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VIRTUAL REALITY FOR BURN REHABILITATION

The use of virtual reality in burn rehabilitation: A systematic review and meta-analysis

Xiaodong Lan, MD; Ziming Tan, MD; Tao Zhou, MD; Zhenjia Huang, BD; Zhiyong Huang, BD; Chao Wang, PhD; Zhenwei Chen, MD; Yan Ma, MD; Tao Kang, BD; Yan Gu, BD; Dehuai Wang, MD; and Yuesheng Huang, PhD

1 Department of burn and plastic surgery, Chengdu Second People’s Hospital, Chengdu, China.
2 Department of Wound Repair; Institute of Wound Repair and Regeneration Medicine, Southern University of Science and Technology Hospital, Southern University of Science and Technology School of Medicine, Shenzhen, China.

Corresponding authors:
Deihuai Wang, MD; Department of burn and plastic surgery, Chengdu Second People’s Hospital, Chengdu, 610021, China; Email: 2219506373@qq.com.
Yuesheng Huang, PhD; Department of Wound Repair; Institute of Wound Repair and Regeneration Medicine, Southern University of Science and Technology Hospital, Southern University of Science and Technology School of Medicine, Shenzhen 518055, China; Email: yshuangtmmu@163.com.

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Abstract

Objectives: We systematically reviewed published clinical trials to evaluate the effectiveness of virtual reality (VR) technology on functional improvement, pain relief, and the reduction of mental distress among burn patients undergoing the rehabilitation.
**Data Sources:** Systematic searches were conducted in four databases, including PubMed, the Cochrane Library, Embase, and Web of Science, from inception to August 2021.

**Study Selection:** Randomized controlled trials (RCTs) evaluating any type of VR for the rehabilitation in burn patients with dysfunction were included.

**Data Extraction:** Two reviewers evaluated the eligibility, and another two reviewers used the Cochrane risk of bias assessment tool to assess the risk of bias. The extracted data included the main results of rehabilitation evaluation (quality of life (QoL), work performance, range of motion (ROM) of joints, hand grip and pinch strength, pain, fun, and anxiety), the application performance of VR (realness and presence), adverse effects (fatigue and nausea), and characteristics of the included studies. Heterogeneity was evaluated using the chi-square tests and I^2 statistics. Random- or fixed-effects models were conducted to pool the effect sizes expressed as standardized mean differences (SMD).

**Data Synthesis:** Sixteen RCTs with 535 burn patients were included. VR-based interventions were superior to usual rehabilitation in QoL and work performance of burn patients, and produced positive effect on the average gain of ROM (SMD= 0.72) as well. VR was not associated with improved hand grip and pinch strength (SMD= 0.50, 1.22, respectively), but was associated with reduced intensity, affective and cognitive components of pain (SMD= -1.26, -0.71, -1.01) compared to control conditions. Ratings of fun in rehabilitation therapy were higher (SMD= 2.38), and anxiety scores were lower (SMD= -0.73) than in control conditions.

**Conclusions:** VR-based burn rehabilitation significantly improves the QoL and work performance of burn patients; increases the ROM gain in the joints; reduces the intensity and
unpleasantness of pain and the time spent thinking about pain; increases the fun in the rehabilitation therapy; reduces the anxiety caused by the treatment; and has no obvious adverse effects. However, it did not significantly improve hand grip or pinch strength.

**Key words:** Burns, Rehabilitation, Virtual reality, Systematic review

**Abbreviations**

QoL: quality of life; VR: virtual reality; PRISMA: Preferred Reporting Items for Systematic reviews and Meta-Analyses; ROM: range of motion; SMD: standardized mean difference; CI: confidence interval; TBSA: total burn surface area; RCT: Randomized Controlled Trial; BSHS-B: Burn Specific Health Scale-Brief; QuickDASH: Quick Disabilities of the Arm, Shoulder and Hand; iADL: Instrumental Activities of Daily Living; HRQoL: Health-related Quality of Life; JTT: Jebsen-Taylor Test of Hand Function; MHQ: Michigan Hand Outcomes Questionnaire; PPT: Purdue Pegboard test; DHI: Duruoz Hand Index; COPM: Canadian Occupational Performance Measure; VAS: visual analog scales; 3D: three dimensional; PC: personal computer; PE: PlayStation II Eye Toy; LMC: Leap Motion Controller; APPT: Adolescent Pediatric Pain Tool; VO₂ peak: peak oxygen uptake.

**Introduction**

Burns are a common accidental injury worldwide [1]. Recent developments in medical technology have helped greatly increase the survival rate of burn patients [2]. However, after wound healing, side effects such as scar contracture and deformity, limb dysfunction, and posttraumatic psychological disorder can seriously affect the patients’ QoL [3]. Burn patients
often have different degrees of joint dysfunction due to limb immobilization, tissue damage, and scar contracture. The main manifestations are the reduction of ROM or weakness of the adjacent joints, inability to complete normal activities, and joint deformities [4]. The incidence of joint dysfunction at discharge in patients with severe burns is 22-42%, and although all joints can be affected, the hands, elbows, and shoulders are the most commonly affected joints [5].

Timely and effective rehabilitation is of great importance for the prevention and treatment of postburn joint dysfunction and can greatly improve the short- and long-term QoL of patients [6]. Therefore, burn rehabilitation has become a hot topic among clinicians who treat burn patients in recent years.

Rehabilitation exercises are necessary throughout the entire burn treatment process, which is long and difficult. Regular and intensive functional exercise is conducive to accelerate wound healing, joint function restoration and the recovery of functional daily living activities [7]. However, traditional rehabilitation therapy with continuous therapeutic exercise including active and passive movement of joints is repetitive, non-engaging, and often experience causes unbearable pain [8]. These factors can have many negative effects on burn patients, such as anxiety or depression, low compliance, and poor treatment effects [8].

Virtual reality is a computer simulation system for creating and experiencing authentic, interactive, and autonomous virtual worlds that provide multisensory experiences to the user. Virtual training scenarios are fun and engaging, and impart to the user a skill, knowledge, or attitude that can be of use in the real world [9]. Early computer-centered VR, such as VR videos, distracts users through one-way presentation. Currently, user-centered VR, such as gamified VR, motivates users to give real-time feedback through two-way interaction [10].
technology has been widely used in medical rehabilitation practice. Multiple studies have shown that VR has substantial effects on the rehabilitation of patients with stroke, Parkinson's disease, and bone, joint and nerve injuries [11, 12]. VR has several advantages with respect to more conventional rehabilitation, such as increased patients’ motivation and engagement, real-time interactivity, the safety of the simulated environment, and greater personalization possibilities [13].

Hoffman et al. are the first to use VR technology to relieve operative pain in burn patients during dressing changes [14]. Subsequently, an increasing number of studies have examined the application of VR in the field of burns, mainly for pain management and psychological intervention during adjuvant therapy [15]. Few studies have been conducted on VR-based burn rehabilitation exercises, and most of them typically focused on the effects of VR on pain and anxiety. There is a lack of objective evaluations of the effect of VR on limb training, and the results of existing studies are controversial. Furthermore, several scholars have raised concerns about fatigue, dizziness, nausea, and other adverse effects caused by VR during rehabilitation therapy [16]. New technology is potentially cumbersome or expensive, and questions remain whether VR is ready for clinical implementation in burn rehabilitation.

Hence, we performed this systematic review to provide a current comprehensive overview on the efficacy of VR for functional improvement, pain relief, the reduction of mental distress in burn patients undergoing rehabilitation therapy. Besides, we also focused on realness, presence and adverse effects in clinical application of VR.

Methods
This study was carried out in strict accordance with the *Cochrane Handbook for Systematic Reviews of Interventions* (http://www.cochranelibrary.com/). All of the procedures of the systematic review and meta-analysis followed the *Preferred Reporting Items of Systematic Reviews and Meta-analyses (PRISMA)* statement. This review was not registered on any platform.

**Literature search:** The keywords "Rehabilitation, Physical Therapy, Burn, Virtual Reality" were used to search the PubMed, Cochrane Library, Embase, and Web of Science databases. The publication time of the literature was from the inception of the database to August 2021 (*Supplementary Material 1*). Additionally, the reference lists from the included articles and relevant reviews were separately assessed to identify additional studies meeting the inclusion criteria of our study.

**Inclusion and exclusion criteria:** The inclusion criteria were as follows: (1) Study type: any RCTs, regardless of the use of blinding; (2) Study subjects: burn patients, regardless of age and sex, no limitation on burn size and depth; (3) Study interventions: the use of VR-based rehabilitation exercises in the VR group, and the use of conventional rehabilitation exercises as usual in the control group; no limitation on the joints suffered from burn, no limitation on the start or duration of rehabilitation therapy for the 2 groups of patients, and no limitation on the type of VR and use of analgesics; (4) Study outcomes: QoL, work performance, hand function, hand grip and pinch strength, scar thickness, ROM of the tested joint, pain, anxiety, fun, compliance, fatigue, nausea, and realness and presence of VR; (5) Sufficient data: availability of sufficient data for a meta-analysis. The exclusion criteria were: (1) Studies that compared VR with other types of adjunctive therapies; (2) Retrospective studies, reviews, case reports,
and conference summaries; (3) Inability to convert and apply the statistical data of the original study; (4) Non-English language publications; (5) Duplicate publications or original papers that could not be obtained through various channels.

**Literature screening and data extraction:** Two researchers independently screened the literature based on the inclusion and exclusion criteria and independently extracted the data using a predesigned data extraction table. Any disagreements during the screening were discussed until a consensus was reached. If disagreements persisted after the discussion, a third party was consulted to resolve the disagreement. The extracted data included the basic information of the included trials, such as the first author and the year of publication; the basic characteristics of the study subjects, such as the number, age, sex, and burn area of the patients; the information of intervention measures, such as the type of VR used, use of analgesic drugs, and tested joints; the main results of rehabilitation evaluation, such as QoL, work performance, hand function, hand grip and pinch strength, scar thickness, ROM of the tested joint, pain, fun, compliance, and anxiety; the application performance of VR, such as realness and presence; adverse effects of VR intervention, such as fatigue and nausea; and the information of literature quality, such as randomization, allocation concealment, blinding method, and data integrity.

**Literature quality assessment:** Two trained researchers used the Cochrane risk of bias assessment tool to independently evaluate the included RCTs in terms of the following 7 indicators: (1) random sequence generation, (2) allocation concealment, (3) blinding of researchers and subjects, (4) blinded evaluation of the study results, (5) data integrity of the study results, (6) selective reporting of the study results, and (7) other biases. Disagreements were discussed until a consensus was reached; if no consensus could be reached, a third party
was consulted to resolve the disagreement.

**Statistical methods:** Meta-analysis was performed using R 4.1 software. Measurement data were expressed as $\bar{x} \pm s$. Weighted mean effect sizes were expressed as standardized mean differences (SMD), and the 95% confidence interval (CI) was calculated. Heterogeneity was assessed using the chi-square tests (test level $\alpha = 0.10$), and the $I^2$ test was used to quantitatively determine the heterogeneity. $P \geq 0.1$ and $I^2 \leq 50\%$ indicated homogeneous results and suggested that a fixed-effects model should be used for the meta-analysis; otherwise, the results indicated the presence of heterogeneity in the study results and suggested that a random-effects model should be used for the meta-analysis. Egger's test was used for bias testing; $P < 0.05$ indicates the presence of publication bias, and $P \geq 0.05$ indicates the absence of publication bias. A sensitivity analysis was performed to evaluate the reliability of the results.

**Results**

**Literature search and screening results**

From the initial searches of each database, 155 relevant articles were obtained. After reading the titles and abstracts, 31 articles that met the criteria were obtained. After the full text was read, 16 articles [17-32] that met the inclusion criteria were finally included. Figure 1 shows the detailed literature screening process.

**Basic information of the included trials**

Table 1 summarizes the basic information of the 16 clinical trials included in this study. Seven trials used a within-subjects design, and the rest adopted a parallel group design. In terms of location, 8 trials were conducted in the United States, 4 trials were conducted in Egypt, and 1
trial each was conducted in Australia, South Korea, China, and South Africa. The included trials comprised 535 burn patients of all ages; 6 trials included children, 6 included adults, and 4 included mixed age groups. Most of the patients were male (400, 74.76%). The burn area of the experimental patients varied significantly, ranging from 0.5-84.0% total burn surface area (TBSA). Seven trials used “Snow World” and other high-level simulation videos to distract the patients; 8 trials used interactive VR games as interventions during the rehabilitation exercises; and 1 trial used exoskeleton equipment as an aid. Three trials mainly focused on hand function exercises and recovery, and the remaining trials focused mainly on the large joints of the upper or lower limbs. The burn patients in 9 trials routinely used analgesic drugs during their rehabilitation exercises. The hand function and daily ability assessment scales used in the trials differed, resulting in difficulties in consolidating the meta-analytical data. However, most of the indicators reported in the literature, such as joint ROM, hand grip and pinch strength, pain, fun, and anxiety, could conveniently be submitted to statistical analysis.

**Bias risk assessment results**

In terms of the evaluation of study quality (Table 2), the random grouping of the subjects was described in detail in 12 trials, and the grouping method was not described in the other trials. Only 2 trials explicitly implemented allocation concealment. Due to the particularities of the intervention measures, it was impossible to blind the experimental subjects and staff. Only 3 trials blinded the evaluators to the outcomes, and most of the trials did not specify relevant information. Most of the trials provided complete data, and even when there were missing data in individual trials, this did not affect the analysis of the results. In 4 trials, partial data were available. All trials had a low risk of selective reporting and other biases. In total (Figure 2), the
risks of bias regarding randomization, data integrity, selective reporting, and other bias were low. The risks of bias for allocation concealment and blinding of outcome evaluation were unclear. The risk of bias for blinding of researchers and subjects was high. In summary, the overall risk of bias for all included trials was low to moderate.

**System evaluation and meta-analysis results**

The included trials used a variety of rehabilitation evaluation methods; particularly common were evaluations of self-care ability, professional ability, and hand function. These data could not be effectively synthesized and analyzed. Therefore, a descriptive summary of these results was provided. Most of the studies showed that compared with those of the control group, the physical function, QoL, and work performance of burn patients who underwent VR-based rehabilitation were significantly improved. Wu et al. used the Burn Specific Health Scale-Brief (BSHS-B), Quick Disabilities of the Arm, Shoulder and Hand (QuickDASH), Instrumental Activities of Daily Living (iADL), and Barthel Index to evaluate hand function. They found that compared with the control group, the burn patients in the VR group showed significant improvement in hand function [27]. Basha et al. showed that compared with the control group, burn patients in the VR group showed significant improvements in heart and lung function, related muscle strength, and systemic or local lean mass after rehabilitation. In addition, the QoL of patients in the VR group was also significantly improved as evaluated by the Health-related Quality of Life (HRQoL) [29]. Joo et al. used the Jebsen-Taylor Test of Hand Function (JTT), Michigan Hand Outcomes Questionnaire (MHQ), and Purdue Pegboard test (PPT) to comprehensively evaluate various hand functions, and the results showed that compared with the control group, the burn patients in the VR group showed significant
improvement in picking up small objects and completing daily life and work activities after the rehabilitation exercises [30]. Kamel et al. showed that there were significant differences in the JTT and Duruoz Hand Index (DHI) hand function scores, satisfaction scores on the Canadian Occupational Performance Measure (COPM), and performance scores between the 2 groups, with the VR group achieving higher scores [31]. Only 1 trial showed that VR-based rehabilitation exercises did not offer any advantages for burn patients. Sharar et al. used the Valpar 9 Whole Body Range of Motion Work Sample Test, Transfer 4, to assess the work and self-care abilities of patients after rehabilitation and found no significant difference between the 2 groups [19].

ROM

Most studies used ROM gain, i.e. the gain in joint activity after rehabilitation exercises, as the primary outcome. Six trials reported the average ROM gain of the tested joints, and there was significant heterogeneity among their results ($P < 0.01$, $I^2 = 73.1\%$). Therefore, a random-effects model was used for the meta-analysis. The results showed that the average ROM gain of all joints was significantly higher in the burn patients in the VR group than in the control group, and the SMD was 0.72 (95% CI: 0.37-1.08, $P < 0.01$), as shown in Figure 3.

Hand grip and pinch strength

A total of 3 trials reported the hand grip and pinch strength results. In terms of grip strength, the heterogeneity among the 3 trials was relatively large ($P = 0.04$, $I^2 = 68.3\%$); therefore, a random-effects model was used for the meta-analysis. The results showed that compared with that of the control group, the hand grip strength of the burn patients in the VR group was not significantly increased, and the SMD was 0.50 (95% CI: -0.32 to 1.32, $P = 0.23$),
as shown in Figure 4. In terms of pinch strength, the heterogeneity among the 3 trials was large (P < 0.01, I² = 92.7%); therefore, a random-effects model was used for the meta-analysis. The results showed that after rehabilitation, the hand pinch strength of the burn patients in the VR group was not significantly greater than that of the control group, and the SMD was 1.22 (95% CI: -0.02-2.47, P=0.05), as shown in Figure 5.

**Pain**

The included trials comprehensively and quantitatively evaluated the pain that the patients experienced during rehabilitation from the 3 dimensions of sensation, emotion, and cognition. Eleven trials provided quantitative data on the sensory component of pain, i.e., pain intensity. Due to the considerable heterogeneity among these trials (P < 0.01, I² = 88.0%), a random-effects model was used for the meta-analysis, and the results showed that VR-based rehabilitation therapy significantly reduced burn patients’ pain intensity during treatment. The SMD was -1.26 (95% CI: -1.96 to -0.55, P < 0.01), as shown in Figure 6. A total of 6 trials quantified the emotional and cognitive components of pain. For these 2 outcomes, there was considerable heterogeneity among the 6 trials (P < 0.01, I² = 72.1%; P < 0.01, I² = 78.7%). A meta-analysis was performed using the random-effects model. The results showed that the burn patients in the VR group had significantly fewer unpleasant feelings and less time to think about pain during rehabilitation than the control group, with SMDs of -0.71 (95% CI: -1.09--0.33, P < 0.01) and -1.01 (95% CI -1.50--0.52, P < 0.01), respectively, as shown in Figures 7 and 8.

**Fun and anxiety**

A total of 4 trials reported the fun scores of burn patients in rehabilitation. Due to the
significant heterogeneity among these trials (P < 0.01, I² = 90.3%), a random-effects model was used for the meta-analysis. The results showed that VR-based burn rehabilitation therapy was more fun than conventional rehabilitation activities, and the SMD was 2.38 (95% CI: 0.66-4.09, P = 0.01), as shown in Figure 9. The burn patients’ anxiety scores during rehabilitation were reported in 5 trials, and the heterogeneity among them was significant (P = 0.02, I² = 66.8%); therefore, a random-effects model was used for the meta-analysis. The results showed that the burn patients in the VR group had significantly less anxiety than those in the control group during rehabilitation, and the SMD was -0.73 (95% CI: -1.35 to -0.11, P = 0.03), as shown in Figure 10.

Application performance of VR

Five trials quantitatively scored the realness and presence of VR as well as the adverse effects associated with it. The results of the literature analysis showed that patients gave high scores for the realness and presence (2.56-5.82 and 3.51-6.38, respectively) of VR used during rehabilitation therapy; the associated nausea and discomfort scores were generally low, ranging from 0 to 1.57.

Other results

The results of 2 trials showed that the proportion of burn patients in the VR group who participated in and completed rehabilitation was 90-96%, which was higher than that in the control group (85-93%) [24, 29], indicating that the patients in the VR group had better treatment compliance. Parry et al. evaluated patients’ fatigue during rehabilitation and found that there was no significant difference in the scores of the two groups (3.9 vs 3.2, P = 0.41) [24]. Wu et al. measured the scar thickness on the dorsal side of the wrist and the back of the hand in
patients before and after rehabilitation, and found that the patients of VR group had significantly thinner scars on the back of the hand after treatment (4.64 vs 4.08, P = 0.01), but there was no such change in the scars on the dorsal side of the wrist (4.38 vs 4.15, P = 0.23) [27].

Sensitivity analysis and publication bias

The sensitivity analysis of each outcome showed that the results of the meta-analysis for hand grip and pinch strength and anxiety were not robust. Four trials contributed to this lack of robustness [17, 18, 27, 31]; therefore, these results should be carefully interpreted (Supplementary Material 2). Egger’s test results showed that there was no publication bias for the outcomes such as average ROM gain, hand grip and pinch strength, fun, and anxiety (P = 0.96, 0.78, 0.99, 0.16, 0.15). But, for the 3 components of pain, i.e., sensation, emotion, and cognition, Egger’s regression test showed some evidence of publication bias (P < 0.05).

Discussion

Our review and meta-analysis found that VR-based burn rehabilitation had better effect in improving the QoL and work performance of burn patients, increasing ROM of joints and fun scores, in receding pain and anxiety, and without obvious adverse effects.

Dysfunction of the affected joints after a burn has a very serious impact on patients’ lives and work, with loss of hand function having an especially profound effect [33]. Three trials used multiple hand function assessment scales and reached a consistent conclusion, i.e., that VR-based hand and wrist rehabilitation therapy has significant effects [27, 30, 31], which is the same as the results that were obtained for a VR intervention for nontraumatic hand dysfunction
rehabilitation in stroke patients [34]. The VR system can simulate various daily scenes, requiring patients to complete various activities accurately, appropriately, and within a reasonable time while providing feedback [35, 36]. These targeted and adjustable individualized rehabilitation exercises significantly improve various physical functions, in addition to the QoL and work performance of burn patients. Surprisingly, VR intervention has a positive impact on the thickness and texture of scars on the hand [27]. We supposed that it mainly benefited from scar stretching caused by more active hand movements in the VR group. However, hand grip and pinch strength, which are important measures of hand function, did not significantly improve. The reason is that the hand function exercise in the VR intervention focused on the stability and flexibility of the proximal muscles of the upper limbs and could not provide effective strength training [35]. Only 3 trials that examined this outcome were included in this study, and they all had small sample sizes; therefore, the results may be unreliable. The sensitivity analysis results also illustrated this point.

Most of the studies used ROM gain, which is closely related to postburn scar formation and joint contracture, as an important outcome of the effect of rehabilitation therapy [5]. In theory, better pain management often means better rehabilitation effects [16], and this study confirmed this point. VR technology alleviated pain during rehabilitation therapy and significantly increased the ROM gain of the tested joints. However, 4 trials showed that compared with the control group, the group that received VR-based rehabilitation exercise did not have significant improvements in ROM [20, 22, 23, 26]. Previous systematic reviews have suggested that ROM gain is a measurement indicator favoring long-term rehabilitation [16]. In the above trials, neither short-term VR intervention nor several courses of VR could fully
demonstrate positive effects [13, 16]. We believe that the duration and frequency of rehabilitation were not the main reasons for the poor effect of VR intervention and that the VR device and type of VR might have been key factors. The VR intervention technique used in the above 4 trials was generally simple and was based on the “Snow World” game first used by Hoffman et al. [14]. The use of VR videos with rich content [32], interactive VR games [24, 25, 27, 28, 31], and high-performance VR systems with wearable devices [30] significantly increased ROM gain. In addition, as the duration of rehabilitation increases, when the activity of the tested joint is close to normal or when severe contractures are present, rehabilitation exercises no longer bring ROM gains. Therefore, final rehabilitation data are not ideal for evaluating the effect of long-term VR intervention, as was strongly demonstrated by Parry et al., whose experimental results showed that the ROM gain in the upper limb joints, such as the shoulder and elbow, of burn patients in the VR group was significantly greater than that of burn patients in the control group at 3 weeks, but there was no significant difference in gain after 6 months [24].

Several previous systematic reviews have shown that VR technology was a good tool for the management of burn pain. But most of reviews only provided general conclusions, did not specifically describe its use for burn rehabilitation [13, 15, 16, 37, 38]; the others presented only descriptive summaries or discussions [36, 39]. Apparently, this study was different than before. We specifically and objectively confirmed that compared with the control treatment, VR-based burn rehabilitation effectively reduced pain intensity, pain unpleasantness, and the time spent thinking about pain, indicating that VR technology plays a significant role in pain management during burn rehabilitation. Pain during rehabilitation therapy is operative pain,
and is an important factor in the patient’s participation in rehabilitation therapy[40]. Drug intervention alone is not effective for this type of pain, and the long-term use of large doses of analgesics easily causes side effects such as vomiting, constipation, respiratory depression, and drug dependence [41]. Based on the gate control theory of pain, VR can draw the patient’s attention to the simulated environment. Since the central nervous system only processes a limited amount of information within a certain period of time, this distraction can weaken the patient’s perception of pain [42]. Up to this point, the analgesic properties of VR had been mostly attributed to its powerful distractive capacity. As an important nondrug analgesia method, VR generally has no side effects and is noninvasive and nonaddictive [37]. In addition, during burn wound debridement and dressing changes, the analgesic effect of VR is not lost or reduced over time [43, 44]. For patients with high initial pain scores, the analgesic effect of VR seems to be more substantial [45]. We believe that these conclusions are also valid when VR is applied for pain management during burn rehabilitation. It is worth noting that for the 3 outcomes of pain that were considered in this study, there was significant reporting bias; however, the sensitivity analysis did not find a specific source of heterogeneity. We believe that there are 3 possible reasons for the publication bias, i.e., (1) The objective heterogeneity of the VR interventions used in the trials, (2) Analgesic drug use was a potential confounder, (3) The difference in the scale and design of the visual analog scale used to quantify pain.

Addressing mental distress such as anxiety during burn rehabilitation is very important, since they seriously affect patient compliance [46]. Fun can be considered synonymous with a positive emotional state. Consistent with almost all similar studies, this study revealed that the use of VR during burn rehabilitation provided strong and lasting enjoyment for the patient [19,
The VR systems used in the included trials were quite different. Early studies used “realness” and “presence” scores to quantify patients’ VR experience [17-20, 23] and believed that a good experience was the basis for VR’s effect [17, 49, 50]. But these studies using immersive VR did not include more interactive training. Some gamified VR seemed to help motivate the patient to perform therapeutic exercises [22, 25, 27, 29]. Overall, regardless of whether VR took the form of videos or games, the burn patients included in the trials gave them high scores for “realness” and “presence”. Interestingly, one trial reported that patients with a presence score greater than 3.4 exhibited better pain reduction during burn wound debridement than those with a presence score less than 3.4 [49]. Therefore, there may be a correlation between the presence score and pain reduction efficacy of VR. Similarly, this correlation also exists in the process of burn rehabilitation. This finding prompted us to improve the efficacy of VR by using better-quality VR products. Furthermore, a RCT noted that the “realness” and “presence” scores given by minors were significantly higher than those given by adults, but
there was no corresponding difference in the analgesic effect of VR [19], which indicates that the VR experience is closely related to age and that VR-based rehabilitation seems to be more suitable for younger burn patients. The continuous improvements in VR technology have led to the creation of a complete set of technical criteria for commercially available VR devices and software[51]. Therefore, several recent studies did not evaluate the VR experiences of the subjects [27-32]. However, the VR experience for special populations, such as burn patients, still needs to be further studied and elucidated.

Five trials evaluated the adverse effects of the VR intervention, such as nausea. Overall, nausea was rare or extremely mild. In these 5 trials, the researchers evaluated only the incidence of nausea during the VR intervention (VR + standard analgesia) and did not perform a comparative analysis with the control group (standard analgesia) [17-20, 23]. Therefore, this adverse reaction cannot be completely attributed to VR and may also be a side effect of opioid analgesics. Another study confirmed that VR intervention did not cause additional physical and mental fatigue in subjects [24]. In addition, no reports on potential eye fatigue, disorientation, headache, or other adverse effects of VR intervention were found.

**Future directions**

VR-based burn rehabilitation has many advantages, but there are many problems associated with its application in practice. The high costs of the research, development, and application of VR technology make it impossible to popularize and promote this method, especially in developing countries [52]. Medical personnel lack systematic knowledge and training on VR, which could affect the effectiveness of VR interventions [53]. VR-related testing, guidance, treatment, cleaning, and maintenance require considerable labor and material
resources, and the feasibility of its clinical application is questionable [54]. Children and elderly adults have a high incidence of burns, but their use of VR is greatly restricted because children have insufficient cognitive ability to comply with the treatment, and elderly adults have very limited acceptance of VR [53]. In addition, most current VR technology requires the use of head-mounted displays, which limits its use in patients with head and facial burns [55]. Fortunately, with the development of science and technology and the continuous efforts of researchers, these problems are being gradually solved. Recently, 2 studies showed that low-cost VR systems have high practicability and effectiveness in burn treatment [56, 57]. In summary, cost control, professional training, VR resource sharing, user-friendly equipment, etc., will be major issues to be addressed in the field.

**Study Limitations**

The main limitations of this study are as follows: (1) The diversity of subjects, environments, intervention measures, and outcome indicators may have led to unexplained heterogeneity. Therefore, the uncertainty regarding the actual effect of VR-based burn rehabilitation therapy is a shortcoming of this study. (2) The included trials generally had small sample sizes, especially the limited numbers of female, and different experimental designs, i.e., within-subject and parallel group trials, which could have also led to inaccurate results. (3) In a few trials, only partial data were available. Although we actively contacted the corresponding authors to obtain complete data, these data could not be obtained. Incomplete data may have adversely affected the results. Equally important, all of the included trials were published in English, and the locations were also concentrated in the United States and Egypt, which may have caused some degree of publication bias. (4) The authors of the included trials did not
provide more underlying characteristic information of patients, so we were unable to perform
valid grouping for some subgroup analyses. Additionally, because the sample size was too
small, the relevant results of subgroup analyses would have been unreliable. Although there are
many shortcomings, this study still provides valuable information, which needs to be further
verified by large, multicenter clinical trials.

Conclusions

According to the current status of evidence, VR-based burn rehabilitation significantly
improves the QoL and work performance of burn patients; significantly increases the ROM
gain of the tested joints; effectively reduces the intensity and unpleasantness of pain and the
time spent thinking about pain; increases the fun of the rehabilitation therapy; further reduces
the anxiety caused by the treatment; and has no obvious adverse effects. However, it does not
significantly improve hand grip and pinch strength. Furthermore, the substantial heterogeneity
of the results cannot be ignored. Many challenges remain in the actual clinical application of
VR. In the future, low-cost and highly operable VR technology may have broad prospects for
application in the field of burn rehabilitation.

References


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Figure legends

Figure 1 The results of the screening process and final article selection.
Figure 2 Risk of bias graph: authors’ judgments about each item of the risk of bias assessment presented as percentages among all included studies.
Figure 3 Forest plot of ROM comparing the adjunctive VR group with the control group. SMD, standardized mean difference; CI, confidence interval; SD, standard deviation.

Figure 4 Forest plot of grip strength comparing the adjunctive VR group with the control group. SMD, standardized mean difference; CI, confidence interval; SD, standard deviation.

Figure 5 Forest plot of pinch strength comparing the adjunctive VR group with the control group. SMD, standardized mean difference; CI, confidence interval; SD, standard deviation.
Figure 6 Forest plot of pain intensity scores comparing the adjunctive VR group with the control group. SMD, standardized mean difference; CI, confidence interval; SD, standard deviation.

Figure 7 Forest plot of unpleasantness scores comparing the adjunctive VR group with the control group. SMD, standardized mean difference; CI, confidence interval; SD, standard deviation.
Figure 8 Forest plot of time spent thinking about pain comparing the adjunctive VR group with the control group. SMD, standardized mean difference; CI, confidence interval; SD, standard deviation.

Figure 9 Forest plot of fun scores comparing the adjunctive VR group with the control group. SMD, standardized mean difference; CI, confidence interval; SD, standard deviation.
Figure 10 Forest plot of anxiety scores comparing the adjunctive VR group with the control group. SMD, standardized mean difference; CI, confidence interval; SD, standard deviation.

### Table 1 Characteristics of included studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Region</th>
<th>Pat. design</th>
<th>Study Age (years)</th>
<th>Sex (M/F)</th>
<th>Mean TBSA (%)</th>
<th>Intervention (VR)</th>
<th>Analgesics</th>
<th>Trai sections (VR/C)</th>
<th>Joint Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoffman(2000)</td>
<td>USA</td>
<td>Within subjects</td>
<td>12</td>
<td>19-7</td>
<td>11/1</td>
<td>21 Spider world</td>
<td>Y</td>
<td>12/12</td>
<td>NR Sensory pain/cognitive pain/affective pain/bothersome/anxiety/nausea/realness/presence(VAS)</td>
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<tr>
<td>Hoffman(2001)</td>
<td>USA</td>
<td>Within subjects</td>
<td>7</td>
<td>9-32</td>
<td>6/1</td>
<td>3-60 Spider/snow world</td>
<td>Y</td>
<td>21/21</td>
<td>NR Maximum ROM(Goniometry); sensory pain/cognitive pain/affective pain/unpleasant/nausea/realness/presence(VAS)</td>
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<tr>
<td>Sharar(2007)</td>
<td>USA</td>
<td>Within subjects</td>
<td>88</td>
<td>6-65</td>
<td>74/1</td>
<td>1.5-60 Snow world</td>
<td>Y</td>
<td>146/14/6</td>
<td>NR Sensory pain/cognitive pain/affective pain/fun/nausea/realness/presence(VAS)</td>
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<tr>
<td>Study</td>
<td>Region</td>
<td>Subjects</td>
<td>Patient Age (M/F/Y)</td>
<td>Sex</td>
<td>Mean TBSA (%)</td>
<td>Intervention (VR)</td>
<td>Joint</td>
<td>Outcomes</td>
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<td>Yohanna (2011)</td>
<td>US</td>
<td>Parallel group</td>
<td>11/13</td>
<td>13/10</td>
<td>6.8 ± 6.1</td>
<td>Wii games (sports/fit)</td>
<td>N</td>
<td>Upper &amp; lower limb</td>
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<tr>
<td>Schmitt (2011)</td>
<td>US A</td>
<td>Within subjects</td>
<td>54/12</td>
<td>44/1.5−50</td>
<td>Snow world</td>
<td>Y</td>
<td>Upper &amp; lower limb</td>
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<tr>
<td>Parry (2015)</td>
<td>US</td>
<td>Parallel group</td>
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<td>14/23.2</td>
<td>PE videogames</td>
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<td>Shoulder &amp; elbow</td>
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<td>Parker (2016)</td>
<td>Australia</td>
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<td>17/0.5−10</td>
<td>Wii games (sports/fit)</td>
<td>N</td>
<td>Upper &amp; lower limb</td>
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<tr>
<td>Wu (2019)</td>
<td>China</td>
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<td>6/10</td>
<td>63.1 ± 14.8</td>
<td>LMC games</td>
<td>N</td>
<td>Hand</td>
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<td>Egypt</td>
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<td>28/13</td>
<td>31/26.7</td>
<td>3D videogame</td>
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<td>Lower limb</td>
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<td>Egypt</td>
<td>Parallel group</td>
<td>20/13</td>
<td>24/51.5</td>
<td>Xbox Kinect Games</td>
<td>N</td>
<td>NR</td>
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</table>

Psychological and environmental problems (BSHS-II); physical function (QuickDASH); daily function (ADL, Barthel index); pinch and grip (dynamometer); RDM of Thumb interphalangeal joint (Goniometry); Scar ultrasonography; Cardiopulmonary fitness (VO2peak)/muscle peak torque (Biodex dynamometer)/whole-body and regional lean.
mass (Dual-energy X-ray absorptiometry)/Health-related quality of life (PedsQL)/enjoyment (Physical Activity Enjoyment Scale)/adherence rate

Performance speed of standardized task (JTT);

pinch and grip (dynamometer); perception of hand function (MHQ); fine hand motor functions and dexterity (PPT)

Hand

Function (JTT, DHI)/daily function (COPM)/

ROM (Goniometry )/ *pinch and grip (dynamometer)

VR, virtual reality; C, control; M, male; F, female; TBSA, total body surface area; Y, routine use of analgesics; N, not use of analgesics; VAS, visual analogue scales (0-10); ROM, range of motion (degrees); 3D, three dimensional; PC, personal computer; PE, PlayStation II Eye Toy; LMC, Leap Motion Controller; BSHS-B, Burn Specific Health Scale-Brief; QuickDASH, Quick Disabilities of the Arm, Shoulder and Hand; IADL, Instrumental Activities of Daily Living; APPT, Adolescent Pediatric Pain Tool; VO2 peak, peak oxygen uptake; PedsQL, Pediatric Quality of Life Inventory; JTT, Jebsen-Taylor hand function test; MHQ, Michigan Hand Outcomes Questionnaire; PPT, Purdue Pegboard test; DHI, Duruoz Hand Index; COPM, Canadian Occupational Performance Measure; NR, no report.

* Kilogram for grip and pinch; *millimeter for scar thickness.

Table 2 Risk of bias assessment of randomized controlled trial.
<table>
<thead>
<tr>
<th>Study</th>
<th>Risk of Bias</th>
</tr>
</thead>
<tbody>
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<td>Sharar (2007)</td>
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</tr>
<tr>
<td>Morris (2010)</td>
<td>+ ? - + + +</td>
</tr>
<tr>
<td>Yohannan (2011)</td>
<td>? - - + + +</td>
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<tr>
<td>Schmitt (2011)</td>
<td>+ ? - ? - +</td>
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<tr>
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<tr>
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<tr>
<td>Soltani (2018)</td>
<td>+ + - ? + +</td>
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<td>Wu (2019)</td>
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<td>Joo (2020)</td>
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<tr>
<td>Kamel (2021)</td>
<td>+ ? - ? + +</td>
</tr>
<tr>
<td>Ali (2021)</td>
<td>+ ? - ? + +</td>
</tr>
</tbody>
</table>

*+* indicates low risk of bias; *-* indicates high risk of bias; *?* indicates unclear or unknown risk of bias.