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A Narrative Review on Virtual Reality Rehabilitation Systems for Onco-Physiotherapy

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Abstract
Rehabilitation is a fundamental component of cancer management, as many survivors experience reduced functional capacity due to the direct effects of the disease as well as the long-term consequences of treatment. Despite clear evidence supporting its benefits, only a small proportion of patients receive adequate physical or cognitive rehabilitation. Multiple factors contribute to this gap in care, including mobility limitations and transportation difficulties that restrict access to rehabilitation centers. The COVID-19 pandemic further emphasized the importance of strengthening telemedicine and home-based rehabilitation strategies to ensure continuity of care when in-person visits are not feasible. In recent years, growing attention has been directed toward the integration of virtual reality into rehabilitation practice. Virtual reality has demonstrated potential to enhance patient adherence and exercise intensity through gamified approaches, recreate realistic environments, and provide multisensory stimulation. In this review, we present an overview of current evidence regarding virtual reality-based interventions in cancer rehabilitation. Although ongoing technological advancements suggest promising future developments, additional randomized controlled trials are necessary to determine whether virtual reality rehabilitation can effectively improve adherence and support telerehabilitation.

Keywords: Virtual Reality, Rehabilitation, Cancer, Lymphedema

Introduction
Cancer remains one of the most significant global health challenges, with 19.3 million new cases reported worldwide in 2020 and projections estimating 28.4 million new cases by 2040 [1]. Although incidence continues to rise—largely due to population growth and aging—mortality rates have steadily declined by approximately 1% per year across both high- and low-income countries and among both sexes [2]. Improvements in early detection and treatment have substantially increased survival, with the 5-year survival rate in the United States rising from 49% in 1979 to nearly 67% in 2015 [3,4]. Consequently, the number of individuals living with a history of cancer is expanding rapidly, with projections indicating growth from 16.9 million to 26.1 million survivors in the US by 2040 [5]. The term "cancer survivors" generally refers to individuals living with the physical and psychological effects of a past or recent cancer diagnosis and its treatment, and some authors extend this definition to include caregivers and family members [6]. These long-term consequences significantly affect physical functioning, as the disease itself, along with surgery, chemotherapy, and radiotherapy, may lead to chronic symptoms and persistent physical and cognitive impairments.

Pain is among the most prevalent chronic symptoms in this population, affecting 55.0% of patients during treatment, 39.3% after curative therapy, and 66.4% of those with advanced or metastatic disease [7]. Ongoing pain diminishes quality of life and contributes to disability. Cancer-related fatigue (CRF) is another highly common symptom, with prevalence ranging from 25% to 99% depending on cancer type, treatment, and patient characteristics [8]. Lymphedema frequently develops following lymph node dissection, radiation therapy, chemotherapy, or combined interventions [9]. Its occurrence varies by cancer type and treatment modality, reaching up to 75% in breast cancer patients after axillary node removal, 14.5–41.4% following chest and breast radiation, 50% in melanoma, and 16% in genitourinary cancers [10,11]. In addition to physical impairments, many survivors report cognitive difficulties involving memory, attention, language retrieval, and processing speed. Often termed "chemo brain," these deficits have traditionally been attributed to chemotherapy-related neurotoxicity [12], though emerging evidence suggests that mild cognitive impairment may precede treatment in some cases [13]. Chemotherapy-induced peripheral neuropathy (CIPN) is another serious adverse effect, with incidence rates ranging from 19% to 85% depending on the drug regimen [14]. It typically presents with distal sensory disturbances such as paresthesia, dysesthesia, pain, or numbness, and may also include motor deficits that impair balance and gait. Symptoms often develop gradually and may persist long after treatment completion.

Evidence indicates that many of these impairments respond positively to rehabilitation interventions, and recent systematic reviews and clinical guidelines have established exercise recommendations tailored to various cancer types [15–19]. Despite these recommendations, referral rates remain low. In a study of 163 breast cancer survivors, 91% reported physical impairments, yet only 30% received appropriate rehabilitation services [20]. Similarly, research involving 3,439 survivors found that 60% expressed unmet needs for physical or psychological rehabilitation [21]. Long-term follow-up of pediatric brain cancer survivors in Norway reported unmet needs in as many as 86% of individuals [22]. Factors contributing to this gap include the gradual onset of impairments and limited early identification within oncology care systems [23].

Even when rehabilitation programs are initiated, discontinuation within the first year is common, often due to limited patient motivation and the repetitive nature of conventional exercise regimens [24]. The COVID-19 pandemic further highlighted structural limitations in delivering home-based cancer rehabilitation [25,26]. Many survivors face mobility restrictions or transportation barriers that hinder attendance at rehabilitation centers. Consequently, growing attention has been directed toward telerehabilitation as a more accessible and potentially safer alternative to traditional models [27–29]. Virtual Reality (VR) has emerged as a promising tool for remotely linking patients and rehabilitation professionals [26,30–34]. Virtual Reality Rehabilitation (VRR) has been explored in multiple clinical populations, including stroke, spinal cord injury, multiple sclerosis, Parkinson's disease, cerebral palsy, and oncology [32,35–40]. Its interactive and game-like characteristics are believed to enhance adherence and increase training intensity [41–43].

The aim of this narrative review is to examine whether VR represents a valuable addition to cancer rehabilitation and to summarize existing evidence in this field. Current literature has either evaluated VR broadly within rehabilitation contexts [41,44] or examined its use in palliative care for acute cancer-related symptoms [45,46]. However, these approaches do not specifically address VR applications targeting chronic, impairment-driven rehabilitation in cancer survivors. Therefore, this review seeks to assess the role of VR in managing long-term functional limitations associated with cancer survivorship and to clarify its potential contribution to comprehensive rehabilitation care.

Methods

Database Search

A comprehensive search of the primary electronic databases, PubMed and Scopus, was conducted from database inception.

The literature search was carried out by the first author. Subsequently, the first and second authors independently reviewed titles, abstracts, and the reference lists of full-text articles to determine eligibility. Any discrepancies were resolved through discussion between the two reviewers.

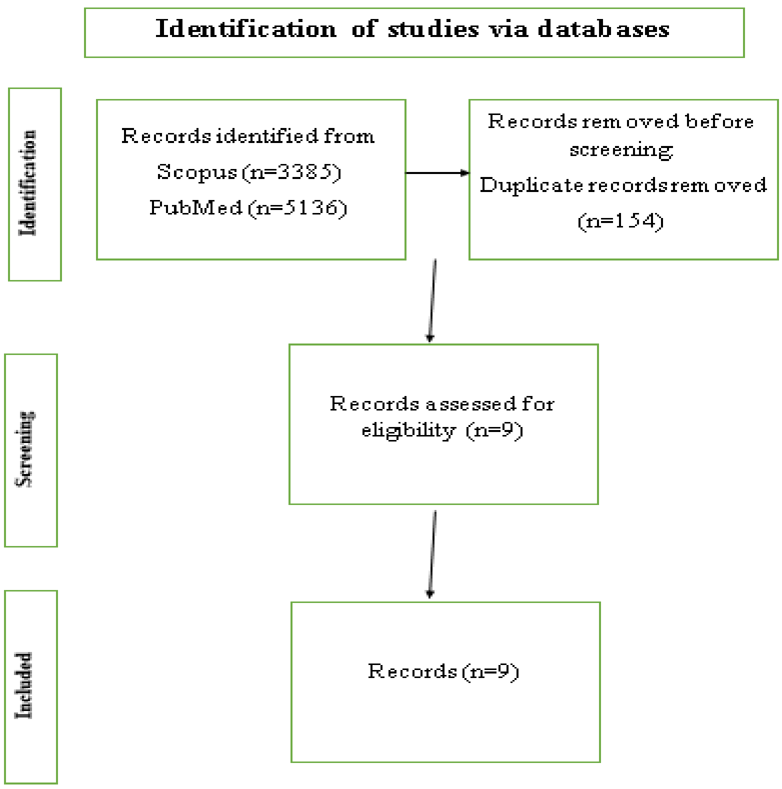
Study selection was guided by the PICOS framework [47]. Eligible studies were required to meet the following inclusion criteria:

Inclusion Criteria

1. population: individuals with a previous or current cancer diagnosis
2. intervention: rehabilitation programs incorporating Virtual Reality
3. comparison (for randomized controlled clinical trials): conventional physiotherapy
4. outcomes: functional measures, pain intensity, lymphedema volume, cancer-related fatigue, adherence to the rehabilitation program, or exercise performance
5. study design: randomized controlled trials (with or without a control group), comparative studies, perspective studies, or feasibility trials. Publications written in English, Spanish, or Italian were included.

Results

The search of the main databases (PubMed, Scopus) produced a total of 7733 results. Duplicate detection led to the elimination of 149 results. After screening through eligibility criteria, a total of nine studies were selected for our review. We will here, therefore, review the design of the included studies.



Atef et al. conducted a quasi-randomized clinical trial comparing the efficacy of VRR and proprioceptive neuromuscular facilitation (PNF) on post-mastectomy lymphedema upper-arm exceeding volume and upper arm function recovery, measured through the QuickDASH-9 scale. The experimental procedure consisted of a 30 min exercise program using a Wii Fit non-immersive VR game. Both the VRR and the PNF procedures were conducted two times per week for a total of 4 weeks. During these sessions, both groups, consisting of 15 women each, also received a procedure of pneumatic compression for the treatment of lymphedema.

Axenie and Kurz conducted a prospective study on the combination of Virtual Reality avatars and Machine Learning to drive patient-tailored CIPN-related motor deficit compensation. They proposed a closed-loop system based on wearable devices designed to precisely assess the kinematics of the sensorimotor deficits. Furthermore, they conceptualized a VR avatar designed to reproduce the patient's movements and to display the discrepancies between the desired movement and the measured/executed one, so as to trigger deficit compensation.

Basha et al. conducted a randomized clinical trial comparing the therapeutic efficiency of non-immersive VR training and resistance exercise training on breast cancer-related lymphedema. The experimental protocol consisted of an exercise program conducted through Xbox Kinect games involving upper arm motion. Both rehabilitation groups, consisting of 30 patients each, received five rehabilitation sessions per week for 8 weeks. The outcome measures included excessive limb volume and pain, measured through the visual analog scale (VAS); the impairment of the upper arm, measured through the Disability of the Arm, Shoulder, and Hand (DASH) questionnaire; shoulder range of motion (ROM); shoulder muscle strength; and hand grip strength.

Feyzioğlu et al., 2019 presented a prospective randomized controlled trial comparing the efficacy of a non-immersive VRR intervention with standard physiotherapy on breast cancer survivors who had undergone surgery with axillary dissection . The experimental and control groups, both consisting of 20 individuals, both received the treatment for 45 min per session and two times a week for 6 weeks. The experimental intervention consisted of playing Xbox Kinect games involving upper arm motion in the presence of a trained physiotherapist. However, the intervention group also received a scar tissue massage for 5 min and passive shoulder joint mobilization for 5 min, performed by the same physiotherapist assisting them. The outcomes considered were pain (VAS), grip strength, functionality (assessed through the DASH questionnaire), muscle strength, ROM, and fear of movement, measured through the Tampa Kinesiophobia Scale (TKS).

Hoffman et al. (2014) conducted a non-controlled trial investigating the feasibility of a home-based VRR intervention on seven lung cancer patients who had received thoracotomy . The home-based rehabilitation program, divided into two phases of 5 and 10 weeks, respectively, consisted of playing Nintendo Wii Fit Plus exergames of gradually increasing intensity and duration 5 days a week. The VRR sessions did not require the presence of rehabilitation professionals. The outcomes considered were the levels of adherence, measured as the days of actual training, exercise performance, cancer-related fatigue (0–10 scale), perceived self-efficacy for fatigue self-management (0–10 scale), and perceived self-efficacy for walking 30 min (%).

House et al. conducted a trial on a sample of six patients to investigate the feasibility of a rehabilitative intervention based on a novel technology, named BrightArm Duo, on breast cancer survivors with post-surgical pain and depression. The novel technological tool tested consisted of a combination of a robotic table for forearm rehabilitation and a computer executing non-immersive VR rehabilitation games. The rehabilitation program consisted of training sessions lasting 20 to 50 min of training twice a week for a period of 8 weeks. The outcomes considered were pain, measured through the Numeric Rating Scale (NRS); arm, hand, and bimanual function measured through the Fulg-Meyer assessment, the Chedokee arm and hand activity inventory, and the Jebsen hand function test; upper arm autonomy in the activities of daily living, measured through the Upper extremity function index (UEFI-20); depression, measured through the Beck Depression Inventory (BDI-II); and cognitive function, measured through the Neuropsychological Assessment Battery (NAB), the Hopkins Verbal Learning Test (HVLT-R), the Brief Visuospatial Memory Test (BVMT-R), and the Trail Making Test (TMT).

Reynolds et al. conducted a pilot study to evaluate the efficacy of two different VRR interventions on pain, CRF, and quality of life. The study involved two groups of 19 and 20 women with metastatic breast cancer who were asked to participate in an immersive home-based VR intervention. The technology involved consisted of a Pico Goblin VR headset playing two different relaxing scenarios. The outcomes considered were pain, measured through the Brief Pain Inventory scale (BPI); quality of life, measured through the EQ-5D-5L scale; fatigue, measured through the Functional Assessment of Chronic Illness Therapy Fatigue scale (FACIT-Fatigue); and depression, anxiety, and stress levels, measured through the short version of the Depression, Anxiety, and Stress Scales (DASS-SF).

Schwenk and colleagues conducted a randomized trial on VR-based balance training. The authors used inertial sensors equipped with gyroscopes and accelerometers on the lower limbs to assess positions and joint angles and a multi-step balance retraining virtual game based on the inputs of the sensors. In particular, the intervention group, consisting of 11 individuals with chemotherapy-induced polyneuropathy, conducted exercises and balance retraining tasks while receiving visual and auditory feedback on their motor errors. The outcomes measured were the sway of the hip, the sway of the ankle, the center of mass movement, gait speed, and fear of falling, measured through the Falls Efficacy Scale (FES-I).

Tsuda et al. conducted a preliminary study on a VR-based exercise program on over 60-year-old hospitalized patients with hematological malignancies receiving chemotherapy. The virtual reality exercise program involved Nintendo Wii Fit games, which were played for 20 min a day, five times a week until hospital discharge. The primary outcomes were adherence rates, physical performance (measured through the Barthel index), muscle strength, and emotive state (hospital anxiety and depression scale).

In summary, eight of the considered studies were clinical trials, with one study conducting a preclinical investigation. Of the clinical trials, four compared VRR to a standard rehabilitation program. One study involved an immersive VR program, while the remaining eight studies used non-immersive VR technology. As for the population considered by the clinical trials, five of the included studies involved breast cancer survivors. As for the outcomes considered, four of the retrieved studies tested VRR on more than one physical impairment. Overall, we found four studies testing the efficacy of VRR on chronic pain, two studies on cancer fatigue, two studies on lymphedema-related excessive arm volume, one on cognitive function, four on motor performance impairment, and two on chemotherapy-induced polyneuropathy. Finally, we here report the results of the two included studies considering adherence rates as an outcome.

Pain

Feyzioğlu et al. did not find a statistical difference in pain. The study, however, found significant differences in the decreased fear of movement as calculated through the Tampa Kinesiophobia Scale. Moreover, House et al. reported a 20% decrease in pain after treatment ($p = 0.1$). Basha and colleagues, comparing non-immersive VR exercise with regular resistance exercise in patients with breast cancer-related lymphedema, found significant differences in pain intensity ($p = 0.002$) between groups. Reynolds et al. found that both scenarios significantly reduced pain (mean difference = −6.01, $p = 0.004$) . To summarize, four of the included studies considered pain as their outcome, but only two found a statistically significant effect.

Fatigue

Hoffman et al. reported statistically significant improvements in both CRF severity and perceived self-efficacy for walking . Reynolds et al. found a statistical difference in pain and at follow-up compared to before the intervention (mean difference −5.00, $p < 0.001$). To summarize, two of the included studies found statistically significant effects of VR on cancer-related fatigue.

Lymphedema

Atef et al. found that both VR and PNF exercise reduced edema, with no significant differences ($p = 0.902$). Basha et al.'s trial showed no significant differences among groups for lymphedema-related excessive shoulder volume (mean difference = −11.1 mL, $p = 0.15$) . In conclusion, none of the included studies found statistically significant evidence in favor of a VRR intervention compared to standard rehabilitation.

Cognitive Impairment

House et al.'s study on VR rehabilitation found it effective on cognitive function, with 10 out of 11 parameters improved ($p = 0.004$).

Motor Performance

The Feyzioğlu trial on arm rehabilitation following mastectomy recorded improvements in range of motion, grip strength, and arm muscle strength but did not find any significant differences with the control group. House et al.'s study, also considering arm rehabilitation in breast cancer patients following surgery, reported a significant improvement of the affected shoulder in 17 of 18 range-of-motion metrics ($p < 0.01$), of which five were above the Minimal Clinically Important Difference. The study also reported a recovery in 13 out of 15 strength and function metrics ($p = 0.02$). Basha et al.'s trial also found statistical differences in physical and motility outcomes (shoulder flexion strength, external rotation strength, abduction strength, and handgrip strength) in favor of the control group, who performed regular resistance exercises. The trial also reported that VRR was, however, significantly superior to standard rehabilitation for the range of motion outcome ($p < 0.001$). Lastly, the Atef et al. trial reported statistically significant differences among the VRR group and the control group regarding the functional improvements of the arm following mastectomy ($p = 0.045$). To summarize, four trials considered motor impairment as their outcome, but only two reported a statistically significant effect of VRR, while one trial found it inferior compared to standard rehabilitation on some of the considered outcomes.

Chemotherapy-Induced Peripheral Neuropathy

Schwenk et al. reported how the sway of the hip, ankle, and center of mass while standing with eyes opened and in a semi-tandem position was significantly reduced in the intervention group compared to the control ($p = 0.010$–0.022 and $p = 0.008$–0.035, respectively, for the two positions). No significant effects were found for balance with eyes closed, gait speed, and fear of falling ($p > 0.05$).

Adherence to Rehabilitation Programs

Tsuda et al. recorded an adherence rate of 66.5% in 88 sessions among 16 hospitalized patients and noted the maintenance of physical performance . The Hoffman et al. study reported a mean adherence rate at the end of Phase I of 96.6% (SD: 3.4%) and of 87.6% (SD: 12.2%) at the end of phase II. To summarize, two studies considered adherence rates as an outcome, but none of the two compared it to standard rehabilitation adherence rates.

In summary, VRR was found to be significantly effective for cancer-related fatigue, cognitive impairment, and CIPN-related balance impairment. VRR was found to be effective for cancer survivors' pain, but only two studies found it significantly superior to standard rehabilitation. The included studies showed mixed results for the motor impairment outcome, with two studies reporting statistically significant data in favor of VRR and one study reporting statistically significant results in favor of the control group for some of the motor performance outcomes. None of the included studies found a statistically significant effect on lymphedema.

Discussion

This review sought to summarize current evidence regarding the integration of Virtual Reality (VR) into rehabilitation programs targeting chronic symptoms and functional impairments in cancer survivors. As previously outlined, the physical and cognitive deficits examined in this review are well-recognized indications for structured rehabilitation interventions. Findings from the included studies indicate that Virtual Reality Rehabilitation (VRR) may be effective in reducing pain among cancer survivors, aligning with earlier reviews demonstrating benefits of VR interventions for both acute and chronic pain conditions. Nevertheless, only two studies demonstrated that VRR was significantly superior to conventional rehabilitation, underscoring the need for further comparative trials.

Regarding cancer-related fatigue, two studies reported statistically significant improvements following VR interventions. This observation is consistent with prior research showing positive effects of VRR on chronic fatigue in other populations, such as individuals with multiple sclerosis. However, earlier oncology-focused studies primarily investigated VR during acute treatment phases, for example during chemotherapy sessions. A 2020 systematic review reported significant reductions in fatigue immediately after VR-assisted chemotherapy infusions. Therefore, additional research is necessary to determine the long-term effectiveness of VRR for chronic cancer-related fatigue.

One study identified positive effects of VRR on balance deficits associated with chemotherapy-induced peripheral neuropathy (CIPN), in agreement with research supporting VR-based balance training in conditions such as diabetic neuropathy, stroke, and age-related balance decline. In contrast, studies evaluating lymphedema-related arm volume did not demonstrate statistically significant superiority of VRR compared with standard rehabilitation. Evidence regarding motor performance outcomes was mixed: two studies favored VRR, whereas another reported better results in certain strength measures within the control group. These findings differ from prior research in other clinical populations—such as cerebral palsy, elderly individuals, and post-stroke patients—where VRR showed stronger effects on motor recovery and strength. Additionally, one study demonstrated cognitive improvements in cancer survivors following VRR, consistent with broader evidence supporting VR interventions for cognitive rehabilitation.

Three of the included studies implemented home-based interventions, a particularly relevant area for oncology populations. Transportation difficulties related to disability have been identified as a major barrier to accessing rehabilitation services. Consequently, telerehabilitation has gained attention as a strategy to improve accessibility. Prior literature also highlights VR as a tool capable of facilitating remote and home-based healthcare delivery.

Within the reviewed studies, Hoffman et al. utilized a Wii Fit system for progressive home-based training with minimal professional supervision, reporting encouraging adherence rates. However, due to the absence of a comparison group, it remains unclear whether VRR improved adherence relative to traditional programs. Reynolds et al. described a home-based VR intervention without professional supervision but did not provide adherence data, although patient feedback suggested enhanced perceived mobility and engagement. Feyzioğlu et al. conducted a randomized trial comparing two home-based interventions; however, the VRR group also received direct physiotherapist-administered mobilization and massage, limiting conclusions regarding remote implementation. Collectively, these findings indicate that additional research is required to clarify whether VRR can effectively support remote supervision and enhance adherence in home-based oncology rehabilitation.

Cost and usability considerations may also limit the feasibility of certain advanced VR systems for home use. Nevertheless, several studies employed commercially available gaming platforms that are widely accessible and potentially already present in patients' homes. Two trials assessed adherence as an outcome, yet both lacked control groups. Further controlled studies are therefore essential to determine whether VRR truly enhances adherence compared with traditional rehabilitation approaches. This hypothesis is supported by prior research suggesting that VR-based programs can improve both adherence and training intensity. Such evidence would be particularly meaningful given the high dropout rates observed within the first year of conventional rehabilitation programs.

One explanation for discontinuation is the repetitive and monotonous nature of traditional exercise regimens, which may reduce patient motivation and confidence. VRR has been proposed as a strategy to increase engagement by introducing interactive and enjoyable elements into therapy. The novelty of immersive environments or head-mounted displays may contribute to patient interest, but sustained engagement likely derives from gamification features, including goal setting, feedback, scoring systems, and reward mechanisms. Moreover, VR environments can simulate real-life tasks, enhancing both physical and cognitive task specificity. By structuring therapy around meaningful and goal-directed activities, VRR may foster greater motivation than conventional facility-based exercise routines.

An additional advantage of VRR lies in its multisensory stimulation capabilities, which may be particularly beneficial for cancer survivors experiencing multiple coexisting impairments. Notably, four studies evaluated VRR across more than one physical deficit, while three assessed both physical and psychological outcomes, and one included cognitive measures. Furthermore, two studies integrated VR with complementary technologies. House et al. combined VR with a robotic rehabilitation table and computerized forearm supports, whereas Schwenk et al. incorporated inertial sensors to provide real-time error-based motor retraining. Previous research has similarly integrated VR with treadmills, data gloves, and robotic orthoses. These findings highlight VR software as a versatile platform capable of interfacing with multiple rehabilitation technologies currently under investigation or clinical use in oncology care.

Conclusions

The reviewed studies, together with existing literature, indicate that Virtual Reality Rehabilitation (VRR) may be particularly suited to the specific needs of cancer survivors, including the demand for home-based interventions, strategies to enhance motivation and adherence, and comprehensive multimodal treatment approaches. However, additional randomized controlled trials are necessary to establish clear evidence regarding the potential benefits of VRR compared with conventional rehabilitation programs. Specifically, it is important to verify whether the engaging and interactive features of VRR, along with its multisensory stimulation, can effectively improve adherence rates. Furthermore, we advocate for the continued development of advanced VRR systems and training protocols designed to facilitate remote connectivity, thereby improving access to healthcare and rehabilitation support. Given the rapid pace of technological innovation, future advancements are expected to enhance the clinical effectiveness, usability, and affordability of VRR systems.

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