

Role of Virtual Rehabilitation in Total Knee Arthroplasty: Functional Outcomes and Cost-Effectiveness

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ABSTRACT

This review article aims to explore the role of virtual rehabilitation in total knee arthroplasty in terms of functional outcomes and cost-effectiveness. Total knee arthroplasty (TKA) is a widely performed surgery for end-stage knee osteoarthritis, requiring supervised rehabilitation for rapid recovery and pain relief. Virtual rehabilitation has been evolving as an alternative to the traditional rehabilitation program in the recent years especially during the predicament of COVID-19 pandemic.

Virtual rehabilitation leverages virtual reality (VR) technology to provide innovative, engaging, and measurable rehabilitation services that can complement or replace traditional therapy approaches. Virtual reality and telerehabilitation represent evolving fields in TKA rehabilitation, offering advantages over traditional therapy in terms of cost-effectiveness, improved outcomes, enhanced exercise adherence, and reduced barriers to accessing postoperative therapy. Despite the need for more research and standardized protocols, VR-based rehabilitation holds significant potential for optimizing the recovery process for patients undergoing TKA. The research indicates that VR-based rehabilitation programs for TKA patients have utilized a variety of interactive virtual environments, gaming activities, and feedback

mechanisms to supplement traditional physical therapy exercises.

Virtual rehabilitation for TKA encourages clinician-patient interaction beyond the hospital setting and offers the advantages of cost savings, convenience, at-home monitoring, and coordination of care, improved functional outcomes, increased exercise adherence, better balance performance, and psychological benefits like reduced stress and anxiety, all of which are geared to improve adherence and overall patient satisfaction.

This review article outlines the importance of virtual rehabilitation in TKA, emphasizing cost-effectiveness and improved balance and function while maintaining enhanced adherence and exercise performance. This article also delves into the mode of administration of VR-based rehabilitation and its delivery, safety concerns, advantages and disadvantages, as well as the most common VR-based rehabilitation protocols for TKA. Further, it discusses the implications of virtual rehabilitation in the healthcare system and future directions for virtual rehabilitation in TKA.

In conclusion, the evidence indicates that virtual physical therapy (PT) with remote clinical oversight is a safe, effective, and more cost-effective alternative to traditional in-person PT for patients undergoing TKA.

Keywords: Virtual rehabilitation, virtual physical therapy, telehealth, telerehabilitation, total knee arthroplasty.

INTRODUCTION

Total knee arthroplasty (TKA) is a common procedure for individuals with end-stage osteoarthritis. [1] Although significant advancements have been achieved in implant design, surgical techniques, and anesthetic modalities, patient satisfaction and perception of success following TKA are relatively low. [2,3] Although various programs of post-operative rehabilitation exist worldwide, physiotherapy is regarded as an essential component in achieving optimal outcomes following TKA. [4] Post-operative progressive exercise program achieves faster recovery, better function, and improved range of motion (ROM). [5]

Physical rehabilitation is an essential component of TKA recovery, helping to restore function, strength, and range of motion. Tailoring rehabilitation programs to individual patient needs and providing options for supervised or unsupervised therapy can optimize outcomes following total knee replacement. [6,7] Rehabilitation starting immediately after surgery is crucial for a successful recovery.

Virtual rehabilitation refers to the use of virtual reality (VR) applications to support or enhance human health and function. Virtual rehabilitation is also called as VR-based rehabilitation or telerehabilitation. It involves the provision of therapeutic interventions using VR hardware and simulations, either as the sole form of rehabilitation or as an augment to conventional therapy. It utilizes VR technology, including head-mounted displays, motion tracking, and interactive virtual environments, to provide rehabilitation services. [8,9] It can be used for various patient populations, such as those with musculoskeletal, post-stroke, or cognitive impairments. Virtual rehabilitation can be

"VR-based", where the rehabilitation is entirely within the virtual environment, or "VR-augmented", where it is combined with conventional physical therapy. The virtual environments and simulations are designed to be engaging and motivating for patients, while also providing objective outcome measures of therapy effectiveness. [9] Virtual rehabilitation can be delivered remotely as "telerehabilitation", allowing patients to access therapy from their homes and be monitored by clinicians at a distance.

The use of virtual rehabilitation, promoted during the COVID-19 pandemic, facilitates contactless delivery as documented in several studies. [10,11]

Virtual reality and telerehabilitation have emerged as innovative approaches in TKA rehabilitation, offering promising benefits for patients undergoing this procedure. Several studies have highlighted the advantages of VR-based rehabilitation following TKA:

- 1. Cost-Effectiveness:** Virtual physical therapy via telerehabilitation significantly reduced healthcare costs 12 weeks post-discharge, matching traditional physical therapy in outcomes such as Knee Injury and Osteoarthritis Outcome Score (KOOS), knee range of motion, gait speed, pain, and hospital readmissions. This indicates that VR-based rehabilitation can be a cost-effective alternative to traditional therapy. [12]
- 2. Improved Balance and Function:** Studies have shown that VR rehabilitation can lead to improved balance performance, as measured by the Berg Balance Scale and Functional Reach Test, compared to traditional rehabilitation. Additionally, VR rehabilitation has been associated with better early balance ability and knee function in comparison to control groups. [12,13]
- 3. Enhanced Adherence and Exercise Performance:** Patients undergoing VR-

based rehabilitation have demonstrated better adherence to exercise regimens. The interactive and engaging nature of VR technology may contribute to increased exercise compliance, which is crucial for successful postoperative recovery. [12]

4. Reduced Barriers to Accessing Therapy:

VR-based rehabilitation has the potential to reduce barriers to accessing postoperative therapy following TKA. By offering a virtual platform for rehabilitation, patients may have increased access to therapy, especially in situations where in-person sessions are challenging to arrange. [12,14]

Administration of virtual reality-based rehabilitation in TKA

Virtual reality-based rehabilitation works in different ways for patients following TKA. VR-based rehabilitation for TKA patients involves using interactive computer environments or games that simulate real-world experiences to deliver rehabilitation exercises and activities. VR-based rehabilitation has the potential to improve pain, function, and balance compared to traditional rehabilitation following TKA. However, further research is still required because the evidence is currently sparse. [12,13] The VR rehabilitation protocols used in the studies varied, but typically involved patients using VR equipment like headsets, sensors, or interactive applications for 10-60 minutes per day, 2-3 times per week, starting early after surgery. [13,14] The VR exercises and activities are designed to simulate real-world tasks like walking, reaching, or balancing, often with visual feedback and gaming elements to engage patients. [13,14] VR-based rehabilitation may have advantages over traditional therapy by reducing barriers to access, increasing exercise adherence, and potentially reducing healthcare costs. [12] However, the effectiveness of VR-based rehabilitation can be influenced by contextual factors like patient expectations, therapeutic

interaction, and familiarity with new technologies. [14]

Based on the evidences, VR-based rehabilitation is administered for patients following TKA in several varied ways maintaining VR rehabilitation protocols. The VR rehabilitation protocols used in the studies varied, but generally involved patients using VR equipment like headsets, sensors, or interactive applications for 10-60 minutes per day, 2-3 times per week, starting early after surgery. The VR exercises and activities were designed to simulate real-world tasks like walking, reaching, or balancing, often with visual feedback and gaming elements to engage patients. [12,13]

Delivery of Virtual Reality Rehabilitation

VR-based rehabilitation is delivered either as an adjunct to traditional in-person therapy or as the primary mode of rehabilitation. The VR rehabilitation is often supervised by a physical therapist who could access training data and provide guidance through web portals or other remote monitoring. VR-based rehabilitation aimed to provide an engaging, interactive experience that could increase exercise adherence and reduce barriers to accessing rehabilitation compared to traditional therapy. [12,13]

Some common virtual reality rehabilitation setups:

Based on the research studies, the following virtual reality-based rehabilitation programs have been used in patients undergoing TKA. [13]

1. Nintendo Wii Fit gaming activity for 15 minutes.
2. Interactive virtual telerehabilitation kit with wireless sensors, interactive patient application, and web portal for therapist - 1 hour per day.
3. VR equipment to row a boat in an immersive virtual environment for 30 minutes, 3 times per day.

4. Avatar and real-time visual feedback via a Kinect sensor, with therapist access to training frequency and exercise evaluations.
5. VR-based rehabilitation programs for 60 minutes per day.
6. Virtual exercise rehabilitation assistant system (VERA) for exercise.
7. VR glasses and a smartphone-based balance game to reach a target while avoiding obstacles.
8. VR glasses to watch a walking video for 10 minutes before exercises, 2 times per week for 3 weeks.

Virtual Exercise Rehabilitation Assistant [15]

The Virtual Exercise Rehabilitation Assistant (VERA) is a telerehabilitation system that uses animated images on displays to coach and demonstrate physical therapy (PT) protocols to patients at home. The system uses three-dimensional motion tracking cameras to detect real-time movements in the patient. Additionally, in order to inform and assist patients in enhancing their performance, this technology can offer real-time feedback. By using visual cameras to capture recordings of patients completing PT exercises, doctors can keep an eye on their development. Additionally, patients have the option to submit workout results and concerns, such as any pain they may have felt while performing an exercise or movement.

This is made possible via the clinician portal, which gives medical professionals the ability to adjust exercise regimens, conduct functional evaluations, and examine patient-reported results.

A dynamic interface on the clinician's end of the system allows them to virtually interact in real time with patients and create and prescribe therapeutic protocols tailored to each patient. Clinicians can examine and track patient-reported outcome indicators, including scores from the Western Ontario and McMaster

Universities Osteoarthritis Index (WOMAC), using the interface. Furthermore, healthcare providers have the ability to evaluate particular functional assessments including range-of-motion and timed up and down tests, in addition to sit-to-stand tests.

The benefits of this telerehabilitation platform include cost savings, convenience, at-home monitoring, and care coordination, all of which are intended to increase patient satisfaction and adherence. It also promoted clinician-patient engagement outside of the hospital setting. Moreover, the biometric information may be utilized to create personalized physical therapy plans that ensure appropriate recovery, something that other telerehabilitation programs that rely on passive movies that can be seen on tablets and smartphones cannot offer. [15]

The VR-based rehabilitation programs normally last for 3 weeks, with patients using VR for 10-20 minutes per session, 2-3 times per week, in addition to their regular exercise program. The evidence suggests this short-term VR-based rehabilitation is being explored as a supplement to traditional rehabilitation after TKA, but more research is needed to establish the optimal duration and effectiveness. [13,14]

Common virtual reality-based rehabilitation protocols for TKA

Based on the several research evidences, the most common VR-based rehabilitation protocols for TKA include:

1. **Interactive virtual reality games and exercises:** Several studies utilized VR-based interactive games and exercises for rehabilitation following TKA. These involved patients interacting with virtual environments and avatars to perform exercises targeting mobility, strength, function, and balance. [12,13,14]
2. **Telerehabilitation with remote clinician oversight:** Some protocols used telerehabilitation systems that allowed

physical therapists to remotely monitor and guide patients through VR-based rehabilitation sessions at home. This involved features like 3D biometrics, avatar coaches, and video conferencing. [12,16]

- 3. Full immersion VR training:** A few studies used fully immersive VR environments where patients were fully engaged in a VR experience for rehabilitation, often combined with other modalities like continuous passive motion machines. [13,14]
- 4. VR-based rehabilitation with dynamometric platforms:** One study used a VR-based rehabilitation program that incorporated a dynamometric platform to challenge patients' stability, weight-shifting, and range of motion.[13]

The research results indicate that these VR-based protocols were generally found to be as effective as or potentially superior to traditional physical therapy for outcomes like pain, function, and proprioception following TKA, though more high-quality research is still needed. [12,13,14] The use of VR-based rehabilitation also has the potential to increase accessibility and adherence to post-operative therapy. [12,16]

There are several advantages and disadvantages of using virtual rehabilitation in TKA.

Advantages of Virtual Reality in TKA rehabilitation

The key advantages of using virtual reality in rehabilitation following TKA are: [12,17]

VR-based rehabilitation improved functional outcomes compared to traditional rehabilitation. Studies have shown that VR-based rehabilitation led to better functional outcomes at 12 weeks and 6 months postoperatively, as measured by the Knee injury and Osteoarthritis Outcome Score (KOOS).

VR-based rehabilitation increased exercise adherence. Patients undergoing VR-based rehabilitation had significantly better adherence to their exercise program compared to traditional rehabilitation.

VR-based rehabilitation reduced healthcare costs. One study demonstrated significant cost savings with the use of VR-based rehabilitation compared to traditional therapy at 12 weeks after discharge.

VR-based rehabilitation improved balance performance. Several studies found that VR rehabilitation improved balance as measured by the Berg Balance Scale and Functional Reach Test, compared to traditional rehabilitation.

VR-based rehabilitation provided psychological benefits. VR can provide psychological suggestions, distract patients, and reduce the perception of pain, thereby increasing motivation for rehabilitation.

Disadvantages of Virtual Reality in TKA rehabilitation

Based on the research findings, the key disadvantages of using VR in rehabilitation following TKA are: [12,13,14]

- VR-based rehabilitation did not show advantages over traditional rehabilitation in improving pain relief. The studies found no significant differences in pain scores between VR-based and traditional rehabilitation at 2 weeks and 3 months postoperatively.
- VR-based rehabilitation did not improve postural control compared to conventional rehabilitation. The systematic review found that VR-based rehabilitation did not have a significant impact on improving postural control following TKA.
- The quality of evidence in the literature is low. The authors noted that more high-quality randomized controlled trials are needed to conclusively prove the advantages of VR-based rehabilitation over traditional methods.

4. There was a moderate dropout rate in some studies, limiting the generalizability of the findings. Contextual, personal, and motivational factors can affect the efficacy of VR-based rehabilitation.
5. VR-based rehabilitation requires specialized equipment and technology, which may not be readily available or accessible in all rehabilitation settings. This could limit the widespread adoption of VR-based approaches.

Safety measures during virtual rehabilitation following TKA

The systematic review and meta-analysis [12] found that VR-based rehabilitation for patients following TKA was generally safe and effective. The review did not report any major safety concerns with the use of VR-based rehabilitation compared to traditional rehabilitation. [12]

The review [16] discussed the importance of high-intensity (HI) rehabilitation programs following TKA, stating that HI programs are safe for individuals after TKA. The review emphasized the need for progressive rehabilitation protocols to ensure safety. [16]

Overall, the search results indicate that virtual and telerehabilitation approaches following TKA are generally safe when implemented with appropriate safety measures and progressive rehabilitation protocols. The key is to ensure patients are properly monitored and the rehabilitation program is tailored to their individual needs and recovery stage. [12,16]

Some patients may experience discomfort such as dizziness during VR-based rehabilitation following TKA. If any discomforts recurred, the VR treatment should be terminated.

VR-based rehabilitation appears to have some advantages over traditional rehabilitation in terms of functional outcomes and cost-effectiveness following TKA, though the evidence is still limited.

The systematic review and meta-analysis found that VR-based rehabilitation

demonstrated improved functional outcomes at 12 weeks [MD -3.32, 95% CI -5.20 to -1.45, moderate certainty evidence] and 6 months [MD -4.75, 95% CI -6.69 to -2.81, low certainty evidence] postoperatively, compared to traditional rehabilitation.[12]

Virtual physical therapy (PT) after TKA is safe, effective, and significantly lowers healthcare costs compared to traditional in-person PT. The study by Bettger et al. found that in the 12 weeks after TKA, median total costs were \$1,050 for patients assigned to virtual PT, compared to \$2,805 for traditional PT. [18] So, as compared to conventional rehabilitation, virtual PT with telerehabilitation for skilled clinical oversight significantly lowered 3-month health-care costs after TKA while providing similar effectiveness. Patients using the virtual PT system also participated in PT more frequently (5.9 days/week vs 3.3 days/week) and had higher exercise adherence (88% vs 65%) compared to traditional PT. [18] VR-based rehabilitation was non-inferior to traditional physical therapy for outcomes like knee extension, knee flexion, and gait speed at 6 weeks, and non-inferior for pain and hospital readmissions at 12 weeks. [18] Piqueras et al. in 2013 demonstrated that virtual rehabilitation was non-inferior to traditional face -to-face rehabilitation in terms of most outcome variables like active knee flexion and pain relief. [19] A meta-analysis has demonstrated that telerehabilitation results in similar pain relief and functional outcomes when compared to face-to-face rehabilitation. [20]

When compared to in-person therapy, telerehabilitation has proven to be less expensive, especially when travel expenses are taken into account. [21, 22]

Clinical trials using telerehabilitation for TKA patients in Canada have shown comparable clinical results, expenses, and patient satisfaction to traditional physical therapy (PT) without introducing new dangers to the patient. [23-27]

The study conducted by Peng et al. shows that VR-based rehabilitation improved pain and function but not postural control following TKA compared to conventional rehabilitation. [13] Yoon et al. in their study found that VR training produced better early balance ability and knee function and VR training in initial post-operative rehabilitation of total knee replacement patients may increase the rate of recovery. [28]

However, one study concluded that VR-based rehabilitation did not show superior benefits over traditional rehabilitation in terms of pain relief, drug use, and other functional outcomes, though it may improve global proprioception. [14] Another study conducted by Barker et al. [29] revealed that home-based rehabilitation did not confer benefits over standard outpatient physiotherapy.

Research studies have reported that VR-based rehabilitation is more cost-effective than traditional rehabilitation for patients undergoing TKA. [12, 18, 30] The available evidence is still limited, and more research is needed to fully understand the potential cost implications of incorporating VR-based rehabilitation programs into the management of TKA patients. [12]

Limitations of virtual reality-based rehabilitation in TKA

There are some limitations of VR-based rehabilitation in TKA.

- 1. Low quality of evidence:** The systematic reviews and meta-analyses indicate that the current evidence on the effectiveness of VR-based rehabilitation for TKA is of moderate to very low quality. [12,13] The small sample sizes and variability in rehabilitation protocols across studies limit the ability to draw definitive conclusions.
- 2. Inconsistent outcomes:** The research results show mixed findings on the benefits of VR-based rehabilitation compared to traditional rehabilitation. While some studies reported improvements in

functional outcomes and balance, others found no differences in pain relief or satisfaction. [12, 13, 14]

- 3. Lack of standardized protocols:** The VR-based rehabilitation programs utilized varied greatly across studies in terms of the specific VR equipment, duration, and frequency of the interventions. This heterogeneity makes it difficult to determine the optimal VR-based rehabilitation protocol. [12,13]
- 4. Limited long-term data:** The available studies primarily reported short-term outcomes up to 6 months postoperatively. The long-term effects of VR-based rehabilitation on TKA patients remain unclear. [12,13]
- 5. Potential barriers to adoption:** Factors such as patient acceptance, access to VR technology, and integration with traditional rehabilitation programs may limit the widespread adoption of VR-based rehabilitation in the TKA population. [13,14]

Thus, while VR-based rehabilitation shows promise, the current evidence is limited by methodological issues and inconsistent findings. Further high-quality research is needed to establish the optimal VR-based rehabilitation protocols and confirm its long-term benefits for patients undergoing TKA. [12,13]

Implications for TKA rehabilitation and health care systems

Virtual and telerehabilitation approaches following TKA are generally safe and effective when implemented with appropriate safety measures and progressive rehabilitation protocols. [31,32] Home-based rehabilitation programs, including monitored home exercise programs, can yield similar outcomes to one-on-one or group-based therapy for TKA patients. Home-based programs offer added benefits like convenience and reduced costs. [16] Early, aggressive mobility interventions in

the acute care setting can improve range of motion and walking ability compared to less aggressive approaches. However, the evidence is limited and more high-quality studies are needed. [33]

The use of clinical pathways and standardized care processes for TKA can help reduce length of stay without increasing readmission rates. This can improve healthcare efficiency. [31] Telerehabilitation and home-based rehabilitation programs following TKA have the potential to reduce healthcare costs compared to traditional in-person rehabilitation. However, the start-up costs of telerehabilitation technologies should be considered. [16] More high-quality, long-term outcome studies are needed to better understand the effects of various rehabilitation interventions and care models on patient outcomes and healthcare utilization after TKA. [33]

Interdisciplinary collaboration between healthcare providers (e.g. nurses, physical therapists, physicians) is important to optimize rehabilitation and recovery for TKA patients in the acute care setting. [33]

Virtual physical therapy is revolutionizing geriatric care by offering personalized support and convenience in several key ways. Virtual Reality Therapy (VRT) has shown promising results in improving balance and mobility in the elderly. Studies have found that VRT can lead to improvements in static balance, gait components, sensorimotor integration, and self-efficacy in fall prevention. [34] The meta-analysis in the review found significant positive effects of VRT on the Berg Balance Scale and Timed Up and Go test. [34]

Virtual physical therapy also allows elderly patients to access care from the comfort of their own homes, which is especially beneficial for those with limited mobility. In-home virtual PT can help reduce the risk of falls, lower the risk of injury, decrease pain from chronic conditions, and enable older adults to maintain an independent lifestyle. Additionally, VR is

being used in "memory therapy" to stimulate the minds of elderly patients with dementia or Alzheimer's disease. These VR experiences can help trigger old memories, reduce aggression, and improve interactions with caregivers. This can greatly improve quality of life and social engagement for those with cognitive impairments.

Overall, the convenience, personalization, and therapeutic benefits of virtual physical therapy are revolutionizing geriatric care by enabling older adults to access specialized treatment tailored to their needs, while avoiding the challenges of traveling to a clinic. This virtual rehabilitation technology is proving to be a valuable tool for optimizing the aging experience.

Future research directions for virtual rehabilitation in TKA

Future research directions for virtual rehabilitation in TKA could focus on the following areas.

- 1. Comparative Effectiveness Studies:** Conduct more comparative studies to assess the effectiveness of VR-based rehabilitation compared to traditional rehabilitation methods in terms of pain management, functional outcomes, and patient-reported outcomes post-TKA. These studies can help establish the superiority of VR-based rehabilitation and its impact on long-term recovery. [12,13]
- 2. Cost-Effectiveness Analysis:** Explore the cost-effectiveness of VR-based rehabilitation programs for TKA patients. Investigate the potential cost savings, healthcare utilization, and patient satisfaction associated with virtual rehabilitation compared to conventional methods. This research can provide valuable insights for healthcare systems and payers. [12]
- 3. Long-Term Outcomes:** Conduct longitudinal studies to evaluate the long-term effects of VR-based rehabilitation on

TKA outcomes, including pain relief, functional improvement, and quality of life. Understanding the sustainability of benefits over an extended period can guide the development of comprehensive rehabilitation protocols. [13]

4. Patient Adherence and Engagement:

Investigate strategies to enhance patient adherence to virtual rehabilitation programs post-TKA. Research on optimizing patient engagement, motivation, and compliance with home-based VR exercises can improve outcomes and recovery rates.

5. Safety and Efficacy: Further explore the safety profile of VR-based rehabilitation in TKA patients, particularly focusing on adverse events, patient tolerance, and the impact on postural control. Research in this area can help refine safety protocols and optimize the use of VR technology in rehabilitation. [13]

By addressing these research directions, future studies can advance the field of virtual rehabilitation in TKA, providing evidence-based insights to enhance patient outcomes, optimize healthcare delivery, and improve the overall quality of care for TKA patients.

CONCLUSION

Virtual rehabilitation aims to provide an engaging, interactive rehabilitation experience for TKA patients that can complement or potentially replace traditional in-person therapy in some cases, though more research is still needed.

This study demonstrates that virtual PT, with remote clinical oversight, achieves functional outcomes comparable to traditional in-person PT for patients recovering from TKA. The virtual rehabilitation appears to be a safe and effective alternative to traditional PT for TKA rehabilitation.

Virtual physical therapy (PT) following TKA has been shown to substantially lower healthcare costs, similar effectiveness,

improved access and compliance and fewer hospital readmissions compared to traditional PT.

The evidences indicate that while VR-based rehabilitation shows promise for improving functional outcomes after TKA, the current evidence is still mixed and more high-quality randomized controlled trials are needed to definitively determine its advantages over traditional rehabilitation. The COVID-19 pandemic has also increased interest in VR-based telerehabilitation as a way to improve accessibility to post-operative therapy.

In conclusion, virtual rehabilitation after TKA offers a cost-effective alternative to traditional rehabilitation, with lower healthcare costs, similar effectiveness in improving functional outcomes, improved patient compliance, and potentially reduced hospital readmissions.

Declaration by Author

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