"Virtual Reality - a distraction technique in dentistry"

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KEYWORDS

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ABSTRACT

Virtual reality (VR) technology is revolutionizing dental care by enhancing patient management, professional education, and procedural efficiency. In clinical settings, VR effectively reduces pain and anxiety by immersing patients in interactive, calming environments, serving as a powerful distraction during dental treatments. Research supports its efficacy in alleviating discomfort and fear across diverse patient demographics. Additionally, VR is transforming dental education by providing simulation-based training that improves psychomotor skills, knowledge retention, and confidence among practitioners. It also aids professionals in visualizing complex anatomical structures for precision in minimally invasive procedures. VR improves patient education by providing interactive visualizations of treatment plans, enhancing communication and comprehension. While challenges like high costs and accessibility remain, technological advancements are making VR more affordable and user-friendly. Future innovations could enable personalized virtual environments tailored to individual patient needs, further enhancing comfort and compliance. As a non-pharmacological tool, VR is set to become an essential component in delivering effective, patient-centered dental care.

Introduction to Virtual Reality in Dental Practice

Virtual reality (VR) technology is rapidly changing the landscape of dentistry and is an innovative solution for both patient management and specialist training.[1] In clinical settings, VR has proven to be a highly effective tool in reducing pain and anxiety associated with dental treatment.[2] VR, by immersing patients in a pleasant and interactive virtual environment, provides a strong distraction and diverts attention from discomfort during treatment.[3,4,5].Its effectiveness has been repeatedly proven by research. Studies have shown that VR significantly reduced patients' reported pain and anxiety during various dental procedures.[6] For example, Fan et al. [7], In a comprehensive study of more than 1,500 patients

aged 0 to 60 years, the effectiveness of VR in reducing discomfort and anxiety during treatment.

Beyond clinical applications, VR is revolutionizing dental education by providing immersive experiences in simulation-based training environments. These platforms allow dental students to practice complex techniques such as administering local anesthesia and extracting teeth in a controlled, risk-free environment. Wiederhold et al. [8] highlighted the role of VR in improving psychomotor skills and knowledge retention through realistic and interactive simulations. It also supports professionals by allowing them to accurately visualize three-dimensional anatomical structures, aiding in minimally invasive surgical procedures. These advances not only improve technical skills but also increase dentists' confidence.

Furthermore, VR has proven to be very useful for patient education. [9] Interactive applications allow patients to explore virtual representations of their treatment plans, helping them to better understand the procedure and reduce anxiety. Hoffman et al. [10] and Furman et al. [11] highlighted that VR applications are superior to traditional distraction methods, such as watching movies, in terms of engaging patients and improving their overall experience. These findings point to the potential of VR as a tool to improve communication between dentists and patients.Although VR offers numerous benefits, challenges remain in its implementation. High cost, limited accessibility, and side effects such as cybersickness have hindered widespread adoption. However, as technology advances, it is expected to become moreaffordable and easier to use. Future applications of VR in dentistry could include personalized intelligent systems that adapt the virtual environment to the patient's individual needs, improving patient comfort and compliance.

In summary, virtual reality (VR) is an innovative, non-pharmacological approach that has the potential to transform dental treatment and education. Its effectiveness in reducing pain and anxiety, enhancing educational experiences, and engaging patients is highly promising. As technology continues to advance, VR is likely to play an increasingly significant role in delivering safe, efficient, and patient-centered dental care.

Mechanisms of Virtual Reality as a distraction tool

Virtual Reality (VR) distraction tools in dentistry function through several interconnected mechanisms that collectively aim to reduce patient anxiety and improve cooperation during dental procedures.

1. Immersive Distraction:

VR creates a fully immersive environment that diverts the patient's attention away from the dental procedure. By engaging multiple senses—visual, auditory, and sometimes tactile—VR captivates the patient's focus, thereby diminishing their awareness of the clinical setting and associated discomfort. This sensory engagement is crucial in reducing anxiety and perceived pain during dental treatments. Tanja-Dijkstra et al. (2019) noted that immersive distraction effectively lowers anxiety and pain perception by shifting attention away from nociceptive stimuli. [12]

2. Cognitive Load Management:

The immersive nature of VR increases the cognitive load on patients, meaning their mental resources are occupied with processing the virtual environment. This heightened cognitive engagement leaves fewer resources available for processing pain signals or anxious thoughts.Hoffman et al. (2000) highlighted this in their seminal study on VR analgesia, demonstrating that VR applications reduce pain perception through attentional displacement.[13]

3. Emotional Modulation:

VR environments can be designed to elicit positive emotional responses, such as calmness or joy, which counteract the negative emotions associated with dental anxiety.[14]The virtual

environment in VR tools can be customized to evoke specific emotional states. For example, serene landscapes, calming music, and interactive games are commonly used to create a sense of relaxation and positive emotional engagement. This mechanism reduces the activation of the sympathetic nervous system, which is typically heightened in anxious patients.[15]

4. Exposure Therapy and Acclimatization:

For patients with significant dental phobias, VR can serve as a tool for gradual exposure therapy. By simulating dental procedures in a controlled virtual environment, patients can become accustomed to the sights and sounds of a dental clinic without immediate stressors.[16] Patients often experience heightened anxiety before the dental procedure even begins. VR can counteract this by simulating non-threatening, relaxing scenarios that condition the patient to associate the dental setting with positive experiences. This exposure helps patients develop familiarity and reduces fear of the unknown. [3]

5. Physiological Relaxation:

Engaging with calming VR content can lead to physiological relaxation responses, such as reduced heart rate and lower blood pressure. [17]

6. Attentional Distraction and Redirection:

VR diverts attention from anxiety-inducing stimuli by shifting focus to the immersive experience. This attentional redirection uses cognitive load theory, which states that the human brain has limited resources for processing information. When these resources are consumed by the VR environment, less cognitive capacity remains to process signals of fear or pain.[18]

7. Blocking Pain Perception through Gate Control Theory:

The gate control theory of pain suggests that the brain prioritizes certain types of sensory input over others. VR distracts the brain by flooding it with competing sensory inputs (e.g., bright visuals, dynamic sounds), which "close the gate" for pain signals traveling from the dental site to the brain.[19]

8. Activation of Reward Pathways in the Brain:

Engaging and interactive VR experiences activate the brain's reward pathways, releasing dopamine and other neurochemicals associated with pleasure and relaxation. This neurophysiological response can counterbalance the release of stress hormones, such as cortisol, creating a calming effect during dental treatments.[20]

9. Behavioral Conditioning for Cooperative Behavior:

For uncooperative patients, VR acts as a positive reinforcement tool. The enjoyable nature of the virtual environment conditions patients, especially children, to associate dental visits with engaging and fun experiences.[21]

10. Real-Time Feedback and Biofeedback Integration:

Advanced VR systems can incorporate biofeedback mechanisms, allowing patients to visualize and control their stress levels in real-time. For example, VR platforms linked to heart rate monitors can guide patients through relaxation exercises, such as deep breathing, within the virtual environment.[22]

11. Modulation of Physiological Responses:

The calming influence of VR has been shown to reduce physiological responses associated with anxiety, such as increased heart rate, elevated blood pressure, and hyperventilation. By inducing a parasympathetic response, VR helps patients relax during procedures.[23]

12. Neuroplastic Effects of Repeated Exposure:

Repeated use of VR in the dental setting can lead to neuroplastic changes that rewire the brain's response to dental stimuli. By consistently associating dental procedures with non-threatening virtual experiences, patients may develop long-term desensitization to previously anxiety-provoking situations.[24]Several mechanisms help virtual reality fight against dental anxiety in patients. A major factor is the use of audiovisual elements in the VR system. According toWiederhold MD (2017), these elements stimulate the patient's senses, which can lead to relaxation. When patients wear VR helmets, they are surrounded by carefully designed sounds and visuals that distract them from the current dental work, which makes the process less intimidating.[8]

Applications of VR in Pediatric Dentistry

In pediatric dentistry, the use of virtual reality has shown promising results. The research indicates that children subjected to dental treatments undergo a substantial reduction in anxiety levels when VR is used compared to traditional methods. Hamdy et al. (2024) and Rosa et al. (2023) have proven that the engaging nature of virtual reality allows young patients to interact with virtual environments, distracting them from the potentially stressful aspects of dental procedures. This distraction is vital to reduce fear and increase comfort levels during treatment. [25]

1. **Behavior management and Reduction of Anxiety**

Dental fear and anxiety are significant factors contributing to the avoidance of dental care, particularly in pediatric dentistry. Children with higher levels of dental anxiety tend to experience more severe dental issues and visit the dentist less frequently compared to their peers. This often results in poorer behavior during dental appointments and lower scores on Frankl's Behavior Rating Scale (FBRS). [26] To address this, effective behavioral guidance techniques combined with appropriate local anesthesia are essential for providing painless dental care, reducing anxiety, and fostering a positive perception of dentistry in children. Among these techniques, distraction stands out as one of the safest and most cost-effective methods for managing behavior in children. [27,15] Virtual reality (VR), in particular, serves as an excellent distraction tool. Considering the safety, affordability, and user-friendly nature of VR headsets, which require no prior training to operate, they offer an accessible solution for minimizing pain and anxiety in pediatric dental patients.[28]

2. **Reduction of pain**

VR works by stimulating the brain's sensory and emotional pathways, effectively altering how the brain processes pain. When children are immersed in a virtual environment, the brain can become less focused on the pain itself, making the experience more tolerable. VR distraction significantly decreased pain perception and state anxiety in children undergoing short invasive dental treatments, highlighting its effectiveness as a behavior modification method.[15] The study on VR analgesia for pediatric dental patients found that VR significantly reduced the perception of both 'worst pain' and 'pain unpleasantness,' improving the overall experience during dental procedures. It highlights VR's effectiveness in managing pain and enhancing patient comfort in pediatric dentistry.[5]

3. **Desensitization and familiarization**

Virtual Reality (VR) has been effectively utilized in pediatric dentistry to familiarize children with the dental clinic environment before their visits, thereby reducing dental fear and

promoting cooperation during actual appointments. A notable example is the development of an interactive VR system named "Dr. Barea," designed for Arabic-speaking children aged 7 to 10. This system includes a 360° VR video that simulates a dental clinic environment, providing educational descriptions of dental tools and procedures engagingly. A feasibility study involving 16 children demonstrated a significant decrease in dental anxiety levels after using the system, indicating its effectiveness in familiarizing children with the dental setting and reducing fear.[29] The other studies also provide evidence that VR can serve as an effective tool for desensitization and familiarization in pediatric dentistry, helping children become accustomed to the dental clinic environment and procedures before their visits.[30]

4. **Patient Education**

Virtual Reality (VR) has emerged as a groundbreaking tool in pediatric oral health education, offering an immersive and interactive experience that effectively engages young learners. A program called "Inside the Mouth" demonstrates the potential of VR by guiding children aged 9 to 12 through a virtual exploration of the oral cavity. The eight-minute interactive video uses VR glasses to break down complex dental concepts, making them more accessible and engaging for kids. Through this program, children can better understand essential oral hygiene practices in a fun and captivating way.

Key elements of the VR experience include visual depictions of dental biofilm, a structure formed by bacteria, food debris, and saliva, emphasizing the need for brushing and flossing to prevent oral diseases. The program also teaches children about the differences between primary and permanent teeth, with a special focus on the first permanent molar's vulnerability to plaque buildup. It includes practical demonstrations of brushing, flossing, and tongue cleaning, reinforcing the importance of a complete oral hygiene routine. By showcasing the benefits of good hygiene and linking it to overall health, this VR approach not only captures attention but also promotes long-lasting understanding and adoption of healthy habits in children.[31]

5. **Special Needs Dentistry**

Virtual Reality (VR) intervention has been shown to significantly reduce anxiety and improve cooperation in children with autism spectrum disorder during dental examinations. [32] Additionally, research indicates that combining audio and VR distraction techniques can effectively guide behavior in children with mild intellectual disabilities during restorative dental procedures, helping to enhance their overall experience and cooperation during treatment.[33]

Efficacy of VR in Reducing Dental Anxiety and Pain

Several studies have investigated the use of VR in the treatment of dental phobia. The immersive nature of VR allows patients to divert their attention from the dental treatment, significantly reducing the psychological and physiological symptoms of anxiety. Studies have shown that distraction techniques are less effective for people who have previously experienced severe or unpleasant pain [34] Hoffman et al. emphasized that the quality of VR equipment is important to enhance thepain relief effect. In the study, patient satisfaction may have been influenced by the use of a high-resolution virtual reality headset, which is significantly different from that used in previous studies [35]. Afunctional magnetic resonance imaging (fMRI) study showed that the analgesic effect of VR was associated with a significant reduction in pain-related brain activity. VR analgesia appears to change the way the brain processespain signals. Recent studies have revealed that VR not only changes pain perception but also reduces pain-related brain activity. [36]

With VR, pain signal processing was reduced in all five major brain regions: the insular cortex, thalamus, anterior cingulate cortex, and primary and secondary somatosensory cortex. These results further support the analgesic effect of VR. [37]. In this study, a comparison between groups showed that VR glasses can effectively affect heart rate. These results are consistent with previous studies by Prabhakar et al. [38], Hoffman et al. [10], and Nilson et al. [39]. They

concluded that audiovisual distraction during dental treatment is more effective in managing anxiety in children than using audio distraction alone [38,10,39]. Hoffman et al. conducted a study using functional magnetic resonance imaging (fMRI) brain scans and found that VR-induced pain relief was associated with a significant decrease in pain-related brain activity. VR analgesia appears to change the way the brain processespain signals.[40]

Reducing Perceived Pain:Studies have found that VR can reduce the perception of pain during dental procedures by changing the way the brain processes pain signals. The immersive natures of VR can reducepain intensity, especially in patients who suffer from severe anxiety. VR can modulate the emotional and sensory response to pain by focusing the mind on a different, immersive experience. Combining painkillers with VR is more effective at relieving pain and suffering than painkillers alone. A recent study tested a waterproof VR systemduring wound cleansing in 11 patients (aged 9 to 40 years). The results showed that VR not only reduced pain scores but also increased participants' enjoyment as they felt more immersed in the VR game.[41]

Calming and Relaxation:

Some VR programs are specifically designed to aid in relaxation. These programs may include guided meditations, calming music, and even virtual trips to peaceful natural environments. This is especially useful for reducing anxiety before and duringdental appointments and creating a more comfortable atmosphere for patients who may be nervous. Investigated the effectiveness of a combination of VR relaxation and morphine for analgesia during burndressing changes. Instead of using distracting programs, researchers developed a psychologist-designed VR relaxation sequence based on the principles of hypnotherapy.[42]

Enhancing Patient Cooperation:

Fear of the dentist often causes patients to avoid necessary treatment or become uncooperative during treatment. VR may promote a more positive association with the dental treatment experience, leading to better cooperation, less avoidance, and more consistent attendance at dental appointments [40]. Recent studies have highlighted the important role of memory, showing that memories of past dental appointments influence people's attitudes towardfuture appointments [43]. The results suggest that distraction with VR during dental treatment may help prevent the formation of vivid memories associated with the treatment experience and break the vicious cycle of dental fear [40].

Effectiveness Across Age Groups:

Studies have found that VR is effective across a range of ages, from children to adults. This is particularly useful for pediatric patients who have difficulty controlling anxiety or sitting still during treatment. For adults, VR can help reduce the stress of procedures such as root canals, fillings, and cleanings. A meta-regression analysis used a random-effects model (using the method of moments) with age as the predictor variable. Results suggested that VR interventions for pain relief were more effective in younger children than in older children [20]. Another possible explanation is that VR is particularly stimulating for young children because they are prone to magical thinking and tend to become fully immersed in imaginative play.[44]Relaxing virtual environments (VEs) can help patients learn and practice anxiety management techniques whileencouraging active participation in treatment and enhancing the therapeutic alliance. However, VR works differently for different people. Depending on factors such as anxiety levels, past experiences, and how well they engage with the virtual environment, some patients may benefit more from VR distraction than others [45].

Comparison of Virtual Reality with Traditional Behavioral Management Techniques

Dental anxiety, especially in children, can be managed using traditional behavioral techniques such as Tell-Show-Do, modeling, and relaxation techniques, which help familiarize patients with dental procedures and promote cooperation. While these methods have been effective, Virtual Reality (VR) offers a more immersive and engaging experience, and diverting attention

from the clinical setting can significantly reduce anxiety and pain. Research suggests that VR outperforms traditional techniques in making dental treatment more comfortable and enjoyable. [46,47] In the following comparison chart, we analyze the effectiveness of VR alongside conventional behavior management strategies to highlight their strengths and impact on patient experience.

Features	VR Technique	Traditional Techniques
Distraction and patient engagement	Provides a strong, engaging distraction from dental procedures and makes them more likely to remain calm and cooperative.	Distraction may be less effective, relying on conversation, music, etc.
Immersion	Highly immersive, blocking out the real-world environment [48]	With limited immersion, the patient remains aware of the dental setting
Consistency	The experience is consistent with VR.	Effectiveness varies based on individual patient differences and practitioner delivery.
Cost	VR devices and systems can be expensive to purchase and maintain and are thus unaffordable for small dental practices or clinics in low-resource settings [49]	Traditional Techniques are affordable for small dentalpractices or clinics in low-resource settings.
Comfortability	VR may not be suitable for everyone, and some patients may find it uncomfortable or ineffective. A small percentage of patients may experience dizziness, nausea, or discomfort when using VR, especially if they are prone to motion sickness [50]	Patient comfort is typically addressed through positioning, relaxation techniques, and communication.
Learning Curve	VR systems can be difficult to switch between procedures and meet theneeds of each patient.[51]	Dentists are typically already trained in these techniques. Patients generally understand the process.
Communication	Patients may not be fully attentive to instructions when they are immersed in the VR environment [52]	Allows for direct, verbal communication between the dentist and patient throughout the procedure
Applicability	Cognitive or visual impairments also prevent patients from benefiting from VR [53]	Applicable to most patients, with tailored approaches
Acceptance	Some patients may be suspicious of new technologies or merely averse to the idea of using VR because of its unfamiliarity [20]	Widely accepted and familiar to most patients

Hygiene Concerns	Cleaning headsets after each use can be very time-consuming [13]	Standard dental hygiene practices are to be followed.
Dependence on Technology	Hardware or software failures may lead to delays during treatment, consuming valuable time. Relying on technology poses a risk, as system malfunctions can disrupt procedures.[20]	No reliance on technology, making it consistently available and easy to implement.
Limited Evidence for Long-Term Benefits	While the short-term benefits of VR distraction are well known, there is limited evidence for its long-term effectiveness and cost efficiency in real-world clinicalsettings [54]	Long-term benefits are well-established for some techniques like cognitive behavioral therapy (CBT).

Challenges and Future Directions in Virtual Reality Integration in Dentistry

The development and application of VR in dentistry require a thorough evaluation of various aspects of virtual reality (VR) technology. Although VR offers many benefits to healthcare, many issues need to be resolved to obtain the maximum benefits [55-58]. Ignoring these limitations can have serious consequences. Identifying current and future applications and implementation hurdles can help professionalsmake strategic decisions regarding the use of VR technology in healthcare. Furthermore, the technological tool itself may contribute tochallengesin clinical practice [59]. The steep learning curve of virtual reality in dentistry is one of its main drawbacks. Using VR systems can be difficult forexperienced doctors and surgeons who are used to traditionalmethods. Another issue is the cognitive load that virtual reality (VR) imposes on the surgeon, who has to focus onthe patient and the virtual screen at the same time. For example, it can be difficult to accurately measure tissue depth using a VR interface. This issue is further exacerbated by thephysical placement of the VR display and tracking sensors [60], which makes it difficult for the surgeonto focus on the surgical field [61]. Bringing the VR screen closer to the patient's head minimizes head movement and distraction. However, further research and development work is needed to explore additional strategies to optimize the integration of VR into dental care [62].

Another major obstacle to the widespread adoption of VR in dental clinics and other facilities is the financial investment. The expensive setup of VR systems and rapid technological advances may reduce profitability in the long run. In addition, in many cases, softwaredevelopers must be involved in customizing the VR platform tothe preferences of a particular surgeon, which further increases costs. VR systems are also susceptible toexceptional software errors and prone to computational glitches [63]. Interruptions in communication due to faulty code can impactclinical outcomes. Incorporating virtual reality (VR) into patient consultations presents challenges, especially in maintaining trust and harmony. Face-to-face interactions are essential to building strong patient-physician relationships, and over-reliance on virtual interfaces can leave patients feeling isolated. [64,65] For example, it can be difficult for patientsto establish a sense of trust and connection when dentists primarily interact with patients through virtual platforms. VR plays animportant role in improving surgical techniques, but the overall impact of VR on patient care must be carefully evaluated to ensure it enhances, rather than diminishes, the quality of interactions andpatientexperience. [66]

Challenges in the clinical phase

1. Devices lack clinical measurement and real-time performance analysis.
2. Lack of realism and precision – technology is not yet at an optimal level.
3. Lack of high and low-speed options for instrumentation.
4. Difficult to translate real-world use cases into the device and use effectively.
5. No voice feedback or voice control capabilities.

Future directions and innovations

For VR to be fully integrated into dentistry, further research and improvements in trackingtechnology are needed. Combining VR with artificial intelligence (AI) and augmented reality (AR) could open up exciting possibilities. For example, AI could help analyze patient data and simulate the placement of different implants, improving the accuracy of treatment plans. It could also predictcomplications and suggest alternative approaches based on the patient's individual needs. AR goes a step further by overlaying virtual images onto the actual surgical scene, allowingdentists to see anatomical structures and implant positions in real-time. This has the potential to make proceduresmore precise and efficient. VR training programs can also be tailored to the individual, providing amore personalized approach to learning new skills. Incorporating VR and AR into dental education could give students hands-on experience withadvanced techniques earlier in their training. If VR devices were more affordable and compatible withcomputers and mobile phones, distance learning could become more accessible to both students andprofessionals. However, traditional hands-on practice will always be important, so finding a balance between VR simulation and real-world training is key. In the future, the integration of VR with big data, cloud computing, 5G, and deep learning will takedental simulators to the next level. These advances could lead to more personalized learningexperiences, making VR an even more valuable tool for the next generation of dentists.

Conclusion:

The application of VR has somewhat improvedtheoretical knowledge acquisition. As they continueto evolve and become more widely accepted, dentists will be better prepared to address clinicalchallenges, ultimately leading to improved patient care andexpertise. Rigorous research and the introduction of standardized practices on a global scale are needed to fully realize the benefits of these new technologies in educational institutions andaddress educators' skepticism. Such an approach is important to maximize the impact of VR on dental education.

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