Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 14, Issue 26s (2025)
https://www.jneonatalsurg.com
OPEN ACCESS

Effectiveness of Virtual Reality-Based Balance Training Following Total Knee Replacement: A Review of Randomized Trials

Saloni S. Parekh[1], Dr. Jafar Khan[2], Dr. Renuka Pal[3], Dr. Deepak Sharma[4], Dr. K.M. Annamalai[5], Dr. Deepak Lohar[6], Dr. Abid R Qureshi[7], Dr. Preksha Jain[8], Dr. Vaishnavi Kania[9], Dr. Suhani Bhatnagar[10]

[1]MPT Scholar, Pacific College of Physiotherapy, Pacific Medical University, Udaipur, Rajasthan, India
[2]Dean and HOD, Pacific College of Physiotherapy, Pacific Medical University, Rajasthan, India
[3]Associate Professor, Pacific College of Physiotherapy, Pacific Medical University, Udaipur, Rajasthan, India
[4]Consultant Senior Physiotherapist, Saint Terrasa Hospital, Udaipur, Rajasthan, India
[5]Consultant Senior Physiotherapist & Director Physio Alliance Apollo Hospital, Ahmedabad, Gujarat, India
[6]Associate Professor, Pacific college of Physiotherapy, Pacific medical university, Udaipur, Rajasthan
[7]Assistant Professor, Pacific college of Physiotherapy, Pacific medical university, Udaipur, Rajasthan
[8]Assistant Professor, Pacific college of Physiotherapy, Pacific medical university, Udaipur, Rajasthan
[9]Assistant Professor, Pacific college of Physiotherapy, Pacific medical university, Udaipur, Rajasthan
[10]Assistant Professor, Pacific college of Physiotherapy, Pacific medical university, Udaipur, Rajasthan

***Corresponding Author:**
Saloni S. Parekh
Email ID: drsaloniparekh@gmail.com

Cite this paper as: Saloni S. Parekh, Dr. Jafar Khan, Dr. Renuka Pal, Dr. Deepak Sharma, Dr. K.M. Annamalai, Dr. Deepak Lohar, Dr. Abid R Qureshi, Dr. Preksha Jain, Dr. Vaishnavi Kania, Dr. Suhani Bhatnagar, (2025) Effectiveness of Virtual Reality-Based Balance Training Following Total Knee Replacement: A Review of Randomized Trials. *Journal of Neonatal Surgery*, 14 (26s), 1215-1221.

ABSTRACT

Background: According to recent Indian surveys, the prevalence of primary knee OA is high. A higher incidence of OA is consistently linked to female gender, age, and a higher BMI. Total Knee Replacement (TKR) is a common surgical option when conservative treatment options such as medication, physical therapy, and lifestyle modifications are ineffective. TKR alongwith physiotherapy is required for faster healing in such patients. Here we are comparing the effect of Virtual Reality (VR)- based rehabilitation and high-intensity exercise program for Total Knee Arthroplasty (TKA).

Methods: In this randomised controlled trial, 60 participants matched the inclusion criteria who underwent Total Knee Replacement (TKR). The study was conducted for a period of 12 months from June 2024 to May 2025. The participants were randomly allotted to VR group (n=30) and a conventional group-high-intensity exercises (n=30). Outcome measures used are the Numeric Pain Rating Scale (NPRS) pain scale, knee range of motion, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and Timed Up and Go (TUG) test.

Result: There were significant changes in within-group differences between the experimental group and the conventional group. The range of mobility demonstrated superior results in VR-based rehabilitation compared to indifferently supporting the experimental group's pain outcome ($p \geq 0.0001$), however the numerical Pain Rating Scale substantially showed no differences between the groups. The experimental group outperformed the conventional group in terms of balance, gait, and functional activities, and the patient's functional independence was attained in nine weeks with VR-based rehabilitation as opposed to high-intensity (HI) exercises.

Conclusion: The VR-based rehabilitation showed better outcomes in pain, range of motion, balance, gait and functional independence than a high-intensity exercise programme.

1. INTRODUCTION

The degeneration of articular cartilage is the main cause of osteoarthritis (OA), a progressive joint disease that is frequently observed in the hands, knees, hips, and spine. Among Indians, especially older adults, it is one of the most common causes of joint pain, stiffness, and decreased mobility.[1] Even though OA causes irreversible joint degeneration, its symptoms are frequently effectively controlled. Frequent exercise, weight management, and prompt medical or rehabilitation care can all help to improve quality of life and slow the progression of disease.[2]

The development and progression of knee OA are influenced by a number of risk factors. These include getting older, being a woman, being overweight or obese, having had joint injuries in the past, having weak muscles, and having limited flexibility. One of these that can be changed is obesity, which raises the mechanical stress on weight-bearing joints like the knees considerably.[3] Symptomatic OA is also frequently associated with lower levels of education, a sedentary lifestyle, a lack of knowledge about joint care, and muscle weakness, particularly in women and urban dwellers.[4]

According to recent Indian surveys, the prevalence of primary knee OA is higher in metropolitan areas (33.2%) than in towns (18.3%), villages (29.2%), and smaller cities (19.3%). While a higher percentage of villagers (44.5%) work in physically demanding jobs, urban areas have a more sedentary lifestyle (32.7%) than villages (28.7%) and towns (18.1%).[5] A higher incidence of OA is consistently linked to female gender, age, and a higher BMI. Research indicates that prevalence rates among women in India range from 31.6% to 77%, while those among men range from 28.1% to 61.5%.[6]

Total Knee Replacement (TKR) is a common surgical option when conservative treatment options such as medication, physical therapy, and lifestyle modifications are ineffective.[7] In order to relieve pain and restore function, this procedure entails replacing the damaged knee joint components with artificial ones made of plastic and metal. An estimated 203 cases of knee OA are reported for every 10,000 person-years worldwide. Over five lakh knee replacement surgeries are carried out annually throughout India, where a sizable portion of patients undergoing TKR have been diagnosed with Anteromedial Osteoarthritis (AMOA).[8]

An orthopedic surgeon performs a comprehensive evaluation, including a physical assessment of joint alignment, strength, and mobility, prior to deciding to perform surgery. The degree of joint damage is also evaluated using X-rays and other imaging procedures. The patient's age, degree of physical activity, joint anatomy, and general health status all influence the choice of surgical method and implant design.[9]

A vital component of functional independence, balance is also essential for preventing falls, particularly in older people and those with neurological or musculoskeletal conditions. Traditional balance training techniques have been employed in physical therapy, but they frequently don't involve patients or provide real-time feedback.[10] As technology has advanced, virtual reality (VR)-based rehabilitation has become a cutting-edge strategy to improve the results of balance training. Virtual reality (VR) offers engaging, interactive activities that activate various senses and promote involvement.[11]

Patients with neurological disorders have shown encouraging improvements in both static and dynamic balance in recent years thanks to virtual reality. In one study, motor-cognitive training with the Nintendo Wii system and balance-focused exercises produced observable improvements that persisted through follow-up evaluations. Additionally, it has been discovered that high-intensity rehabilitation protocols are more successful in enhancing results following TKR.[12]

A number of validated clinical tools are used to evaluate treatment outcomes. A popular tool for assessing pain intensity is the Numeric Pain Rating Scale (NPRS). Joint range of motion can be assessed with the use of goniometers. One popular tool for evaluating pain, stiffness, and everyday functioning in OA patients is the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC). Furthermore, the Timed Up and Go (TUG) test provides a rapid and accurate method of evaluating post-operative and elderly patients' mobility and fall risk.[13]

Therefore, this study was conducted to assess the advantages of balance training in post-operative TKR patients using a virtual reality device and conventional training techniques.

2. 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 60 subjects (30 group A and 30 group B) 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.

3. 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.

4. 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.

5. TREATMENT PROTOCOL

Patients were divided in two groups- Group A : Traditional balance training exercises. Group B : VR-based balance training exercises.

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.

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[14]: 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.[15] 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)[16]

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.

6. 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.

7. 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.

Mean age in Group A was 67.70±5.05 and in Group B was 71.03±3.56. Mean Weight (kgs) in Group A was 80.50±6.76 and in Group B was 80.13±9.88. Mean BMI (Kg/m^2) in Group A was 23.80±2.55 and in Group B was 28.76±3.61.

Table 1: Comparison of VAS Between Groups at Different Time Intervals

	Group A		**Group B**		
	Mean	**SD**	**Mean**	**SD**	**P value**
Pretreatment	8.07	0.78	8.49	0.87	0.06 (NS)
Post Treatment after 4 wks	6.03	0.76	7.01	0.71	<0.001 (HS)
Post Treatment after 8 wks	4.03	0.76	5.21	0.68	<0.001 (HS)
Post Treatment after 12 wks	2.37	0.67	4.39	0.82	<0.001 (HS)

At pretreatment level Group A and Group B had similar VAS ($p > 0.05$). But after 4 weeks of treatment the BBS in Group A increased significantly than Group B, which kept on increasing significantly after 8 & 12 weeks of treatment (4.03±5.21 & 2.37±4.39) in Group A & Group B respectively. This shows that treatment with VR gives much better results than correctional treatment.

At pretreatment (28.20 v/s 26.62) and 4 weeks after treatment (24.20 v/s 24.18) TUG level were almost similar ($p > 0.05$) in both Groups. After 8 (18.17 v/s 22.17) weeks & 12 weeks (14.17 v/s 20.20) of treatment TUG score in Group A significantly decreased than Group B. ($p < 0.001$), showing improvement om Group A (VR) Patients.

Fig. 1: Comparison of TUG Between Groups at Different Time Intervals

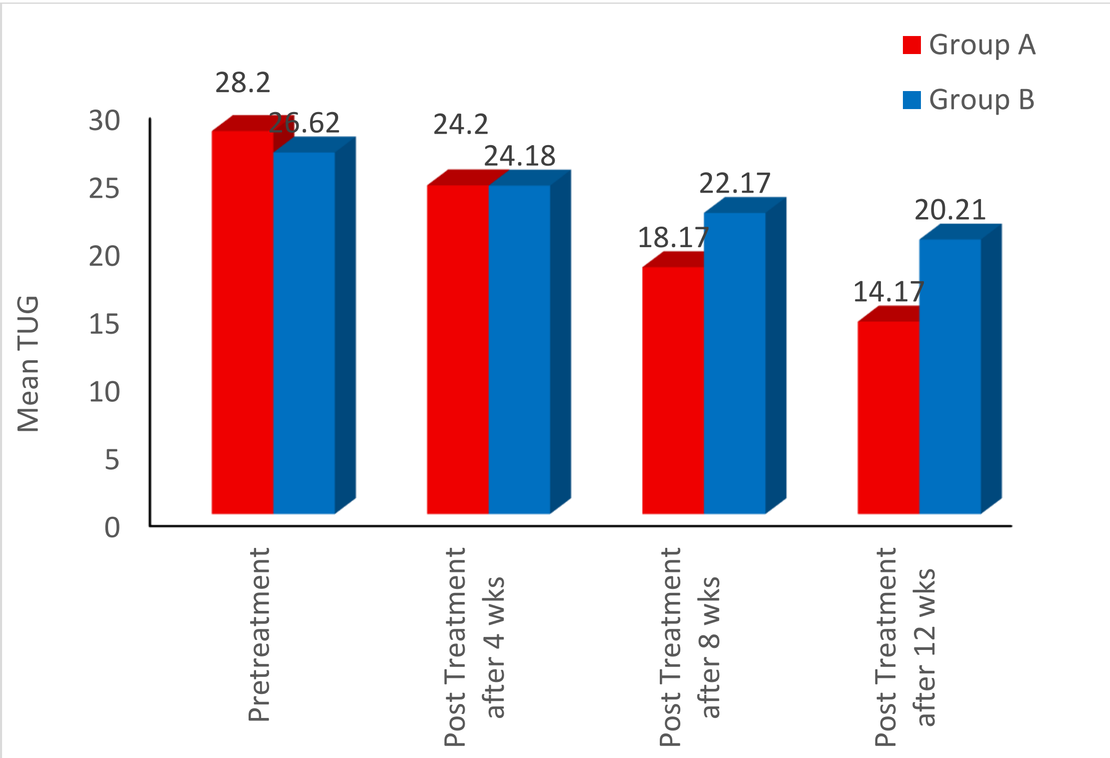

Table 2: Comparison of BBS Between Groups at Different Time Intervals

	Group A		Group B		
	Mean	**SD**	**Mean**	**SD**	**P value**
Pretreatment	13.50	2.18	14.35	3.08	0.22 (NS)
Post Treatment after 4 wks	22.50	3.47	19.50	3.34	<0.001 (HS)
Post Treatment after 8 wks	35.03	3.36	25.03	4.16	<0.001 (HS)
Post Treatment after 12 wks	49.63	4.08	29.63	4.37	<0.001 (HS)

At pretreatment level Group A and Group B had similar BBS ($p > 0.05$). But after 4 weeks of treatment the BBS in Group A increased significantly than Group B, which kept on increasing significantly after 8 & 12 weeks of treatment (35.03 v/s 25.03 & 49.63 v/s 29.63) in Group A & Group B respectively. This shows that treatment with VR gives much better results than correctional treatment.

8. 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 68.20±15.84 and 26.30±4.61 kg/m^2. The male and female count was 25 and 35 in our study. Similar to ours Nishitha et al[17] 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[18] 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.

The Control & VR group pretest values of VAS mean were 8.07 & 8.49 and the post-test values were 6.03 and 7.01 at the end of the 4th week, 4.03 & 5.21 and of the 8th weeks.

According to Nishitha et al[17] in the VR group pretest values of VAS mean were 8.56 and 12.56 and the post-test values were 3.39 and 62.28 at the end of the 2nd week, 2.50 and 81.28 at the end of the 4th week and 1.47 and 105 at the end of the 12th week.

Iwata states that there was no discernible change in gait speed at three weeks following TKI, but it was considerably lower at one and two weeks following the procedure but, here continuous TUG training using the exercise and VR-intervention maintains the activity strength of muscle and it was not measured after the period of rehabilitation. About half of the patients showed improvements above their preoperative scores (TUG, 55%) and gait speed, 50%. According to the research, a potential benchmark for monitoring the early stages of postoperative recovery following TKA could be reaching preoperative mobility within three weeks.

Here in the present study, it shows that the VR-based rehabilitation is superior to the high-intensity exercise program, which shows that there is a significant difference between the VR-based rehabilitation and the high-intensity exercise program. The p-value of <0.0001 indicates that there is a statistically significant difference between the groups and shows that there is rejection of the null hypothesis (H0). This states that the acceptance of alternate hypothesis (H1) and the null hypothesis has been rejected.

In Sanaz et al[19] study Group A and Group B improved in dynamic balance and functional mobility, as measured by the TUG ($p<0.0001$), but with no difference between the groups ($p = 0.235$). Results for maximum walking speed (10mWT), pain (VAS), lower-limb muscular strength (MRC scale), and disability (mBI) showed significant within-group differences ($p<0.0001$) but not between-group differences ($p>0.05$).

9. CONCLUSION

Compared to a high-intensity exercise program, the VR-based rehabilitation demonstrated superior results in pain, balance, gait, and functional independence.

REFERENCES

[1] Reid CR, Bush PM, Cummings NH, McMullin DL, Durrani SK. A review of occupational knee disorders. J Occup Rehabil. 2010;20(4):489-501.

[2] Wang Y, Chu M, Rong J, Xing B, Zhu L, Zhao Y, et al. No association of the single nucleotide polymorphism rs8044769 in the fat mass and obesity-associated gene with knee osteoarthritis risk and body mass index: A population-based study in China. Bone & Joint Research. 2016;5(5):169-74.

[3] Yadav R, Verma AK, Uppal A, Chahar HS, Patel J, Pal CP. Prevalence of primary knee osteoarthritis in the urban and rural population in India. Indian Journal of Rheumatology. 2022;17(3):239-43.

[4] Thati S. Gender differences in osteoarthritis of knee: An Indian perspective. Journal of Mid-life Health. 2021;12(1):16-20.

[5] Cui A, Li H, Wang D, Zhong J, Chen Y, Lu H. Global, regional prevalence, incidence and risk factors of knee osteoarthritis in population-based studies. E Clinical Medicine. 2020;29-30:100587.

[6] Holden MK, Dyar T. Virtual environment training-a new tool for neurorehabilitation? Neurol Report 2002;26(2):62-71.

[7] Adamovich SV, Fluet GG, Tunik E, Merians AS. Sensorimotor training in virtual reality: a review. Neuro Rehabilitation 2009;25(1):29-44.

[8] Esculier JF, Vaudrin J, Beriault P, Gagnon K, Tremblay LE. Home-based balance training programme using Wii Fit with balance board for Parkinson's disease: a pilot study. Journal of Rehabilitation Medicine. 2012;44(2):144-50.

[9] Bade MJ, Struessel T, Dayton M, Foran J, Kim RH, Miner T, et al. Early highintensity versus low-intensity rehabilitation after total knee arthroplasty: A randomised controlled trial. Arthritis Care & Research. 2017;69(9):1360-68.

[10] Stratford PW, Kennedy DM, Woodhouse LJ, Spadoni GF. Measurement properties of the WOMAC LK 3.1 pain scale. Osteoarthritis and Cartilage. 2007;15(3):266-72.

[11] Yu J-H, Nekar DM, Kang H-Y, Lee J-W, Oh S-Y. Comparison of Physical Activity Training Using Augmented Reality and Conventional Therapy on Physical Performance following a Total Knee Replacement: A Randomized Controlled Trial. Appl Sci. 2023;13:894.

[12] Bini S, Mahajan J. Clinical outcomes of remote asynchronous telerehabilitation are equivalent to traditional therapy following total knee arthroplasty: a randomized control study. J Telemed Telecare. 2017;23:239–47.

[13] Bellamy N, Buchanan WW, Goldsmith CH, Campbell J, Stitt LW. Validation study of WOMAC: A health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of [37] the hip or knee. J Rheumatol. 1988;15:1833-40.

[14] Shahrbanian S, Ma X, Aghaei N, Korner-Bitensky N, Moshiri K, Simmonds MJ. Use of virtual reality (immersive vs. non immersive) for pain management in children and adults: A systematic review of evidence from randomised controlled trials. Eur J Exp Biol. 2012;2(5):1408-22.

[15] Huang Q, Lin J, Han R, Peng C, Huang A. Using virtual reality exposure therapy in pain management: A systematic review and meta-analysis of randomised controlled trials. Value in Health. 2022;25(2):288-301.

[16] Garcia-Sanchez M, Garcia-Robles P, Osuna-Perez MC, Lomas-Vega R, Obrero Gaitan E, Cortes-Perez I. Effectiveness of virtual reality-based early postoperative rehabilitation after total knee arthroplasty: A systematic review with meta-analysis of randomised controlled trials. Applied Sciences. 2023;13(7):4597.

[17] Nishitha K, Anitha A, Thaheera D. Effectiveness of Virtual Reality-based Rehabilitation and High-intensity Exercise Program for Total Knee Arthroplasty Patients: A Randomised Controlled Trial. Journal of Clinical & Diagnostic Research. 2024 Nov 1;18(11).

[18] Shaheen AA, Algabbani MF, Alshahrani MM, Alshahrani FA, Alsobayel HI, Omar MT, et al. Efficacy of virtual reality-based rehabilitation following total knee replacement: a systematic review and meta-analysis of randomized control trials. Bulletin of Faculty of Physical Therapy. 2025 Mar 5;30(1):15.

[19] Pournajaf S, Goffredo M, Pellicciari L, Piscitelli D, Criscuolo S, Le Pera D, Damiani C, Franceschini M. Effect of balance training using virtual reality-based serious games in individuals with total knee replacement: A randomized controlled trial. Annals of physical and rehabilitation medicine. 2022 Nov 1;65(6):101609.