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From Fear to Fascination: Using Virtual Reality to Ameliorate Pain and Anxiety in Pediatric Vascular Access Practices during Hemodialysis. A Review Article

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ABSTRACT

Pediatric patients undergoing hemodialysis (HD) frequently suffer considerable pain and anxiety during vascular access steps. Non-pharmacological tools, such as virtual reality (VR), have been illuminated as promising approaches to alleviate these negative experiences. This review presents recent research advances in understanding the power of VR in lowering pain and anxiety in pediatric HD patients. VR, a technology that immerses users in simulated environments, has been shown to successfully distract patients from painful procedures, thereby reducing pain perception and anxiety levels. Research have revealed that VR can obviously decrease pain intensity, anxiety, and better patient satisfaction during vascular access procedures. By providing immersive experiences, VR can redirect attention away from the painful stimulus, modifying the physiological and psychological reactions correlated with pain and anxiety. As VR technology remains to advance, its integration into pediatric HD care has the eventual to pointedly meliorate the quality of life for young patients submit to these procedures.

Keywords: *virtual reality, pediatric, pain, anxiety, vascular access, hemodialysis, and management.*

Abbreviations:

HD	*Hemodialysis*	***HPA***	*Hypothalamic-pituitary-adrenal*
VR	*Virtual reality*	***PTSD***	*Post-traumatic stress disorder*
CKD	*Chronic Kidney Disease*	***FLACC***	*Face, Legs, Activity, Cry, Consolability*
pmarp	*Per million of age-related population*	***FPS-R***	*Faces Pain Scale-Revised*
ESRD	*End-Stage Renal Disease*	***VAS***	*Visual Analog Scale*
CVC	*Central venous catheter*	***HMDs***	*Head-mounted displays*
AVF	*Arteriovenous fistula*	***MOT***	*Multiple Object Tracking*
AVG	*Arteriovenous graft*		

1. INTRODUCTION

During the last three decades, a more than fourfold rise in the percentage of chronic kidney disease (CKD) among pediatric patients has been registered [1]. The global incidence diverges from 55-75 cases per million of age-related population (pmarp) in Spain and Italy [2] to 14.7-103.9 pmarp for children aged between 0-21 years in the United States [3]. In the Arab countries, the prevalence rate differed from 80-120 pmarp in Saudi Arabia to 225 pmarp in Egypt [4].

End-Stage Renal Disease (ESRD) is confirmed as the end-phase CKD, where a permanent injury to the kidneys is obvious and renal replacement treatment is obligatory using peritoneal dialysis, hemodialysis (HD), or kidney transplantation [5].

HD patients, including children, experience extensive pain and anxiety from frequent needle punctures during therapy. Non-pharmacological approaches, such as distraction techniques, may lighten some of this pain [5]. Virtual Reality (VR) has developed as a rising suggesting technology for distraction by suggesting immersive experiences that prompt diversion from the medical procedure. VR can significantly lower the observation of pain and anxiety in pediatric HD patients through the simulation of real-world environments [6, 7].

Virtual reality is now among the most promising non-pharmacological interventions for pain and anxiety related to painful medical phases in children, including vascular access during HD. Its safety and rapid onset of action with few or no side effects have made it a priority to be considered as an alternative to, or prior to, drug administration in selected cases [8]. Pediatric nurses are frontline supporters of the healthcare staff and are key players in managing children's pain and anxiety. Their responsibilities include pain screening, ongoing assessment, diagnosis formulation, implementation of pharmacologic and non-pharmacologic interventions, records, and continuous inference of nursing care [9]. Therefore, this review presents recent research advances in understanding the power of VR in attenuating pain and anxiety in pediatric HD patients.

2. PEDIATRIC PAIN AND ANXIETY DURING HD.

Chronic kidney disease (CKD) is a disorder described by kidney impairment that impairs the filtration of blood, resulting in the accumulation of waste substances, within the body. CKD is usually irreversible and can be progressive, meaning it worsens over time [10]. Common causes of CKD in children younger than five years old include congenital abnormalities including obstructive uropathy, hypoplastic kidney, dysplastic kidney, and aplastic kidney. Kidney diseases in the pediatric population between the ages of five and fifteen, whether inherited or acquired, are frequently the leading causes of CKD [2].

Generally, children with CKD require specific treatments, such as peritoneal dialysis, HD, and kidney transplantation. Nearly two million patients global are dialysis-dependent, with 90% needing HD therapy [11]. HD continues to be the most important treatment option for patients suffering from kidney failure; it filters waste and excess fluid from blood. Blood is usually drawn from the child using a central venous catheter (CVC) or a surgically established arteriovenous fistula (AVF) or graft (AVG) and is passed through a dialyzer—the artificial kidney. The main problem for pediatric patients on HD is the repeated stressful, anxiety-producing, and painful events that accompany the introduction of large-bore needles into the arteriovenous fistula site [12, 13]. On average, more than 20 punctures are made in an AVF each month for a child undergoing a regular session of HD, meaning that he or she will have to face this throughout his or her lifetime [13].

Discomfort associated with potential damage to body tissues is pain, and the corresponding psychological reaction. Children undergo pain and stress as they navigate the avenues of managed disease. Generally, acute pain results from a recent, short-term injury and usually lasts fewer than six weeks. "Procedural pain and anxiety" are the term used to describe distress that arises from medical procedures, intravascular injections, vaccinations, anesthesia processing, and other needle-related methods [14].

The extent of the severity of pain can, in most cases, be attributed to psychological factors that can magnify the extent of pain subjectively experienced by the patient. The anticipation of pain before a venipuncture amplifies the nociceptive signal and is accompanied by increased pain-related brain activity. The social learning process can help develop fear responses, especially in an infant. For example, when a child observes a caregiver's feigned fear response to medical procedures, it amplifies the child's own emotional and physical responses to the same procedure, often leading to an exaggeration of the perception of pain [15].

Dialysis pediatric patients have usually been, and even still are, particularly affected by pain during intravenous procedures, especially with the duration of waiting prior to and when initiating HD. The additional pain can occur because of pre- and during-dialysis anxiety. Hence, the whole process becomes a very painful experience, as pain often results in negative, long-term repercussions. Thus, proper pain management is a priority nursing function [16].

In addition, chronic kidney disease poses a serious risk for anxiety disorders in children. It accentuates genetic and psychosocial factors stemming from the disease process, hospitalization, medical procedures, and potentially other immediate dangers. As a result, these individuals develop anxiety, which further worsens the situation by affecting one or more physiological systems, impacting development, and making adherence to treatment difficult [16, 17].

Anxiety develops when a person feels worried and apprehensive about what might happen or experiences feelings of uncertainty about an unknown future. It is during the entire treatment course of HD that most children experience anxiety. Previous studies have noted that pain, immobility, frequent needling, and other aspects of treatment can aggravate emotional distress, generally increasing fear and anxiety in these children. These negative emotions often affect children's health and prolong their hospital stays. Thus, pain relief should be coupled with proper management of anxiety among the children to enhance the quality of life they and their relatives possess [18].

Additionally, anxiety is an emotional state characterized by responses of worry, tension, racing thoughts, and bodily fluctuations (for example, increased heart rate). It has affective, behavioral, cognitive, and physiological components. Certainly, anxiety, worry, and fear differ, but they often exist as a complex of feelings within fear. The tension, nervousness,

and fear inherent in HD procedures contribute to the sense of anxiety involved during the process [19]. These anxieties range from concerns about negative and distressing thoughts to fears of specific phobias, including those related to needles. As a result of the troublesome nature of anxiety, as well as associated anxieties and phobias, many have an instinctive reaction to flee or avoid something, hence the avoidance of hospital visits. More physiological expressions of anxiety include restlessness, difficulty breathing, trembling, crying, and total withdrawal from social activity or play [20].

Moreover, some children may urinate involuntarily during muscle tightness or attempt to run away, even from experienced doctors. Various reasons contribute to children's anxiety before procedures. Primarily, it's the perceived need of control during the perioperative stage and the mysteries of the procedure that induce anxiety in children. Furthermore, needles and other medical instruments exacerbate anxiety [21]. Several factors predict procedural anxiety in children. For instance, children who are shy or have above-average IQs, but poor adaptive skills are at high risk. In addition, children with pre-existing anxiety, depression, a tendency toward somatization, and afraid temperaments are also more likely to report higher levels of procedural anxiety [21].

Also, an interesting aspect to consider is that children's anxiety about procedures is often predictable from parental anxiety. Furthermore, while some studies have found that negative recollections of former hospital experiences, pediatrician visits, or dental visits determine preoperative anxiety and that such memories persevere into adolescence and rise preoperative anxiety, other studies have produced contrary findings or failed to establish such an association [21-24]. Moreover, the existence of anxiety can cause maladaptive coping methods, such as prevention and repression, which inhibit the child's ability to deal with stress and other sensitive challenges [24]. Attention-seeking behavior may be observed as sleeping patterns become disturbed; consequently, sleep quality deteriorates and impedes the child's recovery [19, 21, 24, 25]. It can also disrupt eating patterns [21, 25].

From a medical standpoint, anxiety increases the requirement for analgesics and therefore influences pain management strategies. An anxious person experiences worse outcomes, such as delayed wound healing, along with a higher predisposition to infection. This occurs because anxiety instigates the hypothalamic-pituitary-adrenal (HPA) axis, resulting in raised levels of cortisol and epinephrine, which affect "natural killer cells" [21]. Beyond the physical realm, procedural anxiety has developmental effects on a child. It can aggravate separation anxiety, which is troublesome for both the child and caregivers [24, 25]. Besides, it is likely to cause post-traumatic stress disorder (PTSD) [21].

Anxiety also renders the recovery process generally slower, and in some cases, it is associated with the incidence of enuresis. Procedure-related anxiety may also incline some children further toward the distress of depression. This emotional and psychological toll significantly affects a child's whole well-being and quality of life during and after operating intervention. Considered in light of these possibilities, managing and addressing preoperative anxiety is therefore an important feature in pediatric anesthesia. Appropriate supportive interventions aimed at reducing anxiety would facilitate the alleviation of physical, emotional, and progressive troubles during the surgical journey and would promote long-term healing [21].

3. PAIN AND ANXIETY MANAGEMENT IN PEDIATRIC HD

The pain experienced by children on frequent HD, secondary to frequent fistula cannulation, causes them discomfort and leads to anxiety, depression, and a diminished quality of life. Effective pain regulation will encourage these patients to accept HD, and their quality of life will be improved [26].

Nurses perform a pivotal responsibility in assessing and regulating pain in pediatric patients. To accurately evaluate pain intensity, nurses should utilize validated pain evaluation tools tailored to the child's developmental stage. For younger children who may not be able to verbally express their pain, the FLACC (Face, Legs, Activity, Cry, Consolability) scale can be employed. This observational scale assesses various behavioral indicators of pain. For older children who can better communicate their experiences, self-report tools such as the Visual Analog Scale (VAS) or the Faces Pain Scale-Revised (FPS-R) can be used. These scales let children to rate their pain severity on a visual scale [27].

Furthermore, nurses must establish a routine for frequent and consistent pain assessments to monitor fluctuations in pain levels. Children may not always vocalize their discomfort, so vigilant observation and the application of appropriate pain assessment tools are essential. By accurately assessing pain and implementing timely interventions, nurses can significantly alleviate the quality of care for pediatric patients and alleviate their suffering [28].

Nurses have been paramount in improving the quality of care, ensuring adequate treatment, and educating patients about their condition and treatment goals to enable them to make informed decisions when their conditions worsen, necessitating HD [29]. Nurses also provide critical support to family members, explaining the HD procedures and addressing their concerns to protect the children. They also form a critical part of the patient evaluation [29]. Another significant aspect of professional nursing practice is pain measurement and management [30]. Indeed, the dimensions of pain are physical and psychological, and effective management strategies should form a core component of training [29, 30].

There are numerous possible methods to reduce the discomfort and anxiety associated with cannula insertion, which may help children better accept treatment and thus improve their quality of life [30, 31]. Methods of pain management are broadly

classified into non-pharmacological and pharmacological interventions [32].

Pharmacological interferences can be used to manage pain during cannulation in pediatric dialysis patients. Topical anesthetics like lidocaine/prilocaine cream (EMLA) or lidocaine patches can numb the skin at the needle insertion site, reducing pain during the procedure. For more severe pain or anxiety, short-acting sedatives (e.g., midazolam) or analgesics (e.g., acetaminophen or ibuprofen) can be administered. In some cases, a combination of local anesthesia and light sedation may be necessary [33]. While opioids like morphine or fentanyl are not commonly used in pediatric dialysis due to potential side effects, they may be considered in severe pain management cases if other methods are ineffective. However, it is important to weigh the potential benefits of opioids against their risks, such as respiratory depression and addiction [34].

Although the defined pain management agents can offer temporary pain relief during invasive events, these agents also have restrictions and adverse effects, which include nausea, vomiting, dizziness, potential unconsciousness, troubled breathing, and other symptoms such as skin swelling.

However, pharmacological interventions could very well complement these non-pharmacological techniques that rely solely on distraction. Practical, emerging non-pharmacological methods have established distraction techniques, such as using music, movies, or toys, to alleviate pain and anxiety. VR is the most recent method for providing distraction during medical procedures and has been found to be even more effective than other standard approaches, most of which rely on computer-generated environments and applications for three-dimensional orientation [25, 34, 35].

4. VR TECHNOLOGY

Coleman et al. (2021) have increasingly advocated that children tend to react more favorably to interactive distractions, such as playing video games, compared to passive distractions, such as watching videos. Cutting-edge modernization has inspired researchers to explore using VR technology for distraction during painful procedures for children [36].

Currently, the use of VR technology has emerged to distract children from pain and anxiety [6]. It is an activated experience, established by hardware and software technology. VR can provide the feeling of real-life environments, allowing the user to see, hear, and feel as if they are in that environment [37]. Also, Pradhan et al. (2021) have proven the influence of VR in reducing pain, anxiety, and distress among children and adults before and during different medical procedures [38]. Because of these reasons, VR applications are gaining momentum compared with pharmacotherapeutic interventions due to their excellent safety profile, rapid onset of action, and very few side effects related to time and exposure [39].

VR is a non-pharmacological strategy used to manage AVF cannulation pain among children. This technique involves distracting the child's concentration from the painful procedure by engaging them in a VR environment that requires a large portion of their conscious attention. The brain accept data about pain from pain receptors through neural signals, and VR distraction techniques work by redirecting the brain's attention to something other than the pain. VR has been found to be more effective than guided visualization, as it provides visual effects in addition to sound, which makes it simpler to attract the child's concentration and increase its efficacy [37, 40].

There are two basic types of VR systems: immersive and non-immersive. Non-immersive VR suggests a computer-generated environment, but it does not create complete immersion. This means that interaction with the digital subject on the screen occurs through a mouse, keyboard, joystick, and so on [41]. Immersive VR technology, on the other hand, generates an artificial, 3D, multisensory environment for a human individual, completely isolating them from the real world [42]. This "immersion" is induced—in the case of head-mounted displays (HMDs), earphones, and other sensory input—and reflexively involves the individual as an active participant within that three-dimensional, computer-generated domain, relying on the combination of real-time computer graphics. The immersive environment can be navigated in VR, either using a joystick or by using a wand. The HMD helmet is an appliance that contains a tracking system along with display optics, providing a VR experience by feeding two separate screens to the user. The user's head position and orientation are monitored to generate an immersive experience of 3D environments, replacing actual physical worlds. The use of HDMI between a computer and headset allows users to navigate or interact in a powerful manner while being present in the invented virtual world [43].

Like most therapeutic methods, VR simulations may also be organized according to procedure types (e.g., a Snow World game applied for burn wound dressing modifications [44]). However, as opposed to other distraction techniques, only VR gives a patient the ability to introvert, browse, and interact in a personalized, computer-generated scenery in real time. VR can be considered one of the best distraction methods for painful medical procedures such as vascular access procedures for children because it completely immerses the patient in a realistic experience with a feeling of presence [43].

5. VR FOR PEDIATRIC PAIN AND ANXIETY MANAGEMENT

Recent studies demonstrate the incredible promise of VR in the treatment of pain and anxiety [45-47]. Malloy and Milling [47] analyzed a substantial average weighted effect size of -0.94 within the literature, indicating that patients using VR distraction during invasive procedures would experience significantly greater pain relief than approximately 83% of patients receiving standard pain management interventions.

According to Dascal et al. [46], the comprehensive review started with a general introduction to VR applications in cognitive and motor rehabilitation, in eating disorder treatment, and as a means of pain distraction. While the studies reviewed varied in design and methods, it produced a large mean weighted effect size of -0.87. This score strengthens the arguments in favor of the clinical potential of VR.

Many recent studies have highlighted the potential of VR as a promising tool in treating pain and anxiety during procedures for pediatric oncology patients, especially for venipuncture. Prior reports have shown great success in the application of VR in children who are able to be completely distracted from the pain during the process, as evidenced by measures of pain and satisfaction. For instance, other studies also showed VR's ability in lessening pain and anxiety during venipuncture in pediatric patients with cancer [48, 49].

Another randomized controlled trial has been published by Gold et al. [50], further supporting the applicability of VR in pain management in children. Participants were pediatric patients undergoing IV placement. The VR group had a multisensory VR experience where they experienced visual, tactile, and auditory activation. The control group accepted only local anesthetic spray. Wong-Baker FACES scale data displayed that the VR group's pain intensity score was lower than that of the control group [50, 51].

An Italian Children's Hospital recently conducted research on the competence of VR analgesia to alleviate pain, lessen anxiety, and improve the overall venipuncture experience for pediatric and adolescent patients suffering from renal disease. The study enrolled 82 patients aged 7 to 17 years, who were randomly designated to a control group that received non-medical conversation, or a VR group that used VR technology during the procedure. The results showed that participants in the VR group rated notably lower pain intensity and unpleasantness compared to the control group. This group also reported a more positive experience during the procedure. No adverse impacts were monitored in this study. It also confirmed that younger children, aged 7 to 11 years, in the VR group experienced more pain diminution compared to older children, aged 12 to 17 years. It appears, therefore, that younger patients may gain more from VR analgesia [6].

Piskorz & Czub [52] studied the efficiency of VR as a potential analgesic and anxiolytic during venipuncture in children. The participants were separated into a VR experimental group and a control group. Subjects in the VR group were involved in a Multiple Object Tracking (MOT) game that needed cognitive effort for distraction. This study revealed that there was a considerable difference in pain levels and stress levels of children subjected to VR compared to the control group. This shows that VR, particularly one that uses MOT-based games, can demonstrate to be a valuable tool for controlling pain in the pediatric healthcare setting. Further, the VR intervention was apparently appropriate for the targeted age group and easily implementable by nurses in clinical practice.

Research has recently shown how capable VR can be in relieving pain and anxiety during venous access port procedures in younger participants. Wolitzky et al. [53] and Gershon et al. [54] have independently derived results showing that the Virtual Gorilla program, developed to teach children aged 7 to 14, is effective in pain and anxiety reduction during access port procedures. Windich-Biermeier et al. [55] investigated how customizable VR experiences reduce procedural stress and anxiety. Although there were no substantial changes in pain judgments between control and experimental groups, the study demonstrated that personalized VR experiences were associated with lower stress and anxiety. These findings indicate that VR could open new perspectives for improving pediatric pain management and possibly anxiety in the context of venous access port procedures.

A collection of studies has established VR to be effective in relieving pain and anxiety during specific medical procedures such as fine needle aspiration biopsy, dressing changes, burn treatment, and intravenous insertion [56-59]. Most importantly, VR is a well-tolerated and highly effective analgesia and sedation instrument in HD patients [60].

Elzeky et al. (2024) examined the VR distraction effects on pain, anxiety, and physiological parameters, as well as satisfaction, among HD patients undergoing AVF puncture. It was conducted among 96 study patients, who were randomly designated to either the VR intervention group or the control group. While the test group undergo a 6-minute immersive VR experience, the control group obtained standard care. The outcomes demonstrated significant pain and anxiety decline in the VR group, as well as improvements in systolic blood pressure and heart rate, compared to the control group. Additionally, patients in the VR group conveyed considerably higher happiness with the procedure [60]. These results indicate that hospital-friendly VR devices might be a complementary to traditional distraction practices for pain relief in invasive procedures. This study also focuses on the promise of VR in the control of pain, anxiety, and physiological stress that accompany AVF cannulation, further studies need to be conducted to evaluate the longer-term impacts of this intervention. It is important to investigate the duration of beneficial effects of VR in patients undergoing chronic dialysis on needle distress. It is also crucial that future developments in this technology consider that the applications may then be made accessible and relevant to a wider and more varied population of HD patients, including children. Audiences for testing and feedback should also be included in input possibilities to align with patient-comfortable settings with VR. Nurse-led research into non-pharmacological, safe, cost-effective interventions, such as using VR, should be further promoted as a way by which patients can benefit while being treated during AVF puncture [60, 61].

6. FUTURE DIRECTIONS FOR VR RESEARCH IN PEDIATRIC HD: IMPLICATIONS FOR NURSING PRACTICE.

It is a technology that brings hope for the future of care and the experience of children receiving HD treatment. For nurses, who provide holistic, patient-centered care, adopting knowledge of VR and integrating it into practice will create opportunities for practice and clinical research challenges. Such research may include the efficacy and use of VR within clinical workflows and considerations that go beyond nursing practice in pediatric HD settings.

The competence of VR to lessen anxiety in patients undergoing procedures is a key area of study. Children with HD undergo repeated invasive procedures, and therefore the efficacy of VR interventions—such as immersive games and guided relaxation—is worth studying. Additionally, how such applications can be integrated into nursing care must be examined.

One other channel is the application of VR in patient education and compliance. CKD and HD are complicated regimens, and VR provides an immersive method of delivering personalized educational content. Studies should evaluate its effect on patient knowledge, retention, and adherence to treatment regimens. VR can also be utilized to facilitate patient-nurse interaction that augments education and support.

Psychosocial advantages are also profound. Chronically ill children, such as those with end-phase renal disease, suffer from social isolation. Normal activities can be replicated by VR and can also promote social interaction to help them cope. How nurses can utilize these interventions and how they affect patient satisfaction and quality of life must be addressed by research.

To develop VR interventions that are appropriate for diverse pediatric populations, with respect to their developmental and cultural needs, it is essential to recognize that children at different ages, stages, ability levels, and overall life contexts will respond differently to VR. The content must be carefully tailored to ensure developmental alignment with the child's cognitive and emotional stage. Moreover, interventions must be culturally informed and attuned to individual needs so that families from diverse backgrounds can relate to the initiatives. Nurses, as primary caregivers, have a major role in identifying those needs and customizing the interventions accordingly.

The implementation of VR in the clinical domain sets the platform for performance implications within nursing workflows. Clearly, this technology appears to have promise for enhancing care, but no nursing responsibility should become more complex through its adoption. More examinations are needed to determine the time and effort nurses expend in managing patients on HD and to uncover other barriers to integrating VR technology into nursing practice. Training and education for nurses in specific skills related to its use will also be vital to addressing these challenges and ensuring successful technology deployment.

The effective incorporation of VR in pediatric HD requires the encouragement of interdisciplinary collaborations. Nurses have a magical role in bridging the gap between patients and their families, and technology developers. Future research should thus focus on developing interprofessional alliances that introduce and appraise VR interventions relevant to the needs of all stakeholders. Also, training models that improve collaboration with other healthcare providers would further strengthen the multidisciplinary utilization of VR in pediatric care.

7. CONCLUSION

The preceding review has highlighted the substantial potential of VR as a non-pharmacological tool for mitigating pain and anxiety in children suffering from HD. By providing immersive and engaging experiences, VR can effectively divert attention from painful procedures, leading to alleviate patient outcomes and quality of life. As VR technology continues to evolve, its integration into pediatric HD care has the power to revolutionize the control of pain and anxiety in this vulnerable population. To fully realize the transformative potential of VR in this context, interdisciplinary collaboration is imperative. A multidisciplinary approach involving healthcare professionals, psychologists, and patient advocates can accelerate the development and implementation of innovative VR solutions.

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