Available online on 15.02.2026 at http://jddtonline.info

Journal of Drug Delivery and Therapeutics

Open Access to Pharmaceutical and Medical Research

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Review Article

Harnessing Virtual Reality for Pain Management: A Comprehensive Systematic Review and Meta-Analysis

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Article Info:

Article History:

Received 19 Nov 2025
Reviewed 11 Jan 2026
Accepted 03 Feb 2026
Published 15 Feb 2026

Cite this article as:

Tharani T, Shruthi R, Mohamed Shaik FJF, Prasanna K, Dhivya K, Harnessing Virtual Reality for Pain Management: A Comprehensive Systematic Review and Meta-Analysis, Journal of Drug Delivery and Therapeutics. 2026; 16(2):105-114 *DOI: http://dx.doi.org/10.22270/jddt.v16i2.7572*

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Abstract

Background: Virtual reality (VR) is marked by both progress and ongoing challenges. Significant advancements have been made in healthcare, where VR is used for therapy, rehabilitation, and medical training. VR holds numerous untapped applications in the medical field, with pain management standing out as a significant yet often overlooked area. Despite its critical importance in disease management and therapy, pain relief remains underemphasized in many healthcare approaches.

Objective: To conduct a systematic review and meta-analysis on the effectiveness of VR in pain management.

Methods: A Comprehensive literature search was conducted across multiple databases, including PubMed, Cochrane Library, Medline, Embase, and PsycINFO, using Boolean operators and adhering to PRISMA guidelines. The search aimed to identify studies evaluating VR-based interventions for pain management, distraction, and reduction. Studies were included based on predefined inclusion criteria, with a focus on those utilizing standardized pain assessment scales. Data extraction encompassed study characteristics, patient demographics, and reported pain outcomes.

Result: Around 20 studies were used to assess the effectiveness of VR as a pain management tool. Of these, 95.2% reported positive outcomes, highlighting VR's effectiveness in pain distraction. These findings emphasize VR's potential as an innovative, non-invasive pain relief method. Studies included various pain scales and diverse age groups. VR was found to be beneficial across medical conditions, reducing reliance on medication.

Conclusion: VR is emerging as a valuable asset in contemporary pain management. Its ability to provide immersive distraction has the potential to transform pain relief protocols, diminish dependence on pharmacological treatments, and improve the patient care experience.

Keywords: Virtual reality, Pain relief, Pain distraction, Pain management

1. INTRODUCTION

Pain, as a type of somatic sensation, is described as a "complicated combination of unpleasant sensory, emotional, and cognitive responses triggered by actual or perceived tissue damage, and expressed through specific autonomic, psychological, and behavioral reactions".[1] Pain is one of the most common symptoms encountered in clinical practice often manifesting as an unavoidable consequence of medical procedures. Transmission of pain begins at the synaptic cleft, where calcium channels are opened by an action potential, thereby releasing neurotransmitters like acetylcholine, dopamine, and Gamma-Aminobutyric Acid (GABA). Opioid receptors and glutamate also play key roles.[2] Pain perception occurs in higher cortical structures, where cognitive and behavioral functions can influence its intensity. The brain may accommodate only a limited number of pain signals; thus cognitive and behavioral functions can modify pain .[3]

Effective pain management is crucial to optimize medical procedure, boost patient satisfaction, reduce anxiety, reduce hospital stay and minimize long term analgesic dependence.Traditionally, pain management has relied on pharmacological treatments, such as analgesics and opioids, and non-pharmacological therapies, including physical therapy, cognitive behavioral therapy (CBT), and acupuncture .[4] However, the growing concerns surrounding the side effects, dependency issues, and the ineffectiveness of medications for some patients have prompted healthcare providers to seek alternative approaches. One promising avenue that has gained considerable attention is the use of (VR) technology for pain management. At its core, VR is a technology that

immerses users in computer-generated environments by leveraging real-world visual perception .[5] It involves three key components. They are i) total immersion, where users wear a sealed headset that blocks external light; ii) stereoscopic vision, where each eye views the same scene from a slightly different angle, simulating three-dimensional vision; iii) Motion capture, which tracks the user's head and controller movements with three or six degrees of freedom, allowing precise interaction within the virtual environment .[6]

The most common psychological approach for managing pain through VR is distraction from the painful stimuli. This method typically involves engaging patients with immersive content, such as interactive computer games or captivating video clips. The concept of using VR to manage pain stems from the principle of distraction therapy, which is rooted in the idea that diverting the patient's attention away from their pain can reduce its perception .[7] By shifting the patient's attention away from the noxious stimulus, the VR experience helps reduce the perception of pain. In addition to pain relief, patients often report enhanced pain tolerance, improved mood, and an overall sense of enjoyment or fun. The immersive nature of VR allows for a temporary mental escape, which can significantly alter the patient's experience of pain and improve their emotional well-being during painful situations .[8] Research suggests that VR can reduce both acute and chronic pain by distracting patients from their discomfort and engaging them in a more pleasant or neutral experience .[9] This has been particularly effective in managing pain associated with burn injuries, post-surgical recovery, and pediatric procedures, where traditional pain relief methods may be limited or ineffective.

Moreover, VR's ability to engage multiple senses simultaneously. Sight, sound, and sometimes touch has shown promise in not only reducing pain perception but also lowering anxiety, improving mood, and facilitating relaxation .[10] This is particularly beneficial for patients suffering from chronic pain conditions, such as fibromyalgia or osteoarthritis, where psychological factors, including stress and anxiety, exacerbate the pain experience. The efficacy of VR in pain management has been demonstrated across various settings, including hospitals, rehabilitation centers, and outpatient clinics .[11] In particular, VR has proven useful in procedural pain management, such as during wound care or chemotherapy, where it helps reduce the need for pharmacological interventions .[12] Clinical trials and case studies have shown that VR not only reduces the reliance on pain medications but also improves patient satisfaction and comfort .[13]

AIM

This study aimed to elucidate the role of VR in pain management, exploring its therapeutic impact across various clinical settings. Emphasis was placed on VR's potential as a non-pharmacological intervention, offering immersive distraction and cognitive engagement. By synthesizing data from multiple studies, the review provides evidence-based insights into VR's efficacy in reducing both acute and chronic pain.

2. METHODOLOGY

2.1. Literature Review

A thorough literature search was carried out through five major databases: PubMed, Medline, Cochrane Library, Embase, and PsycINFO. Medical Subject Headings (MeSH) along with keywords such as "pain management," "virtual reality," "pain distraction," and "immersive therapy" were utilized, with Boolean operators (AND, OR, NOT) employed to narrow down the results. There were no limitations imposed on the publication date or format. The reference lists from included articles were manually examined to locate additional pertinent studies.

2.2. Study Selection

In accordance with PRISMA guidelines, studies were chosen through an initial evaluation of titles and abstracts, with potentially relevant studies then subjected to a full-text review. Inclusion criteria demanded that studies evaluate VR interventions for pain management, utilizing various pain measurement scales. Excluded were studies that concentrated exclusively on procedural anxiety, lacked definitive pain measurements, did not have distinct VR and control groups, or were published in languages other than English. Reviews, letters, case studies, and conference abstracts were also excluded.

2.3. Data Collection

A standardized form for data extraction was employed to gather essential information: study characteristics (author, year, sample size), patient demographics (age, medical condition), details of the intervention (type of VR, control group, session length), pain assessment tools (Visual Analog Scale (VAS), Wong-Baker Faces, Numeric pain rating scale (NRS)), and outcomes (pain scores before and after intervention). To maintain data integrity, double data entry was utilized, with inconsistencies addressed through consensus. A color-coded matrix was created to depict trends in pain reduction visually.

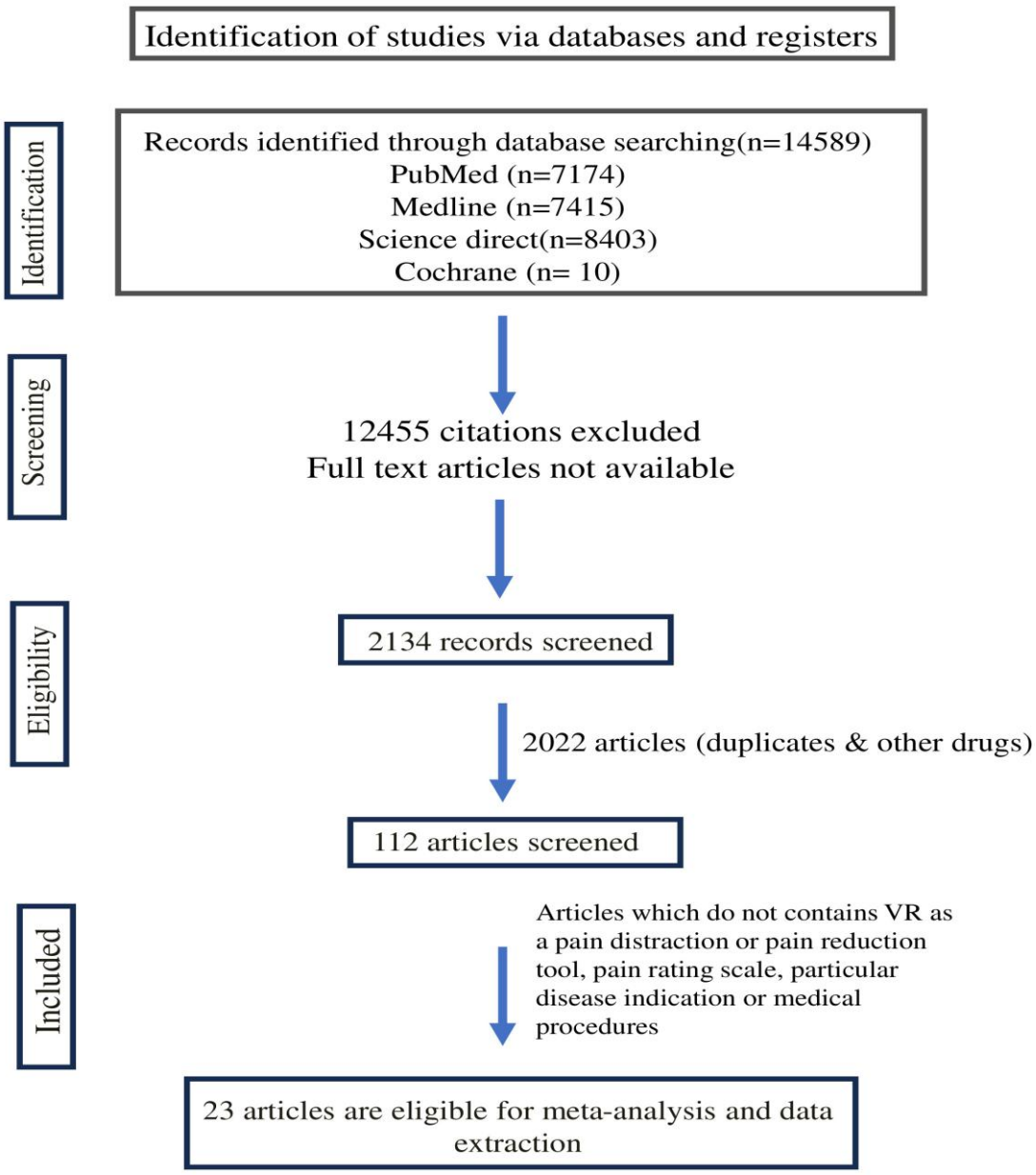
2.4. Search Results

This meta-analysis comprised studies that fulfilled the inclusion criteria, concentrating on the application of VR in pain management across various medical conditions. Quality evaluation ensured methodological soundness, with case series assessed based on study design, participant selection, outcome reporting, and follow-up duration.

2.5. Outcome Evaluation

The main outcome was the comparison of pain scores between the VR and control groups. Secondary outcomes evaluated the effectiveness of VR in various conditions and procedures, along with identifying common pain assessment scales utilized in the studies.

Figure 1: Flowchart Representing the Selection Process



3. RESULTS

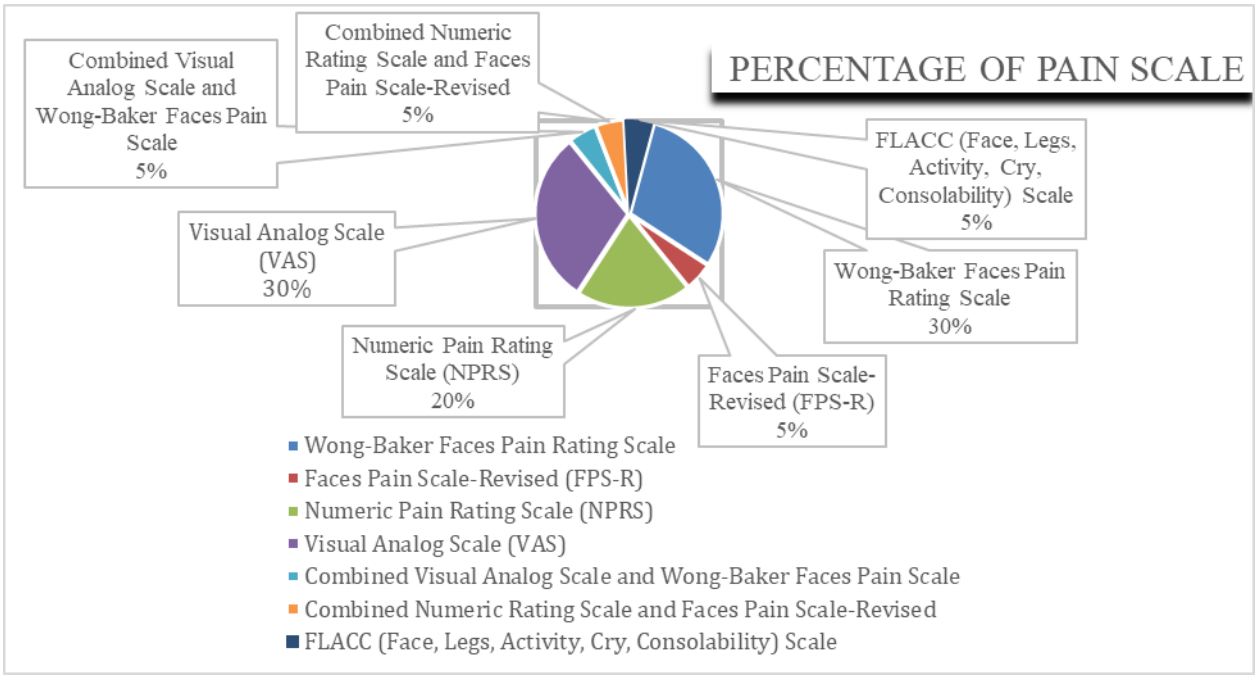
A total of 20 studies were included in this systematic review and meta-analysis to evaluate the effectiveness of VR in pain management. The studies included is shown in Table 1.

Table 1: Characteristics of the Studies Included

S.NO	TITLE	AUTHOR	YEAR
1.	effect of virtual reality distraction on pain and anxiety during infiltration anesthesia in paediatric patients: a randomized clinical trial [14]	Osama M. Felemban	2021
2.	effect of virtual reality distraction on pain and anxiety during dental treatment in 5- to 8-year-old children [15]	vabitha Shetty	2019
3.	Efficacy of virtual reality to reduce chronic low back pain: Proof-of-concept of a non-pharmacological approach on pain, quality of life, neuropsychological and functional outcome [16]	Federica Alemanno	2019
4.	virtual reality for pediatric needle procedure pain: two randomized clinical trials [17]	Evelyn Chan	2019
5.	distraction using virtual reality for children during intravenous injections in an emergency department: a randomized trial [18]	Yen-Ju Chen RN	2019
6.	the effect of virtual reality and kaleidoscope on pain and anxiety levels during venipuncture in children [19]	Tuba Koç Ozkan	2019
7.	the effect of virtual reality on children's anxiety, fear, and pain levels before circumcision [20]	Esra Tural Buyuk	2021
8.	virtual reality as distraction analgesia and anxiolysis for pediatric otolaryngology procedures [21]	Katherine Y. Liu	2020
9.	the effects of virtual reality training on clinical indices and brain mapping of women with patellofemoral pain [22]	Naghmeh Ebrahimi	2021
10.	the effects of showing images of the fetus with the virtual reality glass during labor process on labor pain [23]	Bihter Akin	2021
11.	the effects of virtual reality versus exercise on pain, functional, somatosensory and psychological outcomes in patients with non-specific chronic neck pain [24]	David Morales Tejera	2020
12.	the effect on virtual reality on evoked potentials following painful electrical stimuli and subjective pain [25]	E. J. Lier	2020
13.	the impact of virtual reality on chronic pain [26]	Ted Jones	2016
14.	impact of virtual reality on peri-interventional pain, anxiety and distress in a pediatric oncology outpatient clinic [27]	Alicia Reitze1	2024
15.	Virtual reality environment using a dome screen for procedural pain in young children during intravenous placement: A pilot randomized controlled trial [28]	Ha Ni Lee	2021
16.	virtual reality distraction induces hypoalgesia in patients with chronic low back pain: a randomized control trial [29]	Thomas Matheve	2020
17.	a prospective double-blind pilot randomized controlled trial of an "embodied" virtual reality intervention for adults with low back pain [30]	Christopher Eccleston	2022
18.	virtual reality immersion method of distraction to control experimental ischemic pain [31]	Florella Magora MD	2006
19.	virtual reality as a distraction therapy during cystoscopy: a clinical trial [32]	Diego Inácio Goergen	2022
20.	effects of virtual reality on pain during venous port access in pediatric oncology patients: a randomized controlled study [33]	Remziye Semerci	2020

Various pain scales were used in each of these studies and the pain scores achieved before and after the VR intervention were collected. Out of 20 studies, 6 studies (30.0%) employed the Wong-Baker Faces Pain Rating Scale, 6 studies (30.0%) relied solely on the Visual Analog Scale (VAS), 4 studies (20.0%) used the Numeric Pain Rating Scale (NPRS), 1 study (5%) utilized the Faces Pain Scale-Revised (FPS-R), 1 study (5%) employed both the VAS and the Wong-Baker Faces Pain Scale, 1 study (5%) combined the Numeric Pain Rating Scale with the Faces Pain Scale-Revised and 1 study (5%) used the FLACC (Face, Legs, Activity, Cry, Consolability) Scale as shown in Figure 2. This diversity in pain measurement approaches underscores the varied methodologies adopted to assess the impact of VR on pain management, highlighting the need for standardized protocols to facilitate cross-study comparisons.

Figure 2: Pain Scales Used in the Studies Included



The sample size ranges from 20-1000, with age groups spanning from 2 to 82 years. Table 2 represents the number of patients involved in the study, categorized by age limit, along with the number of patients in the VR intervention group and the control arm. 10 out of 20 studies (50.0%) enrolled adults only, while the remaining 10 studies (50.0%) focused on pediatric participants. This distribution highlights the diverse application of VR across different age groups in pain management. It also includes the pain scores observed for both the VR group and the control group, as well as the difference in pain scores between the two groups.

Table 2: Pain Score Obtained in the VR and Control Groups

Study No.	Total Sample Size	AGE Range	Sample Size in VR Group	Sample Size in Control Group	Pain Score in VR Group	Pain Score in Control Group	Difference
1	50	6 to 12	25	25	2.40 ± 2.82	2.72 ± 2.99	0.32
2	120	5 to 8	60	60	2.42 ± 1.47	5.60 ± 1.22	3.18
3	20	19 to 72	20	20	3.00 ± 2.43	7.50 ± 1.94	4.50
4	123	4 to 11	64	59	3.35 ± 2.38	4.35 ± 2.95	1.00
5	136	7 to 12	68	68	2.76 ± 1.80	2.76 ± 1.80	0.00
6	139	4 to 10	46	43	1.18 ± 0.75	3.16 ± 1.38	1.98
7	78	5 to 10	40	38	0.85 ± 1.21	3.13 ± 2.70	2.28
8	56	7 to 17	30	23	54.84 ±15.31	47.53 ± 13.24	-7.31
9	26	18 to 40	13	13	4.68 ± 1.44	6.74 ± 0.45	2.06
10	112	>18	50	50	2.67 ± 1.91	3.11 ± 1.47	0.44
11	44	18 to 65	22	22	3.17 ± 1.54	5.59 ± 1.35	2.42
12	30	>18	20	10	2.60 ± 0.00	5.70 ± 0.00	3.10

13	30	50	30	0	1.58 ± 0.00	2.55 ± 0.00	0.97
14	57	6-18	29	28	3.00 ± 0.00	4.00 ± 0.00	1.00
15	19	2-6	9	10	3.15 ± 0.00	5.95 ± 0.00	2.80
16	84	18-65	42	42	5.00 ± 2.70	7.20 ± 2.00	2.20
17	34	>18	11	23	3.58 ± 2.31	4.24 ± 2.88	0.66
18	20	32.5	10	10	2.34 ± 2.76	5.03 ± 3.35	2.69
19	159	63.6	80	79	2.00 ± 3.00	2.70 ± 6.70	0.70
20	71	7 – 18	35	36	2.70 ± 6.70	2.00 ± 3.00	0.70

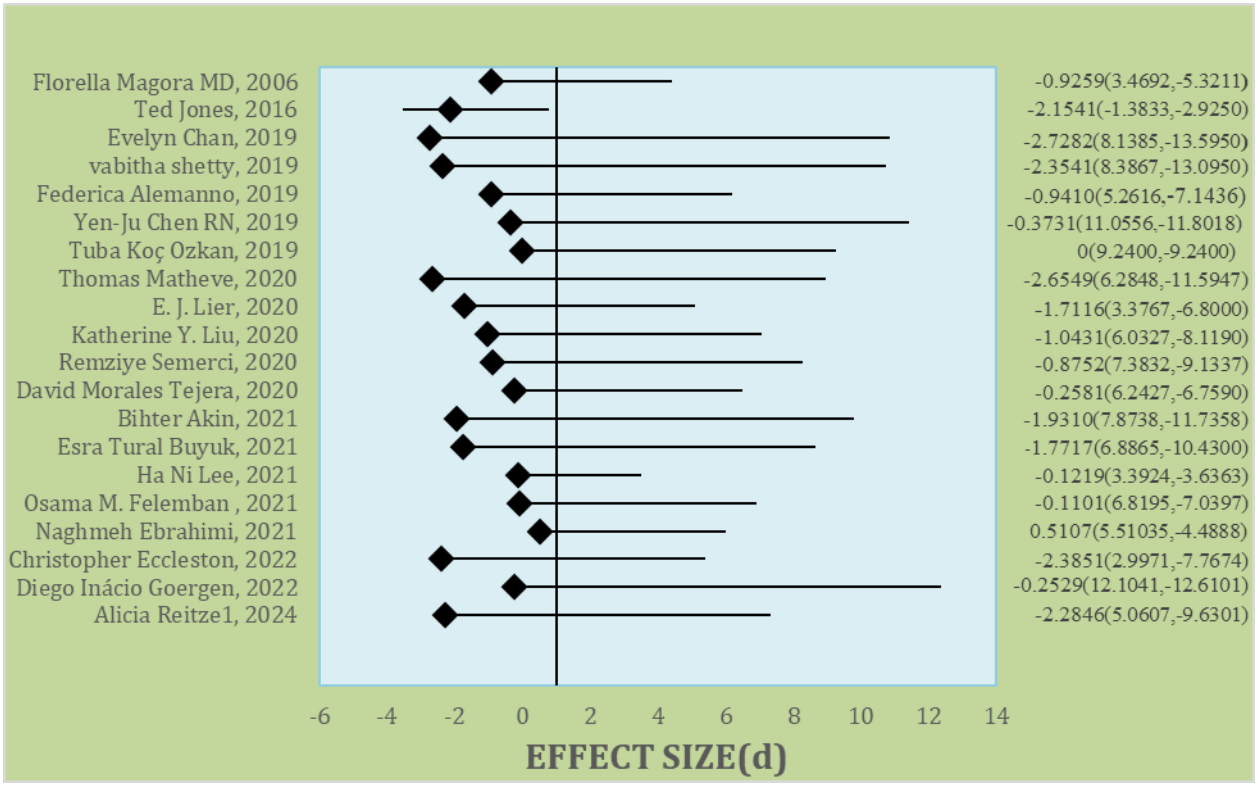
Our meta-analysis evaluated 20 studies on the effectiveness of VR as a tool for pain reduction. Of these, 19 studies (95.2%) reported positive outcomes, demonstrating that VR is an effective and innovative approach to pain management as shown in Table 3. This strong consensus underscores the potential of immersive technology in transforming pain relief strategies.

Table 3: Effectiveness of VR in the Included Studies

S.no	Complication	Painscale used	Implication	Conclusion
1.	pain during infiltration anesthesia in pediatric patients	Wong Baker Faces pain rating scale	Pain distraction	Effective
2.	Dental treatment	Wong Baker Faces pain rating scale	Pain distraction	Effective
3.	chronic back pain	11point numeric pain rating scale	pain reduction	Effective
4.	needle procedure pain	face pain scale-revised	Pain distraction	Effective
5.	intravenous injection	Wong Baker Faces pain rating scale	pain distraction	Effective
6.	Venipuncture	Visual Analogue Scale, Wong-Baker Faces Pain Scale	pain reduction	Effective
7.	Circumcision	Wong Baker Faces pain rating scale	Pain distraction	Effective
8.	Pediatric Otolaryngology Procedures	Wong Baker Faces pain rating scale	pain reduction	Effective
9.	patellofemoral pain	visual analog scale rating	pain reduction	Effective
10.	Labor Pain	visual analog scale rating	pain reduction	Effective
11.	Non-specific Chronic Neck Pain	visual analog scale rating	pain reduction	Not effective
12.	Painful electrical stimuli	Numeric pain rating scale	pain distraction	Effective
13.	chronic pain	visual analog scale rating	analgesia	Effective
14.	pain and anxiety in pediatric oncology	Numeric pain rating scale and Faces Pain Scale - Revised	pain distraction	Effective
15.	pain in children during intravenous placement:	Face, Legs, Activity, Cry, Consolability (FLACC) scale	pain distraction	Effective
16.	chronic low back pain:	Numeric pain rating scale	pain distraction	Effective
17.	low back pain	Numeric pain rating scale	pain reduction	Effective
18.	Ischemic Pain	visual analog scale rating	pain unpleasantness	Effective
19.	Cystoscopy	visual analog scale rating	pain distraction	Effective
20.	venous port access in pediatric oncology	Wong-Baker FACES Pain rating scale	pain reduction	Effective

The effect of VR technology for pain reduction is displayed in Figure 3. The forest plot indicated that most studies reported a negative effect size, suggesting VR effectively reduces pain. While some studies show strong, reliable effects, others have wider confidence intervals, reflecting variability in populations, VR protocols, and pain assessment methods. Despite this heterogeneity, the overall trend supports VR as a promising tool for pain management, warranting further analysis to explore influencing factors.

Figure 3: Meta-analysis on the Effectiveness of VR Technology for Pain Reduction Compared to Control Group



DISCUSSION

This systematic review highlights the growing body of evidence supporting VR as an effective tool for pain management across various clinical settings. Despite differences in study design, patient populations, and clinical contexts, VR consistently reduced pain perception. Technological advances over the last five years have significantly contributed to this trend, making VR more accessible through portable, affordable, and user-friendly devices, shifting from bulky headsets to smartphone-integrated systems.

VR's role in operative care exemplifies its transformative potential. Mixed reality technologies, such as those used during the complex separation of conjoined twins, allowed surgeons to plan and rehearse intricate procedures in a virtual environment, enhancing surgical precision and outcomes .[34] While this case represents a highly specialized application, it underscores VR's broader utility in improving preoperative planning and intraoperative navigation.

In chronic pain management, VR offers a promising non-pharmacologic option. A systematic review by Smith et al.[35] demonstrated VR's effectiveness in reducing acute pain and anxiety in various inpatient populations. VR achieves this through distraction-based mechanisms that engage cognitive and sensory pathways, thereby modulating pain perception without pharmacological intervention. In oncology, VR is gaining traction as a supportive therapy. Groninger et al.[36] found that VR provided superior non-pharmacologic pain relief compared to control groups in hospitalized cancer patients, with benefits persisting beyond the VR sessions. VR not only alleviates physical pain but also offers psychological relief, which is crucial for patients coping with distressing cancer treatments.

VR has also shown success in perioperative and procedural settings. An umbrella review by Viderman et al.[37] confirmed VR's ability to reduce interventinol and procedural pain in both pediatric and adult populations. By decreasing preoperative anxiety and postoperative discomfort, VR contributes to a more positive patient experience and can reduce reliance on opioids, addressing concerns about opioid overuse and addiction.

For fibromyalgia patients, VR has demonstrated effectiveness in mitigating widespread musculoskeletal pain. Pourmand et al.[38] suggested that VR's immersive environments offer both distraction from pain signals and potential therapeutic benefits for associated mood disorders such as depression and anxiety.

Advancements in VR technology have also improved its application in acute trauma care. Maani et al.[39] introduced a robotic VR goggle holder during burn wound debridement for soldiers, enhancing stability and immersion.

Earlier research laid the foundation for VR's role in pain management. Patterson et al.[40] demonstrated VR hypnosis as a tool for reducing procedural pain in burn injury patients. Although the initial studies had limitations, they provided a springboard for more robust clinical trials exploring VR in diverse pain management contexts.

Recent studies by Wiechman et al.[41] have extended VR's applications beyond procedural pain to address background pain in trauma patients, traditionally managed by opioids or epidurals. Their findings suggest VR may offer sustained relief from ongoing pain, opening new avenues for non-opioid interventions in critical care.

In-home VR therapy is an emerging trend for managing chronic pain, particularly chronic low back pain (cLBP). Maddox et al.[42] demonstrated the durability of VR therapy benefits up to 18 months post-treatment. The feasibility of at-home interventions supports patient-centered care and expands access to effective, non-pharmacological pain management.

Beyond pain relief, VR has demonstrated benefits in reducing anxiety and fatigue, especially in oncology settings. Burrai et al.[43] found VR provided a pleasant, cybersickness-free experience during antiblastic therapies, improving patient comfort. These findings highlight VR's potential role in holistic patient care.

Finally, VR has shown promise in obstetric pain management. Carus et al.[44] reported that VR significantly improved pain scores during labor's latent phase and enhanced maternal satisfaction.

LIMITATIONS AND FUTURE IMPLICATIONS

VR has made great progress, but it still has some challenges. One major issue is the high cost of VR headsets and computers, making it less accessible. Some users also experience motion sickness, dizziness, or eye strain. Another limitation is the lack of high-quality VR content, especially in education and professional fields. Current VR devices are often bulky and require wired connections, limiting movement. While VR aims to be realistic, it still struggles with lifelike graphics and interactions. Excessive use can also lead to social isolation and health concerns like eye strain and posture problems. Privacy and security issues arise as VR systems collect user data.

Despite these challenges, VR has a bright future. Technology is improving, making headsets lighter, wireless, and more affordable. With 5G and cloud computing, VR will become smoother and more accessible. It will also change how people work and socialize, with virtual meetings and online spaces like the metaverse. AI will create smarter virtual environments, and VR will play a bigger role in healthcare, helping with therapy and training doctors. Education and job training will also benefit from immersive learning experiences. As haptic feedback improves, VR will feel more realistic, making it an important part of daily life in the future.

CONCLUSION

Our review synthesized evidence from various medical disciplines assessing the effectiveness of VR technology. Despite some variability, the reduction in pain perception remained consistent across diverse clinical settings, procedures, and patient populations. This suggests VR is a versatile and effective tool for managing pain, with proven benefits across different healthcare contexts. Hence, future research should focus on optimising VR applications for specific procedures and patients, refining the technology to improve its efficacy and investigating its integration into routine clinical practice. As VR technology advances, its widespread use in healthcare and pain management provides a non-invasive and cost-effective alternative to conventional methods.

Acknowledgement: The authors express their gratitude to the principal and management of C.L. Baid Metha College of Pharmacy for their encouragement, support, guidance, and facility for the research work.

Author's Contribution: All authors contributed to the study conception and design, the analysis and interpretation of the data, and the drafting and revising of the article, and were involved in the final approval of the version to be published.

Conflict of Interest: The authors do not have any conflict of interest.

Funding: Nil

Ethical Approval: Not Required

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