

Virtual reality distraction for pain control during periodontal scaling and root planing procedures

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Patients' anxiety and fear-related behaviors not only are difficult to manage but also can affect dental treatment, compliance and oral health.¹⁻³ Allaying apprehension may be especially difficult if a patient's qualms and avoidance of treatment are not simply based on a phobia, but are associated with actual painful experiences encountered during dental visits.⁴⁻⁶

Unfortunately, many dental treatments performed without anesthesia, such as nonsurgical periodontal procedures, can be painful. Periodontitis, a chronic inflammatory disease affecting the gingiva, periodontal ligament and bone around the teeth, is characterized by bone resorption, apical migration of the attachment and subsequent periodontal pocket formation.⁷ Scaling and root planing (SRP) is an essential component of successful periodontal therapy.⁸

Because SRP can be painful,^{9,10} patients undergoing it may need local anesthesia or other methods of pain control such as cognitive behavioral treatment,¹¹ administration of nitrous oxide¹² or intravenous administration of sedatives. Clinicians also have used

ABSTRACT

Background. Although pain management during periodontal treatment usually is achieved with anesthesia, alternative methods are available. The authors conducted a study to evaluate the analgesic effect of immersive virtual reality (VR) during periodontal scaling and root planing (SRP) procedures.

Methods. The authors recruited 38 patients. They used a within-patient/split-mouth design. Patients received SRP under three treatment conditions in three quadrants. The three conditions were control, watching a movie and VR. After each SRP procedure, patients responded to questions about their discomfort and/or pain by using a visual analog scale (VAS) (range, 0 to 10 in which lower numbers indicate less pain or discomfort). The authors also recorded patients' blood pressure (BP) and pulse rate (PR). Patients were asked which of the three treatment modalities they preferred.

Results. The mean (\pm standard deviation) VAS scores for five questions pertaining to control, movie and VR were 3.95 ± 2.1 , 2.57 ± 1.8 and 1.76 ± 1.4 , respectively. Paired *t* tests revealed that VAS scores were significantly lower during VR compared with the movie ($P < .001$) and control ($P < .001$) conditions. Similarly, BP and PR were lowest during VR, followed by the movie and control conditions. Patients reported that they preferred the VR condition.

Conclusion. The results of this study suggest that use of immersive VR distraction may be an effective method of pain control during SRP procedures.

Clinical Implications. Practitioners can use immersive VR distraction for pain control during SRP procedures.

Key Words. Virtual reality; pain control, dental anxiety; periodontal scaling and root planing; analgesia.

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distraction techniques, such as watching movies, listening to music and playing video games, to reduce pain.^{13,14}

VIRTUAL REALITY

One of the more interactive distraction techniques involves immersive virtual reality (VR). VR technology allows users to interact with a simulated environment. Most VR environments provide the user with both visual and auditory experiences; some even include an avatar (graphical representation of oneself) to provide an additional sense of presence within the VR environment. Immersive VR has been shown to distract patients effectively during gastric laboratory procedures,¹⁵ as well as patients with burns from pain and anxiety during wound care and physical therapy.¹⁶ Hoffman and colleagues¹⁷ also reported its effectiveness in laboratory studies of pain.

In addition, Hoffman and colleagues¹⁸ showed that during removal of staples from skin grafts in patients with burns, patients who used immersive VR experienced less pain than did those playing a video game. In addition, patients with burns who used VR noted that they spent less time thinking about their pain, their wound care procedures or both.

Hoffman and colleagues¹⁹ investigated whether VR analgesia could reduce pain during periodontal treatment of two patients. Their results and those of the aforementioned VR studies¹⁵⁻¹⁹ suggest that immersive VR might be a viable non-pharmacological analgesic.

We conducted this study to evaluate the analgesic effect of immersive VR during SRP. The specific aims were to determine whether there were differences in pain levels and vital signs (pulse rate [PR] and systolic and diastolic blood pressure [BP]) between patients in a control group and those in distraction groups, as well as to determine whether patients had a preference for one type of distraction method or preferred no distraction.

PATIENTS AND METHODS

Patients. We recruited adults with mild, moderate or severe periodontitis who needed SRP in all four quadrants. Dental students and clinical faculty members identified potential participants during an initial or a routine clinical examination in the main clinic at Case Western Reserve Uni-

versity (CWRU) School of Dental Medicine, Cleveland. We invited these patients, along with patients referred for a periodontal consultation in the graduate periodontal clinic to participate. All patients received written information about the study from one of us (E.F.). Participants received SRP at no cost.

The criteria for selection were good general physical and mental health, the ability to understand oral and written instructions, and the ability to use a finger-trigger computer mouse. For this study, we determined good general health according to the patient's responses to items on the health history form, such as no need for premedication for SRP, controlled BP and controlled diabetes. Additional dental criteria included a minimum of five teeth per quadrant and one or more sites in each quadrant with

periodontal pocket depths (PDs) of 4 millimeters or greater. We obtained study approval from the CWRU Institutional Review Board and, before participating, each patient reviewed the protocol and signed a consent form.

Methods. We used a within-subject/split-mouth design to minimize the effects of confounding factors. Because all patients needed SRP in four quadrants, they experienced all three treatment conditions. The treatment conditions were control (no distraction) and two distraction methods: immersive VR and watching a movie. One of us (E.F.) performed three SRP procedures (each 20 minutes in duration) in each patient during one appointment. After each of the three procedures, patients completed a questionnaire; they then underwent the fourth SRP procedure.

A dental assistant arbitrarily assigned the sequence of treatment conditions (control, VR, movie), as well as the quadrant (maxillary right, maxillary left, mandibular right, mandibular left) for each patient. So that the dentist could not identify which treatment condition (movie, VR, control) was in operation, patients wore the same type of goggles and headgear during all SRP pro-

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ABBREVIATION KEY. **BP:** Blood pressure. **C:** Control. **CWRU:** Case Western Reserve University. **DAS:** Dental Anxiety Scale. **M:** Movie. **PDs:** Pocket depths. **PR:** Pulse rate. **SRP:** Scaling and root planing. **VAS:** Visual analog scale. **VR:** Virtual reality.



Figure 1. Patient wearing goggles and headgear during a scaling and root planing procedure.

cedures (Figure 1).

SRP procedure. The clinician (E.F.) obtained demographic information during her review of each patient's health history. During the periodontal examination, she measured the PD to the nearest millimeter by using a UNC probe (Hu-Friedy, Chicago) at six sites per tooth. The dentist used ultrasonic scalers and sharp hand curettes to perform SRP. She treated the root surfaces with standard curettes (Gracey 1/2, 7/8, 11/12, 13/14 curettes, Hu-Friedy), which were sharpened before use.

Heart rate and BP. We measured each patient's heart rate and BP throughout the treatment by using a digital BP monitor (CASMED 750 [CAS Medical Systems, Branford, Conn.] with Masimo SET pulse oximetry [Masimo, Irvine, Calif.]). We used patients' PR and BP as recorded at the start of SRP and at the end of the procedure for the statistical analysis. At the end of treatment, the dental assistant asked patients to identify which of the three treatment conditions they preferred and recorded their responses in the medical record.

To test interrater reliability, two investigators (E.F., R.S.) measured the PD in four quadrants of three patients (a total of 12 quadrants). We determined the interrater reliability by calculating intraclass correlation coefficients. Similarly, we determined the intrarater reliability of the investigator by repeating PD measurements in three patients (a total of 12 quadrants) on separate occasions and then calculating the intraclass correlation coefficients. We confirmed the reproducibility of the VAS pain score responses by repeating the SRP procedures and administering the VAS pain questionnaire under the same con-

ditions (control, movie, VR) three months later in the three patients.

To ensure that the quadrants treated were similar within the same participant, we used paired *t* tests to compare the mean probing depths, the greatest probing depth in each of the four quadrants, clinical attachment levels and number of teeth. We then compared these variables between the control and movie conditions, control and VR conditions, and VR and movie conditions.

Distraction methods. Using immersive VR and watching a movie were the two distraction methods used in this study. For immersive VR, we used a Silicon Graphics Octane/MXE workstation with Octane Channel Option (Silicon Graphics, Mountain View, Calif.) coupled with a V8 head mount display (Virtual Research Systems, Santa Clara, Calif.) to create an immersive, three-dimensional, interactive, computer-simulated environment. The virtual environment created for our study was a botanical garden in Second Life (Linden Lab, San Francisco), a virtual world accessible via the Internet.

Using a handheld mouse, patients explored the VR world and chose their own pathways through the VR environment by controlling the direction and gaze of the avatar. For example, patients could choose to walk or fly through and about the botanical garden. We chose the animated feature "Cars" (The Walt Disney Company, Los Angeles) as the movie because it is nonviolent and inoffensive. Patients watched the first 20 minutes of the movie.

To determine patients' level of anxiety before the SRP treatments, we instructed them to complete the validated Corah Dental Anxiety Scale (DAS).²⁰⁻²³ The scale ranges from 4 to 20, with scores of 13 or higher indicating high dental anxiety.²⁰

Visual analog scale. The primary dependent variables were the patient's self-ratings of pain and sense of presence in the VR or movie environment. We measured pain and presence on a visual analog scale (VAS) that was 10 centimeters in length. The VAS scale, one of the most commonly used pain measurement tools, has an analog format: a horizontal line represents a continuing range of values.^{24,25} We chose this instrument because it is easy to use, it is valid and reliable,^{26,27} and it has been used in previous studies to evaluate pain during periodontal treatment, as well as to evaluate the analgesic effect of VR distraction.^{19,28} We used the identical questionnaire items and associated VAS scoring system used by Hoffman and colleagues¹⁹ in their case study of

VR analgesia during SRP. In our study, the dental assistant asked patients to make a mark on the line indicating the severity or level of pain. She then recorded the measurement to the nearest centimeter.

Questionnaire. Immediately after each SRP procedure, patients completed a short questionnaire about their pain and discomfort levels.¹⁹ The questionnaire consisted of 11 items related to pain, sense of presence in the distraction environment and discomfort. Patients responded to each item on the 0- to 10-cm VAS scale, with lower numbers indicating less pain or discomfort and higher numbers indicating greater pain or discomfort. We also calculated a mean pain score for patients' responses to the first five questions (that is, pertaining to time spent thinking about the pain, unpleasantness of the procedure, tooth and gum discomfort, worst pain during the visit and average pain during the visit).

We administered the first five questions after each of the three treatment conditions. After SRP with the two distraction modalities, we also asked patients to respond to three additional questions (pertaining to nausea experienced during VR or the movie, perceptions of feeling part of the virtual world or the movie, and perceptions of how real objects in the virtual world or the movie seemed). Hoffman and colleagues¹⁹ used these three distraction-related questions to assess any negative physical effects and to determine the degree to which a patient's perception of presence—specifically pertaining to the VR environment—might be relevant. We also asked patients to specify the treatment condition they preferred: no distraction, watching a movie or VR distraction.

Statistical analysis. We used statistical software (SPSS Version 16 for Windows, SPSS, Chicago) to analyze the data. We calculated correlation coefficients to test intrarater and interrater reliability. We analyzed parametric variables by using the *t* test and conducted χ^2 analyses for nonparametric variables. In addition, we used paired *t* tests to compare both of the treatment groups with the control group and the treatment groups with each other.

RESULTS

Thirty-eight patients volunteered for the study. The intraclass correlation coefficients were good (> 0.9) for both interrater and intrarater reliability in the measurement of periodontal PDs. Table 1 presents study population data. We found no significant dif-

TABLE 1

Patient information for total population and according to sex.

VARIABLE	MEN (n = 17)	WOMEN (n = 21)	TOTAL (N = 38)
Race/Ethnicity, No. of Patients			
White	9	11	20
African American	8	10	18
No. of Smokers	2	3	5
Mean \pm SD* Age, Years	46.8 \pm 13.2	45.2 \pm 12.3	45.9 \pm 12.6
Mean \pm SD No. of Teeth	26.5 \pm 3.3	24.9 \pm 3.6	25.6 \pm 3.5
Mean \pm SD DAS† Score	8.6 \pm 3.5	9.3 \pm 2.8	9.0 \pm 3.1
No. of Patients With Anxiety‡	3	3	6

* SD: Standard deviation.
† DAS: Dental Anxiety Scale.²⁰
‡ Anxiety according to DAS score of 13 or higher.

ferences between men and women with regard to age, ethnicity, number of teeth, smoking status or DAS scores. A DAS score of 13 or higher indicates dental anxiety.²⁰ Six patients (three male and three female) had DAS scores of 13 or higher. The mean (\pm standard deviation [SD]) DAS score for these six patients was 14.5 (\pm 1.4).

The dental assistant distributed the treatment conditions evenly between the maxilla and mandible. In the maxillary arch, the dentist performed 17 SRP procedures during VR, 18 SRP procedures during the movie and 19 SRP procedures during the control condition. Similarly, in the mandibular arch, the dentist performed 21 SRP procedures during VR, 20 SRP procedures during the movie and 19 SRP procedures during the control condition. The dental assistant also evenly distributed the sequence of treatment conditions (that is, VR, movie or control) among patients in the study.

We compared greatest probing depth, mean probing depth, clinical attachment level and number of teeth; paired *t* tests showed no statistically significant differences in quadrants between control and movie, movie and VR, and control and VR (Table 2).

The reproducibility of the VAS pain scores was good; the intraclass correlation coefficients were greater than 0.9. Both the VR and movie conditions resulted in statistically significantly lower reported pain levels (lower VAS scores) compared

TABLE 2

Clinical characteristics according to treatment condition, with paired *t* tests comparing control with movie, movie with VR* and control with VR.

VARIABLE	MEAN (\pm SD) ^{†‡} GREATEST PROBING DEPTH, mm [§]	MEAN (\pm SD) PROBING DEPTH, mm	MEAN (\pm SD) CLINICAL ATTACHMENT LEVEL, mm	MEAN (\pm SD) NUMBER OF TEETH
Control	6.34 (\pm 1.82)	3.49 (\pm 1.21)	3.54 (\pm 1.14)	6.61 (\pm 1.05)
Movie	6.58 (\pm 2.09)	3.43 (\pm 0.98)	3.61 (\pm 1.07)	6.76 (\pm 0.97)
Virtual Reality	6.82 (\pm 2.27)	3.36 (\pm 1.17)	3.52 (\pm 1.22)	6.92 (\pm 0.85)
Control Versus Movie	<i>P</i> = .443	<i>P</i> = .527	<i>P</i> = .466	<i>P</i> = .295
Movie Versus VR	<i>P</i> = .391	<i>P</i> = .353	<i>P</i> = .256	<i>P</i> = .373
Control Versus VR	<i>P</i> = .077	<i>P</i> = .078	<i>P</i> = .771	<i>P</i> = .083

* VR: Virtual reality.
[†] SD: Standard deviation.
[‡] Unless otherwise indicated.
[§] mm: Millimeters.

TABLE 3

Mean VAS* scores, according to treatment condition, with paired *t* tests comparing control with movie, movie with VR[†] and control with VR.

VARIABLE	MEAN (\pm STANDARD DEVIATION) VAS SCORE [‡]				
	Questionnaire Item 1 [§]	Questionnaire Item 2 [¶]	Questionnaire Item 3 [#]	Questionnaire Item 4 ^{**}	Questionnaire Item 5 ^{††}
Control	3.89 (\pm 2.5)	3.97 (\pm 2.2)	3.95 (\pm 2.4)	4.29 (\pm 2.4)	3.66 (\pm 2.0)
Movie	2.42 (\pm 1.9)	2.39 (\pm 2.0)	2.50 (\pm 1.9)	3.13 (\pm 2.3)	2.39 (\pm 1.8)
VR	1.82 (\pm 1.3)	1.66 (\pm 1.5)	1.58 (\pm 1.3)	2.16 (\pm 2.1)	1.58 (\pm 1.4)
Control Versus Movie	<i>P</i> < .001	<i>P</i> < .001	<i>P</i> < .001	<i>P</i> < .001	<i>P</i> < .001
Movie Versus VR	<i>P</i> = .019	<i>P</i> = .006	<i>P</i> < .001	<i>P</i> < .001	<i>P</i> = .001
Control Versus VR	<i>P</i> < .001	<i>P</i> < .001	<i>P</i> < .001	<i>P</i> < .001	<i>P</i> < .001

* VAS: Visual analog scale. Lower scores indicate less pain or discomfort.
[†] VR: Virtual reality.
[‡] Unless otherwise indicated.
[§] Time spent thinking about the pain. All questionnaire items were based on those by Hoffman and colleagues.¹⁹
[¶] Unpleasantness of the procedure.
[#] Tooth and gum discomfort.
^{**} Worst pain during the dental visit.
^{††} Average pain during the dental visit.

with those in the control group with regard to total VAS scores, as well as VAS scores for the individual questions. As shown in Table 3, the mean VAS pain ratings for the first five items on the questionnaire were consistently highest for the control condition, followed by the movie, and lowest for VR. Table 3 also shows *P* values of paired *t* tests for the three conditions for questionnaire items 1 through 5. The mean (\pm SD) VAS pain scores for items 1 through 5 combined were 1.76 (\pm 1.4) for VR, 2.57 (\pm 1.8) for the movie and 3.95 (\pm 2.1) for the control condition. Paired *t* tests revealed a significant difference between the control and movie conditions (*P* < .001), the control and VR conditions (*P* < .001) and the movie and VR

conditions (*P* < .001). Figure 2 shows these results.

We tested the sequence of treatment conditions (VR, movie or control) for each dependent variable. The results showed that the order of the conditions did not influence the reported level of pain. Figure 3 illustrates the common pattern of mean VAS pain scores for different sequences of treatment conditions: the control condition consistently received the highest VAS score, followed by the movie and then VR. Of the three questions related to nausea, feeling part of VR or the movie, and the reality of the objects in the virtual world or movie, the results show a significant difference in VAS scores only for the question about nausea. Five patients noted that they experienced mild

nausea during the VR condition but not while watching the movie ($P = .014$, paired t test).

Paired t tests showed no significant differences between BP measurements at the start of the SRP procedure and those at the end of the procedure, with one exception. Table 4 shows the mean systolic and diastolic BP measurements. The exception occurred during viewing of the movie, when the mean initial systolic BP measure was lower than that at the end of the procedure (129.4 mm Hg versus 131.3 mm Hg, $P = .044$). Patients' vital signs during SRP under the two distraction conditions were significantly lower than those under the control condition, and vital signs during VR were lower than those during the movie (Table 4).

The results showed that the six patients who were more anxious (based on DAS scores ≥ 13) had higher VAS scores than did patients who were less anxious; however, independent t tests showed no statistical differences.

In response to the question about which treatment condition patients preferred, approximately two-thirds responded that they preferred VR, while one-third preferred watching the movie; only one patient preferred the control condition.

DISCUSSION

VR. The hypothesis of this study—immersive VR has a greater analgesic effect

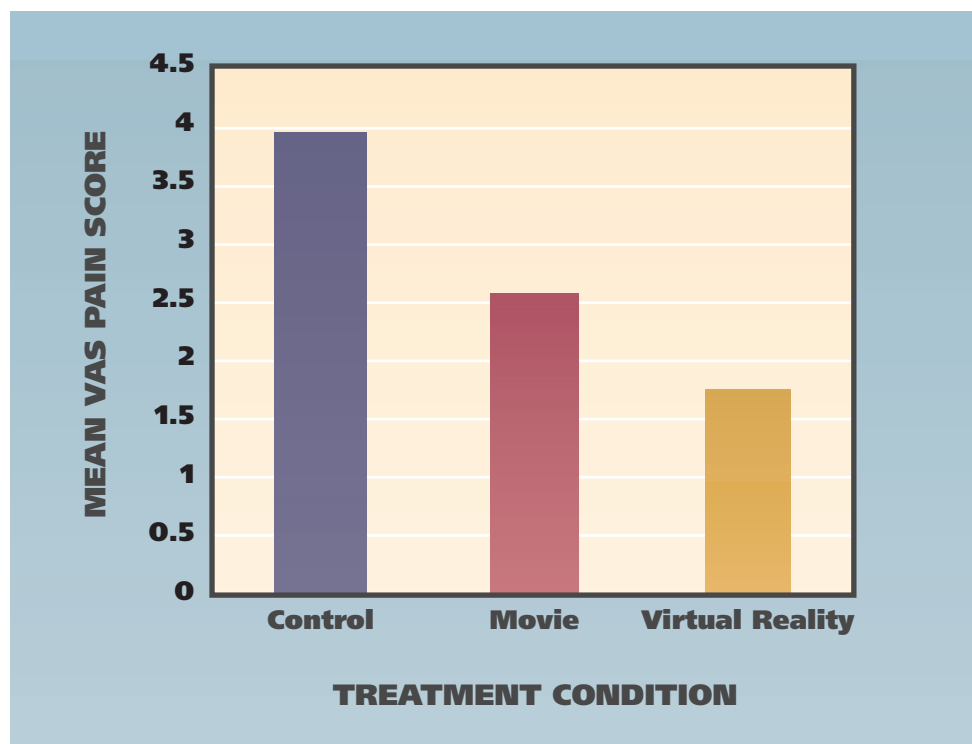


Figure 2. Participants' mean visual analog scale (VAS) pain scores for questionnaire items 1 through 5¹⁹ combined (that is, pertaining to time spent thinking about the pain, unpleasantness of the procedure, tooth and gum discomfort, worst pain during the visit and average pain during the visit) for the three treatment conditions (control, movie, virtual reality immersion).

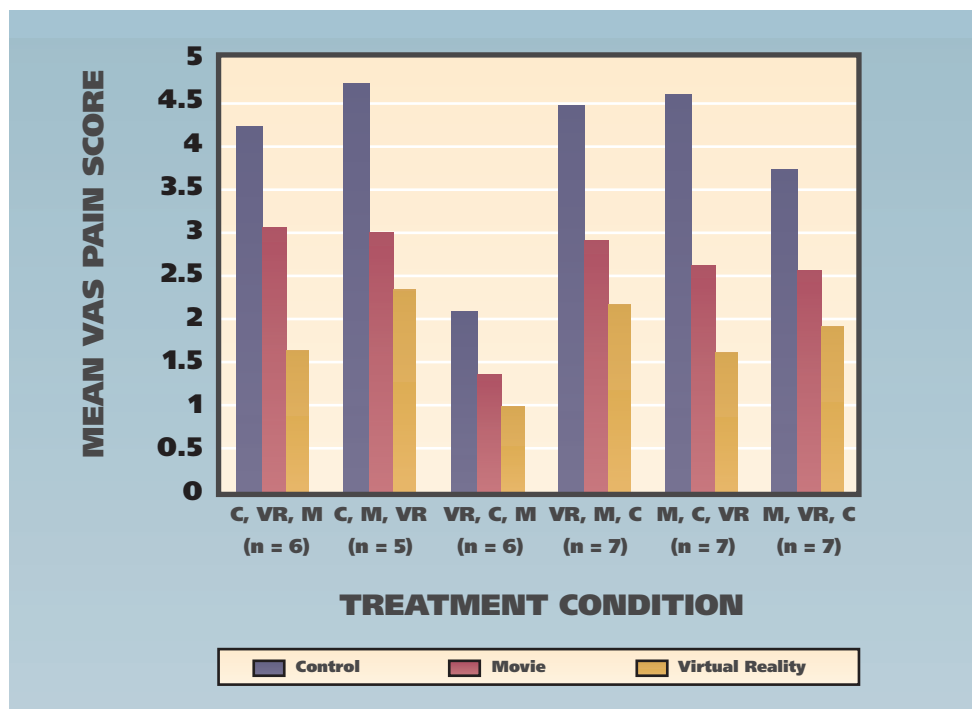


Figure 3. Graphic representation of mean visual analog scale pain scores during scaling and root planing procedures for the three treatment conditions (control [C], no distraction; distraction with virtual reality [VR]; and distraction with the movie [M]), according to the sequence of treatment conditions for patients.

TABLE 4

Blood pressure and pulse rate, according to treatment condition, with paired *t* tests comparing control with movie, movie with VR* and control with VR.

VARIABLE	MEAN (± STANDARD DEVIATION) [†]			
	Systolic Blood Pressure, mm Hg [‡]	Diastolic Blood Pressure, mm Hg	Initial Pulse, BPM [§]	Pulse at Completion of Treatment, BPM
Control	133.7 (± 15.7)	86.0 (± 8.9)	76.7 (± 9.5)	79.0 (± 10.8)
Movie	130.4 (± 14.8)	83.3 (± 10.8)	69.0 (± 9.0)	70.2 (± 9.0)
VR	125.6 (± 12.6)	81.0 (± 9.0)	67.5 (± 7.4)	68.3 (± 7.7)
Control Versus Movie	<i>P</i> = .013	<i>P</i> = .016	<i>P</i> < .001	<i>P</i> < .001
Movie Versus VR	<i>P</i> = .001	<i>P</i> = .039	<i>P</i> = .112	<i>P</i> = .029
Control Versus VR	<i>P</i> < .001	<i>P</i> < .001	<i>P</i> < .001	<i>P</i> < .001

* VR: Virtual reality.
[†] Unless otherwise indicated.
[‡] mm Hg: Millimeters of mercury.
[§] BPM: Beats per minute.

than no distraction or the movie distraction—was proved. The results of our study show that use of VR was an effective pain management technique for patients undergoing SRP procedures. Approximately two-thirds of the study population reported that they preferred the VR distraction method during SRP procedures, one-third preferred to watch the movie and only one patient preferred no distraction at all. Not only did patients prefer interacting with the VR environment and report lower levels of pain, but also they had significantly lower PR and BP measurements during the VR experience.

Pain is difficult to assess because it consists of both physical and psychological components. One variable for which we tried to control was anxiety, because previous studies found that patients who were more anxious—those with higher DAS scores—were more likely to report a higher pain response than were other patients.²⁹ Therefore, we instructed patients to complete the DAS before treatment. We expected that the more anxious patients would perceive more pain. Although there was a trend for more anxious patients to have VAS scores higher than those of less anxious patients, the differences were not statistically significant. This may be due to the fact that we categorized only six patients as being more anxious or because their mean DAS scores were just above 13.

For pain to be experienced, some level of attention is required.³⁰ Hoffman and colleagues³¹ believed that the nonpharmacological analgesic effect of VR can be explained by its ability to draw

a person's attention away from the actual treatment environment. VR is interactive and multisensory (for example, patients concentrate on controlling an avatar, hearing different sounds such as those of waterfalls and birds, and seeing a relaxing botanical garden environment). The interactive aspects of VR compete for patients' attention, thus minimizing their ability to process incoming pain signals.^{31,18} We believe that these multisensory, interactive aspects of VR make it a mesmerizing experience, effectively competing for patients' attention.

Consistent with this attention hypothesis, the results of a recent double-masked, laboratory-controlled thermal pain study showed significantly greater pain reduction in a group of participants who experienced high-tech VR distraction (designed to maximize the participants' illusion of entering the virtual world) compared with participants who experienced low-tech VR distraction (designed to minimize the illusion of entering the computer-generated VR environment).³² The authors found a VR dose-response relationship.

Hoffman and colleagues¹⁷ conducted a study that involved the use of functional magnetic resonance imaging brain scans, the results of which demonstrated that VR analgesia was accompanied by large reductions in pain-related brain activity. VR analgesia appeared to change the way the brain processes incoming nociceptive signals. During VR, all five brain regions of interest—anterior cingulate cortex, primary

and secondary somatosensory cortex, insula and thalamus—processed fewer pain signals.¹⁷ These results provide complementary evidence of the effectiveness of VR analgesia.

The patients in our study, similar to the two patients in the study by Hoffman and colleagues,¹⁹ reported that VR significantly reduced their awareness of dental pain. Patients' VAS scores were significantly lower for sensory pain (rating of worst pain and average pain) and affective pain (rating of unpleasantness of the experience and tooth and gum discomfort) and indicated a large reduction in the amount of time spent thinking about the pain during SRP procedures.

Movie. Although watching the movie during the SRP treatment was not as effective as using VR, patients did report experiencing significantly less pain and discomfort than they did during the control condition (no distraction). This can be explained, in part, by the passive nature of watching a movie, which may serve only to relax and/or partially distract the patient from his or her pain. The results also may be related to the movie's genre, content or both. To minimize the variables associated with the distraction conditions, we used the same VR environment (the botanical garden) for all patients, and all patients watched the same nonviolent family movie. It is possible that had patients been able to choose the VR environment and/or the movie, their level of distraction might have varied. One patient noted that he had seen "Cars" at least three times with his children and did not really enjoy seeing it again. Investigators in future studies should consider including a choice of movie and VR environment as variables.

Physiological measurements. In our study, participants' physiological measurements of PR and BP were lower while they watched the movie than they were during the control condition; PR and BP were even lower during use of VR. These findings support the belief that visual indexes of pain response (such as VAS scores) are positively correlated with the heart rate as an autonomic indicator of pain sensitivity.^{33,34}

Simulator sickness, a form of motion sickness characterized by nausea,³⁵ may present a problem for some patients. In our study, five (13 percent) of 38 patients reported experiencing mild nausea during the VR condition. Therefore, patients with severe susceptibility to motion sickness probably should not experience VR.

CONCLUSION

The results of this study suggest that immersive VR distraction may be an effective method of pain control during SRP procedures. Future studies should include larger patient populations, more practitioners using different types of immersive reality environments and a variety of movie genres. ■

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