

Review Article

Virtual Reality (VR) in Medicine: A Systematic Review of Current Applications of VR and Potential Applications to Pediatric Orthopaedic Surgery

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BACKGROUND

One of the most interesting emerging trends in healthcare is the use of virtual reality (VR) as a modality for pediatric pain management—with additional applications including anxiety, fear, and other strong emotions related to healthcare states. VR has been used for pain relief in chronic pathologies such as sickle cell disease, during procedures like blood draws, and post-operatively. In orthopaedics, bone pin and cast removal are common clinical procedures that are associated with anxiety and discomfort, especially in pediatric populations. Virtual reality may serve a purpose as a distraction to reduce the anxiety and fear that patients experience during those procedures. In this review, we aim to report the state of VR as it applies to pediatric healthcare and make recommendations for areas of future exploration, such as in orthopaedic surgery.

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Dr. Seeley earned his medical degree from Thomas Jefferson University. He completed his residency in orthopaedic surgery at the University of Michigan Hospitals and Health Centers, and a fellowship in pediatric orthopaedics at the Children's Hospital of Philadelphia. He is certified by the American Board of Orthopaedic Surgery.

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Methods

A systematic search query was conducted in the databases PubMed and Embase using the terms “virtual reality” AND “pediatrics” AND “pain.” Between both databases, 303 articles were returned. Titles and abstracts were reviewed to screen for relevant articles and duplicate articles were eliminated, resulting in the final inclusion of 76 articles in a summary table.

Results

Immersive VR was used in 64% of studies (n=49) and Gameplay VR was used in 25% of the studies (n=19). Most VR use occurred during the medical procedure (n=56). The most common application of VR to date has been pain (n=67), followed by anxiety (n=45), and then fear (n=12). The most common conditions that VR was used for were venipuncture (n=26), burn wound care (n=13), surgical procedures (n=11), and dental procedures (n=9).

Conclusions

While heavily reported on, procedures such as venipuncture and wound care are not the only potential application for VR intervention. Given the favorable findings of pain, anxiety and fear reduction in other areas, we recommend continuing to explore the use of VR in orthopaedic settings, such as bone pin and cast removal. There may be further benefit from VR use in fracture reduction and post-operative pain management. The potential for VR to improve clinical experiences for patients is yet to be fully appreciated and uncovering applications in new areas of medicine will help to benefit a greater patient population.

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INTRODUCTION

Patients undergo a variety of invasive medical procedures annually, ranging from venipuncture to surgery under general anesthesia (Ploghaus et al. 2001). A considerable proportion of these interactions are associated with anxiety and pain, both of which can influence patient behavior and subsequently impact recovery and long-term health outcomes (Meentken et al. 2017). Unfortunately, these feelings are especially true in pediatric populations, which can lead to fear and distress in medical environments. To help prevent these feelings and complications, methods to alleviate emotion through distraction or education should be investigated. Technological innovations, such as virtual reality (VR), provide the opportunity to improve the experience of children in this regard.

The advent of VR as a healthcare tool over the past decade has brought with it an explosion of research forays into new applications of the technology. One of the most interesting that has emerged is VR as a modality for pediatric pain management—with other ideas in this area in-

cluding anxiety, fear, and other strong emotions related to healthcare states. VR has been used as a pain management tool for chronic conditions, such as sickle cell disease, during procedures like blood draws, and for post-operative pain management. The versatility of VR makes it a feasible option for pain management, offering distraction to decrease levels of fear and anxiety, and may apply broadly across age groups.

Given the increasing advantages of VR, it is crucial to explore the unique applications in the field of medicine. For example, in orthopaedics, bone pin and cast removal are common clinical procedures that are associated with anxiety and discomfort, especially in pediatric populations. Virtual reality may serve a purpose as a distraction to reduce the anxiety and fear that patients experience during those procedures. VR is a difficult area to investigate, as no standards currently exist to describe its applications, clinical use, or outcome metrics. Furthermore, several different intervention categories exist under the VR umbrella, and each has been used at various procedural timepoints. In this review, we aim to report on the state of VR as it applies



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to pediatric healthcare and make recommendations for areas of future exploration, such as orthopaedic surgery.

METHODS

A search query was conducted in the databases PubMed and Embase using the terms “virtual reality” AND “pediatrics” AND “pain.” A systematic review format was followed, guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Reference lists of relevant articles were compared to prevent missing or overlapping literature. Inclusion criteria were defined as study subject age less than or equal to 25 years and the study intervention was use of VR. Exclusion criteria included articles with subjects greater than 25 years of age and lack of VR as an intervention. Between both databases, 303 articles were returned. Titles and abstracts were reviewed to screen for relevant articles, duplicate articles were eliminated, resulting in the final inclusion of 76 articles (Figure 1). Full texts of those 76 articles were analyzed and data regarding year of publication, the ages of the cohort, conditions where the VR was used, questionnaires used to determine pain/anxiety/fear, the type of VR used, and the timing of the VR intervention was synthesized and recorded in a summary table.

RESULTS

1. MODALITIES

a. IMMERSIVE

- Immersive VR, where patients are subjected to a number of interactive landscapes and environments, was used in 64% of studies (n=49), where study subjects are placed in landscapes with attractive scenery but no objective other than to interact with the environment (Wong, Lui, and Choi 2019).

b. SIMULATION

- Another mechanism of use within the VR platform is to simulate interventions for psychotherapy, with studies showing applications for the development of coping mechanisms for aversive stimuli in rehabilitation, generalized anxiety disorder, and prevention and treatment of eating disorders (Parsons et al. 2007). Three studies used VR to simulate imaging procedures or anesthesia in pediatric patients as a

means of preparation—thus reducing anxiety and fear.

c. DOME SCREEN

- While all other variations of VR have used head-mounted devices (HMDs) for delivery, one study found VR using a dome screen to be effective at distraction during intravenous placement in children from 2-6 years of age (Lee et al. 2021). Importantly, this shows that for younger patients or those who will not comply with an HMD, there are still modalities for delivering VR and the same benefits may still apply.

d. GAMEPLAY

- Gameplay VR, where subjects can interact and play games within the virtual environment, was used in 25% of the studies (n=19). A study of pediatric patients undergoing venipuncture found significant reductions in pain intensity when VR was administered as a multiple object tracking (MOT) task (Piskorz and Czub 2018).

2. TIMEPOINTS

a. INTRAPROCEDURAL

- Most VR use occurred during the medical procedure (n=56), with previous reviews in this area showing efficacy of VR in relieving pain and anxiety in pediatric patients through the mechanism of distraction—but in the same breath called for additional research into VR as a pre-procedural preparation tool (Eijlers, Utens, et al. 2019).

b. PERIPROCEDURAL

- Some studies were done both before and during the procedure (n=8), and a few more used VR only prior to the procedure (n=7), all of which found a significant reduction in perioperative anxiety (Jung et al. 2021).

c. POSTPROCEDURAL

- Several more studies used VR post-operatively for pain control (n=3), demonstrating the versatility of VR in a variety of conditions and clinical environments.

3. OUTCOME MEASURED

a. PAIN

- The most common application of VR to date has been pain relief (n=67). Most work here has

been centered around the use of needles, with VR significantly reducing pain related to intravenous cannulation and venipuncture in four separate trials (Chan et al. 2019; Dumoulin et al. 2019; Chen et al. 2020; Ustuner Top and Kuzlu Ayyıldız 2021). Further studies in this area have found similar reductions in port-related needle pain (Gerçeker et al. 2021; Semerci et al. 2021).

b. ANXIETY

- Anxiety is another widely studied application (n=45). Routine blood work has emerged as a standard highlight of the efficacy of VR, with patients reporting significant reductions in pre-procedural anxiety (Gold and Mahrer 2018). Interventions such as this, if standardized, may influence compliance rates in a population known for hesitancy with blood draws. Other applications have been shown to reduce anxiety, including VR distraction during invasive dental procedures (Shetty, Suresh, and Hegde 2019).

c. FEAR

- An interesting emerging application of VR is the reduction of fear in the medical setting (n=12). Patients in the VR intervention group of one study reported both significantly reduced pain-related fear and recalled pain-related fear after medical procedures related to burns or fractures (Le May, Hupin, et al. 2021).

4. CLINICAL APPLICATION

a. PROCEDURAL

- The most common condition that VR was used for was venipuncture (n=26), wherein it has been shown as an effective tool in fear relief, as one study found nearly 95% of patients rating improvements in anticipated procedural fear vs actual fear (Chad, Emaan, and Jillian 2018). Further use here involving children undergoing surgical procedures (n=11) found that pediatric patients exposed to VR prior to and up until induction of anesthesia were significantly less anxious than their control group counterparts (Jung et al. 2021). A study of pediatric cancer patients undergoing invasive medical procedures with either no distraction, computer screen distraction, or VR distraction found lower pain and anxiety ratings, lower pulse, and fewer observed behavior instances of distress throughout the procedure in the VR group (Gershon et al. 2003). Burn patients (n=13), children undergoing dental procedures (n=9), children with chronic pain conditions, such as sickle cell disease and inflammatory bowel diseases (n=5) have all further found relief through use of VR with respect to a combination of pain, anxiety, and fear.

b. IMAGING

- Three studies investigated imaging, with one aimed at comparing tablet and VR-based distraction in children undergoing chest radiography, finding procedure time, need for parental presence, and number of repeated procedures to be significantly lower in the VR intervention group (Ryu et al. 2021). In addition to boosting the efficacy of the imaging study, this implicates VR as potentially protective against additional radiation exposure in pediatric patients. There is room for further work here, however, as another study in this area found no reduction in anxiety when using VR in a simulated pediatric MRI scan (Stunden et al. 2021).

c. BEHAVIORAL HEALTH

- Perhaps the area with the most potential for VR therapy is psychology, and specifically neuropsychology. An emerging clinical use of VR here is as a neurocognitive assessment tool in children with ADHD and as an intervention for reducing body image disturbances in children with eating disorders (Parsons et al. 2017; Ferrer-García and Gutiérrez-Maldonado 2012).

5. OUTCOME ASSESSMENT

a. DATA SCALES

- Many of the studies in this area rely on scores from questionnaires to quantify significant outcomes such as pain, anxiety, and fear. Common indices used include the Visual Analog Scale (VAS), Wong-Baker FACES Pain Rating Scale, Face, Legs, Activity, Cry, and Consolability-Revised (FLACC) scale, Childhood Anxiety Meter (CAM), Children's Fear Scale (CFS), and the Venham situational anxiety scale (Piskorz and Czub 2018; Chen et al. 2020; Chad, Emaan, and Jillian 2018; Walther-Larsen et al. 2019; Goldman and Behboudi 2021).

b. PHYSIOLOGIC MEASUREMENTS

- Several studies also recorded or called for physiologic measurements, such as heart rate, oxygen saturation, and salivary cortisol levels to have objective assessments of pain, anxiety, and fear (Shetty, Suresh, and Hegde 2019; Stunden et al. 2021). Reductions in these metrics yield yet another way to measure efficacy of a treatment modality.

c. SATISFACTION

- One study that found no difference in pain scores between pediatric cohorts undergoing venous cannulation also measured satisfaction scores and found significantly higher satisfaction in the study group (Walther-Larsen et al. 2019). Another study in this area measuring pain and anxiety in pediatric laceration repair found that while there was no significant differ-

ence in VR as compared to standard of care (SOC), children rated the VR experience more positively (Goldman and Behboudi 2021). Even when the addition of this modality does not correlate with pain relief, it still appears to be a significant factor in the quality of the procedural experience. Therefore, while the above scales and physiologic measurements are effective at capturing changes in mental and biochemical states, they fall short of capturing the full benefit of VR.

d. CLINICAL MEASUREMENTS

- Furthermore, other outcome metrics may have more clinical relevance. One study reported a significant reduction in the need for rescue analgesia in children undergoing tonsillectomy or adenoidectomy who received VR (Eijlers, Dierckx, et al. 2019). The side effects of the medications used in these situations make this a clinically important finding. A study of patients undergoing minor surgical procedures compared the use of VR and local anesthesia to the SOC (general anesthesia) and found procedural length and pain scores to be similar but found the recovery time in the experimental arm to be significantly lower (Taylor et al. 2021).

DISCUSSION

Advances in VR technology and its applications in medicine are rapidly progressing, and this is evident in our review of the literature. Eighty-three percent of the articles included in our analysis have been published since 2018 (Figure 2). The earliest publication regarding VR was published in 2006, where it was first applied as a pediatric pain distraction for intravenous (IV) catheter placement. While the use of VR continues to expand in certain healthcare settings, so too must the applications where it can be used based on an understanding of the current state. Overall, virtual reality was found to benefit the patient's experience regarding pain, anxiety and fear in comparison to the standard of care. While heavily reported on, procedures such as venipuncture and wound care are not the only potential application for VR intervention (Figure 3). There are many other areas within medicine poised to reap the benefits of VR therapy. Prominent among them is the realm of pediatric orthopaedics, wherein procedures like bone pin removal and cast removal each contain several elements that VR has shown to improve, such as pain, fear and anxiety. However, very few studies have explored the use of this technology for orthopaedic applications (Le May, Tsimicalis, et al. 2021; Firoozabadi et al. 2020). Given the favorable findings of pain, anxiety and fear reduction in other areas, we recommend continuing to explore the use of VR in orthopaedic settings. In addition to those mentioned above, further studies should explore the potential VR ben-

efit in fracture reduction and post-operative pain management.

We found immersion and gameplay to be the most prevalent modalities of VR in pediatrics (Figure 4). Immersive and gameplay VR modalities engage users in a virtual environment that they can interact in and "disconnect" from their real world surroundings. For example, by putting on the VR headset, patients can be "placed" in a number of virtual environments, such as a variety of landscapes or locations. The underlying mechanism of how these virtual environments decrease pain stimuli was proposed by Lazarus and Folkman and used by Wong et al. to design a study for pediatric patients undergoing venipuncture. This theory suggests that spinal cord structures that transmit pain to the cerebral cortex can be overcome if there are greater sensory stimuli occurring simultaneously (Wong, Lui, and Choi 2019). Therefore, use of immersive and gameplay VR may provide adequate sensory distraction to impair afferent pain transmission, leading to decreased pain perception. However, to our knowledge, there is currently no data comparing the results of different modalities. This raises the question of whether there are differences in efficacy between types of VR, with further research necessary to elucidate these differences. We recommend further work to be aimed at comparing inter-modality efficacy.

Furthermore, there is no existing literature describing which modality is best at which time point, or at which time point a particular outcome is most significant. Tentative conclusions from the data summarized above indicate that intra-procedural and post-procedural VR may be more effective at pain relief while pre-procedural VR may be more effective at anxiety relief. This is crucial to know because it allows for the most effective implementation of the intervention. For example, pediatric patients undergoing bone pin removal are often anxious, therefore, it may be beneficial to implement a VR intervention to decrease the anxiety associated with that outpatient orthopaedic procedure. We thus recommend that future research aim to define the specific merits of VR as an intervention at each timepoint.

If VR is to succeed in the medical marketplace, algorithms must be developed to inform clinicians of which modality to use and when to use it for each desired outcome. We thus recommend that future research assess the relationship between parameters such as timepoint and modality and outcomes such as pain, anxiety and fear. Furthermore, metrics must move towards standardization for inter-study comparison in this area. As it stands, the bevy of rulers by which outcomes are reported neither capture the full effect individually nor allow for quality data to be synthesized effectively. Once these parameters are established, future work will be more capable of solidifying the specific effect of VR modalities and intervention timing on current outcomes such as pain, fear, and anxiety. The data reported in this review suggest there is room for VR to replace general anesthesia for minor procedures in the future, thereby reducing both the additional recovery time needed for general anesthesia and the potential complications that come with it. However, with so many different rulers used for effect quantification, inter-study compari-

son in this area has been significantly impeded in the past. We thus recommend future studies attempt to standardize the measurement of outcomes. Additionally, standardization would offer a concrete method for evaluating new outcomes such as the use of VR as a tool for psychotherapy. We thus recommend that future studies attempt to investigate applications of VR outside of the established paradigms.

Across the publications in our review, a total of 5043 patients were included, with an age range from 6 months to 25 years old. The age ranges of the cohorts varied significantly, with most having greater than a 5-year age gap between the youngest and oldest patients, and 13% of studies (n=10) restricting their age limits to less than four years apart between the youngest and oldest patients. More demographics are listed in Table 1, including year of publication, number of patients in the cohort, age ranges, type of VR used, and context for the use of VR. This shows the ability of VR to be applicable to various age groups and stages of development. It stands to reason that with the immersive environment adolescents are exposed to currently in the areas of computer and console-based gaming, they might be both quicker to integrate a VR treatment program and to find more total utility out of it than an older cohort. Future work should compare VR efficacy amongst age cohorts to determine if a difference exists.

Literature regarding the use of VR in pediatric settings is expanding rapidly. However, the realm of application for VR needs to be further explored in various settings, such as in outpatient orthopaedic surgery and post-operative pain management. Few institutions are exploring the use of VR in outpatient pediatric orthopaedic settings, such as bone pin, cast and suture removal, without any published results to our knowledge. There are also trials assessing its use in adult acute pain settings, such as after total knee arthroplasty. However, pediatric patients may also be at risk for chronic musculoskeletal pain. While there are currently trials in progress assessing the use of VR in chronic low back pain in adults, there may also be opportunities to determine whether VR can improve pain in various chronic pain conditions, such as overuse injuries, fibromyalgia or complex regional pain syndrome.

Additionally, there are still questions to be answered regarding the variation of VR efficacy between treatment modalities and age cohorts. The benefit of using VR to improve clinical experiences for patients is just beginning to be understood and uncovering applications in new areas of medicine will help to benefit a greater patient population.

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