Virtual Reality Pain Control During Burn Wound Debridement in the Hydrotank

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Objective: Most burn-injured patients rate their pain during burn wound debridement as severe to excruciating. We explored the adjunctive use of water-friendly, immersive virtual reality (VR) to distract patients from their pain during burn wound debridement in the hydrotherapy tank (hydrotank).

Setting: This study was conducted on inpatients at a major regional burn center.

Patients: Eleven hospitalized inpatients ages 9 to 40 years (mean age, 27 y) had their burn wounds debrided and dressed while partially submerged in the hydrotank.

Intervention: Although a nurse debrided the burn wound, each patient spent 3 minutes of wound care with no distraction and 3 minutes of wound care in VR during a single wound care session (within-subject condition order randomized).

Outcome Measures: Three 0 to 10 graphic rating scale pain scores (worst pain, time spent thinking about pain, and pain unpleasantness) for each of the 2 treatment conditions served as the primary dependent variables.

Results: Patients reported significantly less pain when distracted with VR [eg, "worst pain" ratings during wound care dropped from "severe" (7.6) to "moderate" (5.1)]. The 6 patients who reported the strongest illusion of "going inside" the virtual world reported the greatest analgesic effect of VR on worst pain ratings, dropping from severe pain (7.2) in the no VR condition to mild pain (3.7) during VR.

Conclusions: Results provide the first available evidence from a controlled study that immersive VR can be an effective nonpharmacologic pain reduction technique for burn patients experiencing severe to excruciating pain during wound care. The potential applications of VR analgesia to other painful procedures (eg, movement or exercise therapy) and other pain populations are discussed.

Key Words: analgesia, burn pain, wound care, distraction, virtual reality

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Wound care performed on conscious patients with severe burn injuries is widely considered one of the most painful medical procedures. The majority of patients with burns severe enough to require hospitalization report severe to excruciating pain during wound care, despite medication with powerful opioid analgesics.[1,2]

Appropriately dosed pharmacologic analgesics typically work well for reducing pain in burn patients during rest or when not undergoing medical procedures. However, during daily wound care procedures when patients have their bandages removed, their wounds cleaned, assessed, disinfected, and rebandaged, opioid analgesics alone often fail to adequately control the pain. In some instances, patients undergoing such procedures sit partially submerged in a stainless steel bathtub of water (hydrotank), to facilitate bandage removal and wound cleansing. Wound care is typically most painful early in the recovery process,[3] when patients are most likely to have their burn wound care performed in the hydrotank. Although undermedication contributes to problems with excessive pain,[4] increasing opioid dose is not always advisable because of increased side effects seen at higher doses, including nausea, constipation, sedation, itching, urinary retention, cognitive impairment, and respiratory depression.[5]

DISTRACTION

Psychologic factors such as attention can influence the subjective experience of the pain.[6–8] Although there is some evidence that distraction can help reduce pain,[9,10] much of the research exploring the analgesic effectiveness of pain distraction has been conducted in laboratory studies that may not generalize to the more complex environment of clinical settings. The relationship between attention and pain may be complicated by the moderating influence of a number of factors, for example, distraction seems to work under some conditions and some situations

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but not others, even in the controlled laboratory settings.[11–13] A stronger, more effective distraction technology robust to variations in treatment procedures, which consistently yields clinically meaningful reductions in clinical procedural pain, would be valuable.

IMMERSIVE VIRTUAL REALITY

Researchers have recently proposed that immersive virtual reality (VR) can serve as an unusually powerful psychologic pain control technique.[14] Pain requires attention[13,15] and VR is thought to be especially effective at luring the spotlight of attention away from the painful procedure and into the computer-generated virtual world. The illusion of going into the 3-dimensional computer-generated world (known as presence) is uniquely compelling in immersive VR. Researchers predict that patients who experience a stronger illusion of going into the virtual world will be more distracted by VR, and will thus report more pain reduction than those who experience a less compelling illusion of "presence" in the virtual world.[16]

Clinical research has begun exploring the use of immersive VR pain control.[17,18] In a preliminary case study, VR distraction reduced pain during staple removal from burn skin grafts more effectively than a 2-dimensional video game.[19] Both patients reported feeling more present in the computer-generated world during the VR condition than during the video-game condition. Furthermore, 1 patient reported a very strong illusion of going into the virtual world, and reported dramatic reductions in his pain during staple removal while in VR. In contrast, the second patient reported only a moderate illusion of going into the virtual world, and a moderate amount of pain reduction during staple removal while in VR. Compared with standard of care (no distraction), burn patients consistently report clinically meaningful (ie, > 30%) reductions in pain during wound care and physical therapy sessions while in VR.[14,19–21] Furthermore, although larger studies with longer treatment durations are needed, preliminary results indicate that VR does not decline in analgesic effectiveness when used on multiple occasions.[14]

SnowWorld (www.vrpain.com) was the first immersive VR software designed for treating pain. SnowWorld was specifically designed to reduce pain experienced by burn patients during medical procedures (Fig. 1). Some patients report that pain during wound care reminds them of their original burn injury/accident. In SnowWorld, patients "go into" an icy, cool 3-dimensional virtual environment.

VR analgesia was designed on the basis of the principles of immersion described by Slater and Wilbur.[22] According to Slater and Wilbur,[22] VR presence is a subjective illusion created in the user's mind (ie, a psychologic state of consciousness). In contrast, immersion is an objective, measurable description of the sensory input that a particular VR system delivers to a participant. Although presence and immersion are distinct concepts, increasing the immersiveness of a VR system is predicted to increase the illusion of presence in VR and this relationship is often found. For example, increasing the size of the eyepieces in the VR helmet (ie, field of view[23]) and adding or improving the quality of sound in VR[24] have both been shown to increase participants' subjective illusion of presence inside the virtual world. Tracking the orientation of the patient's head such that what the patient sees in VR changes as the patient moves his/her head around can also enhance presence,[24] as can tactile augmentation (ie, adding tactile feedback to virtual objects[25]), but neither head tracking nor tactile cues were used in the present study. One recent study showed that a low tech VR system (no head-tracking, low-quality helmet, and no sound effects) led to a less compelling illusion of presence and less pain reduction than a "high-tech" VR system with head-tracking, high-resolution video, and stereophonic sound.[16]

Immersive VR blocks the user's view of the real world, and presents patients with a view of a computer-generated world instead. The helmet and headphones exclude sights and sounds from the hospital environment, providing converging evidence from the virtual world to multiple senses, (both sight and sound). Patients are able to interact with the virtual world by moving their joystick

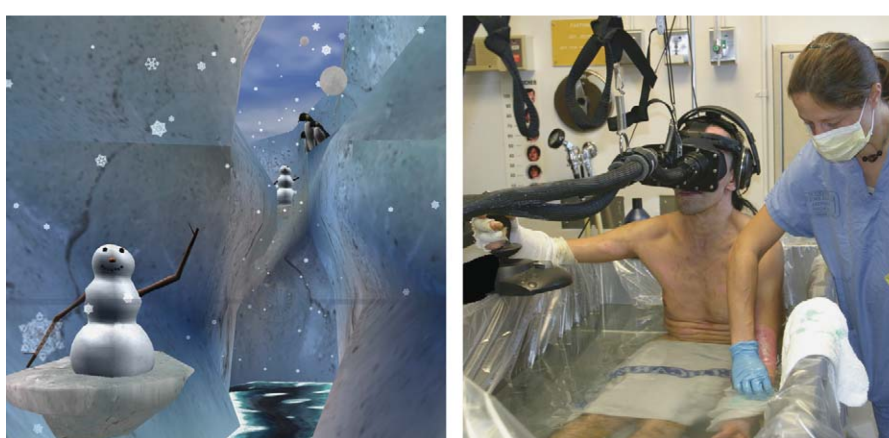

FIGURE 1. Right image: an adult burn patient using the water-friendly fiber-optic VR helmet to escape into SnowWorld pain distraction (shown on left) during wound debridement in the hydrotank. Instead of using electrons (electricity) the water-friendly helmet delivers photons (light) to the patient through the large black cables. Image on left by Ari Hollander, www.Imprintit.com, copyright, Hunter Hoffman, UW. Photograph on right, and copyright Hunter Hoffman, UW.

to look around and aim, and pull the trigger to shoot snowballs. Snowballs serve as a very simple human-computer interface for patients to interact with the virtual world with minimal motion of their bodies (it is important for patients to remain still during wound care).

Specific to the setting of a patient sitting half submerged in a tub of water, water-friendly VR delivery is accomplished with a photonic, nonelectric system. In our system developed for the present study, video images are guided in the form of light from a distant source (eg, projectors) via glass fiberoptic cables to 2 eyepieces/displays positioned about an inch in front of the user's eyes. In the 'water-friendly' system, we created, navigation and user interaction with the virtual world is provided by use of a manual joystick (Fig. 1).

Eccleston and Crombez[13] have developed a theoretical model emphasizing that pain requires attention, and pain plays an interruptive function. More specifically, according to Eccleston and Crombez,[13] "pain interrupts, distracts, and is difficult to disengage from." Pain is a warning signal and is attentionally demanding because of its survival/protective function. Pain "ruptures behavior, and imposes a new action priority to escape."

McCaul and Malott[26] proposed that "stimulus intensity is an important determinant of whether and when an distraction will occur. In other words, as a painful stimulus reaches some intense level, it will begin to attract attention and impede the effectiveness of the distraction." Recent researchers have further argued that distraction will probably fail if the pain is perceived as very threatening, for instance in high-pain catastrophizers, who have shown difficulty disengaging attention from pain information.[27] Thus, in theory, powerful affective characteristics of the pain could also limit the efficacy of pain distraction techniques.

In contrast, preliminary evidence from a single case study suggests that VR distraction with SnowWorld works even during the most painful portions of wound care procedures conducted in the hydrotank.[18] Although encouraging, such case studies are scientifically inconclusive by nature. The present study is the first controlled study to quantify whether VR can reduce "severe to excruciating" subjective pain reports in burn patients undergoing burn wound care in the hydrotank (a notoriously painful setting).

METHODS

Participants

Eleven patients aged 9 to 40 years (mean age, 27 y), with burns severe enough to require hospitalization and inpatient care were studied, and underwent wound debridement by a nurse at the University of Washington Burn Center at Harborview Medical Center. Patients were recruited by a research nurse, in conjunction with wound care nurses who identified potential enrollees who were experiencing excessive pain, despite pharmacologic analgesics, during wound care in the hydrotank. The study was open to both sexes; however, all 11 of the patients were male and provided oral and written, informed, Institutional Review Board (IRB)-approved consent. All but one of the patients had upper extremity injuries, whereas 1 patient had a lower extremity injury. Patients were treated only 1 time in this study, and patients were aware that this was a 1-treatment study.

Standard opioid analgesics and benzodiazepines were administered at the discretion of the burn center staff 30 to 45 minutes before the procedure, and were not affected by participation in this study. As a result, a within-subject design was used to ensure that the level of pharmacologic analgesia was the same in both the VR and control conditions during the same wound care procedure for each patient. Our "within wound care" design (ie, having 1 treatment condition and 1 control condition during a single wound care session) also circumvented potential day-to-day variations in sensitivity to pain during the procedure.[3,28] A 6-minute segment of the wound care procedure during which the patient had previously experienced the most pain (identified from previous days' procedures) was divided into 2 equivalently painful 3-minute wound care segments. During one of the 3-minute sessions the participant received no VR distraction (ie, standard premedication only). During the other 3-minute treatment session, the participant wore the water-friendly VR helmet and underwent the wound debridement while experiencing immersive, interactive VR. The order in which the control condition and the treatment condition were administered was randomized such that each treatment condition had an equal chance of occurring first or second for each patient.

During 2 brief pauses in the wound care procedure (once after each 3-min intervention period), patients completed 3 subjective pain ratings using 0 to 10 labeled Graphic Rating Scales (GRSs) with respect to the preceding 3 minutes of wound care. Such pain rating scales have been shown to be valid through their strong associations with other measures of pain intensity, and through their ability to detect treatment effects.[29,30] The specific queries used in the current study were designed to assess the cognitive component of pain (amount of time spent thinking about pain), the affective component of pain (unpleasantness), and the sensory component of pain (worst pain). Affective and sensory pain are 2 separately measurable and sometimes differentially influenced components of the pain experience.[31,32] Gracely et al,[32] have shown ratio scale measures such as the labeled GRSs used in this study to be highly reliable. In addition, a single GRS rating of user presence in the virtual world (to what extent did you feel like you "went into" the virtual world, adapted from Slater et al[33]) was recorded, and a GRS rating of "fun" during wound care was measured.[18] Hendrix and Barfield[24] showed the reliability of a similar VR presence rating. The measure's ability to detect treatment effects[16,25] is preliminary evidence of our VR presence measure's validity. Finally, nausea was assessed by GRS rating in an effort to identify the incidence of this component of simulator sickness sometimes associated with VR use.[34] The use of these various GRS assessment tools in VR analgesic studies is described in detail elsewhere.[16]

The VR system consisted of a Dell (www.dell.com) 530 workstation with dual 2 GHz CPUs, 2 GB of RAM, a GeForce 6800 video card. A Toroid Isolation Transformer was used. SnowWorld VR pain control software (www.vrpain.com) was run on a Windows 2000 operating system. While in high-tech VR, paticipants followed a predetermined path, ''gliding'' through an icy 3-dimensional virtual canyon. Participants 'looked'' around the virtual environment, aimed with a Microsoft SideWinder joystick, and pushed a trigger button to shoot virtual snowballs at virtual snowmen, igloos, and penguins (Fig. 1). Participants saw the sky when they looked up (by moving their joystick), a canyon wall when they looked to the left or right, a flowing river when they looked down, and heard sound effects (eg, a splash when a snowball hit the river). Participants wore the custom water-friendly VR helmet, which completely blocked the participants' view of the real world (Fig. 1). This helmet has approximately 105-degree horizontal field of view for each of the round eyepieces with 100% overlap between the right and left eye images. InFocus LP70 projectors served as the image sources. The factory lenses of the projectors were replaced with 1:1 relay lenses. Instead of magnifying the small images onto a large projector screen with factory lenses, the relay lenses were used to focus the images onto one 10 mm × 8 mm end of a 1000 × 800 fiberoptic glass image guide (one image guide per eye). These 15-foot long glass image conduits transmitted the images to the patient in the form of photons not electrons (ie, light, not electricity). Near the patient's head, the images from the image guides were then expanded with image tapers/magnifiers, and optics lenses were used to focus the images at infinity, to help give patients the illusion that they were inside the computer-generated environment as they looked into the goggles at SnowWorld. Elsewhere, we describe a similar fiberoptic VR helmet designed to allow participants to go into VR during functional MRI brain scans, another environment hostile to the use of conventional electronic VR helmets.[35,36]

RESULTS

Mean pain ratings were lower during VR than in the control condition (no distraction) for all 3 pain measures, and the differences were all statistically significant (Table 1A). Mean nausea ratings were negligible (< 1 on a 0 to 10 scale), and mean presence ratings were 3.4. As shown in Table 1B, the 6 patients with the highest presence ratings showed significant reductions in worst pain ratings. These 6 patients also showed significant reductions in pain unpleasantness, Time spent thinking about pain, and significant increases in Fun during VR. In contrast, the 5 participants whose presence ratings were below the mean showed no significant reduction in worst pain ratings, no significant reduction in pain unpleasantness, and no significant increase in fun during VR (Table 1C). But they did show a significant reduction in time spent thinking about pain during VR. The 6 patients with the highest pain intensity during no VR (worst pain > 7.6, n = 6) reported a 41% reduction in pain intensity (worst pain) during VR (not shown in the table).

TABLE 1. Mean Pain Ratings During no VR (control condition) vs. the Virtual Reality Condition

	Control Condition	VR Condition	$t(10)$ Value	P
A. All patients, n = 11, mean scores (SD)				
Worst Pain	7.6 (1.9)	5.1 (2.6)	2.92	0.015
Unpleasant	6.7 (1.6)	4.1 (2.8)	2.84	0.017
Time	7.6 (3.1)	3.6 (2.5)	5.24	< 0.001
Fun	0.9 (1.6)	3.8 (3.3)	2.95	0.015
	Control Condition	**VR Condition**	**$t(5)$ Value**	**P**
B. Patients with presence > 3.4, n = 6, mean scores (SD)				
Worst Pain	7.2 (1.7)	3.7 (2.1)	2.92	< 0.05
Unpleasant	6.5 (1.2)	2.5 (1.6)	5.48	0.003
Time	6.7 (3.6)	2.3 (1.6)	3.53	0.017
Fun	1.5 (2.0)	5.7 (3.2)	2.64	< 0.05
	Control Condition	**VR Condition**	**$t(4)$ Value**	**P**
C. Patients with presence < 3.4, n = 5, mean scores (SD)				
Worst Pain	8.1 (2.1)	6.8 (2.2)	1.38	0.24 NS
Unpleasant	6.9 (2.0)	6.0 (2.7)	< 1 NS	NS
Time	8.8 (2.2)	5.2 (2.5)	3.88	< 0.05
Fun	0.2 (0.5)	1.6 (1.5)	1.87	0.14 NS

For all statistical comparisons reported in this study the $\alpha = 0.05$.

DISCUSSION

Results of the current study demonstrate that immersive VR reduced the reported pain intensity, pain unpleasantness, and the amount of time burn patients spent thinking about their pain during burn wound debridement. These results provide the first available evidence from a controlled study that VR can reduce severe to excruciating pain during burn wound debridement, and extreme pain did not seem to prevent virtual reality distraction from being effective, because the 6 patients with the highest worst pain ratings still showed a 41% reduction in pain during VR. In addition, this is the first study to show that a photonic, water-friendly VR delivery system may serve as a useful pain reduction technology for patients with burn injuries who require wound care in the hydrotank, where conventional electronic VR delivery systems are not feasible because of potential patient safety hazards.

There were some limitations in the current study. Although care was taken to standardize the treatment protocol, the nurses performing the wound care were aware of the treatment condition and could have inadvertently treated patients more gently in VR. A double blind replication of the present study, although challenging to perform, would be ideal. However, previous reports of VR analgesia in experimental pain settings have shown similar magnitude reductions in pain during VR, using more careful (eg, single and double blind) designs.[16,37]

A functional neuroimaging study recently corroborated participants' subjective pain reports with objective neural correlates of VR analgesia. In a study using a unique magnet-friendly fiberoptic wide field of view VR helmet,[36,38] healthy volunteers received brief thermal pain stimuli at a safe, painful but tolerable temperature, every 30 seconds for 6 to 7 minutes. Participants received three 30-second pain stimuli with no VR (control condition) and three 30-second pain stimuli while playing SnowWorld (treatment order randomized). The experimental design allowed researchers to calculate the amount of pain-related brain activity during VR versus no VR. Significant reductions in subjective pain ratings during VR were accompanied by significant (> 50%) reductions in pain-related brain activity in all 5 regions of interest in the neuroanatomic "pain matrix," consisting of the insula, thalamus, anterior cingulate cortex, primary and secondary somatosensory cortices[36] (see also Hoffman et al[39]).

The results of the present clinical study are consistent with a growing literature implicating an attentional mechanism for VR analgesia. Consistent with our fundamental assumption that VR is attention demanding, previous researchers found that VR reduces performance on a conventional divided attention task.[40] And the amount of VR pain reduction seems to show a dose-response relationship.[16] Just as increasing opioid dose typically increases the amount of opioid analgesia, improving the quality of the VR system has been shown to increase the amount of VR analgesia. For example, in one recent study, participants blind to the experimental manipulation were randomly assigned to wear either a "low-tech" VR helmet or a "high-tech" VR helmet. Participants wearing the low-tech VR helmet showed much less reduction in pain than participants who received the identical VR system but with a high-tech wide field of view VR helmet.[37] In that study, only one-third of the participants in the low-tech helmet group showed clinically meaningful (> 30%) reductions in pain intensity, whereas nearly two-thirds of participants in the high-tech helmet group showed clinically meaningful reductions in pain.

The custom water-friendly VR helmet used in the present study is a novel, unique, nonelectronic VR delivery system, and not commercially available. New display technologies that allow such safe but lighter weight wide field of view water-friendly VR delivery with head-tracking (as opposed to the current use of a manual joystick) would be ideal, and such technologies may be on the horizon.[17]

To summarize, the present study provides encouraging initial support for the use of VR as a technique for controlling pain during burn wound care in the hydrotank. Additional empirical studies with longer treatment durations are needed to determine whether VR can become a viable form of nonpharmacologic pain control in everyday medical practice. Because burn wounds are widely considered to be among the most painful injuries that a person can experience, analgesic techniques that are effective with burn wound care will likely also be effective in other painful medical procedure settings. Consistent with this notion, case studies have found that VR reduces pain during dental/periodontal procedures,[41] during endoscopic urologic procedures such as transurethral microwave thermotherapy for ablation of the prostate,[42] VR reduces pain associated with passive range of motion exercises during physical therapy for burn patients,[14,20] and physical therapy exercises for cerebral palsy patients during painful physical therapy rehabilitation after Single Event Multilevel Surgery.[43] These VR pain distraction physical therapy studies involving limb motion may anticipate future studies exploring the use of VR for indirectly treating chronic pain via motion therapy.

Psychosocial factors are associated with chronic pain syndromes.[44] And chronic pain patients may have a reduced fitness level compared with the healthy normals.[45] Pain can influence people's motor control strategies,[46] moving in ways that minimize their pain but minimizing motion therapy in the process. And people show a bias to focus their attention toward pain or impending pain.[47] In the future, VR distraction may prove useful, for example, in facilitating exercise in patients with chronic musculoskeletal or pain conditions (see other articles in this special issue on pain and motion). VR distraction can facilitate exercise/motion by reducing pain that inhibits motion, and VR can also help motivate patients to move (eg, designing patient-VR interactions that require patient movement). Although the analgesic effects of VR are typically thought to disappear when the helmet is removed, the physical movements made while in VR may have long-term benefits for the patient. Furthermore, VR may help patients realize the value of focusing their attention away from their pain during everyday pain episodes, even when VR is no longer available. Because excessive pain remains a widespread medical problem, and because these preliminary results support the notion that VR might prove valuable for pain control, additional research on this topic is warranted.

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