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Virtual reality for pain and anxiety during dental anaesthesia: A randomized trial

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Abstract:

Local anaesthesia injection is a major source of dental pain and anxiety among adolescents. Therefore, it is of interest to evaluate the effectiveness of immersive virtual reality (VR) distraction during local anaesthesia administration in 50 first-time dental patients aged 12-19 years. Participants were randomized to VR or conventional care, with heart rate, anxiety and pain assessed using standard clinical measures. The VR group showed significantly lower heart rate, pain and anxiety scores than the control group (all $p < 0.001$). Thus, immersive VR is an effective, safe and low-cost adjunct for reducing pain and anxiety during local anaesthesia in adolescent dental patients.

Keywords: Adolescents, anxiety, distraction, local anaesthesia (LA), pain, virtual reality (VR)

Background:

Pain is defined by the International Association for the Study of Pain as an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage [1]. In dentistry, untreated dental caries involving the pulp is a major cause of orofacial pain in both children and adults, making effective pain control essential during treatment [2]. Local anaesthesia (LA) is the primary method used to eliminate procedural pain; however, the injection itself is frequently associated with fear and anxiety, particularly among younger patients [3]. Dental anxiety is characterized by apprehension and fear related to dental treatment and is a significant contributor to delay or avoided dental care, ultimately compromising oral health outcomes [4]. Behavior guidance techniques are widely recommended to reduce anxiety during dental procedures. Among these, distraction is recognized by the American Academy of Pediatric Dentistry as an effective non-pharmacological approach that diverts the patient's attention away from unpleasant stimuli [5]. Conventional audio-visual distraction has showed favorable outcomes in reducing anxiety and improving patient cooperation during dental treatment. Virtual reality (VR) represents an advanced form of distraction that creates an immersive, computer-generated environment, engaging multiple sensory pathways simultaneously and minimizing awareness of the clinical surroundings [6]. According to the limited-capacity theory of attention, immersive distraction reduces the cognitive resources available for processing painful stimuli, thereby decreasing the perception of pain and anxiety during treatment [7]. Recent randomized controlled trials and systematic reviews have showed that VR distraction significantly reduces pain and anxiety during various dental procedures, including local anaesthesia administration, restorative treatment and pulp therapy, while remaining safe, non-invasive and well accepted by patients [8]. However, most published studies have focused on children younger than 12 years, using cartoon-based VR content and behavioral assessment scales specifically designed for pediatric populations. Adolescents differ from younger children in cognitive maturity, emotional responses and the ability to provide reliable self-reported assessments of pain and anxiety. Furthermore, evidence regarding the effectiveness of VR distraction during local anaesthesia administration in adolescents remains limited, particularly when both objective physiological parameters and subjective patient-reported

outcomes are evaluated together [9]. Therefore, it is of interest to evaluate the effectiveness of virtual reality distraction on dental pain and anxiety during local anaesthesia administration among adolescents.

Materials and Methods:**Study design and setting:**

This was a two-arm, parallel-group, randomized controlled trial with a 1:1 allocation ratio, conducted at a private dental educational institute between October 2025 and November 2025. The trial was designed, conducted and reported in accordance with the CONSORT 2010 statement. Ethical approval was obtained from the Institutional Ethics Committee and the trial was registered (CTRI/2025/07/091692). As all participants were minors, written informed consent was obtained from a parent or legal guardian and written assent from each participant before enrolment.

Participants and eligibility:

Healthy, cooperative adolescents aged 12-19 years attending the dental clinic for the first time and requiring non-urgent treatment under local anaesthesia were eligible, provided they had no known allergy or sensitivity to local anaesthetic agents. Participants were excluded if they had a history of epilepsy or a diagnosed anxiety disorder, or any condition contraindicating the use of a head-mounted display. The 12-19-year band corresponds to the WHO definition of adolescence and represents the developmental period least studied in the VR distraction literature; adolescents also possess the cognitive and linguistic maturity to operate an immersive headset, choose age-appropriate content and complete self-report instruments reliably and dental anxiety arising at this age frequently persists into adulthood, making the group a clinically important target for early intervention.

Sample size:

The sample size was estimated for the comparison of mean scores between two independent groups using an a priori power calculation in G*Power 3.1. Assuming a two-sided significance level of 0.05 and 80% power and based on the effect size reported in a previous comparable trial of VR distraction during infiltration anaesthesia, a minimum of 25 participants per group was required, so 50 participants (25 per group) were enrolled.

Pilot study:

Before the main trial, a pilot study on 10 participants tested the feasibility of the protocol, standardised the data-collection procedure and confirmed the suitability of the instruments; pilot data were not included in the final analysis.

Randomization, allocation concealment and blinding:

A 1:1 randomization sequence was generated using computer software by an investigator not involved in recruitment or outcome assessment. Allocation concealment used sequentially numbered, opaque, sealed envelopes, opened only after a participant had been enrolled and seated. Owing to the visible nature of the VR headset, neither participants nor the operator administering LA could be blinded to group assignment; however, data entry and statistical analysis were performed by an investigator blinded to allocation.

Interventions:

At the start of the visit, every participant chooses a video from a pre-loaded list. In the VR distraction (test) group, participants wore a head-mounted display (Meta Quest 2) through which the selected video was played, with audio delivered through the headset's integrated speakers; LA was then administered while the participant viewed the video. In the control group, LA was administered conventionally, without VR. In both groups, the same operator used the same local anaesthetic agent and injection technique.

Outcome measures:

Anxiety was assessed using two measures. First, heart rate (beats/min) was recorded with a pulse oximeter at three time points as an objective indicator of anxiety: at baseline once the participant was seated; during LA administration at needle insertion; and after LA administration. Second, a five-item self-administered questionnaire was completed at the end of the procedure to assess perceived anxiety. Pain during LA administration was assessed using a Numeric Rating Scale (NRS, 1-10). The primary outcomes were self-reported pain and anxiety; heart-rate change was a secondary outcome.

Statistical analysis:

Data were analysed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were expressed as means and standard deviations. Within-group changes in heart rate across the three time points were analysed using repeated-measures ANOVA, with the Tukey honestly significant difference test for pairwise comparisons. Between-group differences in heart rate at each time point and in pain and anxiety scores were compared using the independent-samples t-test. A p-value < 0.05 was considered statistically significant.

Results:

A total of 50 participants completed the trial, 25 in the VR distraction group and 25 in the control group, with no participant lost to follow-up or excluded. All participants were aged 12-19 years and none had previous dental experience. Overall, 29 participants (58.0%) were male and 21 (42.0%) were

female. The two groups were comparable at baseline, with no significant difference in mean heart rate before the procedure (test 103.68 vs. control 104.08 beats/min; $p = 0.844$; **Table 3**). Within the VR distraction group, mean heart rate fell progressively from 103.68 beats/min at baseline to 89.60 beats/min during injection and 84.28 beats/min after injection, a statistically significant change ($F = 61.60$; $p < 0.001$). In the control group, mean heart rate remained essentially unchanged (104.08, 105.64 and 104.68 beats/min; $F = 0.30$; $p = 0.742$) (**Table 1**). Pairwise Tukey comparisons confirmed that, in the VR group, heart rate during and after injection was significantly lower than at baseline (mean differences of 14.08 and 19.40 beats/min; both $p < 0.001$), whereas no time point differed significantly in the control group (**Table 2**). Although baseline heart rate did not differ between groups, heart rate was significantly lower in the VR distraction group both during injection (89.60 vs. 105.64 beats/min; $t = -8.69$; $p < 0.001$) and after injection (84.28 vs. 104.68 beats/min; $t = -10.76$; $p < 0.001$) (**Table 3**). Self-reported pain and anxiety were significantly lower in the VR distraction group than in the control group. Mean pain scores were markedly lower in the VR group ($t = -32.60$; $p < 0.001$), as were mean anxiety scores ($t = -12.74$; $p < 0.001$) (**Table 4**). Consistent with these findings, the large majority of participants in the VR group reported little or no anxiety during LA administration.

Table 1: Within-group comparison of mean heart rate (beats/min) at the three time points (repeated-measures ANOVA)

Group	Time point	Mean	SD	F	p-value
VR distraction	Baseline	103.68	7.48	61.60	< 0.001
	During injection	89.60	4.96		
	After injection	84.28	6.47		
Control	Baseline	104.08	6.82	0.30	0.742
	During injection	105.64	7.78		
	After injection	104.68	6.93		

SD, standard deviation. $p < 0.05$ considered significant.

Table 2: Pairwise comparison of mean heart rate between time points (Tukey HSD test)

Group	Time (I)	Time (J)	Mean diff. (I-J)	p-value
VR distraction	Baseline	During injection	14.08	< 0.001
	Baseline	After injection	19.40	< 0.001
	During injection	After injection	5.32	0.012
Control	Baseline	During injection	-1.56	0.724
	Baseline	After injection	-0.60	0.953
	During injection	After injection	0.96	0.885

Only non-redundant pairwise comparisons are shown. $p < 0.05$ considered significant.

Table 3: Between-group comparison of mean heart rate (beats/min) at each time point (independent-samples t-test)

Time point	Group	Mean	SD	t	p-value
Baseline	VR distraction	103.68	7.48	-0.20	0.844
	Control	104.08	6.82		
During injection	VR distraction	89.60	4.96	-8.69	< 0.001
	Control	105.64	7.78		
After injection	VR distraction	84.28	6.47	-10.76	< 0.001
	Control	104.68	6.93		

SD, standard deviation. $p < 0.05$ considered significant.

Table 4: Between-group comparison of mean pain and anxiety scores (independent-samples t-test)

Outcome	Group	Mean	SD	t	p-value
Anxiety	VR distraction	10.84	1.18	-32.60	< 0.001

	Control	20.00	0.76		
Pain (NRS)	VR distraction	3.56	1.26	-12.74	< 0.001
	Control	7.28	0.74		

NRS, Numeric Rating Scale; SD, standard deviation. $p < 0.05$ considered significant.

Discussion:

For decades, pharmacological methods have been the primary approach for controlling pain and anxiety during dental treatment, although non-pharmacological techniques have gained increasing importance in recent years. Among these, virtual reality (VR) provides immersive multisensory distraction that redirects attention away from painful stimuli. Recent systematic reviews and meta-analyses have demonstrated that VR significantly reduces dental pain and anxiety across various procedures and age groups [10]. However, evidence regarding adolescents remains limited. The present study demonstrated that VR distraction significantly reduced heart rate, pain and anxiety during local anaesthesia administration compared with conventional care. Heart rate decreased from 103.68 to 84.28 beats/min in the VR group, whereas no meaningful reduction was observed in the control group. These findings agree with previous randomized trials reporting lower physiological stress and improved behavior among children using VR during dental procedures [11]. In contrast, some studies have reported no significant reduction in heart rate with VR or audiovisual distraction, suggesting that treatment type, level of immersion and patient characteristics may influence physiological responses. Nevertheless, the concurrent reduction in heart rate and self-reported anxiety observed in the present study strengthens the consistency of the findings [12]. The reduction in anxiety scores is consistent with previous clinical studies demonstrating that VR distraction improves patient cooperation and decreases anxiety during pediatric dental treatment. Although some investigations have reported limited effectiveness of VR in reducing anxiety during invasive procedures, these differences may be attributed to variations in study design, VR content and the degree of immersion provided by the devices [13, 14]. Furthermore, no significant gender-related difference in anxiety was observed in the present study, indicating that the beneficial effects of VR may be independent of sex. Pain perception is influenced by both physiological and psychological factors. According to the limited-capacity theory of attention, immersive VR occupies multiple sensory channels, thereby reducing cognitive processing of painful stimuli. The significantly lower pain scores observed in the VR group are consistent with previous randomized trials and recent meta-analyses demonstrating the analgesic benefits of VR during local anaesthesia and other dental procedures [15, 16]. However, a few studies have reported no significant reduction in pain with audiovisual distraction, highlighting that the effectiveness of distraction depends on the intervention, procedure and patient population [17, 18]. Overall, the present findings support the growing evidence that immersive VR is a safe, effective and low-cost adjunct for reducing pain and anxiety during local anaesthesia administration in adolescents. Promoting positive dental experiences during adolescence may improve treatment

acceptance and reduce long-term dental anxiety and avoidance behavior.

Conclusion:

VR distraction significantly reduced anxiety, pain and heart rate during local anaesthesia in adolescents compared with conventional care. VR distraction may serve as a simple, safe, non-pharmacological aid for behaviour guidance during short invasive dental procedures. Larger multicentre trials are needed to confirm these findings and assess their long-term effects on dental attendance.

Strengths and limitations:

The principal strengths of this trial are its randomized controlled design with concealed allocation, its focus on the under-studied adolescent age group and its combination of an objective physiological outcome (heart rate) with subjective self-report of pain and anxiety. Several limitations should be acknowledged. The visible nature of the VR headset made blinding of participants and operator impossible, which may introduce performance and detection bias; only the analyst was blinded. The single-centre design and modest sample size (50 participants) limit the precision of the estimates and the generalizability of the findings. Only first-time attendees undergoing short, non-urgent procedures were included, so the results may not extend to patients with established dental anxiety or to longer, more invasive treatments. Heart rate is an indirect proxy for anxiety and can be influenced by factors unrelated to the dental procedure. Possible VR-related adverse effects such as cybersickness were not formally assessed and no longer-term follow-up was undertaken. Future multi-centre trials with larger samples, validated anxiety scales, assessment of cybersickness and longer follow-up are warranted.

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