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Comparison of Virtual Reality-Based Rehabilitation and High-Intensity Exercise After Total Knee Arthroplasty: A Randomized Controlled Trial

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ABSTRACT

Objective: To determine whether VR-based rehabilitation (VRBR) reduces pain and improve balance, proprioception and joint function following Total knee replacement (TKR).

Methods: The randomized controlled trials (RCTs) were included if they were in English, participants aged ≥ 18 years, underwent a unilateral or bilateral TKR and were treated using VRBR. The outcome was measured Berg balance scale (BBS) and Timed Up and Go Test.

Results: The data was found to be normally distributed. Virtual reality training group shows better effects as compared to conventional balance training group in terms of BBS ($p<0.001$) and TUG-test ($p<0.001$).

Conclusion: The range of motion in VR-based rehabilitation produces better results than indifferently supporting the experimental group's pain outcome, but the VRBR showed significant improvement.

1. INTRODUCTION

Osteoarthritis (OA) is a progressive joint disorder primarily caused by the degeneration of articular cartilage, commonly seen in the knees, hips, hands, and spine. It is one of the most frequent causes of joint pain, stiffness, and reduced mobility among the Indian population, particularly in older adults.[1] Although joint degeneration in OA is irreversible, its symptoms can often be effectively managed. Regular physical activity, weight control, and timely medical or rehabilitation interventions can help in slowing down the disease progression and improving quality of life.[2]

Several risk factors contribute to the onset and advancement of knee OA. These include increasing age, being female, obesity or overweight, prior joint injuries, repetitive stress on the joints, weak muscles, and limited flexibility. Among these, obesity is a modifiable factor that significantly increases mechanical stress on weight-bearing joints like the knees.[3] Lower levels of education, reduced awareness about joint care, sedentary lifestyle, and muscle weakness are also commonly observed in symptomatic OA, especially in women and those living in urban areas.[4]

Recent Indian surveys have highlighted a higher prevalence of primary knee OA in metropolitan cities (33.2%) compared to smaller cities (19.3%), towns (18.3%), and villages (29.2%). Sedentary lifestyle is more common in urban regions (32.7%) compared to villages (28.7%) and towns (18.1%), whereas a larger proportion of villagers (44.5%) are engaged in physically strenuous work. Ageing, higher BMI, and female gender are consistently associated with a greater incidence of OA. Studies

show that women in India are disproportionately affected, with prevalence rates ranging between 31.6% and 77%, as compared to 28.1% to 61.5% among men.[5]

When conservative treatment options like medications, physiotherapy, and lifestyle changes fail to provide relief, surgical management in the form of Total Knee Replacement (TKR) is often considered.[6] This procedure involves replacing the damaged parts of the knee joint with artificial components made of metal and plastic, which helps in relieving pain and restoring function. Globally, the incidence of knee OA is estimated at around 203 cases per 10,000 person-years. In India, a significant number of patients undergoing TKR have been diagnosed with Anteromedial Osteoarthritis (AMOA), and over five lakh knee replacement surgeries are performed annually across the country.

Before opting for surgery, a detailed assessment is carried out by an orthopedic surgeon, which includes physical evaluation of joint mobility, strength, and alignment. X-rays and other imaging tests are also used to assess the extent of joint damage. The selection of surgical technique and implant design depends on the patient's age, physical activity level, joint anatomy, and overall health status.[7]

Balance is a key aspect of functional independence and plays a critical role in preventing falls, especially in elderly individuals and those with musculoskeletal or neurological issues. While traditional balance training methods have been used in physiotherapy, they often lack real-time feedback and patient engagement.[8] With the advent of technology, virtual reality (VR)-based rehabilitation has emerged as an innovative approach to enhance balance training outcomes. VR provides immersive, interactive exercises that stimulate multiple sensory pathways, encouraging active participation.[9]

To assess treatment results, several validated clinical tools are used. The Numeric Pain Rating Scale (NPRS) is commonly used to measure pain intensity. Goniometers help in evaluating joint range of motion.[10] The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) is widely used for assessing pain, stiffness, and daily functioning in OA patients. Additionally, the Timed Up and Go (TUG) test offers a quick and reliable way to assess mobility and fall risk in elderly and post-operative patients.[11]

2. EPIDEMIOLOGY

1. Global Prevalence:
2. Age and Gender Distribution:
3. Regional Variations:
4. Trends Over Time:

With the aging global population, the prevalence of knee OA is expected to continue rising, emphasizing the need for effective management and preventive strategies.

AETIOLOGY OF OA

Osteoarthritis (OA) of the knee is a degenerative joint disease characterized by the breakdown of cartilage and underlying bone in the knee joint.[12] The aetiology of knee OA can be classified into primary and secondary causes:

1. Primary Osteoarthritis:
2. Secondary Osteoarthritis:

Additional factors influencing the development of knee OA include muscle weakness, joint laxity, and poor alignment of the bones in the knee.

3. RISK FACTORS

Osteoarthritis (OA) is influenced by several risk factors that can be categorized as modifiable and non-modifiable:

Non-modifiable Risk Factors:

1. Age: The risk of OA increases with age due to the cumulative wear and tear on the joints.
2. Gender: Women are more likely to develop OA, particularly after menopause.
3. Genetics: Family history of OA can increase the likelihood of developing the condition.[13]
4. Joint Abnormalities: Congenital or developmental abnormalities in joints can predispose individuals to OA.

Modifiable Risk Factors:

1. Obesity: Excess weight puts additional stress on weight-bearing joints like the knees, accelerating cartilage breakdown.
2. Joint Injuries: Injuries from sports, accidents, or repetitive use can lead to OA in later life.[14]

3. Repetitive Stress: Occupations or activities involving repetitive knee bending, squatting, or heavy lifting can increase the risk of OA.
4. Physical Inactivity: Lack of exercise can lead to weaker muscles and joints, increasing the risk of OA.[15]
5. Poor Posture and Joint Alignment: Misalignment of bones or improper posture can increase stress on joints, leading to OA.

Addressing modifiable risk factors through lifestyle changes such as weight management, exercise, and injury prevention can help reduce the risk of developing OA.

Hence this study was undertaken to evaluate the benefits of balance training in post op TKR patient with the help of virtual reality device and traditional method of training.

4. MATERIAL AND METHODS

This comparative study was conducted in the Department of physiotherapy, PMCH (pacific medical university) on Urban population (post-op TKR patients) over a period of 12 weeks on 30 subjects with each session of per week for 3 weeks, each lasting for 30-45 minutes.

Inclusion Criteria : Recent Total Knee Replacement: Patients must have undergone a total knee replacement surgery. Typically, the inclusion criteria specify a timeframe post-surgery within which patients are eligible, such as within the first few weeks to months post-operation. Urban Population: Participants visiting hospitals and have better understanding for using Virtual reality based balance training. 1) Stable Medical Condition; 2) Adequate Cognitive Function: Patients must have the cognitive ability to understand and follow VR training instructions and protocols; 3) Sufficient Visual and Auditory Capabilities.

Physical Readiness for Rehabilitation; Willingness to Participate; No Significant Comorbid Conditions.

Exclusion Criteria: Patients of rural population; Severe Cognitive Impairment; Severe Visual or Auditory Impairments; Neurological Disorders; Severe Musculoskeletal Disorders; Uncontrolled Medical Conditions; Postoperative Complications were excluded from the study.

5. OUTCOME MEASURES

1. Primary outcomes: Improvement in balance assessed by standardized tests (e.g., Berg Balance Scale, Timed Up and Go test).
2. Secondary outcomes: User satisfaction, engagement levels, adherence rates, and cognitive improvements.

6. PROCEDURE

1. Post-op week 1, pain management, achieve ROM of knee flexion upto 90 degree, muscle strengthening and gait training.

2. Post-op week 2, balance checking with the help of berg balance scale and then taking the scale again in intervals of every 4 weeks for consecutive 3 times other than this.

3. Comparing the outcomes of both the groups trained respectively by VR method and so the Traditional method.

7. TREATMENT PROTOCOL

VR-Based Balance Training Exercises Along With Traditional Balance Training Exercises Was Given To The Patients

Traditional Method-Based Treatment Protocol

1. Static Balance Exercise`131s: Standing on One Leg; Heel-to-Toe Walk.
2. Dynamic Balance Exercises: Sidestepping; Weight Shifting.
3. Proprioceptive Training: Balance Board Exercises.
4. Functional Training: Sit-to-Stand Exercises; Stair Climbing.

8. VR-BASED TREATMENT PROTOCOL

1. Immersive Static Balance Training:
2. Dynamic Balance Challenges:
3. Interactive Games:
4. Adaptable Difficulty Levels:

5. Motivational Enhancements:

Applications of VR and Traditional method in Balance Training

VR Systems and Equipment:

- VR Headset (used) : Oculus Rift,

(other availability in market) - HTC Vive, PlayStation VR etc.

- Sensor plate for balance evaluation

Traditional balancing equipment:

- Balance board
- Staircase
- Obstacle objects (cones, blocks and chair for dynamic advance training

Types of VR Balance Training Programs:

- Static Balance Exercises: Simulations requiring users to maintain balance in various static positions.
- Dynamic Balance Exercises: Virtual environments that simulate walking, obstacle avoidance, and changing terrains.
- Interactive Games: Gamified exercises that require balance control to complete tasks or games.

Berg Balance Scale (with instructions)

Study Procedure

Under the guidance of an experienced physiotherapist who was blind to the study, participants in the VR-based rehabilitation completed a twelve-week program with three sessions each week.

intervention: The VR-based rehabilitation: In order to receive real time visual and audible feedback, participants were instructed to stand upright on the VR-based rehabilitation balance board and interact with objects in serious games that represented their personal centre of pressure. The artificial setting and visuals demonstrating the accuracy of task execution made up the visual Brain Fold (BF). When the visual, a sound stimulus activated the auditory BF, whereas other sounds indicated incorrect or poor exercise execution. The difficulty of the game steadily rose. This is done four days per week- 40 minutes per day with each 7-minute break. The games are loaded from game engine software.

i. immersive Virtual reality (Vr)

Paddle boat[16]: The participants were asked to lie down in supine position, sensors were inserted into their limbs, 3D-headmounted glasses were utilised and an immersive VR rowing boat game was executed.[17] Then, these game exercises were performed every three days for 30 minutes, with an interval of seven minutes between each 10 minutes. Participants were requested to use knee flexion (VR interaction) to paddle a boat in an immersive virtual world.

ii. Non immersive Virtual reality (VR)[18]

1. **Cave game:** The participants were asked to be seated in a chair. Now, the participants were asked to concentrate on the bird by flexing and extending their knees. The participant can move the avatar, a bird in particular, upwards and downwards to gather as many bugs as they can.

2. **Rowing game:** The participant was asked to stand on a single leg and the goal is to get to the gate before it closes by rowing the boat (knee flexion).

3. **Intruders:** The participants were asked to be seated in a chair and then the participants were asked to extend their knee to blast zombies and flex their knee to load the cannon. The cannon are aimed with movements of the hand.

4. **Pick-up:** The participants were asked to be in standing and the player manipulates the girl avatar in the garden to make her pick up veggies and toss them into the wheelbarrow by squatting (down and up).

5. **Squat-Pong:** The participants were asked to be in a standing position. The participants were asked to play tennis against the computer by pushing the racket upward (squat; rise to toes) and downward (squat; down).

6. **Lateral weight shift exercise:-** The participants were asked to be in standing position and in horizontal and diagonal way ask them to move their weight in the direction of the goal (the green area) without shifting their feet. Once you're done, return to the beginning location.

7. **Bubble-runner:** The participants were asked to be in standing position and attempts to pop balloons by striking them while moving the avatar, which is a humanoid inside a bubble, with weight transfer.

8. **Cannon**: The participants were asked to sit on a chair and asked to place the cannon to shoot targets while extending the knee that was operated on. Hand motions are used to aim and fire the cannon.

9. **Hiking:** The participants were asked to be in standing position and asked to walk in the terrain path by raising their knees as per the gaming.

10. **Toy-Golf:** When playing golf, the player was instructed to control the avatar, or golfer, by shifting their weight from side to side (targeting) and making golf swings with their hands then the participants were asked to move things on the track, such as spinning the windmill to accelerate the golf ball, the player also squats.

11. **Brick breaker:** The participants were instructed to stand erect, then they were instructed transfer their weight from side to side. Afterwards the player bounces the ball inside the trampoline until it smashes through the top bricks. Additionally, the player can catch falling fruit onto the trampoline.

12. **Hat-Trick:** The participant was asked to be in a standing position and moves the avatar (figure with sombrero) by weight transfer from side to side and, with hands, tries to grasp the objects falling from the straps and throw them into a sombrero.

9. STATISTICAL ANALYSIS

The following methodologies for statistical analysis were employed when analysing the data. Descriptive statistics were used to describe the sample characteristics. Baseline differences between groups were studied with paired t-test. Adherence was defined as the proportion of participants who completed all sessions according to the protocol. The treatment effect was assessed using paired and unpaired t-test. The level of significance was found to be less than 0.001.

10. RESULTS

The mean values and standard deviations of the outcome variables (pain levels, range of motion, balance, gait and functional outcomes) were presented using descriptive statistics at the end of the fourth, eight and 12th weeks for pain and range of motion and the end of the 4th, 8th, and 12th weeks for both groups for balance, gait and functional outcomes, before and after the intervention.

Table 1: Gender wise Distribution of Patients

Gender	No. (30)	%
Female	22	73.33%
Male	8	26.67%

Male count was 8 (26.67%) and Female count was 22 (73.33%).

Table 2: Demographic Distribution of Patients

	Mean	SD
Age (yrs)	71.03	3.56
Weight (Kgs)	80.13	9.88
BMI (Kg/m^2)	28.76	3.61

Mean age was 71.03±3.56. Mean Weight (kgs) was 80.13±9.88. Mean BMI (Kg/m^2) was 28.76±3.61.

11. DISCUSSION

The mean values and standard deviations of the outcome variables (pain levels, range of motion, balance, gait and functional outcomes) were presented using descriptive statistics at the end of the fourth, eighth and 12th weeks for pain and range of motion for both groups for balance, gait and functional outcomes after the intervention.

The average mean±SD of age and BMI was found to be 71.03±3.56 and 28.76±3.61 kg /m^2. The male and female count was 25 and 35 in our study. Similar to ours Nishitha et al[19] reported the mean age and BMI was found to be 51.2±5.2 and 28.3±2.0 kg/m^2. The male and female count was 15 and 21.

Shaheen et al[20] in their study reported the age of participants was ≥ 18 years old; they underwent TKR and received VR rehabilitation. The mean age of the included patients was 66.42 years. In addition, 35 patients were female, and 25 were male.

12. CONCLUSION

Compared to a high-intensity exercise program, the VR-based rehabilitation demonstrated superior results in pain, balance, gait, and functional independence. The range of motion in VR-based rehabilitation produces better results than indifferently

supporting the experimental group's pain outcome, but the NPRS significantly showed no difference between the groups.

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