulation.[23] This neurobiological foundation helps explain VR's effectiveness across various clinical contexts.

In recent years, VR has gained attention as a potential tool for pain relief in pediatric patients following surgery. We conducted a comprehensive literature search to identify relevant studies on

the use of VR interventions for postoperative pain management in the pediatric population. The findings of these studies are summarized in this narrative review to provide insights into the potential efficacy and benefits of VR as a non-pharmacological tool to assist in alleviating postoperative pain in children. We review the major concepts related to VR, the use of VR in various clinical situations, and the practicality of VR for pain management. Lastly, the potential future directions for VR are presented.

Methods

A systematic and comprehensive literature search was performed in the PubMed, EMBASE, PsycINFO, and CINAHL electronic databases from database inception through June 2023. The search was performed using a combination of MeSH terms and free-text keywords, Controlled vocabulary terms (e.g., "virtual reality", "video games", "pediatrics") and keywords (e.g., "VR", "postoperative pain") were used to capture all relevant articles. Boolean operators (AND, OR) were used to refine the search. Titles and abstracts were screened for relevance by two independent reviewers. Full-text articles were retrieved for eligible studies. Discrepancies were resolved through discussion. A total of 8 articles were included in the final review based on relevance and quality of evidence. The search encompassed articles focusing on the use of VR in various pain therapy methods, the practicality of VR for pain alleviation, and key findings and future directions of VR use. The inclusion criteria for this review consisted of randomized clinical trials as well as observational, cohort, and case-control studies.

Ethical Considerations

This viewpoint article examines published literature and does not involve direct human subject's research. The original studies cited in this review underwent their own respective ethical review processes as documented in their publications. No new patient data was collected, analyzed, or presented in this manuscript. No informed consent was necessary for the preparation of this viewpoint article.

Studies and Outcomes

DISTRACTION THERAPY (VR-D)

Distraction-based VR therapy (VR-D) focuses on using VR as a tool for distraction from painful stimuli. Although the literature is mixed regarding distraction alone, using augmented distraction with VR provides an immersive and engaging experience that may be more effective than distraction alone.[24–26] By focusing their attention on the virtual environment, the perception of pain by a patient can be reduced. VR experiences can range from interactive games to calming visual and auditory simulations.

In a single-center, prospective, pilot study, Olbrecht et al. provided a single virtual reality distraction (VR-D) session to 50 children after surgery, providing them the option to play one of several VR games.[15] The study included patients who had undergone several different types of procedures, all of whom required pain management by the Acute Postoperative Pain Service: 19 (38%) had abdominal surgery, 17 (34%) had Nuss repair of pectus excavatum or other chest surgery, and 14 (28%) had orthopedic procedures (such as posterior spinal fusion or major hip surgery). Prior to the VR session, patients completed validated questionnaires including the Pain Catastrophizing Scale for Children and Child Anxiety Sensitivity Index to assess whether these factors influenced VR-D effectiveness. Pain and anxiety were assessed at baseline prior to the VR-D session and at 3 time points after VR-D (immediately and 15- and 30-minutes after the experience). Immediately after VR-D, pain intensity decreased (median change -1.0, $p < 0.0001$), remaining significant at 15 minutes (median change 0, $p = 0.02$), but not at 30 minutes. Pain unpleasantness (how much discomfort the pain was causing the patient) decreased immediately following VR-D (median -1.0, $p < 0.0001$), remaining significant at both 15- and 30-minutes ($p = 0.0008$ and $p = 0.0001$). Finally, anxiety decreased immediately after VR-D (median 0, $p < 0.0001$) and at 15 minutes (median 0, $p = 0.0014$). Adjusted analyses showed significant decreases in pain intensity and unpleasantness after VR-D versus baseline. Reductions were also significant at later time points for pain unpleasantness but not intensity. No adjusted differences were seen for anxiety. Given that this study was not a randomized controlled trial, there were multiple limitations,

particularly in the lack of a control group. In addition, patients received only one VR-D session, there was variability in the timing of the session, and a heterogeneous patient population was included. Nevertheless, this pilot study showed the feasibility of using VR-D in children after surgery and provided preliminary evidence that a single VR-D session may be associated with a reduction in pain intensity and unpleasantness in children after surgery, laying the foundation for a larger randomized controlled trial to assess the efficacy and optimal timing/duration of VR for pediatric postoperative pain management.

Buyuk et al. assessed the effectiveness of a VR intervention following circumcision in 5- to 10-year-old boys in a randomized controlled trial.[16] The study included 78 subjects who were divided into a control group (n=38) and an experimental group (n=40). The control group received standard care before surgery. The experimental group received a VR intervention in addition to standard care before surgery. Two VR programs were chosen for the study: one simulated walking through the Amazon rainforest, and the other simulated water skiing. Before surgery, the children in the experimental group were allowed to view one of the VR programs for an average of 4.5 minutes. Data was collected using the children's fear scale (CFS), the children's anxiety meter scale (CAM-S), and the Wong-Baker Faces Pain Rating Scale (WBS). Compared with the control group, children in the experimental group who received the VR intervention had significantly reduced CAM-S and CFS scores both before and after surgery. Furthermore, the experimental group's postoperative WBS scores were considerably lower. The study's greatest limitation, however, was that analgesic consumption was not consistently tracked between the groups thereby adding significant risk for a confounding factor that would influence results. This study was notable because it was designed as a randomized controlled trial and demonstrated the potential benefits of adopting VR intervention to reduce pre- and postoperative anxiety, fear, and pain in children undergoing circumcision. Nevertheless, these limitations make it somewhat difficult to interpret the results.

Specht et al. conducted the first randomized study to examine the effects of VR as a non-pharmacologic intervention in the immediate postoperative period. The study used block randomization through REDCap, with stratification by surgery type, age group (7-12 and 13-18

years), and gender. Patients were randomized to using either VR (n=50) using Oculus Go devices preloaded with the immersive Nature Treks VR application, or an iPad tablet (control, n=56) preloaded with Child Life Specialist-approved educational games for 30 minutes after surgery in the postoperative anesthesia care unit (PACU).[27] To maintain blinding, patients and guardians remained unaware of the alternative study arm until PACU discharge, and all participants received 5-10 minutes of device familiarization before surgery. Assessments were done at multiple time points. Prior to surgery, patients self-reported pain using the WBS and anxiety using the Spilberger State Trait Anxiety 6-question Short Form (STAI) scale. Caregivers assessed their child for pain using the Visual Analog Scale (VAS). In the PACU, pain (VAS, WBS), anxiety (STAI) and Face, Legs, Activity, Cry, Consolability (FLACC) scores were repeated before the intervention; and FLACC assessments were done at baseline and 10-, 20-, and 30-minutes during the intervention. Follow-up was done with the Post Hospitalization Behavior Questionnaire for Ambulatory Surgery (PHBQ-AS) at 2-3 days and 7-10 days after discharge. After adjusting for age, gender, and pre-operative anxiety, patients using VR had significantly lower pain scores compared to the iPad group ($p = 0.021$). Younger patients (aged 7-12 years) were more likely to have decreased pain scores during VR use compared to older patients (aged 13-18 years), even after adjusting for treatment group, gender and STAI ($p = 0.044$). This was most significant after 20-30 minutes of VR use ($p = 0.0003$). Younger patients had higher odds of withdrawal or exclusion from the study compared to older patients, after adjusting for treatment group, gender and STAI (odds ratio 2.95, $p=0.021$). There was no significant difference in opioid consumption between the VR and iPad groups ($p = 0.766$). Pre-operative and post-operative self-reported pain scores were not significantly different between groups ($p = 0.821$ and $p = 0.932$ respectively), but at the 7-10 day follow-up, PHBQ-AS scores were significantly lower in the VR group ($p=0.006$). Younger patients were also found to have higher odds of decreased FLACC scores over time regardless of intervention group ($p<0.05$). In summary, VR was more effective than iPad use in reducing observational pain scores (FLACC), especially in younger patients, but there was no difference in opioid consumption or patient-reported pain scores between the groups. Limitations of this study included premature study termination due to COVID-

19, with only 106 of a planned 150 patients included in the study. There was also a self-selection bias as this study recruited voluntary participants. There was also variability in child self-reports and the use of multiple research assistants to assess patient outcomes. Nevertheless, this randomized controlled trial provides preliminary evidence that VR can reduce observational pain scores in children after surgery compared with a similar iPad distraction intervention. However, limitations like the smaller sample size preclude definitive conclusions.

Another randomized controlled trial conducted by Kumari et al. evaluated the effectiveness of VR as a distraction tool for children undergoing dental procedures.[28] The study included 200 subjects, with 100 allocated to the immersive VR group and 100 to the non-immersive VR group. During the immersive VR intervention, children played videogames using a hand-held controller, allowing them to explore and interact with the VR environment. For non-immersive VR, participants watched a cartoon movie. All participants were given a few minutes to familiarize themselves with the VR headset and controller prior to treatment initiation. Then a local anesthetic gel was placed followed by local anesthetic injection. Immediately after the local anesthetic injection, the VR equipment was retrieved from the patient, and the child's pain perception was assessed using VAS and WBS, and anxiety was evaluated via the Faces version of the Modified Child Dental Anxiety Scale (MCDAS(f)) in local language. Various dental procedures were then performed. Pre-operatively, mean MCDAS scores were similar between the immersive (29.20 ± 3.197) and non-immersive (29.09 ± 3.803) ($p=0.82$) groups. Postoperatively the non-immersive group had higher MCDAS scores (20.72 ± 2.822) compared to the immersive group (10.99 ± 2.227 , $p=0.00$). Post-operatively, the non-immersive VR group had higher VAS pain scores (2.72 ± 0.99) compared to the immersive group (0.75 ± 0.88 , $p=0.00$). Similarly, postoperative WBS scores were higher in the non-immersive group (2.78 ± 1.097) versus the immersive group (0.82 ± 1.104 , $p=0.00$). In summary, both the VAS and WBS pain scales indicated significantly higher postoperative pain levels in the non-immersive versus immersive VR groups. The immersive VR environment was more effective in reducing perceived pain during intraoral injections. This study had some limitations. While the study examined immersive and non-immersive VR effects on pain perception, it did not examine

differences in the time to achieve immersion or variable effects between genders. Secondly, the authors did not compare pain perception based on patient education level or social status. Additionally, the bulkiness of the VR device may limit applicability for younger age groups and future research should explore different device sizes and collaborate with manufacturers to develop more user-friendly devices suitable for all age groups.

EXPOSURE THERAPY (VR-E)

VR-based exposure therapy (VR-E) combines VR technology with exposure therapy to mimic any triggers, stressors, or fears a patient may have, exposing the patient to these triggers/stressors in a VR environment. Such triggers may include sights, sounds, smells, and vibrations that create realistic versions of the traumatic or stressful experience. This can be particularly useful for individuals with chronic pain or phobias. By gradually exposing them to their fears in a virtual setting, it helps desensitize their response to pain and anxiety.[29]

Eijlers et al. conducted a single-center, single-blinded randomized controlled trial in accordance with CONSORT guidelines to investigate if VR-E before surgery could reduce anxiety, pain, and delirium following surgery.[17] Block randomization was performed, stratified by type of surgery: adenoidectomy and/or tonsillectomy, insertion of tympanostomy tubes, maxillofacial and dental procedures or other ENT procedures. Assessments after randomization were performed by a blinded researcher in the holding area and during induction of anesthesia, and by blinded recovery nurses postoperatively. Participants included children aged 4 to 12 years undergoing elective maxillofacial, dental or ENT day care surgery, with 94 randomized to VR-E versus control/care as usual (CAU, n=97). The VR environment was designed to mimic the real operating room and medical staff, familiarizing children with the surgical environment and procedures via an interactive, developmentally-appropriate context using child-friendly, interactive computer-generated graphics presented via a head-mounted display for approximately 15 minutes. Two age-appropriate versions were created for children 4-7 and 8-12 years old. The study assessed child anxiety at multiple time points using the modified Yale Preoperative Anxiety Scale (mYPAS) including at hospital admission (VR-E median 26.7 vs CAU 26.7, $p=0.697$), in the holding area (VR-E 28.3 vs CAU 28.3, $p=0.765$),

and during the induction of anesthesia (VR-E 40.0 vs CAU 38.3, $p=0.862$). Self-reported anxiety on VAS was also measured at admission (VR-E 3.0 vs CAU 1.5, $p=0.407$), in the holding area (VR-E 3.0 vs CAU 3.5, $p=0.753$), and postoperatively ($p>0.05$ at all postoperative time points). Pain was assessed in the recovery room through child self-report on the Faces Pain Scale - Revised (FPS-R) (VR-E 2.0 vs CAU 2.0, $p=0.699$), nurse observation with the FLACC scale (VR-E 0.0 vs CAU 0.0, $p=0.669$), and parent report on the Parents' Postoperative Pain Measure (PPPM) (VR-E 3.0 vs CAU 3.0, $p=0.410$). Emergence delirium was measured by the Paediatric Anaesthesia Emergency Delirium (PAED) scale and was not significantly different between groups ($p=0.266$). The only significant finding was that after tonsillectomy, the VR-E group required less postoperative rescue analgesia (55%) compared to controls (95.7%; $p=0.002$). In this study, VR-E did not significantly reduce postoperative anxiety, postoperative pain, or emergence delirium compared to standard care, but was associated with a reduction in postoperative rescue analgesia after tonsillectomy. The strengths of this study included a large sample size, limited missing data, standardized assessment tools, blinding of participating staff, and a narrow range of surgical procedures. However, the study also had limitations, including the use of only one postoperative assessment, the lack of measurement of satisfaction with VR-E, a large number of children discontinuing study participation ($n=21$), and the exclusion of the most anxious children in the study population.

Yaz et.al. conducted a randomized control trial following CONSORT guidelines, with 132 children block randomized into 3 equal groups: educational animation VR ($n=44$), documentary VR ($n=44$), and control ($n=44$). The study used validated assessment tools including the Children's Fear Scale and Wong-Baker Faces Pain Rating Scale, administered through an information form.[14] A short, animated video was shown to the educational animation VR group (AG) to educate participants on preoperative and postoperative procedures. It covered the step-by-step process from the child's initial hospital visit for examination and vital sign checks, wearing a surgical gown, going to the operating room, and postoperative care including pain assessment. The documentary VR group (DG) saw a short documentary video with instrumental music that included forests, trees, and flowers. The documentary film was chosen by the researchers and consultant based on the

cognitive levels of the children. The control group (CG) received routine care.[14] At baseline, there were no significant differences between the three groups in mean self-reported (AG 2.89 ± 0.72 , DG 2.82 ± 0.58 , CG 2.98 ± 0.66 ; $p < 0.001$) and parent-reported fear scores (AG 2.77 ± 0.71 , DG 2.52 ± 0.62 , CG 2.68 ± 0.67 ; $p < 0.001$). After watching the video, the animation group had significantly decreased self- and parent-reported mean fear scores (decrease from 2.89 ± 0.72 to 0.91 ± 0.85 and 2.77 ± 0.71 to 1.3 ± 0.76 , respectively; $p < 0.001$). The differences in the change in fear scores between pre- and post-video were significantly greater for the educational animation group compared to the documentary ($p < 0.001$ for child and parent ratings) and control groups ($p < 0.001$ for child and parent ratings). Intergroup comparison of mean pain scores showed an overall difference between groups ($p < 0.001$). Based on children's self-reports, pain scores were lower in the animation group compared to control and documentary, with no difference between the documentary and control groups ($p = 0.097$). However, both parent and nurse evaluations of children's pain found that scores were lower in the animation versus documentary and control groups. Additionally, parents and nurses reported a statistically significant difference in pain scores between documentary and control groups ($p = 0.035$ for parents, $p = 0.029$ for nurses), unlike the children's self-reports. In this study, VR-E was effective in reducing preoperative fear and postoperative pain. While this intervention shows promise, larger studies are needed to better assess the value of this therapy.

GUIDED RELAXATION-BASED VR (VR-GR)

Combining strategies of traditional mind–body therapies, such as relaxation, slow breathing, mindfulness, and biofeedback, with the immersive nature of VR opens new possibilities for multimodal analgesia and has the potential to simultaneously minimize acute postoperative pain and opioid consumption. VR-GR is a promising mechanism to deliver mind–body-based therapy (guided relaxation) and potentially enhance the effectiveness of these techniques to promote pain relief.[30]

Olbrecht et al. provided a single 10-minute VR-GR session to 51 children and adolescents after surgery using the Mindfulness Aurora application, an application that provides a guided

relaxation session.[18] Patients were followed by the Acute Pain Service and completed the Pain Catastrophizing Scale for Children (PCS-C) and Child Anxiety Sensitivity Index (CASI) before the intervention. Using the Mindfulness Aurora application, which provides a guided relaxation session, the study assessed changes in pain intensity (primary outcome) and pain unpleasantness and anxiety (secondary outcomes) at immediate, 15-minute, and 30-minute post-intervention timepoints. Pain intensity decreased immediately ($p<0.001$) and at 30-minutes ($p=0.04$) following the session, but not at 15-minutes ($p=0.16$) after VR-GR compared to baseline. Pain unpleasantness decreased at all evaluated time points ($p<0.001$). Anxiety decreased immediately ($p=0.02$) but not at 15- or 30-minutes after VR-GR. Patients with higher anxiety sensitivity scores had greater reductions in pain intensity ($p=0.04$) and unpleasantness ($p=0.01$). This study also assessed patient and parent satisfaction with VR. Overall, 96% of children would recommend VR and 88% believed they felt calmer and could better tolerate pain after VR-GR. Parents reported similarly positive experiences. While this is the first study to combine VR with mind-body therapy for pediatric postoperative pain, limitations of this study included the lack of a control group, potential interaction effects with the study team, no data on analgesic use, variable timing of the postoperative visit, and potential bias in self-reported outcomes. In addition, given that this study was not a randomized clinical trial, no causative relationships between VR-GR and effects on pain and anxiety can be drawn. However, this pilot study provides initial evidence that a single VR-GR session is associated with a reduction in pain intensity and unpleasantness in children after surgery. These effects were immediate and sustained for up to 30-minutes after the experience. This study also lays the foundation for and highlights the need for a randomized controlled trial assessing the use of VR-GR to reduce pain, anxiety, and opioid consumption in children and adolescents having surgery.

BIOFEEDBACK-BASED VR (VR-BF)

More recently, biofeedback-based VR (VR-BF) has emerged as a potentially novel method to reduce pain, anxiety, and opioid consumption in children after surgery. Biofeedback (BF), a nonpharmacological, complementary therapy, teaches patients skills necessary for behavioral adjustments that affect involuntary systems. Slow breathing, for example, increases heart rate

variability (HRV), which reduces pain by downregulation of the sympathetic nervous system.[19] VR-BF is a technique that uses VR to deliver BF, thereby increasing the immersion of this therapy. To date, no randomized clinical trial has been performed utilizing VR-BF for pain and anxiety management and, as such, it remains unclear how this therapy needs to be integrated in perioperative management.

Orgil et al. proposes a single-center, randomized pilot trial with 70 patients, aged 12-18 years, undergoing surgery expected to cause moderate-severe pain requiring at least one night of hospitalization. Participants will be randomized to VR-BF using the ForeVR VR platform for breathing exercises (n=35) or control group using the Manage My Pain, a commercially available pain management application (n=35).[31] VR-BF will be used preoperatively for education and training, and postoperatively for pain management. The primary outcome focuses on feasibility metrics including recruitment, enrollment, retention, and protocol adherence, while secondary outcomes assess VR-BF acceptability and pilot efficacy measures including pain, anxiety, and opioid consumption. Participants will document session usage and pain, and anxiety measures using the numerical rating scale. Some limitations of this planned study include limits in generalizability, both based on the specific patient population used as well as the academic healthcare setting. Nevertheless, if feasibility of this intervention is demonstrated, a larger clinical efficacy trial will then be warranted.

VIRTUAL REALITY COGNITIVE BEHAVIORAL THERAPY (VR-CBT)

VR can also be used as a tool in conjunction with cognitive behavioral techniques (CBT) to manage pain. By combining VR environments with cognitive strategies, individuals can learn to identify and challenge negative thoughts and emotions associated with pain. This approach modifies the perception and interpretation of pain, leading to reduced suffering.[32] VR-CBT combines many of the prior-mentioned principles of other VR strategies that help the patient focus on biofeedback (breathing pattern), while also providing distraction and immersive enjoyment. The FDA recently approved the use of a VR-CBT device for use in adult patients with diagnosed chronic back pain, however, the use of this technique in pediatric patients has not yet been explored.

Implementation Challenges and Clinical Integration

While VR shows promise for pediatric pain management, there are also potential barriers to the widespread implementation of VR devices, such as cost, access to technology, and staff training requirements. These challenges can significantly impact the adoption and sustainability of VR programs in healthcare settings and must be addressed for successful clinical implementation.

Financial considerations present a significant initial barrier. Initial costs include purchasing VR headsets, software licenses, and the necessary infrastructure to support the technology.[33] For many healthcare systems, particularly those in underserved areas, these expenses can be prohibitive.[34] In addition, ongoing operating expenses, including maintenance and software updates, and replacement of worn components must be considered as well.[33,35] Access to VR technology poses another barrier, disparities in technology availability can exacerbate existing inequalities in patient care. Hospitals in urban areas may be more likely to secure funding for advanced technologies like VR compared to those in rural or underserved urban settings.[35] These inequities in access may limit the potential benefits of VR and hinder universal integration into pediatric pain management and therapeutic programs. In the healthcare facilities that are able to implement VR, additional logistical challenges must be considered, such as the need for dedicated spaces where the technology can be utilized safely and effectively, as well as dedicated spaces for proper storage of VR devices while maintaining proper infection control protocols. Inadequate space or resources to support these conditions further complicates the availability and utilization of VR. [33,36]

Lastly, staff training represents another crucial consideration for successful VR implementation. Proficiency in VR equipment setup, maintenance, and troubleshooting is necessary to ensure proper patient use.[37] This training must be integrated into existing staff education programs while minimizing disruption to clinical care. Clear protocols must be established for documenting VR usage in medical records and coordinating care between team members. Healthcare organizations must carefully consider these financial, technical, and training challenges when developing implementation strategies to ensure successful and sustainable VR program integration into clinical

practice.

Discussion

Principal Findings

This review highlights VR's potential as a complementary tool for pediatric perioperative pain, with evidence supporting short-term reductions in pain and anxiety—particularly in anxious or younger patients. However, effects are often transient (15–30 minutes) and limited by variability in protocols, hardware challenges, and a lack of standardized dosing. While promising, larger studies are needed to optimize VR integration, including repeated sessions, objective pain measures, and cost-effective implementation tailored to surgical context and developmental stage. Collaboration between clinicians and developers will be critical to advance this field.

In this narrative review, we analyzed 8 studies using VR as an intervention for perioperative pain and anxiety management in pediatric patients. Out of these, 6 were randomized controlled trials and 2 were prospective pilot studies. The studies investigated various VR modalities including VR distraction (VR-D), guided relaxation-based VR (VR-GR), and VR exposure (VR-E). Two prospective pilot studies from Olbrecht et al. demonstrated promising preliminary results. In their VR-D study, they found that there was immediate decrease in pain intensity that lasted up to 15 minutes post-intervention, as well as pain unpleasantness reduction persisting for 30 minutes. The VR-GR trial found similar transient reductions in pain intensity and anxiety but was not clinically significant (defined as a reduction of ≥ 2 points on the NRS or 30% reduction in pain). The transient nature of VR's analgesic effects warrants careful consideration in future research and clinical applications. The finding that pain relief diminishes within 15-30 minutes post-intervention suggests that the mechanisms of VR-mediated pain relief may be primarily active during the immersive experience. Several factors could influence the duration of pain relief, including the type of VR content (distraction versus guided relaxation), level of patient engagement, and timing of the intervention relative to pain peaks. The observation that patients with higher anxiety sensitivity scores experienced greater pain reduction suggests that patient characteristics may also play a role in the sustainability of VR's effects. Understanding these factors is crucial for optimizing VR

interventions and potentially extending their therapeutic benefits.

Among the randomized controlled trials, Buyuk et al. found that patients who underwent circumcision and used VR had significant reduction in anxiety and fear scores both pre- and post-operatively, with reduced postoperative pain scores as measured by the Wong-Baker Scale. Specht et al. demonstrated VR's superiority for immediate postoperative pain management over iPad use, with notably better outcomes in younger patients despite a higher withdrawal rate. Kumari et al. specifically assessed immersive versus non-immersive VR during dental procedures, finding both methods effective for anxiety reduction but superior pain control with immersive VR during intraoral injections. Eijlers et al. conducted a larger trial to investigate the VR exposure before elective day care surgery. While they found no significant impact on anxiety or emergence delirium, they did observe a clinically important reduction in rescue analgesia following more painful surgeries. Yaz and Yilmaz found that educational animated VR movies effectively reduced both preoperative fear and postoperative pain scores compared to control groups. The ongoing trial by Orgil et al. is investigating the feasibility of perioperative biofeedback-based VR integration.

Limitations and Generalizability

Several important limitations were noted across these studies. First, the lack of standardization in VR session timing and duration makes comparisons across studies challenging. Future studies should establish protocolized VR dosing schedules. Second, potential self-reporting bias in pain assessments may affect reliability, particularly in younger children. While some studies (e.g., Buyuk et al.) used parent/researcher observations, future trials could integrate objective biomarkers (e.g., heart rate variability) to complement subjective measures. Third, varying control group designs (e.g., standard care vs. active comparators like iPads) impact interpretation of results. Meta-analyses should account for these differences through subgroup analyses. Fourth, studies by Olbrecht et al. did not evaluate changes in opioid consumption or control for pain medication usage, potentially confounding pain score reductions. Their VR sessions were also single sessions with irregular timing, limiting generalizability. Future work should track analgesics systematically and test repeated VR sessions. Fifth, in Buyuk et al.'s study, only parents and

researchers evaluated pain score measurements, introducing potential observer bias. Blinded assessors could mitigate this in future trials. Sixth, Specht et al.'s study was ended prematurely because of the COVID-19 pandemic, had no power estimates, and might have been biased by self-selection. These issues likely reduced statistical robustness. Replication with larger, randomized samples is needed. Seventh, Eijlers et al.'s study excluded the most anxious patients (those receiving anxiolytic premedication), potentially underestimating VR's effects in high-anxiety populations. They also reported that 21 children (particularly ages 4–5) discontinued due to bulky headsets. Newer, child-specific VR hardware may improve adherence. Finally, Orgil et al.'s study noted that academic hospital settings and specific demographics limited generalizability. Community-based trials are warranted to assess real-world applicability.

Major versus minor surgeries

While this narrative review encompassed studies looking at a wide variety of types of surgeries, further analysis into the efficacy of VR interventions on type of surgery could help provide clearer guidelines for patient selection for VR use for pain management. A systemic review and meta-analysis by Ding et al classified studies, mostly utilizing distraction-based VR, into major and minor surgery groups based on prior literature, finding that VR was able to reduce pain after both major and minor surgeries. However, the specific efficacy of pain relief may vary, since major surgery puts a greater degree of pain stimulus on patients, resulting in a higher degree of pain intensity.[38] Thus, the type of surgery is an important consideration into whether a patient should be offered VR therapy for pain management, as its efficacy can vary based on baseline pain.

Long-term Efficacy and Follow-up

While the current evidence suggests VR as a promising non-pharmacological intervention for perioperative pain management in pediatrics, the transient nature of its analgesic effects remains a significant consideration. The feasibility of repeated VR sessions in the pediatric perioperative period have not yet been explored, the feasibility of repeated VR sessions in other settings have been assessed. A randomized controlled trial performed by McConnell et al explored the feasibility

of incorporation of guided relaxation-based VR into a physical therapy program for chronic back pain.[39] Patients in the VR group engaged in 12 sessions, 21 minutes each, over the course of 6 weeks. Results of this study suggests that repeated VR sessions over multiple weeks may be acceptable and feasible. Another study by Malik et al involved eight, 35-minute interactive, distraction-based VR sessions over a 4-week period as an intervention for chronic pain in patients with multiple sclerosis. This study concluded that repeated VR sessions are feasible.[40,41] While these studies are not specific for pediatric perioperative pain management, they do suggest that repeated VR sessions are feasible, however, studies specifically addressing repeated VR use in the perioperative period are warranted to understand optimal timing and frequency of interventions for maximizing therapeutic value in this unique clinical context.

Comparison with Other Non-Pharmacological Methods

VR offers unique advantages compared to traditional non-pharmacological pain management approaches. Unlike music therapy, which primarily provides passive distraction, VR creates an immersive environment that actively engages multiple sensory systems.[42] While cognitive-behavioral therapy (CBT) requires multiple sessions to develop coping strategies, VR can provide immediate pain relief through distraction and may be more engaging for pediatric patients. [43] However, VR's higher cost and technical requirements may limit its accessibility compared to simpler interventions like music therapy or guided imagery. These comparisons highlight VR's potential role as a complementary tool within a comprehensive pain management strategy rather than a replacement for existing approaches.

Future Directions

Future research should monitor analgesic consumption and integrate objective pain assessments while evaluating cost-effectiveness and implementation strategies in clinical settings. Future developments should focus on creating standardized protocols for different surgical procedures and age groups, developing more ergonomic and child-friendly VR devices, and establishing clear guidelines for optimal timing and duration of VR interventions. Collaboration

between healthcare providers, VR developers, and researchers will be essential to create age-appropriate content and address current technical limitations. Additionally, larger multi-center trials are needed to validate these findings across diverse patient populations and clinical settings. The collective findings from these studies provide a foundation for future research while highlighting the potential use of VR technology in pediatric pain management.

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Abbreviations:

BF: Biofeedback

CAM-S: Children's Anxiety Meter Scale

CAU: Care as usual

CBT: Cognitive behavioral therapy

CFS: Children's Fear Scale

DTAC: Digital technology acceptance criteria

FLACC: Face, Legs, Activity, Cry, Consolability

FPS-R: Faces Pain Scale-revised

HRV: Heart rate variability

MCDAS(f): Faces version of Modified Child Dental Anxiety Scale

mYPAS: Modified Yale Preoperative Anxiety Scale

NICE: National Institute for Health and Care Excellence

PACU: Postoperative anesthesia care unit

PAED: Pediatric Anesthesia Emergency Delirium Scale

PHBQ-AS: Post Hospitalization Behavior Questionnaire for Ambulatory Surgery

PPAS: Persistent pain after surgery

PPPM: Parents Postoperative Pain Measure

STAI: State Trait Anxiety 6-question short form

VAS: Visual Analog Scale

VR: Virtual Reality

VR-BF: Virtual Reality-Biofeedback

VR-CBT: Virtual Reality-Cognitive Behavioral Therapy

VR-D: Virtual Reality-Distraction Therapy

VR-E: Virtual Reality-Exposure Therapy

VR-GR: Virtual Reality-Guided Relaxation-based Therapy

WBS: Wong Baker FACES Pain Rating Scale

References

1. Forgeron PA, Finley GA, Arnaout M. Pediatric pain prevalence and parents' attitudes at a Cancer Hospital in Jordan. *J Pain Symptom Manage*. 2006;31(5):440-448.
2. Taylor EM, Boyer K, Campbell FA. Pain in hospitalized children: A prospective cross-sectional survey of pain prevalence, intensity, assessment and management in a Canadian pediatric teaching hospital. *Pain Res Manag*. 2008;13(1):25-32.
3. Cummings EA, Reid GJ, Finley AG, McGrath PJ, Ritchie JA. Prevalence and source of pain in pediatric inpatients. *Pain*. 1996;68(1):25-31.
4. Gan TJ. Poorly controlled postoperative pain: Prevalence, consequences, and prevention. *J Pain Res*. 2017;10:2287–2298.
5. Kozlowski LJ, Kost-Byerly S, Colantuoni E, et al. Pain prevalence, intensity, assessment and management in a hospitalized pediatric population. *Pain Manag Nurs Off J Am Soc Pain Manag Nurses*. 2014;15(1):22-35.
6. Harbaugh CM, Lee JS, Hu HM, et al. Persistent opioid use among pediatric patients after surgery. *Pediatrics*. 2018;141(1):e20172439.
7. Pagé MG, Stinson J, Campbell F, Isaac L, Katz J. Identification of pain-related psychological risk factors for the development and maintenance of pediatric chronic postsurgical pain. *J Pain Res*. 2013;6:167-180.
8. Fortier MA, Chou J, Maurer EL, Kain ZN. Acute to chronic postoperative pain in children: preliminary findings. *J Pediatr Surg*. 2011;46(9):1700-1705.
9. Rabbitts JA, Fisher E, Rosenbloom BN, Palermo TM. Prevalence and predictors of chronic postsurgical pain in children: A systematic review and meta-Analysis. *J Pain*. 2017;18(6):605-614.
10. Dorkham MC, Chalkiadis GA, von Ungern Sternberg BS, Davidson AJ. Effective postoperative pain management in children after ambulatory surgery, with a focus on tonsillectomy: barriers and possible solutions. *Paediatr Anaesth*. 2014;24(3):239-248.
11. Rabbitts JA, Zhou C, Groenewald CB, Durkin L, Palermo TM. Trajectories of postsurgical pain in children: risk factors and impact of late pain recovery on long-term health outcomes after major surgery. *Pain*. 2015;156(11):2383-2389.
12. Callinan CE, Neuman MD, Lacy KE, Gabison C, Ashburn MA. The initiation of chronic opioids: A survey of chronic pain patients. *J Pain*. 2017;18(4):360-365.
13. Manchikanti L, Singh A. Therapeutic opioids: a ten-year perspective on the complexities and complications of the escalating use, abuse, and nonmedical use of opioids. *Pain Physician*. 2008;11(2 Suppl):S63-88.
14. Yaz ŞB, Yilmaz HB. The Effects of Designing an educational animation movie in virtual reality on preoperative fear and postoperative pain in pediatric patients: A randomized controlled trial. *J Perianesth Nurs*. 2022;37(3):357-364.
15. Olbrecht VA, O'Connor KT, Williams SE, et al. Transient reductions in postoperative pain and anxiety with the use of virtual reality in children. *Pain Med*. 2021;22(11):2426-2435.
16. Buyuk ET, Odabasoglu E, Uzsen H, Koyun M. The effect of virtual reality on Children's anxiety, fear, and pain levels before circumcision. *J Pediatr Urol*. 2021;17(4):567.e1-8.
17. Eijlers R, Dierckx B, Staals LM, et al. Virtual reality exposure before elective day care surgery to reduce anxiety and pain in children: A randomised controlled trial. *Eur J Anaesthesiol*. 2019;36(10):728-737.
18. Olbrecht VA, O'Connor KT, Williams SE, et al. Guided relaxation-based virtual reality for acute postoperative pain and anxiety in a pediatric population: Pilot observational study. *J Med Internet Res*. 2021;23(7):e26328.
19. Orgil Z, Karthic A, Bell N, et al. Dataset used to refine a treatment protocol of a biofeedback-based virtual reality intervention for pain and anxiety in children and adolescents undergoing surgery. *Data Brief*. 2023;49:109331.
20. Gold JI, Belmont KA, Thomas DA. The neurobiology of virtual reality pain attenuation. *Cyberpsychology Behav Impact Internet*. 2007;10(4):536-544.
21. Hoffman HG, Richards TL, Van Oostrom T, et al. The analgesic effects of opioids and

- immersive virtual reality distraction: evidence from subjective and functional brain imaging assessments. *Anesth Analg*. 2007;105(6):1776-1783.
22. Bantick SJ, Wise RG, Ploghaus A, Clare S, Smith SM, Tracey I. Imaging how attention modulates pain in humans using functional MRI. *Brain J Neurol*. 2002;125(Pt 2):310-319.
 23. Hoffman HG, Richards TL, Coda B, et al. Modulation of thermal pain-related brain activity with virtual reality: evidence from fMRI. *Neuroreport*. 2004;15(8):1245-1248.
 24. Tashjian VC, Mosadeghi S, Howard AR, et al. Virtual reality for management of pain in hospitalized patients: Results of a controlled trial. *JMIR Ment Health*. 2017;4(1):e9.
 25. Eccleston C. Chronic pain as embodied defence: implications for current and future psychological treatments. *Pain*. 2018;159 Suppl 1:S17-S23.
 26. Spiegel B, Fuller G, Lopez M, et al. Virtual reality for management of pain in hospitalized patients: A randomized comparative effectiveness trial. *PloS One*. 2019;14(8):e0219115.
 27. Specht BJ, Buse CR, Phelps JR, et al. Virtual reality after surgery-A method to decrease pain after surgery in pediatric patients. *Am Surg*. 2023;89(4):596-602.
 28. Kumari S, Bahuguna R, Garg N, Yeluri R. Immersive and non-immersive virtual reality distraction on pain perception to intraoral injections. *J Clin Pediatr Dent*. 2021;45(6):389-394.
 29. Krzystanek M, Surma S, Stokrocka M, et al. Tips for effective implementation of virtual reality exposure therapy in phobias—A systematic review. *Front Psychiatry*. 2021;12:73735.
 30. Olbrecht VA, Williams SE, O'Connor KT, et al. Guided relaxation-based virtual reality versus distraction-based virtual reality or passive control for postoperative pain management in children and adolescents undergoing Nuss repair of pectus excavatum: protocol for a prospective, randomised, controlled trial (FOREVR Peds trial). *BMJ Open*. 2020;10(12):e040295.
 31. Orgil Z, Johnson L, Karthic A, et al. Feasibility and acceptability of perioperative application of biofeedback-based virtual reality versus active control for pain and anxiety in children and adolescents undergoing surgery: protocol for a pilot randomised controlled trial. *BMJ Open*. 2023;13(1):e071274.
 32. Noble T, Boone L, El Helou A. The role of virtual reality as adjunctive therapy to spinal cord stimulation in chronic pain: A feasible concept? *Front Pain Res*. 2023;4:1094125.
 33. Kouijzer MMTE, Kip H, Bouman YHA, Kelders SM. Implementation of virtual reality in healthcare: a scoping review on the implementation process of virtual reality in various healthcare settings. *Implement Sci Commun*. 2023;4(1):67.
 34. Hoffman HG, Meyer WJ, Ramirez M, et al. Feasibility of articulated arm mounted oculus rift virtual reality goggles for adjunctive pain control during occupational therapy in pediatric Burn patients. *Cyberpsychology Behav Soc Netw*. 2014;17(6):397-401.
 35. Garrett B, Taverner T, McDade P. Virtual reality as an adjunct home therapy in chronic pain management: An exploratory Sstudy. *JMIR Med Inform*. 2017;5(2):e11.
 36. Li L, Yu F, Shi D, et al. Application of virtual reality technology in clinical medicine. *Am J Transl Res*. 2017;9(9):3867-3880.
 37. Trost Z, Zielke M, Guck A, et al. The promise and challenge of virtual gaming technologies for chronic pain: the case of graded exposure for low back pain. *Pain Manag*. 2015;5(3):197-206.
 38. Ding L, Hua H, Zhu H, et al. Effects of virtual reality on relieving postoperative pain in surgical patients: A systematic review and meta-analysis. *Int J Surg*. 2020;82:87-94.
 39. McConnell R, Lane E, Webb G, LaPeze D, Grillo H, Fritz J. A multicenter feasibility randomized controlled trial using a virtual reality application of pain neuroscience education for adults with chronic low back pain. *Ann Med*. 56(1):2311846.
 40. Malik M, Shaw M, Palmeri M, Charvet L. Virtual reality as an intervention for chronic pain in multiple sclerosis. *Neurology*. 2021;96(supplement):4626.
 41. Shaw MT, Palmeri MJ, Malik M, Dobbs B, Charvet LE. Virtual reality is a feasible intervention platform in multiple sclerosis: A pilot protocol and acute improvements in affect. *Mult Scler J - Exp Transl Clin*. 2021;7(2):20552173211006139.

42. Won AS, Bailey J, Bailenson J, Tataru C, Yoon IA, Golianu B. Immersive virtual reality for pediatric pain. *Children*. 2017;4(7):52.
43. Indovina P, Barone D, Gallo L, Chirico A, De Pietro G, Giordano A. Virtual reality as a distraction intervention to relieve pain and distress during medical procedures: A comprehensive literature review. *Clin J Pain*. 2018;34(9):858-877.



Table 1: Characteristics and findings of virtual reality studies for pediatric perioperative pain management

Study	Design	Population/Sample Size	VR Modality	Key Findings	Limitations
Olbrecht et al.	Single-center, prospective pilot study	50 children post-surgery (38% abdominal, 34% chest, 28% orthopedic); Ages 7-21 years	Distraction-based VR (VR-D) with choice of games	Pain intensity decreased immediately ($p<0.0001$) and at 15 min ($p=0.02$); Pain unpleasantness decreased up to 30 min ($p=0.0001$); Anxiety decreased up to 15 min ($p=0.0014$)	No control group; Single VR session; Variable timing of sessions; Heterogeneous population; No analgesic use data
Buyuk et al.	Randomized controlled trial	78 boys undergoing circumcision (40 VR, 38 control); Ages 5-10 years	VR-D (Amazon rainforest/water skiing simulation)	Reduced CAM-S and CFS scores pre/post-surgery; Lower postoperative WBS scores in VR group	Analgesic consumption not tracked; Limited pain score measurements; Only parent and researcher evaluations
Specht et al.	Randomized controlled trial	106 patients (50 VR, 56 iPad); Ages 7-18 years	VR-D using Treks Nature VR	Lower FLACC scores with VR vs iPad ($p=0.021$); Better response in younger patients (7-12 years); No difference in opioid consumption	Premature termination (COVID-19); Self-selection bias; Multiple assessors
Kumari et al.	Randomized controlled trial	200 children (100 immersive VR, 100 non-immersive); Ages 6-12 years	VR-D during dental procedures	Lower pain with immersive VR (VAS 0.75 ± 0.88 vs 2.72 ± 0.99); Reduced anxiety in both groups	Device size limitations; No analysis of immersion time
Eijlers et al.	Single-center, single-blinded RCT	191 children (94 VR-E, 97 control); Ages 4-12 years	Exposure-based VR (VR-E) mimicking OR environment	No effect on anxiety/pain/delirium; Reduced rescue analgesia after tonsillectomy (55% vs 95.7%, $p=0.002$)	Single postoperative assessment; High discontinuation rate ($n=21$); Excluded most anxious

Study	Design	Population/Sample Size	VR Modality	Key Findings	Limitations
					patients
Yaz et al.	Randomized controlled trial	132 children (44 educational VR, 44 documentary VR, 44 control); Ages 6-12 years	VR-E and VR-D	Lower pain scores in animation group; Significant reductions in preoperative fear	Limited assessment timepoints; Further validation needed
Olbrecht et al.	Pilot observational study	51 children post-surgery; Ages 7-21 years	Guided relaxation-based VR (VR-GR) using Mindfulness Aurora application	Pain intensity decreased immediately (p<0.001) and at 30 min (p=0.04); Pain unpleasantness decreased at all timepoints; Anxiety decreased immediately (p=0.02)	No control group; Variable timing; No analgesic data; Single session
Orgil et al.	Proposed randomized pilot trial	70 adolescents (35 VR-BF, 35 control); Ages 12-18 years	Biofeedback-based VR (VR-BF)	Study ongoing - Primary outcome: feasibility of VR-BF integration	Limited generalizability; Specific age group; Academic setting

This table presents a comprehensive overview of 8 published studies investigating virtual reality (VR) interventions for perioperative pain management in pediatric populations. The study designs include 6 randomized controlled trials (RCTs) and 2 prospective observational pilot studies, with sample sizes ranging from 50 to 200 participants. The patient populations encompass children and adolescents aged 4-21 years undergoing various procedures including major surgeries (abdominal, chest, orthopedic), minor procedures (circumcision, dental interventions), and day surgeries (ENT, maxillofacial). Four distinct VR modalities are represented: distraction-based VR therapy (VR-D), exposure-based VR therapy (VR-E), guided relaxation-based VR therapy (VR-GR), and biofeedback-based VR therapy (VR-BF). Intervention timing varied across studies, with applications occurring pre-operatively, immediately post-operatively in PACU, or during later recovery phases. Primary outcomes assessed include pain intensity and unpleasantness using validated pediatric measures (NRS, VAS, Wong-Baker FACES, FLACC), anxiety scores (STAI, CFS, CAM-S), and analgesic consumption. Key methodological limitations are noted for each study, highlighting challenges in the current evidence base including heterogeneous interventions, variable assessment timing, and inconsistent control conditions. These studies collectively demonstrate preliminary evidence for VR's potential in reducing pediatric perioperative pain and anxiety, with effects that appear time-limited and potentially influenced by patient characteristics such as

age and baseline anxiety.

