

Effectiveness Of Virtual Reality Rehabilitation In Patients With ACL Reconstruction: A Descriptive Review

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Abstract

BACKGROUND: The knee is the largest joint in the human body. The ligaments are the prime assurance for the stability of the same. The primary objectives of Anterior Cruciate Ligament (ACL) restoration surgery are to rectify aberrant movement patterns, knee stability while secondary objective focuses on restoration of high functional activity. Virtual reality (VR) is one of the new potential technologies being introduced to increase the efficacy of orthopaedic procedures.

METHOD: PubMed, Web of Science, Scopus were the included databases The reviews included a manual searched of relevant reference lists and citation tracking of key publications where research papers included studies from 2009 - 2024 out of which 21 articles were examined based on inclusion and exclusion criteria.

RESULT: The evaluated publications demonstrated the necessity of VR-based therapy for post-anterior cruciate ligament reconstruction (ACLR) and its efficaciousness in improving patients' functional recovery, strength, range of motion, and patient involvement.

KEYWORDS: Anterior cruciate ligament reconstruction, Effectiveness, Knee Joint, Post-operative rehabilitation, Virtual Reality

INTRODUCTION

The knee which is the body's largest joint enables flexion, extension, and minor rotation, stabilized by ligaments protecting cartilage, meniscus, and bursae, with motion influenced by soft tissue, dysfunction, and muscle tightness [1].

One of the most crucial functions of the knee joint is mechanical stability, which is mostly provided by ligaments. Among these ligaments is the anterior cruciate ligament (ACL), which is involved in knee movement and is crucial for neuromuscular stability. The ACL is responsible for over 50% of ligament injuries, particularly when mechanoreceptors in the joint are destroyed by total fiber loss [2].

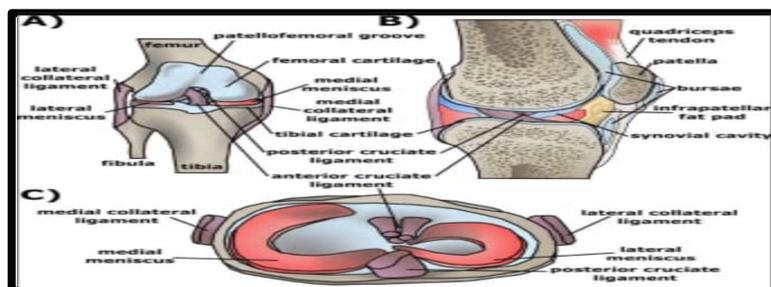


Figure 1: Knee joint: The schematic shows structures and tissues in-A) frontal, B) sagittal and C) Transverse planes.

The stretching of ACL is starting from the lateral condylar junction and goes beneath the insertion to the central tibial plateau. At both of its insertion sites, the ACL cross-sectional area is larger than that of the central mass. It has an uneven cross-sectional form as well [3].

ACL is considered to be the most frequent injury portion with also the ligament which can be surgically repaired in the body. During athletic activities, ACL injuries frequently happen [4].

ACL damage accounts for about 26% of all internal injuries and is frequently sustained in high-force sports [5]. Every year, there are over 200,000 injuries to the ACL, of which 100,000 result in knee reconstructions [6]. In addition to providing rotational stability in the frontal and transverse planes, the ACL limits anterior tibial translation into the femur and stabilizes knee movement [7]. Proprioceptive changes also affect other parameters, including physical activity, balance, healing, and re injury [8]. The tearing of the ACL and the mechanical sensors within it disrupt the transmission of sensory motor impulse in the knee. The neuromuscular after effects of ACL damage are crucial to take into account since they influence show the injured body heals or reconstructs [9]. The current course of treatment for a full ACL injury is surgical repair. An autograft and allograft tendon from the patella tendon or medial hamstring is required to restore developing anatomical function. Returning to sports after ACL reconstruction (ACLR) requires a lengthy and laborious rehabilitation process that typically takes six to nine months. After undergoing ACL restoration, athletes frequently complain that their recuperation is going far more slowly than they had anticipated [10]. The method that is carried out is rehabilitation in order to lessen the effects of motor restriction. Following an ACL reconstruction, there is a rehabilitation phase to enhance knee functionality and capacity. Rehabilitation plays a vital function and following surgery, the recuperation process takes a long time [11].

Orthopedic surgeries are fraught with difficulties, such as exorbitant costs, a significant chance of complications, and an extended recuperation period for patients. Among these encouraging one such technology is immersive Virtual Reality (VR), which enables the construction and modification of virtual bodies and realistic three-dimensional environments. The term VR describes a computer-generated environment or stimulation that submerges the user in an interactive, three-dimensional world that is usually accompanied by sight, sound, and occasionally touch, giving the impression that the user is actually there. Construct a false impression. In order to engage with the virtual world, users of VR usually does ahead-mounted display (HMD) that covers their eyes and ears and utilize gloves or portable controllers [12]. Using six different pieces of computer hardware and software, interactive stimulation allows users to interact in environments that look and experience what is known as VR—a world and experiences that seem real [13].

The newest form VR, which is utilized in several tasks or methods, pilot training, and medical training, including surgery, psychotherapy, and physiotherapy for rehabilitation [14]. A computer-generated, three-dimensional stimulated environment is provided by VR where spectators are accommodated with a virtual world that seems to have authentic sounds and pictures. It offers an interactive setting where users can communicate, view, and alter computer-generated virtual worlds, improving education for a number of reasons. In an attempt to provide the community with the greatest care and assistance available, more medical professionals have turned to VR for rehabilitation during the past 20 years [15].

VR has been used to treat various musculoskeletal disorders, including adhesive capsulitis, arthritis, fibromyalgia, and post-knee arthroplasty pain, showing significant benefits and serving as a therapeutic aid for musculoskeletal and neurological conditions [16]. VR can be non-immersive, semi-immersive, or immersive depending on the virtual world, the consistency of the synthetic inputs, and the user's isolation from outside stimuli (such room light) [17].

Motion tracking systems record patient movements using sensors. Contact and non-contact sensors can both be used to collect movement data on patients. Contact sensors are capable of gathering accurate data, but they need to be connected to the patient's body. Applications for wireless and adaptable data collecting are possible using a non-contact sensor such as Kinect. Here, you can click or tap to insert text. Use unity software and a Kinect sensor. Develop a rehabilitation interface that allows users to practice their leaping and walking actions. A matching movement in the user's body can be caused concurrently by motion sensors and cameras. Movement of the virtual body (visual-motor coincidence) that uses haptic feedback to give the user the impression that the virtual object is touching them simultaneously at the appropriate spot on their real body (visual-tactile sense) [18]. Because VR assures that all individuals are examined in equal conditions and enables the uniform delivery of both visual and audible input; it might be a useful tool. You can also interact with environments that are not possible to develop in the real world. Few researches have looked into the

opinions of patients with musculoskeletal problems regarding VR-based therapy; currently, only the view points of neurological patients have been studied mostly [19]. Abnormalities of the musculo skeletal system are the most frequent source of long term pain and disability, contributing to 24% of days with reduced activity and 54% of all long-term injuries [20].

OBJECTIVES OF THE STUDY:

- The primary objectives of ACL restoration surgery are to rectify aberrant movement patterns, knee stability.
- The secondary objective focuses on restoration of high functional activity VR are one of the new potential technologies being introduced to increase the efficacy of orthopaedic procedures.

METHODOLOGY

STUDY DESIGN: A literature review was conducted which summarizes and evaluates the existing literature on the same.

ETHICAL STATEMENT

Ethical Approval/Patients consent: Not applicable as it does not involve human and animal participants.

FUNDING: No funding received.

SEARCH STRATEGY:

Database: The databases include PubMed, Web of Science, Scopus. The reviews included a manual searched of relevant reference lists and citation tracking of key publications.

Time period: The time period of taken articles was from between 2009-2024. In addition to using electronic databases, the review would also manually search of pertinent reference lists and note the citations of important works.

TABLE 1: Mesh words:

S.NO.	Mesh word
1.	Knee joint
2.	Anterior cruciate ligament reconstruction
3.	Post-operative rehabilitation
4.	Physiotherapy interventions
5.	Virtual reality
6.	Effectiveness
7.	Exergaming
8.	Balance
9.	Physical activity
10.	Psychological effect
11.	Feedback
12.	Orthopedic treatment
13.	Musculo skeletal disorder

Boolean operators: Searched terms had been identified based on the researched question and had been combined used Boolean operators (and, or) to refine the searched results.

SELECTION OF STUDIES FOR THE REVIEW:

Screening of articles: The titles and abstracts of all identified papers were examined separately by two reviewers in the

first phase, and the full-text review of a subset of the articles was considered in the second step. 55 studies that passed the initial screening were then undergone full text reviews where 21 studies that met the inclusion criteria had been included in the final review.

STUDYPARTICIPANTS:

Previous articles consisting of ACL rehabilitation patients who have received VR-based rehabilitation as part of their post-operative care.

Inclusion Criteria:

- The articles which included specific quantitative or qualitative outcomes related to the effectiveness of VR rehabilitation in ACL reconstruction patients.
- The studies that focused on VR rehabilitation interventions implemented during the post-operative phase following ACL reconstruction.

Exclusion Criteria:

- Studies in which the participants had injuries other than ACL were excluded.
- Articles which consisted of exercise intervention other than VR were excluded.
- Articles included other conservative treatments like pharmacology.

INTERVENTION:

The Primary elements of the search strategy included the Following term: **Virtual Reality.**"The use of interactive simulations created with computer hardware and software to provide users opportunities to participate in environments that look and feel similar to real objects and events" is the definition of VR, a new technology [21].

Table 2: Detailed descriptions of each VR-based rehabilitation session

Content	Session	Detailed description
1.Yoga Training	<ul style="list-style-type: none"> • Palm tree • Warrior 	In order to maintain balance, participants stood on the board, raised their toes, aligned their heels, flexed their knees on the board, extended one leg back, and kept their arms straight.
2. Strength Training	<ul style="list-style-type: none"> • Balance bridge • Single-leg extension 	In a supine position, participants lifted their hips and flexed one leg while extending the other leg in front of them. 6 repetitions at 90°. Then next, participants moved the ipsilateral upper limb in the opposite direction while raising and extending a straight leg for 6 repetition

The clinical outcomes that the rehabilitation professional can potentially target through VR in different conditions include but are not limited to motor control, balance, gait, Strength, pain control, improved physical endurance, mental well-being, reduced fatigue, and better cognition [15].



Figure 2: Examples of participant's movements while engaging in VR-based rehabilitation: (a) hip and knee extension in single-leg extension, (b) hip and knee flexion in single-leg extension, (c) weight shifting side to side with hip and knee flexion in Ski Slalom, and (d) keeping balance in Tightrope Walk [19].

Comparators: Enhancing activation timing, sequencing, and responsiveness which enable dynamic knee stiffness and stability constituted as the main goal of neuromuscular training. The goal of neuromuscular training is to ensure that the contributions from the hip, knee, and ankle joints of the lower extremities are appropriately balanced by using the postures and alignments necessary to prevent knee injuries or re-injuries during functionally meaningful sports motions. Enhancing lower extremity strength, power, or endurance with traditional resistance training served as a very successful way to boost athletic performance. Progressive resistive knee flexion and extension exercises were initiated for the patients. Patients began cycling to strengthen their quadriceps and hamstrings once they were able to fully bear their own weight. Single-leg balance activities were then initiated. Coordination and contractions [22]. VR rehabilitation may lead to comparable or even superior outcomes compared to conventional methods in terms of improving functional recovery, range of motion, strength, and patient engagement.

OUTCOMES MEASURES:

These were measured by:

Visual analogue scale (VAS): For ACLR rehabilitation, the most commonly used scale is VAS. A horizontal or vertical line with numerical values ranging from 0 to 10 or 100 is used in this straightforward and trustworthy tool; 0 denotes no pain, while 10 or 100 denote the worst pain conceivable. Patients are asked to mark the point on the line that corresponds to their level of pain.

International Knee Documentation Committee score (IKDC): In order to estimate knee function, the International Knee Documentation Committee score (IKDC) was created for the subjective evaluation of ACLR results. The IKDC score is determined as $(\text{IKDC Score} \frac{1}{4} [\text{sum of items}/\text{maximum possible score}] \times 100)$.

TABLE 3: PICO TZBLE FOR INCLUDED STUDIES

POPULATION	ACLR rehabilitation patients
INTERVENTION	VR-based rehabilitation Immersive VR
COMPARATORS	Conventional rehabilitation: Neuromuscular training
OUTCOMES	Measured by: <ul style="list-style-type: none"> • Visual analogue scale (VAS) • IKDC score

RESULT

Patients with ACL ligament disease frequently have ACLR surgery to reduce discomfort and increase mobility [23]. One study took into account that during the first stage of ACL reconstruction, playing Nintendo Wii virtual games as part of an accelerated rehabilitation program did not improve pain; function, COG, or balance measures but later stages implemented a great improvement [16]. Another study concluded that using VR in practice teaching protocol showed a vital and significant improvement in strength and lower limb functional activities [14]. Moreover, VR interventions have been shown to reduce pain perception and anxiety during rehabilitation, especially in the early stages post-surgery. The summary of the same are provided below:

Table 4:

1	Effects of inclusion of proprioception training in the recovery of adults submitted to ACLR surgery	Da Silva Costa, WD Guilherme, VR Rinaldi et.al	2019	A Systematic Review	Studies lasting 2–12 weeks showed positive effects on stability, balance, functionality, and strength, but no significant improvements in the control group regarding adjustment. Effects varied by duration.
2	Applications VR in Practice Teaching of Sports Rehabilitation Major	Fang M, You F & Yao R	2021	Survey	Total participants=40 Score before the experiment=71.26 Score after the experiment=79.92
3	Current perspectives and clinical practice of physiotherapists on assessment, rehabilitation and return to sport criteria after ACL injury and reconstruction. An online survey of 538 physiotherapists	Korakakis V, Kotsifaki A, Korakaki A et.al	2021	Online Survey	Of 538 participants, 58.7% returned to sports within 6–9 months. Limb symmetry index revealed significant variations in strength and lower limb function in 74.1%.
4.	Influence of VR Games on Knee Proprioception after ACLR.	Ahmed M, Amin W, Ayoub A et.al	2020	Randomized Controlled Trial	Among 100 participants, Groups A and B showed positive improvements in pre- and post-tests.

DISCUSSION

Post-ACLR rehabilitation has evolved, with protocols varying in exercise type, duration, and intensity. While traditional methods emphasize strengthening, range of motion, and gait training, studies show Nintendo Wii-based rehabilitation achieves similar functional outcomes and knee motion improvements [6]. Wii programs can serve as effective alternatives to conventional therapy, though larger studies are needed. Traditional approaches often lack neuroplasticity promotion, sensory stimulation, and motor learning, which VR-based rehabilitation can address. VR programs, tailored to injury severity and difficulty levels, enhance patient satisfaction and target outcomes like motor skills, balance, strength, pain relief, mental health, and endurance, offering innovative rehabilitation possibilities [20]. The interactive and immersive nature of VR appears to enhance patient engagement, which is crucial for adherence and optimal rehabilitation outcomes. Improved functional parameters such as range of motion, muscle strength, and proprioception suggest that VR can positively influence neuromuscular recovery.

CONCLUSION

VR technology holds great potential for enhancing rehabilitation, particularly for knee surgeries like ACLR. Studies highlight VR's benefits in improving functional outcomes, adherence, and motivation. Its applications extend to musculoskeletal and neurological conditions, aiding motor recovery, upper extremity function, and balance, especially in stroke survivors. It offers improved functional outcomes, greater patient engagement, and psychological benefits. Its interactive nature makes rehabilitation more engaging, potentially leading to better adherence and outcomes. As technology advances, VR may become increasingly accessible and integrated into mainstream physiotherapy practices. Despite promising results, challenges remain, including standardizing protocols, managing cyber sickness, and equipment costs. Integrating AI into VR platforms could further personalize rehabilitation. While VR shows promise for neurological and orthopedic rehabilitation, further research and innovation are needed to overcome barriers and fully harness its potential for improved patient outcomes.

Conflict of Interest: Nil

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