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SYSTEMATIC REVIEW

Clinical efficacy and patients' perception of virtual reality during wound care in adults: A systematic review with meta-analysis of randomised clinical trials

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Abstract

This study was aimed to review Virtual Reality's (VR) impact on pain, anxiety, opioid usage, physiological and behavioural responses, and patients' experience during wound care (WC) in adults. We searched multiple databases (Embase, Medline ALL, Web of Science Core Collection, Cochrane Central Register of Controlled Trials, CINAHL, Scopus and Google Scholar) from inception until January 27th, 2023. Included studies compared VR alone or as an adjunct to standard WC with standard WC or other distraction methods, in adults with burn or non-burn-related wounds. The risk of bias was assessed using the revised Cochrane risk-of-bias tool for randomised parallel-group and crossover trials. The review followed PRISMA guidelines for reporting. Fourteen studies were eligible for inclusion. The meta-analysis was limited to studies comprising solely of adult participants. VR reduced pain intensity compared to standard WC in all study designs. Despite not being included in the meta-analysis due to reasons such as mixed population or lack of sufficient statistical data, other studies showed significant pain reduction using VR. Additionally, VR improved patients' experience of WC. No clear effect was found on other outcomes including anxiety, opioid usage and physiological and behavioural responses. VR shows promise in reducing acute pain and enhancing patients' experience of WC. The observed variations in the effects of VR at group and individual levels indicate the need for a personalised treatment plan by selecting the *right* VR for the *right* patient given at the *right* time.

KEYWORDS

anxiety, debridement, procedural pain, virtual reality

Abbreviations: CI, confidence interval; PICOT, patient, intervention, comparison, outcome, and type of study; PRISMA, preferred items for systematic reviews and meta-analysis; RoB2, revised cochrane risk of bias tool for randomized trials; SD, standard deviation; SD_{diff}, standard deviation of differences; SMD, standardised mean difference; VR, virtual reality; WC, wound care.

Masood Mazaheri and Raoul F. Crooijmans contributed equally to this work.

1 | INTRODUCTION

Wound care (WC) interventions such as dressing removal, wound cleansing and dressing application are often associated with severe pain,[1] with dressing removal identified as the most painful procedure.[2] Not only pain itself but also the psychological components of pain, including anticipation of pain and its associated anxiety can induce delayed wound healing,[3,4] through mechanisms such as immune suppression.[4]

Analgesic medications, mainly opioids, are the gold standard for pain management during WC. However, high dose/long-term opioid use risks bowel dysfunction,[5] nausea and vomiting,[6] respiratory suppression,[7] reduced sex hormones[8] and changes in physiological responses to pain such as hyperalgesia,[9] tolerance,[10] physical dependence[11] and addiction[12] but can also result in delayed wound healing.[13] Due to analgesic drawbacks including side effects and high costs, new non-pharmacologic pain interventions have been developed in recent years.

Various non-pharmacologic treatments, like distraction, are used alongside standard WC to address the diverse components of pain, which encompasses more than just sensory experience, with other affective and cognitive components potentially involved.[14] Distraction can modulate pain perception as pain is a partially controlled cognitive process that relies on limited attentional resources.[15] Distraction can be achieved through passive methods, such as watching TV, or through active engagement in an interactive task,[16] like Virtual Reality (VR). VR allows realistic exploration and interaction with computer-generated environments. VR has the potential to reduce pain when combined with pain medications during WC,[17–19] but this is based on individual small sample studies (in most cases) with inconsistent results. Combining VR study results provides a more precise VR efficacy estimate and allows for investigating disparity in effects.

No systematic reviews have focused on the impact of VR on pain and anxiety during WC among adults.[20–22] Age-related differences in response to injury and healing, like slower wound healing in adults compared to children,[23] suggest that the VR effects in children cannot be applied to adults. We searched for systematic reviews on the aforementioned outcomes in the adult population and found that all focused on the effect of VR on burn WC, mostly in children (search terms/results available on request). Therefore, this review aims to investigate the efficacy of VR during WC in adults, with pain and anxiety as primary outcomes, opioid usage, physiological/behavioural responses and the patients' perception of the VR experience as secondary outcomes.

2 | METHODS

2.1 | Protocol

The reporting of this review followed the reporting Preferred Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [Data S1].[24]

2.2 | Eligibility criteria

The PICOT (Patient, Intervention, Comparison, Outcome and Type of study) construct was used to inform the eligibility criteria.

2.3 | Population

Adult patients with either burn or non-burn-related wounds undergoing dressing change.

2.4 | Intervention

VR applied alone or as an adjunct to standard WC.

2.5 | Comparison

Standard WC with or without other forms of distraction.

2.6 | Outcome

Pain and anxiety as primary outcomes and opioid usage, physiological or behavioural responses and patients' perception of VR as secondary outcomes.

2.7 | Type of studies

1. Randomised clinical trials in the form of either parallel-group trials, where participants are randomly allocated to VR intervention to compare with standard WC and/or other distraction interventions, or crossover trials, where participants are allocated to a random sequence of VR and No-VR interventions.
2. Qualitative research as another design used to describe patients' subjective experience of VR.

2.8 | Literature search strategy

Databases searched included Embase (Embase.com), Medline ALL (Ovid), Web of Science Core Collection (Web of Knowledge), Cochrane Central Register of Controlled Trials (Wiley), CINAHL (EBSCO) and Scopus (Scopus.com) from inception until January 27th, 2023, with a supplementary search conducted on Google Scholar (see Data S2 for the details of search strategy per database). Reference lists of included studies were manually searched for supplementary sources. The search was restricted to studies carried out in the adult population.

2.9 | Selection of studies

Two review authors (MM and RC) independently assessed retrieved studies' eligibility according to inclusion criteria, with discrepancies resolved through discussion. The last review author (EC) was consulted in cases where any disagreements remained unresolved.

2.10 | Data extraction

Using a data extraction form, the two first review authors (MM and RC) independently extracted information regarding study design (parallel-group or crossover trials and/or qualitative research), participants (country, setting, number, age and sex of participants along with their wound characteristics including wound type, time since onset, size and location), interventions (pre-procedure medications, type of interventions, visual and auditory components of VR intervention together with length and frequency of VR application), outcomes (measurement tool as well as the timing of outcome measurement) and results (number of participants included in the analysis, mean and standard deviation [SD] of outcomes per group and their statistical significance). Disagreements were resolved through discussion or, if required, by consulting the last review author. In cases where the timing of outcome measurement and numerical results were difficult to obtain from the journal articles, the original investigators were contacted for the necessary information.

2.11 | Risk of bias

Using the revised Cochrane risk-of-bias tool for randomised trials (RoB 2.0), tailored for parallel-group and crossover trials,[25] the first two review authors independently assessed the RoB. The RoB 2.0 was used to assess bias across multiple domains, including bias arising from the randomisation process, deviation from intended intervention (effect of assignment to intervention), deviation from intended intervention (effect of adhering to intervention), missing outcome data, measurement of outcome, selection of the reported result and carry-over effects (in the case of crossover trials). Each domain is composed of a group of signalling questions or reasonably factual questions with *yes/probably yes/probably no/no/no information* response options. The responses are fed to algorithms that provide proposed judgement of RoB at the domain level. The RoB for each domain is graded as 'low', 'some concerns' or 'high'. The overall RoB is judged as either 'low' in case there is a *low RoB for all domains*, 'some concerns' whenever there are *some concerns in at least one domain* and 'high' if there is a *high RoB in at least one domain* or *some concerns for multiple domains*. Disagreement between reviewers was resolved by consensus.

2.12 | Data synthesis

For studies involving more than two interventions, only VR versus No VR comparison was synthesised. Separate analyses were conducted for parallel-group and crossover trials based on their respective designs, before being merged. Due to heterogeneity in measurement scales, we used standardised mean difference (SMD) and its error to represent the treatment effect. For the synthesis of data from parallel-group trials, we simply used the means and SDs of outcome measures reported separately for VR and No VR groups. However, the synthesis of data from crossover trials is not as straightforward. In contrast to parallel-group trials, data from crossover trials should be analysed using a method of analysis specific to paired data.[26] Individual patient values for 'VR' minus 'No VR' periods form the building blocks for this analysis but were often not published. The mean of differences could be readily calculated, as it was equivalent to the difference of means, but a lack of information regarding within-subject effects of VR intervention in many studies caused difficulty in obtaining SD of differences (SD_{diff}). When SD_{diff} was unavailable, we calculated it using the individual raw data reported in the paper or the reported t statistics or p value. To determine the standard error of SMD, we used the method described by Elbourne et al.[26] to calculate the correlation between measurements during VR and No VR periods. If only mean and SD of VR and No VR measurements were given, we approximated the paired analysis using the lowest correlation value obtained from other studies. Due to few studies reporting a change from baseline for VR and No VR interventions, post-treatment measurement data were analysed for both parallel-group and crossover trials (see the results section).

The above parameters were entered into RevMan 5.4.1 with the following input parameters: continuous data for parallel-group trials and generic inverse variance for crossover trials (data type), inverse variance (statistical method), random effects (analysis model), standardised mean difference (effect measure), totals and sub-totals (totals) and 95% (study confidence interval [CI] and total CI). Chi-square and I^2 statistics represented the presence and extent of statistical heterogeneity or variability in intervention effects, respectively. To assess the uncertainty associated with estimating I^2, 95% CI was calculated using the method suggested by Borenstein et al.[27] $p < 0.05$ means that variation between studies is not due to chance alone. Sensitivity analysis was implemented after excluding trials with a high RoB.

3 | RESULTS

3.1 | Literature search

A total of 2281 studies were identified through the initial database and Google search (Figure 1). Once duplicates were removed and 1375 titles and abstracts were screened, 52 articles were deemed suitable for full-text review. Fourteen studies[17–19,28–38] finally met the eligibility criteria.

3.2 | Description of study design and participants

Table 1 provided a summary of 14 studies (published 2007–2022) including 12 randomised trials (3 with a parallel-group design[28–30] and 9 with a crossover design[17–19,31–35,38]) and 2 non-randomised trials (1 mixed quantitative-qualitative[36] and 1 qualitative[37]).

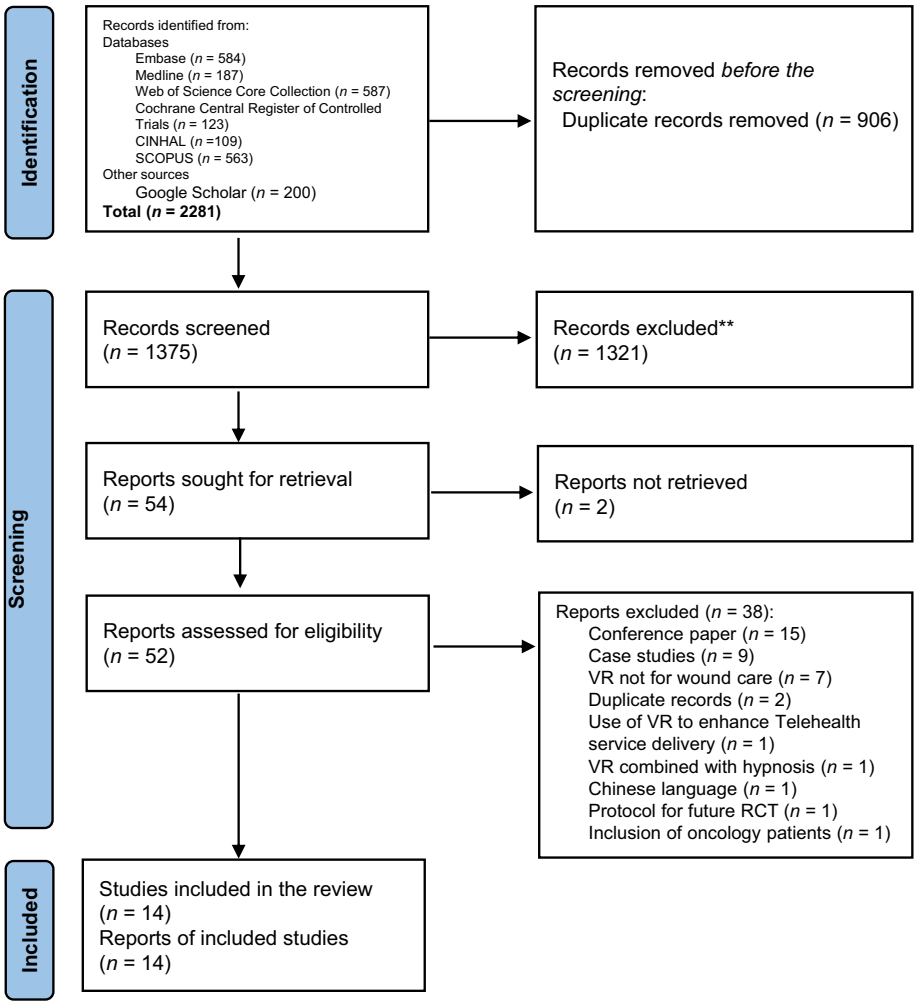

FIGURE 1 Flow diagram demonstrating study selection.

Most studies were conducted in Western countries, including the US ($N = 6$[17,18,31,33,34,36]), UK ($N = 2$[19,37]) and Netherlands ($N = 2$[35,38]). Only four studies[28–30,32] originated from non-western countries and one of these recruited Chinese-speaking people from China and Canada.[28] Most studies ($N = 10$[17–19,28,29,33–35,37,38]) were conducted in an inpatient WC setting, three in an outpatient setting[30,32,36] and one in both settings.[31] A total of 525 subjects were recruited, with 340 subjects being studied in parallel-group trials (range: 60–182), 170 subjects in crossover trials (range: 4–48) and 15 subjects in non-randomised trials. Only two studies recruited males exclusively,[17,18] while others included both sexes with males comprising 63.4% ($N = 333$) overall. Most studies targeted adults aged 18–65 years, while a few included children/adolescents[17,31,35,38] or older adults[19,34] to a limited extent. However, the studies' average age skewed towards adults. In one study[31] that partially targeted children and adolescents, only data from adults were analysed.

3.3 | Description of wound characteristics

Burn-related wounds were the most commonly studied, reported in 11 publications,[17–19,29,31,33–38] followed by non-burn-related wounds due to surgery,[28] injuries,[30] neuropathy[32] and necrotizing fasciitis or large decubitus ulcers[34] (Table 1). One of eight studies reported chronic ulcers (>6 weeks),[32] while seven included acute wounds (<2.5 weeks).[28–30,33,35,37,38] Burn-related wound size varied from <3% to 21% of total body surface area.[18,19,29,31,33–38] Wound location varied within and between studies, including extremities,[17,19,30,31,33,36,37] trunk[19,28,31,33,36,37] and head/neck.[18,31,36,37]

3.4 | Description of interventions

Most studies utilised VR as an adjunct to enhance 'standard WC' (Table 1), primarily pharmacologic analgesics.[17–19,28,31,33–35,38] A minority of studies did not clearly mention analgesics[29,36,37] and two studies did not use any analgesics during WC.[30,32] VR plus standard WC was compared to standard WC in all except one study.[17–19,28–35,37,38] Two studies[29,38] compared VR plus standard WC to other types of distraction plus standard WC, which included watching movies or images on 2D screens such as TV[38] or LCD,[29] listening to relaxing sounds[29] or music[38] or having non-medical conversations.[38] Two studies[31,37] also compared active VR plus standard WC with passive VR plus standard WC (see the following paragraph).

Different modes of VR were used to present the 3D virtual world. Active VR, where the subjects could interact with the VR environment

TABLE 1 Characteristics of included studies: study design, participants demographics and clinical information and interventions.

Authors	Study design	Subject characteristics (country; setting; N; male/female; age)	Wound characteristics (type; time since onset; size; location)	Intervention characteristics					
				Pre-procedure medication	Groups	Visual distraction (device; scenario)	Auditory distraction (device; audio)	Length	Frequency
Ding et al. 2019[28]	Quantitative, parallel-group trial	China and Canada; inpatients; 182; 72/110; 45.8 (range: 18–65; SD: 12.6) VR: 91; 34/57; 46.3 (11.8) No-VR: 91; 38/53; 45.2 (12.6)	Post-hemorrhoidectomy wound; Day 2 post-surgery; NR; Peri-anal	Analgesics, Flurbiprofen axetil	• VR • No VR	eMagin Z800 3DVISOR; SnowWorld V2.1 (*3D, interactive*)	IVR headset (integrated audio system); NR	The entire WC procedure, 21.2 (3.8) min	One single session of VR, one single session of No-VR
Ebrahimi et al. 2017[29]	Quantitative, parallel-group trial	Iran; inpatients; 60; 34/26; NR VR: 20; 9/11; 32 (8) Multimedia: 20; 14/6; 34 (10) No VR/Multimedia: 20; 11/9; 39 (12)	Burns; 42 to 72 h; 15% (6%) for VR, 15% (7%) for Multimedia, 16% (6%) for No VR/Multimedia; NR	NR	• VR • Multimedia • No VR/Multimedia	NR; Images of waterfalls shown on a VR-headset (*3D, non-interactive*) or LCD (*2D, non-interactive*)	VR headset or LCD (integrated audio system); waterfall sounds	NR	Five single sessions of VR and 5 single sessions of Multimedia, done on separate consecutive days (Days 3 to 7)
Guo et al. 2015[30]	Quantitative, parallel-group trial	China; outpatients; 98; 85/13; 18–65 VR: 49; 45/4; 30.13 (19.54) No VR: 49; 40/9; 32.05 (17.43)	Hand injury including soft tissue, cuts, skin avulsion, nail bed, finger and hand damage; within 3 days; NR; hand	No use of analgesics within 72 h	• VR • No VR	NR; Experience of mysterious dream planet, Avatar movie (*3D, non-interactive*)	Headphones; movie audio	5 min	One single session of VR, one single session of no-VR, three dressing changes per session
Patterson et al. 2022[31]	Quantitative, crossover trial	US; in/outpatients; 48; 34/14; 8–65 ($n = 4 < 18$, $n = 44 > 18$ year)	Burn due to flame, grease, scald, flash and others; NR; 14% (range: 1%–50%, SD: 10.1); leg, hand, arm, back, face, stomach, foot, chest, neck and buttocks	Opioid analgesics	• VR (computer-generated) • VR (picture) • No VR	NVIS MX90 VR goggles; SnowWorld (*3D, interactive*), nature pictures (*3D, non-interactive*)	Earphones (Noise-cancelling Bose Q35); VR (picture): relaxing sounds from nature (e.g. birds singing, crickets chirping); VR (computer-generated): sound effects (e.g. mammoths trumpeting angrily when hit by a snowball) and background music from SnowWorld	5 min per intervention type	Computer-generated VR and picture VR ($n = 48$), done in the same WC procedure on the first day with a randomised order, followed by computer-generated VR and no VR ($n = 13$, 12 adults, 1 child), done in the same WC procedure on a second day with a randomised order
de Araújo et al. 2021[32]	Quantitative, crossover trial	Brazil; outpatients; 17; 15/2; ≥18	Non-burn wound (predominantly neuropathic ulcers due to diabetes and venous ulcers); Chronic (>6 weeks); NR; NR	No analgesics before dressing	• VR • No VR	Oculus Go; Heavenly and realistic places experience (*3D, non-interactive*)	VR headset (integrated audio system); location-specific spatial sounds	The entire WC procedure, 22 min on average	VR and No VR, done on separate days (7 days apart), with a randomised order

(Continues)

TABLE 1 (Continued)

Authors	Study design	Subject characteristics (country; setting; N; male/female; age)	Wound characteristics (type; time since onset; size; location)	Intervention characteristics					
				Pre-procedure medication	Groups	Visual distraction (device; scenario)	Auditory distraction (device; audio)	Length	Frequency
Phelan et al. 2021[19]	Quantitative, crossover trial	UK; inpatients; 5; 2/3; 48.2 (range: 19–68; SD: 19.7)	Burn (flash and scald); NR; 18–20% (flash), 3–4% (scald); hand, arm and leg (flash) and leg, abdomen and thigh (scald)	Analgesics	• VR • No VR	Oculus Rift; Puzzle-based experience (*3D, interactive*) Basketball experience (*3D, interactive*)	VR headset (integrated audio system); game sounds such as sound effects and ambient sound	The entire WC procedure, 36.2 (range: 12–70, SD: 22.1)	VR and No VR, done on different days, with a randomised order
Bermo et al. 2020[33]	Quantitative, crossover trial	US; inpatients; 4; 3/1; 38 (19–54)	Burn (fire and contact); Day 1 or later (acute); 16.8% (range: 3–31%; SD: 13.4%); leg, flank, foot and posterior calf	Opioid analgesics	• VR • No VR	Oculus Rift; SnowWorld (*3D, interactive*)	Earphones; music from SnowWorld	NR	VR and No VR, done on two consecutive days, with a randomised order
McSherry et al. 2018[34]	Quantitative, crossover trial	US; inpatients; 18; 13/5; 38.4 (range: 20–73; SD: 15.5)	Partial or full-thickness burn wounds or complex non-burn wounds (e.g. necrotizing fasciitis or large decubitus ulcers); NR; >5% for burn wounds and NR for non-burn wounds; NR	Opioid analgesics, Fentanyl (20 min before the WC procedure)	• VR • No VR	NVIS MX 90; SnowWorld (*3D, interactive*)	Earphones (Logitech Wireless Gaming Headset G930); music and sound effects from SnowWorld	The entire WC procedure, 29.9 min (Range: 10–55, SD: 12.9)	VR and No-VR, done sequentially, with a randomised order
Faber et al. 2013[35]	Quantitative, crossover trial	The Netherlands; inpatients; 36; 30/6; 27.9 (range: 8–57; SD: 14.8)	Burn; within 14 days of hospitalisation (minimum stay >4 days); 8.4% (range: 0.25–25.5%; SD: 6.6); NR	Opioid and non-opioid analgesics	• VR • No VR	Cybermind Hi-Res900 3D; SnowWorld (*3D, interactive*)	VR headset (integrated audio system); NR	NR	One to up to seven single sessions of VR, done on consecutive days, preceded by 1 day of No-VR
Maani et al. 2011[18]	Quantitative, crossover trial	US; inpatients; 12; 12/0; 22 (20–27)	Combat-related burn; NR; 20.68% (4.0–57.5%); NR (but face/head wounds included)	Opioid analgesics and/or ketamine (20 min before WC procedure)	• VR • No VR	Rockwell Collins SR-80A; SnowWorld, 2006 (*3D, interactive*)	Noise-cancelling earphones; background music (by Paul Simon) and a sound effect from SnowWorld (e.g. a splash when a snowball hit the river)	5.7 min[3–11] per intervention type	VR and No-VR, done in the same WC procedure, with a randomised order
Hoffman et al. 2008[17]	Quantitative, crossover trial	US; inpatients; 11; 11/0; 27 (9–40)	Burn; NR; NR; upper extremity ($n = 10$) and lower extremity ($n = 1$)	Opioid analgesics and benzodiazepines (30–45 min before the WC procedure)	• VR in hydro tank • No VR in hydro tank	Custom-made; SnowWorld (*3D, interactive*)	Headphones; sound effects from SnowWorld (e.g. a splash when a snowball hit the river)	3 min per intervention type	VR and No-VR, done in the same WC procedure, with a randomised order
Twillert et al. 2007[38]	Quantitative, crossover trial	The Netherlands; inpatients; 19; 12/7; 30 (8–65)	Burn; within 7 days of hospitalisation (minimum stay >4 days); 7.1% (0.5–21.5%); NR	Analgesics	• VR • Other distractions • No VR/other distractions	Cybermind Hi-Res900 3D; SnowWorld V2.1 (*3D, interactive*) TV, music, non-medical conversation, child care worker	VR headset (integrated audio system); sound effects from SnowWorld	Entire wound dressing (19.2 min)	VR and other distractions, done on separate days preceded and followed by 1 day of No-VR

TABLE 1 (Continued)

Authors	Study design	Subject characteristics (country; setting; N; male/female; age)	Wound characteristics (type; time since onset; size; location)	Intervention characteristics					
				Pre-procedure medication	Groups	Visual distraction (device; scenario)	Auditory distraction (device; audio)	Length	Frequency
Ford et al. 2018[36]	Mixed, quantitative-qualitative	US; outpatient; 10; 8/2; 47.10 (14.71)	Burn; NR; < 1–40%; shoulder, arm, hand, chest, leg, foot, neck, abdomen and back	NR	• VR	iPod Touch embedded in Sunnypeak VR headsets; Table Mountain sunset, reindeer race in Norway, scuba diving at a coral reef, exploring Amsterdam, riding a roller coaster, playing soccer, swinging through a city and riding motocross *(3D, non-interactive)*	Headphones (Sentey Flow LS 422); sound from VR application (three participants did not wear headphones)	8.30 (7.02) min	VR done in a single WC session
Furness et al. 2019[37]	Qualitative	UK; inpatient; 5; 2/3; 48.2 (19.7)	Burn (flash, flame and scald); 0.5–2.5 weeks; *median*: 18% (3–20%); face, arm, hand, thigh, leg and abdomen	NR	• VR (active) • VR (passive) • No VR	Oculus Rift CV1; VR (active): Flocker and Basket(ball) (*3D, interactive*) VR (passive): Watching videos seeing the world from the viewpoint of an eagle, swimming with dolphins or exploring a space station (*3D, non-interactive*)	NR	NR (dressing change time: majority lasting 25–40 min [range: 12–70])	VR (active), VR (passive) and no-VR done separately, with a randomised order

Abbreviations: NR, not reported; SD, standard deviation; WC, wound care.

TABLE 2 Risk of bias assessment for pain (VR vs. no VR) in randomised clinical trials and crossover trials.

Author	Design	Domain 1 risk of bias arising from the randomisation process	Domain S risk of bias arising from period and carryover effects	Domain 2 Risk of bias due to deviations from the intended interventions (effect of assignment to intervention)	Domain 2 Risk of bias due to deviations from the intended interventions (effect of adhering to intervention)	Domain 3 missing outcome data	Domain 4 Risk of bias in the measurement of the outcome	Domain 5 risk of bias in the selection of the reported result	Overall risk of Bias
Ding et al. 2019[28]	Quantitative, RCT	Some concerns	–	Low	Low	Low	Some concerns	Some concerns	Some concerns
Ebrahimi et al. 2017[29]	Quantitative, RCT	Some concerns	–	High	Low	High	High	Some concerns	High
Guo et al. 2015[30]	Quantitative, RCT	Some concerns	–	Low	Low	Low	Some concerns	Some concerns	Some concerns
Patterson et al. 2022[31]	Quantitative, crossover trial	Some concerns	Some concerns	Some concerns	Low	Low	High	Low	High
de Araújo et al. 2021[32]	Quantitative, crossover trial	Low	Low	Low	Low	Low	Some concerns	Some concerns	Some concerns
Phelan et al. 2021[19]	Quantitative, crossover trial	Some concerns	Low	Low	Some concerns	Low	Some concerns	Low	Some concerns
Bermo et al. 2020[33]	Quantitative, crossover trial	Some concerns	Some concerns	High	Low	Low	High	Some concerns	High
McSherry et al. 2018[34]	Quantitative, crossover trial	Low	Low	High	High	Low	High	Some concerns	High
Faber et al. 2013[35]	Quantitative, crossover trial	High	Low	High	High	Low	High	Some concerns	High
Maani et al. 2011[18]	Quantitative, crossover trial	Some concerns	High	Low	Low	Low	High	Some concerns	High
Hoffman et al. 2008[17]	Quantitative, crossover trial	Some concerns	Some concerns	Low	Low	Low	High	Some concerns	High
Twillert et al. 2007[38]	Quantitative, crossover trial	Some concerns	Some concerns	Low	Low	Low	Some concerns	Some concerns	Some concerns

TABLE 3 Effect of VR on *pain*.

Authors	Outcome (measure)	Time point	No VR Mean (SD)	VR Mean (SD)	N	Difference
Ding et al. 2019[28]	Pain (VAS)[a]	5 min, during the WC procedure	6.85 (1.69)	6.09 (1.59)	91 (No VR) 91 (VR)	S
		10 min, during the WC procedure	7.80 (1.78)	6.53 (1.80)	91 per group	S
		15 min, during the WC procedure	8.28 (1.60)	5.76 (1.65)	91 per group	S
		20 min, during the WC procedure	7.26 (1.10)	5.58 (1.53)	91 per group	S
		5 min, after the WC procedure	4.28 (1.33)	4.26 (1.31)	91 per group	NS
Ebrahimi et al. 2017[29]	Pain (VAS)	Day 1	5.85 (1.72)	5.45 (1.98)	20 per group	NS
		Day 2	6.10 (1.65)	5.45 (2.35)	NR	NS
		Day 3	5.95 (1.63)	5.65 (2.03)	NR	NS
		Day 4	6.25 (2.02)	5.70 (2.12)	NR	NS
		Day 5	5.60 (1.35)	5.35 (2.68)	NR	NS
Guo et al. 2015[30]	Pain (VAS)[a]		7.64 (3.41)	2.63 (1.27)	49 per group	S
Patterson et al. 2022[31]	Worst pain (GRS)		6.42 (3.29)	5.46 (2.73)	12[b]	S
	Unpleasantness (GRS)		5.42 (3.45)	4.88 (2.49)	12[b]	NS
	Time thinking of pain (GRS)		5.75 (3.39)	2.83 (1.70)	12[b]	S
de Araújo et al. 2021[32]	Pain (VAS)[a]	During the WC procedure	7.52 (0.70)	1.58 (1.50)	17	S
		After the WC procedure	6.11 (1.90)	1.23 (1.25)	17	S
Phelan et al. 2021[19]	Pain (VAS)	During the WC procedure	5.25 (1.55)	4.40 (1.71)	5	S
		Immediately after the WC procedure	2.13 (1.49)	4.20 (4.54)	5	NR
		2 h after the WC procedure	1.25 (1.89)	5.10 (4.19)	5	NR
		4 h after the WC procedure	1.50 (1.08)	4.63 (4.35)	5	NR
Bermo et al. 2020[33]	Worst pain (VAS)		8.8 (1.3)	9 (1.2)	4	NS
	Time thinking of pain (VAS)		10.0 (0)	5.2 (1.6)	4	S
McSherry et al. 2018[34]	Pain (VNS)[a]		5.7 (2.6)	5.8 (2.9)	15	NS
Faber et al. 2013[35]	Worst pain (VAT)	Day 1	4.63 (NR)	3.53 (NR)	36	S
		Day 2	4.54 (NR)	3.71 (NR)	30	S
		Day 3	4.92 (NR)	3.69 (NR)	17	S
		Day 4	6.53 (NR)	6.56 (NR)	7	NS
		Day 5	6.32 (NR)	4.36 (NR)	3	NS
		Day 6	6.31 (NR)	3.42 (NR)	3	NS
Maani et al. 2011[18]	Worst pain (GRS)		6.25 (2.51)	4.50 (2.01)	12	S
	Unpleasantness, (GRS)		6.25 (2.17)	2.83 (1.97)	12	S
	Time thinking of pain, (GRS)		7.58 (2.39)	2.17 (2.00)	12	S
Hoffman et al. 2008[17]	Worst pain (GRS)		7.6 (1.9)	5.1 (2.6)	11	S
	Unpleasantness, (GRS)		6.7 (1.6)	4.1 (2.8)	11	S
	Time thinking of pain (GRS)		7.6 (3.1)	3.6 (2.5)	11	S
Twillert et al. 2007[38]	Pain (VAS)	Day before VR versus Day VR	5.52 (2.45)	2.83 (2.03)	19	S
		Day after VR versus Day VR	4.33 (2.02)	2.83 (2.03)	14 (VR) 19 (No VR)	S

Abbreviations: GRS, Graphic Rating Scale; NS: non-significant; S, significant; SD, standard deviation; VAS, Visual Analog Scale; VAT, Visual Analog Thermometer; VNS, Verbal Numeric Scale; WC, wound care.

[a]The pain was measured before the WC procedure as well but no significant difference was observed between VR and No VR conditions or groups.

[b]Results reported only for adult participants.

using a mouse, remote control or head tracker, was used in 10 out of 14 studies.[17–19,28,31,33–35,37,38] SnowWorld was predominantly used in eight studies,[17,18,28,31,33–35,38] where subjects threw snowballs at objects. Two other studies had interactive VR environments where subjects directed sheep into their pens[19,37] or threw balls into a basket,[19,37] using a remote controller and head tracker. Passive VR, where subjects only observed the VR environment, was used in six studies.[29–32,36,37] Examples included watching movies, videos or images. Two studies[31,37] utilised both active and passive VR. Sound effects were included in all studies except for a few,[28,35,37] and they were relevant to the VR environment. For instance, a splash was heard when a snowball hit the river in SnowWorld.

VR experience duration ranged widely from 3 to 36 min but typically lasted 5 and 20 min. It is unclear whether this disparity was due to WC procedure differences or design choices, as few studies reported the relation between VR and WC timing. Except for 3 studies,[29,31,35] VR intervention comprised of only one session. Single sessions of VR and No VR were conducted on the same or separate days. Longer exposure studies had 2[31] to 7[35] VR sessions, with one study using 5[29] sessions, all of which were conducted on separate days.

3.5 | Risk of bias

Seven studies had a *high* RoB and five studies had *some concerns* (Table 2). Both groups had either a high RoB or some concerns in measuring the outcome measure domain.

3.6 | Effect of interventions

The meta-analysis included studies that only recruited adults[18,19,28–34] and measured pain outcomes using comparable instruments on a 0–10 rating scale (Visual Analog Scale, Visual Analog Thermometer, Verbal Numeric Scale and Graphic Rating Scale). For studies with a mixed population[17,35,38] or non-pain outcomes, a narrative synthesis was used due to heterogeneity in measurement or inadequate studies.

3.6.1 | VR versus no VR

Pain

Results were presented separately for pain intensity,[17–19,28–35,38] unpleasantness[17,18,31] and time spent thinking of pain[17,18,31,33] (Table 3). Two crossover trials lacked sufficient statistical information for either pain intensity[32] or time thinking of pain[33] and were instead assessed qualitatively rather than included in the meta-analysis.

Although the change from baseline is a stronger method for meta-analysis than comparing final values, it could not be used due to limited studies providing pain intensity *before* WC.[28,30,32,34] Nonetheless, most studies documented pain levels experienced *during* WC, enabling us to estimate the immediate effects of VR quantitatively[18,19,28–34] or qualitatively.[17,35,38] Two studies[19,28] examined the longer-term effect of VR by measuring pain intensity *after* WC was terminated, but due to a scarcity of data, it was not possible to evaluate this effect

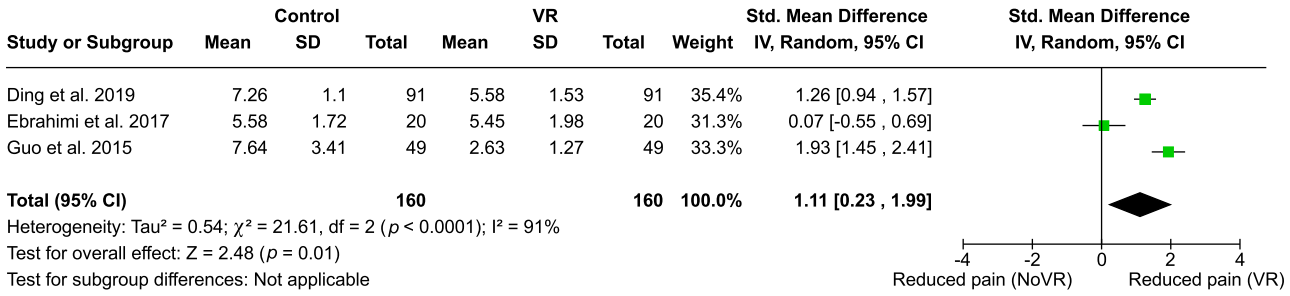

FIGURE 2 Effect of VR versus No VR on pain intensity in studies with parallel-group design.

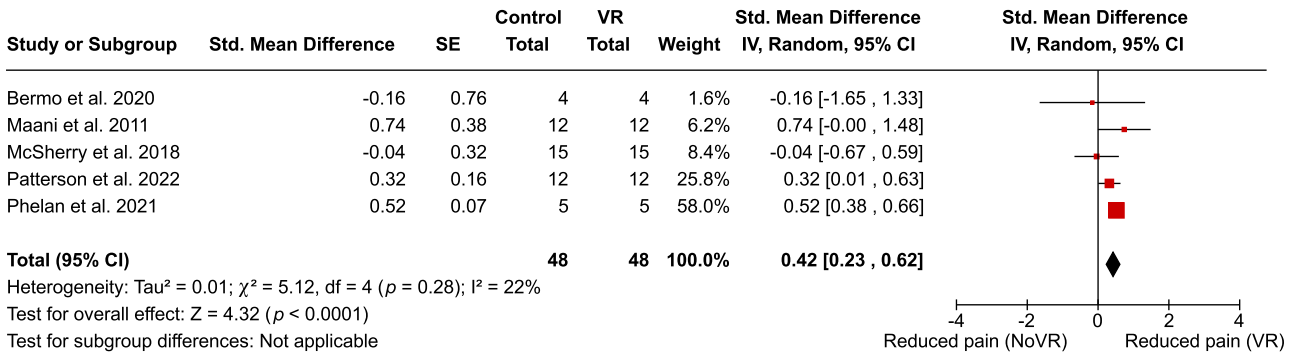

FIGURE 3 Effect of VR versus No VR on pain intensity in studies with crossover design.

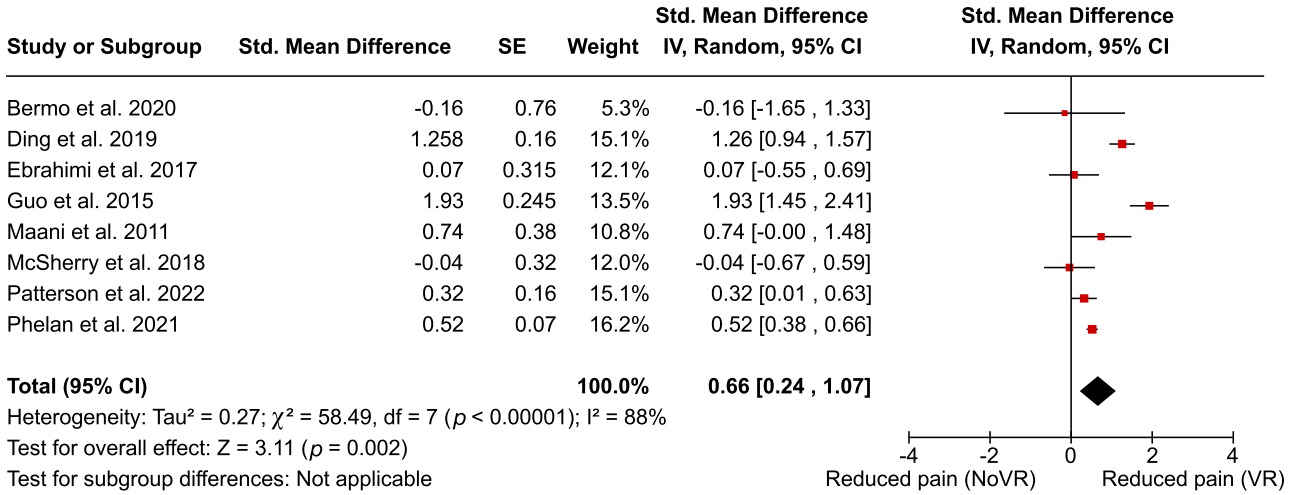

FIGURE 4 Effect of VR versus No VR on pain intensity in studies with parallel-group and crossover design.

TABLE 4 Effect of VR on *anxiety*.

Authors	Outcome measure	No VR mean (SD)	VR mean (SD)	N	Difference
Phelan et al. 2021[19]	VAS, during the WC procedure	5.63 (3.15)	3.60 (3.36)	5	S
McSherry et al. 2018[34]	VNS (0–10)[a]	3.5 (2.6)	3.5 (3.0)	15	NS
Twillert et al. 2007[38]	State verson of Spielberger State Trait Anxiety Inventory (20–80)	37.38 (NR)	35.33 (4.3)	19 (no VR) 10 (VR)	NS

Abbreviations: GRS, Graphic Rating Scale; NS, non-significant; S, significant; SD, standard deviation; VAS, Visual Analog Scale; VNS, Verbal Numeric Scale; WC, wound care.

[a]Anxiety was measured before the WC procedure as well but no significant difference was observed between VR and No VR conditions or groups.

quantitatively. For other aspects of pain, studies documented unpleasantness experienced and time that patients spent thinking of pain *during* WC.

VR reduced pain intensity in all study designs, including parallel-group (pooled SMD: 1.11 [0.23–1.99], $p = 0.01$; Figure 2), crossover (pooled SMD: 0.42 [0.23–0.62], $p < 0.0001$; Figure 3) and their combination (pooled SMD: 0.66 [0.24–1.07], $p < 0.01$; Figure 4); However, high statistical heterogeneity was present for parallel-group ($\chi^2 = 21.6$, $p < 0.0001$, $I^2 = 91\%$, 95%CI [76%–96%]) and combined study designs ($\chi^2 = 58.5$, $p < 0.00001$, $I^2 = 88\%$, 95%CI [79%–93%]), while negligible statistical heterogeneity was found for crossover design ($\chi^2 = 5.1$, $p = 0.28$, $I^2 = 22\%$, 95%CI [0%–67%]). Excluding studies with a high RoB had no substantial impact on the effect estimates for parallel-group (pooled SMD: 1.57 [0.91–2.23], $p < 0.001$) and combined study designs (pooled SMD: 1.21 [0.42–1.99], $p < 0.01$), while the high RoB in all but one of the crossover studies prevented the performance of a sensitivity analysis. Studies that were not included in the meta-analysis due to either insufficient statistical information[32] or mixed age population[17,35,38] have demonstrated significant pain reductions through the use of VR (Table 3).

No longer-term effects were detected or reported in a parallel-group study[28] measuring 5 min after completion of WC intervention or in a crossover study[19] measuring 2 and 4 h after intervention completion.

The effect of VR on unpleasantness was not found to be significant (pooled SMD: 0.73 [−0.66–2.12], $p = 0.30$; Figure S1), even with a substantial statistical heterogeneity ($\chi^2 = 2.69$, $p = 0.10$, $I^2 = 63\%$, 95%CI [0%–91%]). However, it significantly reduced the time patients spent thinking of their pain (pooled SMD: 1.37 [0.29–2.45], $p = 0.01$; Figure S2), with negligible statistical heterogeneity ($\chi^2 = 1.39$, $p = 0.24$, $I^2 = 28\%$, 95%CI [0%–0.73%]). Other studies not in the meta-analysis found that VR reduced pain unpleasantness[17] and time spent thinking of pain.[17,33]

Anxiety

Three crossover studies measured VR's direct effect on anxiety, two[19,34] using 0–10 rating scales (Visual Analog Scale and Verbal Numeric Scale) and the other[38] using the State version of Spielberger State–Trait Anxiety Inventory, a 20 item tool assessing state anxiety (Table 4).

One study reported a positive effect of VR on anxiety in a very small patient group (N = 5),[19] while the other two larger studies did not find any significant change in anxiety following VR use.[34,38]

Opioid usage

Three crossover studies assessed VR's direct effect on opioid medication for pain management; two investigated immediate effects[33,34] and one assessed both immediate and longer-term effects[35] (Table S1). In two studies, opioid usage was measured by the amount

of intravenous fentanyl administration and patient requests for administration[34] and the amount of oral morphine equivalent administration.[35] One study lacked a clear definition of opioid equivalent usage.[33]

Two larger studies had contradictory findings: one found a decrease in the need and requests for intravenous fentanyl administration following VR,[34] while the other found no change in the required oral morphine equivalent.[35] The latter study detected no effect of VR for up to six treatment sessions. The null effect was also reported in the third study but with a small sample size ($N = 4$).[33]

Physiological reactions and behavioural changes

Two studies, one with a parallel group[28] and another with a crossover design,[32] measured heart rate, blood oxygen saturation, systolic and diastolic blood pressure, body temperature, pallor, sweating, the facial expression of pain, body movement and protective posture as indicators of physiological and behavioural changes during WC interventions (Table S2). Outcomes were measured during or immediately after the WC procedure, indicating direct VR effects.

The larger parallel-group study reported no change in heart rate and blood oxygen saturation,[28] while the smaller crossover study found a positive effect on heart rate, blood pressure, facial expression and protective posture, but no effect on other variables including temperature, blood oxygen saturation, sweating and body movement.[32]

Patient-reported experience

Patients' perception of the VR experience was assessed through several aspects, including presence,[17,18,30,31] fun,[17,18,31,33] nausea,[17,18,31,35] realism,[31] satisfaction,[32,36] discomfort,[32] general experience[34] and perceived time of dressing change[38] (Table S3). Patients rated their responses on a 0–10 rating scale or Likert-type scale.

Two studies[17,31] reported mild and one study[18] found moderate presence when asking about the extent to which patients 'went inside' the VR game. All 4 studies measuring fun reported more pleasure during VR compared to No VR. Nausea incidence associated with VR use was negligible. Patients reported that objects seen in VR environments are 'somehow' real. Patients were satisfied, very satisfied or extremely satisfied with VR overall,[32,36] but satisfaction was reduced when asked specifically about distraction or pain reduction.[36] The majority of patients reported a lack of discomfort associated with VR use and were 'likely' or 'very likely' to use it for their next WC procedure or recommend it to other patients. One study reported perceived time of the WC procedure 5 min shorter than the real-time (19.2 min), ranging from 25 min shorter to 20 min longer than the real-time, but the results should be considered carefully.

Two studies[36,37] used a qualitative approach to understand patients' experience of VR. Patients initially felt anxious about using VR, but eventually became satisfied and desired to use it again in the future. However, not all patients recommended VR use for those with extremely painful burns.[36,37] VR was found to be distracting, due to either diverting patients' attention from pain or preventing them from looking at the WC procedure and consequently helped them tolerate the procedure.[36,37] VR was associated with reduced anxiety,[37] improved pleasure and enjoyment[36,37] and increased control over the situation.[37] Patient-medical staff interaction, such as appreciating patients' voluntary participation[36] and improved training of medical staff,[36,37] affected patients' satisfaction. Patients reported logistical concerns regarding VR equipment (e.g., bulkiness, too many wires, the comfort of use in persons with glasses) and application (e.g., lack of variety in VR applications or their short duration).[36] Patients also had mixed experiences with VR audio, with some reporting a positive effect and others presenting concerns regarding the interfering effect of audio on their ability to hear medical staff.[36]

3.6.2 | VR versus other types of distraction

Pain

Two studies, one with a parallel group[29] and one with a crossover design,[38] compared VR with other types of distractions including watching images on LCD or watching TV with or without headphones, listening to music or having a conversation with a caregiver.

One study found that watching images on LCD outperformed VR only on day 4 of a 5-day intervention,[29] but no correction was made for multiple comparisons. In another study, there was no difference between single-session exposure to VR and watching TV.[38]

Anxiety

No difference in anxiety levels, measured using the State version of Spielberger State–Trait Anxiety Inventory, was found between single sessions of VR intervention and watching TV.[38]

3.6.3 | Active VR versus passive VR

Pain

A single crossover study compared active VR (computer-generated games) and passive VR (still pictures) on pain, but found no difference.[31]

Patient-reported experience

A quantitative study found that active VR (computer-generated game) was linked to heightened fun but diminished realism compared to passive VR (still pictures), but both types of VR had similar effects on pain unpleasantness and presence in VR.[31]

In a qualitative study, patients' subjective experience of active VR (herding sheep through various obstacles or making basketball shots) and passive VR (watching videos seeing the world from the viewpoint of an eagle, swimming with dolphins or exploring a space station) were investigated.[37] Active VR was found to be superior in distraction and reduction of pain and anxiety compared to passive VR and patients also reported finding it more fun.

4 | DISCUSSION

Our review is the first to study the clinical efficacy and perception of VR in adults undergoing WC. VR shows promising effects on reducing pain and enhances patients' WC experience. However, evidence is limited and inconsistent to support VR's superiority to standard WC in reducing anxiety and opioid usage or improving physiological and behavioural responses.

4.1 | Distraction features: VR versus no VR

Most studies suggest VR reduces pain as an adjunct to standard WC, mainly through distraction. Since attentional capacity is limited[39] and pain competes for attentional resources with other demanding tasks,[40] VR can distract some attention away from pain processing, resulting in a reduced perception of pain intensity. VR may also induce an analgesic effect by visually and acoustically blocking the surrounding environment, such as wounds and medical staff, during WC procedures. However, the relative contribution of these two mechanisms to pain reduction remains unclear.

VR had a significant impact on pain intensity (medium to large effect), but there was a wide variation in the results for parallel-group and combined parallel-group and crossover studies. This diversity in effect measures could be due to either patient or intervention characteristics. For instance, parallel-group studies differed in terms of wound characteristics (e.g., burn[29] versus injury[30] versus post-surgical[28] wound), type of intervention (e.g., active[28] vs. passive VR[29,30]), length of VR application (e.g., ~5 min[30] vs. >~20 min[28]) and year of study conduct.

Heterogeneity is not limited to inter-study differences but also occurs within study populations. For example, Twillert et al.[38] found that while most participants benefited from VR, it increased pain intensity in a small subset of participants and the amount of pain reduction varied among those who benefited. Individuals' coping strategies, specifically approach versus avoidance coping strategies,[41] and their impact on distraction tendency may explain variation among patients. Approach coping strategy involves focusing on the stressor, while avoidance coping strategy involves diverting attention from the stressor. VR may have no or negative effects on those with an approach coping strategy,[42] who may experience uncertainty due to an inability to observe medical staff activities when using a VR headset.[43] Two-thirds of the studies included in this review found VR to be ineffective in reducing anxiety, possibly due to this explanation. Due to individual and group variations in response to VR interventions, personalised treatment plans are crucial, involving selecting the appropriate VR application and delivering it at the optimal time. Future research should explore patient- and therapy-related determinants of VR success and develop a toolkit for customised VR treatments to match specific patients' needs.

Several factors may explain the discrepancy between the studies on the effect of VR on opioid usage. These may include differences in patient populations (burn patients[35] vs. patients with combined burn and non-burn wounds[34]), the type of pain medication (oral morphine[35] vs. intravenous fentanyl administration[34]) and the use of more advanced VR technology in recent years (2013[35] vs. 2018[34]). However, as there is still very limited research on this topic, further studies are needed to fully comprehend the impact of VR on opioid usage.

VR improved the conscious subjective rating of pain but did not show significant changes in physiological and behavioural indicators of pain. The relevance of these measures as indicators of pain, particularly acute pain—which is the focus of our study, is still controversial despite limited evidence of their response to VR.[44] Future studies should also consider other indicators of acute pain, such as heart rate variability,[44] rather than relying solely on heart rate.

Both quantitative and qualitative research showed promising results for patients' perception of the VR experience. Overall, VR induced 'presence' and elicited positive emotions, with minimal nausea occurrence. However, the perception of the VR experience varied among patients. Some patients found that the audio component of VR hindered their interaction with staff, emphasising the need for personalised VR treatment based on individual preferences. Participants also reported concerns with 'bulky' headsets or 'too many' wires but advances in VR technology are making headsets smaller, cheaper and more advanced.

4.2 | Immersive features: VR versus other distractions and active VR versus passive VR

More attention-demanding distraction techniques are theoretically more effective at reducing pain.[15] VR's immersive nature demands greater attentional resources, leading some researchers to predict its superiority over other distraction techniques for pain management. Additionally, active VR is expected to be more effective than passive VR, as it involves user interaction, leading to greater distraction from pain. However, available evidence did not support the belief that immersive VR enhances pain management when comparing VR to other distractions and active VR to passive VR. Possibly, the technologies used in the above studies were not immersive enough. To demand more attention and leave less capacity for processing pain, future VR technologies should incorporate multiple sensory components, including visual, auditory, tactile and kinesthesia, based on multiple resource theory.[45]

Despite some limitations such as lack of long-term VR data, this study's comprehensive analysis of various outcomes involving pain, anxiety, opioid usage, physiological and behavioural responses and patients' perception of the VR experience is a strength that contributes to the understanding of the potential benefits of VR in pain management. Moreover, this review overcame the challenge of including both parallel-group and cross-over studies in a meta-analysis by analysing the results separately and together while recognising the nature of cross-over trials and avoiding the assumption of no correlation between VR and No VR measurements in an individual.

In this research, our emphasis has been exclusively directed towards the utilisation of VR within the context of WC. However, it is

worth noting that the potential of this technology extends beyond WC, with encouraging outcomes emerging in diverse areas such as surgery. A recent review[46] has organised the advantages into several categories, including enhancing preoperative education, providing support for mental well-being, managing pain, as well as facilitating pre- and post-operative rehabilitation. An additional application of either VR[47] or augmented reality[48] is improving preoperative surgical planning.

5 | CONCLUSION

VR reduces pain and improves patients' experience of acute WC. However, evidence for its effectiveness in other outcomes is limited and inconsistent. Variations in patient- and VR-related characteristics may contribute to differences in effect estimates. More research, including parallel-group trials, is needed to study the long-term effects of VR and how patient- and therapy-related characteristics affect its efficacy.

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CONFLICT OF INTEREST STATEMENT

The authors do not have any conflict of interest to declare regarding this study.

DATA AVAILABILITY STATEMENT

All included studies and their data sources are cited in the references.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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