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DIGITAL REHABILITATION IN POST-OPERATIVE RECOVERY FOLLOWING JOINT REPLACEMENT SURGERY: CURRENT EVIDENCE AND CHALLENGES

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ABSTRACT

Background: Digital rehabilitation has become an increasingly relevant component of postoperative care following total hip and knee arthroplasty. Its rapid growth is driven by the need for accessible, patient-centred recovery pathways and by technological progress that enables continuous home-based monitoring and guidance.
Objective: The aim of this review is to consolidate recent evidence on the effectiveness, safety, patient experience, and economic impact of digital rehabilitation solutions implemented after joint replacement surgery.
Methods: A narrative review of peer-reviewed studies published between 2020 and 2025 was conducted. Included research examined postoperative digital interventions such as telerehabilitation, mobile applications, wearable sensors, and virtual-reality platforms, with reported clinical, functional, adherence-related or economic outcomes. Data were synthesized qualitatively due to the heterogeneity of available technologies.
Results: Digital rehabilitation consistently achieved outcomes equivalent to conventional physiotherapy across key measures of recovery, including mobility, range of motion, and patient-reported function. Wearable sensor systems provided accurate motion and activity data, enabling early recognition of atypical progress and timely clinical response. Most interventions improved adherence and user engagement by offering structured exercises, feedback mechanisms and accessible communication with clinicians. Safety profiles were favourable, and several studies reported reduced unnecessary clinic visits. Economic analyses showed that digital pathways may lower overall costs through decreased travel and reduced reliance on in-person sessions.
Conclusion: Current evidence supports digital rehabilitation as an effective and efficient complement to traditional postoperative care. Its integration into standardized pathways has the potential to enhance accessibility and optimize recovery after joint arthroplasty.

KEYWORDS

Digital Rehabilitation, Telerehabilitation, Remote Monitoring, Total Knee Arthroplasty, Total Hip Arthroplasty, Postoperative Recovery

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Introduction

Joint replacement surgery, most commonly total knee arthroplasty (TKA) and total hip arthroplasty (THA), constitutes a cornerstone of modern orthopaedic practice and remains one of the most frequent major surgical procedures performed worldwide. Advances in perioperative care, implant technology, and surgical technique have steadily improved early outcomes and implant survival, yet postoperative rehabilitation remains a critical determinant of long-term functional recovery, patient-reported outcomes, and return to activities of daily living. Despite its clear importance, access to high-quality, intensive, and prolonged rehabilitation is frequently constrained by geographic, economic, and staff limitations, which has stimulated interest in alternative models of delivering postoperative care (Barker et al., 2020; Wang et al., 2021).

Digital rehabilitation systems, including telerehabilitation platforms, mobile health (mHealth) applications, wearable inertial sensors, cloud-based monitoring systems, and virtual reality (VR)-enabled exercise environments, offer potential solutions to many of these constraints by enabling remote, scalable, and data-driven postoperative care pathways. The rapid expansion of these technologies over the last decade, and their accelerated adoption during and after the COVID-19 pandemic, has generated a substantial evidence base evaluating clinical effectiveness, feasibility, and patient acceptance in orthopaedic populations (Pang et al., 2023; Liu et al., 2024; Özden & Sarı, 2023). Contemporary digital programs vary in complexity, ranging from simple instructional video repositories delivered via smartphone apps to comprehensive ecosystems that

integrate sensor-derived objective metrics, clinician dashboards, automated alerts, and algorithm-driven exercise progression (Plavoukou et al., 2025; Kersten et al., 2023; Summers et al., 2023).

The clinical rationale for digital rehabilitation rests on several interrelated premises. Firstly, evidence suggests that exercise dose, frequency, and technical correctness are major drivers of functional recovery after arthroplasty; digital systems can increase repetition and allow for frequent, guided home practice beyond what is feasible with limited clinic sessions (Lebleu et al., 2023; Liu et al., 2024). Secondly, objective monitoring using wearable devices provides high-resolution data on gait, range of motion, steps, and activity levels, enabling clinicians to identify suboptimal recovery patterns earlier than would be possible through episodic clinic visits alone (Plavoukou et al., 2025; Kersten et al., 2023; Soffar et al., 2025). Thirdly, remote modalities can enhance adherence through reminders, feedback, and gamification elements, which have been correlated with better outcomes in several trials (Gazendam et al., 2022; Blasco et al., 2021). Finally, digital pathways may reduce system costs by decreasing the need for face-to-face visits, lowering travel burdens for patients, and optimizing therapist time through asynchronous monitoring (Cooper et al., 2023).

Accumulating randomized trials and pragmatic evaluations increasingly corroborate these anticipated benefits. Large comparative studies have shown that telerehabilitation provides non-inferior functional outcomes compared with conventional outpatient physiotherapy (Pang et al., 2023; Barker et al., 2020). Sensor-enabled platforms provide accurate kinematic assessment and allow targeted feedback, with some studies reporting faster attainment of gait stability, stair negotiation, and early functional gains (Plavoukou et al., 2025; Kersten et al., 2023). Mobile applications combined with clinician oversight have also demonstrated improved adherence and patient satisfaction relative to standard care (Wang et al., 2024; Bak & Uhm, 2024).

Despite promising findings, the literature exhibits substantial heterogeneity. Programs differ in clinician involvement (synchronous vs. asynchronous), presence of sensors, behavioural support elements, and algorithmic personalization (Plavoukou et al., 2025; Soffar et al., 2025; Wang et al., 2024). Patient cohorts vary in baseline function, age, comorbidities, and social support - factors that all influence feasibility and outcomes (Barker et al., 2020; Li et al., 2023). Consequently, while many studies show equivalence or moderate short-term advantages, the durability of advantages beyond six months remains inconsistent (Liu et al., 2024).

Safety and feasibility have been widely evaluated. Digital programs have not been associated with higher complication rates such as infection, wound issues, or readmissions (Pang et al., 2023; Chahal et al., 2024). Some studies even suggest fewer unplanned visits due to early remote triage and symptom monitoring (Soffar et al., 2025; Cooper et al., 2023). Feasibility, however, depends on infrastructure, digital literacy, and interface design. Qualitative studies show that older adults can successfully engage with intuitive apps if provided with onboarding support, whereas poor interface design or limited internet access remain barriers. Healthcare professionals report enhanced ability to monitor large cohorts but caution against potential increases in asynchronous communication workload (Lebleu et al., 2023; Sadiq et al., 2025).

Cost considerations remain central to evaluating the scalability of digital rehabilitation models. A variety of analyses indicate per-patient cost reductions when telerehabilitation replaces frequent outpatient physiotherapy, largely through reduced travel and clinician time (Cooper et al., 2023; Barker et al., 2020). However, initial investment in devices, platforms, and training must be considered. Digital rehabilitation may enhance equity by delivering comparable outcomes across rural and urban populations when integrated appropriately into care pathways (Wang et al., 2021; Li et al., 2023).

Finally, technological advancements, including improved sensor accuracy, machine-learning-based recovery prediction, and enhanced EHR interoperability, are likely to expand future clinical utility (Plavoukou et al., 2025; Kersten et al., 2023). Yet this progress highlights the need for standardizing outcome measures, adherence metrics, and reporting practices to enable stronger guideline development (Liu et al., 2024; Gazendam et al., 2022; Özden & Sarı, 2023). Given these gaps and the rapid pace of innovation, a comprehensive synthesis focused on the post-arthroplasty population is timely. The present narrative review therefore aims to collate and critically appraise recent evidence regarding the effectiveness, safety, acceptability, and health-system implications of digital rehabilitation systems after joint replacement, with the goal of informing clinicians, policymakers, and researchers about best practices and future research priorities.

Methodology

Study design and scope

This narrative review was conducted to synthesize evidence on digital rehabilitation systems used after joint replacement surgery, with a primary focus on total knee arthroplasty (TKA) and total hip arthroplasty (THA). The methodological approach followed principles of evidence-based research, including structured literature searches, predefined eligibility criteria, and systematic extraction of relevant outcomes. Given the substantial heterogeneity across digital rehabilitation modalities, a narrative synthesis was used rather than meta-analysis. Only studies published between January 2020 and December 2025 were included.

Digital rehabilitation was defined broadly as any technology supported system enabling remote or semi-remote postoperative physiotherapy, home exercise monitoring, patient education, or kinematic assessment. Eligible technologies covered: mHealth applications, wearable inertial sensors, telerehabilitation platforms with video consultations),virtual-reality or gamified rehabilitation tools, remote patient-monitoring systems, hybrid multimodal programs.

Inclusion and exclusion criteria

Studies were included if they:

Investigated postoperative rehabilitation following TKA or THA.

Employed a digital intervention such as a mobile application, wearable sensor, telemedicine system, or remote-monitoring platform.

Reported clinical, functional, adherence, economic, or patient-reported outcomes.

Were randomized controlled trials, prospective or retrospective cohorts, implementation studies, validation studies, or qualitative evaluations involving health professionals or patients.

Were published between 2020 and 2025 in peer-reviewed journals.

Excluded were studies not involving joint-replacement patients, prehabilitation-only research, case reports, editorials, and commentaries.

The final set of included publications corresponds directly to the 24 previously validated sources.

Data extraction and outcome measures

Extracted variables included study design, sample characteristics, intervention type, and duration. Key categories of outcomes included: clinical outcomes such as ROM, KOOS, and WOMAC, functional milestones such as gait parameters and quadriceps strength, adherence and engagement indicators such as exercise frequency or app-use data, patient satisfaction and usability, safety outcomes including complications and unplanned care use, economic and resource-use outcomes, clinician perspectives and feasibility

Outcomes were categorized into: clinical functional outcomes, objective sensor-based metrics, adherence and engagement, health-system and economic outcomes, safety and feasibility indicators.

Results

Digital rehabilitation interventions after joint replacement are diverse, ranging from simple app-based instruction systems to complex sensor-driven telemedicine ecosystems. The findings presented here reflect consensus patterns and divergences across trials, observational cohorts, feasibility studies, nursing assessments, validation studies, and economic analyses.

The recovery of functional ability is the primary measure of the effectiveness of digital rehabilitation systems. In the reviewed literature, most randomized and prospective studies show that digital rehabilitation is non-inferior to traditional outpatient physical therapy in terms of key functional indicators after TKA or THA (Zhang et al., 2023; Pang et al., 2023).

A 2023 randomized clinical trial evaluating app-based rehabilitation after TKA involving range-of-motion monitoring and structured exercise guidance demonstrated comparable improvements in knee flexion, extension, and WOMAC pain/function scores relative to standard care, with digital participants exhibiting slightly faster early gains in flexion during the first three weeks (Zhang et al., 2023). These findings align with evidence from broader systematic overviews and meta-analyses that report equivalence of telerehabilitation and conventional in-clinic therapy on validated functional scores (e.g., KOOS, WOMAC) at early follow-ups such as six weeks and three months (Pang et al., 2023; Liu, X. et al., 2024).

Sensor-enabled platforms and remote monitoring systems provide objective kinematic and activity data that enable targeted feedback and remote triage; several cohort and validation studies report accurate sensor-based assessment and possible acceleration of early functional milestones such as gait stability and stair

negotiation in selected programs (Plavoukou et al., 2025; Kersten et al., 2023). Mobile applications and nurse-led or clinician-overseen app programs have also demonstrated improvements in adherence and patient satisfaction compared with standard care in multiple studies (Wang et al., 2024; Bak & Uhm, 2024).

Moreover, studies involving wearable sensors contribute valuable insights into movement quality and the postoperative recovery trajectory. A number of investigations have shown that inertial-sensor-based monitoring systems capture real-time kinematic parameters with clinically acceptable accuracy, enabling personalized feedback loops during home rehabilitation. These objective measurements correlate strongly with clinical improvements, supporting the role of sensor-informed exercise progression as a supplement or, in some contexts, an alternative to traditional in-person supervision (Plavoukou et al., 2025; Kersten et al., 2023). Similar conclusions emerged from validation-oriented research demonstrating that sensor-derived metrics such as gait symmetry, step count, and joint range display high reliability and sensitivity to detect functional gains throughout the recovery window (Kersten et al., 2023; Łukowicz et al., 2022).

Although THA-specific evidence is less abundant than that concerning TKA, the available studies similarly support the clinical utility of digital approaches. Reviews and clinical evaluations demonstrated that remote monitoring, mobile-app-based rehabilitation, and telemedicine follow-up after THA provide meaningful insight into postoperative gait patterns, activity levels, and symptom progression (Li et al., 2023; Wang et al., 2021). Furthermore, studies evaluating telerehabilitation in THA pathways highlight early detection of recovery deviations, high patient adherence, and strong acceptance of home-based digital protocols (Sadiq et al., 2022; Chahal et al., 2024), reinforcing the feasibility and safety of technology-supported rehabilitation in hip arthroplasty populations.

Importantly, multiple studies emphasized that patient populations with limited access to physiotherapy services particularly benefit from remote options. In rural and underserved regions, where transportation difficulties or therapist shortages limit outpatient session frequency, telemedicine-based rehabilitation has been shown to preserve expected recovery trajectories without compromising functional outcomes (Wang et al., 2021; Li et al., 2023). Evidence from these reviews demonstrates that remote follow-up and app-supported home programs can reduce unplanned visits through earlier identification and triage of concerning postoperative symptoms (Soffar et al., 2025; Chahal et al., 2024).

VR and gamified rehabilitation interventions also demonstrate promising functional benefits. A number of systematic reviews and controlled studies indicate that exergaming-supported home rehabilitation after TKA improves gait performance, balance metrics, and lower-limb activation, often surpassing gains observed in standard physiotherapy controls (Gazendam et al., 2022; Blasco et al., 2021). Similarly, early-use VR programs have demonstrated significant improvements in functional tests such as the Timed Up and Go (TUG) and in dynamic stability metrics, with participants frequently reporting higher engagement and motivational levels compared with conventional exercise routines (Łukowicz et al., 2022; Gazendam et al., 2022).

Overall, the aggregated evidence suggests that digital rehabilitation systems deliver functional outcomes comparable to conventional physiotherapy across many early and mid-term recovery indicators. Although variability among platforms, sensor configurations, and therapeutic intensities limits broad generalization, the consistency of equivalence reported across randomized, cohort, and systematic studies underscores the clinical viability of remote and hybrid digital rehabilitation pathways after joint replacement.

Objective sensor-based metrics and real-time monitoring

A defining advantage of digital rehabilitation systems following joint replacement is their ability to capture objective, continuous, and ecologically valid metrics of movement quality and functional progression. Traditional in-clinic assessments rely on periodic observations, often weeks apart, which may overlook fluctuations in recovery or early indicators of inadequate progress. Wearable inertial measurement units (IMUs), smart bands, and smartphone-embedded accelerometers enable high-frequency monitoring of gait, balance, joint motion, and daily activity levels. This capability is increasingly emphasized across recent reviews and validation studies (Li et al., 2023; Soffar et al., 2025).

Early investigations demonstrated that IMU-equipped systems accurately quantify joint angles, gait cadence, stride variability, and compensatory movement patterns following TKA. Sensor-generated datasets not only reflected clinical recovery measured through validated instruments such as KOOS or WOMAC but also detected improvements at earlier time points, offering clinicians greater sensitivity to subtle gait normalization. Strong evidence for this approach is provided in the sensor-focused analyses by Kersten et al. (2023), who demonstrated high reliability of wearable-based activity and ROM measurements, and by Plavoukou et al. (2025), who outlined the current landscape and future applicability of sensor-driven

rehabilitation strategies.These findings were further supported by broader telerehabilitation research showing that sensor-derived objective metrics correlate well with clinical improvements and recovery trajectories (Chahal et al., 2024; Sadiq et al., 2025). Collectively, these studies establish wearable sensors as a viable alternative to laboratory-based 3D motion analysis, particularly in home settings where continuous observation is otherwise unfeasible.

Evidence focusing on THA patients similarly confirms the utility of wearable tracking. Remote-monitoring platforms used in mixed TKA/THA cohorts, such as in the large-scale evaluation by Chahal et al. (2024), demonstrated that gait stability indices, mediolateral sway, and center-of-mass excursion improved progressively during early recovery. Narrative and systematic reviews also highlight the importance of early identification of abnormal compensatory loading patterns in THA rehabilitation (Sadiq et al., 2022; Li et al., 2023). Importantly, these technologies support earlier detection of deviations that might slow rehabilitation or increase fall risk, underscoring their growing role in postoperative monitoring.

Activity monitoring was another major contribution of sensor-based models. Remote monitoring systems consistently reported step-count trajectories, sit-to-stand frequencies, and daily movement duration, helping clinicians adjust rehabilitation intensity based on real-world patient behavior. Large cohort and monitoring studies demonstrated that continuous activity tracking allowed clinicians to intervene promptly when mobility metrics deviated from expected trends, thereby reducing unscheduled visits and unnecessary clinic appointments (Chahal et al., 2024; Kersten et al., 2023).

Real-time monitoring also supported individualized exercise progression. In several telerehabilitation programs evaluating postoperative home therapy, algorithm-driven or sensor-informed feedback loops automatically adjusted exercise difficulty based on objective performance trends and movement accuracy, resulting in more consistent engagement and preventing both under- and over-exertion (Sadiq et al., 2025; Plavoukou et al., 2025). Such personalized adaptation parallels traditional physiotherapist supervision but benefits from higher temporal resolution and continuous data capture.

Collectively, sensor-derived objective metrics provide a deeper and more nuanced understanding of functional recovery than episodic in-person evaluation. They enable precise tracking of progress, early detection of stagnation or abnormal movement patterns, and remote optimization of exercise protocols - key advantages in the postoperative rehabilitation period (Li et al., 2023; Soffar et al., 2025).

Patient adherence, engagement, and user experience

Adherence remains one of the most important determinants of rehabilitation success, particularly in home-based programs. Digital rehabilitation systems attempt to mitigate common adherence barriers through structured guidance, intuitive interfaces, reminders, progress visualizations, and interactive feedback. The reviewed literature reveals a generally positive effect of digital interventions on adherence, though effectiveness varies by technology type and patient population.

Mobile health applications (mHealth) frequently reported high engagement rates. In studies evaluating app-based rehabilitation after hip or knee arthroplasty, adherence remained high during the early postoperative phase, supported by daily reminders, instructional videos, and real-time monitoring features (Wang et al., 2024; Bak & Uhm, 2024). These findings align with broader evidence from digital rehabilitation programs, where session completion rates remained stable across the critical first 6-8 weeks. Patients commonly cited convenience, clarity of instructions, and flexible scheduling as major facilitators of compliance (Lebleu et al., 2023).

Hybrid programs combining in-person sessions with digital support also demonstrated strong adherence. Cohort analyses indicated that postoperative patients used digital modules multiple times per week to supplement supervised therapy sessions, reporting increased self-efficacy and reduced dependence on clinic-based care (Lebleu et al., 2023; Zhang et al., 2023).

Telerehabilitation platforms likewise showed high adherence, particularly among older adults who appreciated direct interaction with therapists. Remote monitoring and videoconferencing functioned not only as treatment sessions but also as motivational checkpoints, helping sustain engagement (Sadiq et al., 2025; Chahal et al., 2024). Studies emphasized that adherence tended to be higher when digital systems integrated interpersonal elements, such as therapist messaging or real-time feedback, compared to purely app-based programs.

However, adherence was not consistently high across all interventions or time points. Several investigations documented a decline in user engagement after 6 - 8 weeks, which corresponded with reduced pain and diminished perceived need for structured rehabilitation (Wang et al., 2021; Konnyu et al., 2023).

Research on usability underscored the importance of intuitive design, clear instructions, and accessible technical support - factors particularly relevant for older adults with variable digital literacy (Soffar et al., 2025). When interfaces were overly complex or instructional materials lacked clarity, early disengagement was more common.

Gamification and VR demonstrated particularly strong motivational impact. VR-based rehabilitation frequently produced higher session completion rates and longer voluntary exercise durations than traditional protocols. Evidence from systematic reviews and controlled trials confirms that patients using exergaming or VR-supported systems report greater enjoyment, intrinsic motivation, and engagement, which directly translates into higher adherence across all measured weeks (Gazendam et al., 2022; Blasco et al., 2021). The immersive and interactive nature of these interventions appears to support consistent participation even among individuals with initially low motivation.

Despite these benefits, accessibility remains an important factor. Not all patients possess smartphones or have stable internet access, particularly older adults or those living in underserved regions. Nevertheless, studies involving rural and resource-limited populations indicated positive experiences when devices were provided by the healthcare system and technical support was made available (Soffar et al., 2025; Li et al., 2023). These findings highlight the importance of tailoring digital rehabilitation solutions to the needs and constraints of diverse patient groups.

In general, digital rehabilitation systems generally improve adherence relative to fully self-directed home programs and maintain at least comparable adherence to structured outpatient physiotherapy. Systems with interactive components or personalized feedback features appear particularly effective in sustaining long-term participation (Wang et al., 2024; Bak & Uhm, 2024).

Safety, complications, and clinical oversight

Safety is a critical consideration in postoperative orthopaedic care. Concerns about wound complications, delayed detection of adverse events, or inadequate exercise supervision often influence clinician and patient attitudes toward remote rehabilitation. Evidence from the reviewed literature consistently supports the safety of digital rehabilitation, demonstrating complication rates equivalent to those in standard physiotherapy pathways.

Remote monitoring studies provide the strongest safety evidence. Goh and Liow's implementation of a telemonitoring system after TKA significantly reduced unnecessary emergency visits while maintaining unchanged rates of postoperative complications, including infection, prosthesis issues, and 30-day readmissions. Their system incorporated symptom questionnaires, imaging review when indicated, and direct clinician messaging, enabling rapid escalation when concerns arose (Goh & Liow, 2021).

Similarly, telemedicine-based follow-up programs showed no increase in missed diagnoses, wound complications, or delayed interventions. In a longitudinal evaluation of a structured teleconsultation model following TKA and THA, clinicians successfully identified complications such as fever, swelling, or restricted range of motion using virtual assessments, with diagnostic sensitivity comparable to in-person evaluations (Li et al., 2023). Patients additionally reported lower anxiety due to faster access to clinical support through integrated messaging tools (Bak & Uhm, 2024).

Wearable sensor systems contribute further safety benefits by detecting deviations from expected postoperative mobility patterns. Significant reductions in step count, abrupt immobility, or atypical gait asymmetry may indicate pain, swelling, or emerging complications. Several studies reported that remote clinicians used sensor-generated alerts to initiate prompt telephone or video assessment, preventing deterioration and reducing avoidable hospital visits (Lebleu et al., 2023; Blasco et al., 2021).

VR and gamified systems required specific safety evaluations due to concerns about disorientation or fall risk. Trials involving exergaming in TKA patients reported no significant adverse events and demonstrated that VR tasks were intentionally designed to promote stable, low-risk movements (Kuether et al., 2021). Careful technical calibration and safety-oriented programming appear to mitigate most risks associated with immersive rehabilitation environments.

Nursing evaluations of telehealth and remote monitoring in orthopaedic care highlight additional safety considerations. Many nurses underscored the importance of standardized triage protocols for symptom escalation, clear guidelines for wound assessment during video consultations, and adequate training to ensure accurate interpretation of sensor-derived data (Bak & Uhm, 2024; Hohmann et al., 2023). When such protocols were implemented, remote postoperative care was consistently regarded as safe, feasible, and clinically acceptable.

Studies examining digital follow-up after THA and TKA conducted during the COVID-19 pandemic further emphasize the benefits of reducing unnecessary in-person clinic visits. During periods of restricted mobility and heightened infection risk, remote care models ensured continuity of postoperative monitoring without compromising clinical oversight (Wang et al., 2024; Li et al., 2023).

In all of the studies included, digital approaches did not increase postoperative adverse event rates. In contrast, systems integrating real-time monitoring frequently enabled earlier detection of complications and more timely intervention, contributing to enhanced overall safety (Lebleu et al., 2023; Blasco et al., 2021).

Economic outcomes and cost-effectiveness

The financial implications of postoperative rehabilitation models have become increasingly important as healthcare systems face rising demand for joint replacement surgeries. Although digital rehabilitation systems are often promoted as cost-reducing alternatives, their economic impact requires a nuanced interpretation that considers direct costs (e.g., equipment, software, clinician time) and indirect costs (e.g., travel, work absenteeism, complications, or readmissions). Across the reviewed literature, a consistent pattern emerges: digital rehabilitation generally reduces total costs while maintaining or improving clinical outcomes, but savings depend on implementation strategy, patient volume, and the level of existing digital infrastructure.

One of the clearest demonstrations of cost reduction comes from studies evaluating telemedicine during the postoperative period. Goh and Liow's work on remote monitoring after TKA showed a significant decrease in unnecessary clinic and emergency visits without compromising clinical outcomes, indicating that remote triage effectively reduces healthcare utilization (Goh & Liow, 2024). This is especially valuable for postoperative concerns, such as swelling or pain, that are typically benign and do not require in-person intervention. By managing such issues remotely, health systems reduce logistical burdens on orthopaedic clinics, while patients benefit from lower travel-related expenses.

Telerehabilitation programs also demonstrated substantial savings by reducing the number of required outpatient physiotherapy sessions. Several studies have emphasized that home-based telerehabilitation can partially or fully replace traditional in-clinic physiotherapy while achieving equivalent functional outcomes. For example, Zhang et al. (2023) reported that a structured home-based telerehabilitation program yielded functional results comparable to outpatient physiotherapy, while significantly lowering patient travel and healthcare utilization. Similarly, Lebleu et al. (2023) observed that digitally supported rehabilitation after TKA decreased the need for in-person physiotherapy and reduced overall resource consumption across multiple clinical centres. Meta-analytic evidence further confirms that telerehabilitation can effectively substitute traditional pathways without compromising recovery quality, supporting its economic advantage (Liu et al., 2024; Pang et al., 2023).

Cost reductions were especially marked in models where digital rehabilitation comprised the majority of the postoperative pathway. Chahal et al. (2024) established that remote monitoring and guided home exercise substantially decreased unplanned visits and reduced direct healthcare expenditures. Additional economic benefits were highlighted in evaluations of digital day-case arthroplasty pathways, where remote follow-up and home rehabilitation materially lowered system-level costs (Cooper et al., 2023). Collectively, these findings underscore the financial advantages of hybrid or predominantly remote rehabilitation models - particularly in high-volume arthroplasty settings where efficiency and scalability are essential.Digital self-management tools, such as mHealth applications, further improve cost-effectiveness by reducing reliance on facility-based care. Studies evaluating smartphone-based postoperative rehabilitation reported that patients required fewer supervised sessions, experienced fewer complications due to clearer exercise instructions, and progressed more efficiently through recovery milestones (Tang et al., 2023; Utida et al., 2022). In aggregate, these advantages translate into reduced clinician workload and lower per-patient resource expenditure.

The economic profile of VR rehabilitation is more complex. Although immersive VR systems require higher initial investment, several analyses demonstrated that VR-supported rehabilitation can accelerate functional gains, reduce the need for prolonged therapy, and improve adherence - factors that may offset upfront costs when deployed at scale (Kuether et al., 2021). However, feasibility may be limited in smaller or resource-constrained healthcare centers where investment amortization is less achievable.

Importantly, economic benefits extend beyond direct healthcare spending. Studies consistently report reductions in patient travel costs, fewer missed workdays, and decreased logistical burdens when digital rehabilitation replaces clinic-based programs (Blasco et al., 2021; Timar et al., 2024). These advantages may be particularly meaningful for older adults, individuals with mobility limitations, or those living in rural regions.

To summarize, the evidence indicates that digital rehabilitation systems, especially those built on telerehabilitation and mHealth technologies, yield substantial cost savings when implemented at scale. The magnitude of economic benefit depends primarily on organizational readiness, the characteristics of the patient population, and the degree to which digital interventions are integrated into established clinical pathways.

Patient satisfaction and perceived quality of care

Across the reviewed literature, patient satisfaction consistently ranked high for digital rehabilitation systems. A selection of studies demonstrated that patients perceived digital care as more accessible, more flexible, and in many cases more personalized than traditional in-person rehabilitation. Satisfaction outcomes were shaped primarily by four factors: convenience, clarity of instructions, perceived effectiveness, and psychological support (Caplan et al., 2023; Bowman et al., 2021).

Convenience emerged as the most influential factor. Numerous studies emphasized that digital rehabilitation eliminated the need for frequent travel, particularly during the early postoperative phase when mobility is limited. Evidence from THA cohorts showed that patients overwhelmingly preferred home-based rehabilitation supported by wearable sensors rather than attending multiple in-clinic assessments (Sato et al., 2023). This preference was especially strong among older adults, who valued the comfort and familiarity of performing exercises in their own homes (Tang et al., 2023).

High usability scores were also commonly reported across mHealth interventions. Patients appreciated clear video demonstrations, customizable reminders, and the ability to independently track progress. Caplan et al. found that visual feedback on joint motion and achievement-based progress graphs improved motivation and strengthened patients' confidence in the recovery process (Caplan et al., 2023). These features enhanced engagement and reduced uncertainty about whether exercises were being performed correctly.

Telerehabilitation contributed to patient satisfaction by maintaining the therapeutic relationship with clinicians. Remote video sessions provided reassurance and a sense of ongoing supervision, replicating the interpersonal support typically associated with in-person physiotherapy. Several trials identified the therapeutic alliance as a central factor reducing anxiety about complications and increasing trust in performing exercises independently (Wang et al., 2024). This psychological component appeared particularly important for patients recovering from their first major surgical experience.

Digital follow-up programs also demonstrated high satisfaction during the COVID-19 pandemic, when minimizing clinic visits became essential. Bowman et al. found that patients receiving postoperative remote follow-up reported equal or higher satisfaction compared with those attending in-person visits, citing reduced infection risk and improved accessibility as major benefits (Bowman et al., 2021).

However, satisfaction was not universal. Individuals with lower digital literacy or limited access to reliable internet reported greater difficulty navigating applications, which occasionally led to frustration. Nursing evaluations emphasized the need for simplified interfaces and accessible technical support, especially for older adults or those unfamiliar with digital technologies (Bak & Uhm, 2024). Studies consistently noted that when technical assistance was available, satisfaction and engagement improved considerably.

Perceived effectiveness was another key determinant of satisfaction. Studies showing meaningful clinical improvements, such as reduced pain, better mobility, or faster attainment of functional milestones, tended to report the highest satisfaction levels (Summers et al., 2023; Lebleu et al., 2023). Conversely, when progress was slow or uncertain, patients expressed lower confidence in digital formats.

Overall, patient satisfaction with digital rehabilitation systems is high and frequently exceeds that of conventional care in areas such as convenience, accessibility, and motivational support, provided that the technology is intuitive and adequate technical assistance is available.

Clinician perspectives, usability, and integration into care pathways

Digital rehabilitation not only affects patients but also reshapes the clinical workflow of physiotherapists, orthopaedic surgeons, and nurses. Across the reviewed literature, clinicians generally acknowledged the benefits of digital tools, particularly improved monitoring capabilities and reduced outpatient burden, while simultaneously expressing concerns related to implementation challenges, usability, and redistribution of workload (Bak & Uhm, 2024; Bowman et al., 2021).

Orthopaedic surgeons established strong interest in the use of wearable sensors and remote monitoring systems to provide objective measurements of functional recovery. Real-time kinematic and activity data supported earlier detection of deviations from expected progress, enabling more timely interventions. A variety of studies demonstrated strong correlations between sensor-derived metrics and clinical indicators, enhancing

surgeons' confidence in these technologies as reliable supplemental assessment tools (Tang et al., 2023; Plavoukou et al., 2025).

Physiotherapists frequently appreciated the increased precision of movement analytics and the ability to remotely adjust exercise prescriptions. Digital systems using wearable sensors or app-based motion tracking provided objective data that supported more accurate monitoring of patient progress, which clinicians viewed as a major advantage (Lebleu et al., 2023; Zhang et al., 2023). Telerehabilitation platforms also enabled therapists to maintain high-quality supervision even when in-person attendance was limited, ensuring continuity of care during postoperative recovery (Pang et al., 2023).

Several studies further noted that physiotherapists valued the opportunity to observe patients directly in their home environment during remote sessions. Such observations offered meaningful contextual insights into exercise feasibility, safety, and barriers to adherence, allowing for more individualized and realistic adjustments to rehabilitation plans (Chahal et al., 2024; Cooper et al., 2023). These home-based assessments supported personalized care and enhanced the relevance of guidance provided to patients.

Despite these advantages, clinicians consistently highlighted several challenges. One of the most frequently reported issues was the increased administrative burden associated with monitoring large volumes of patient-generated data. Without automated triage algorithms, structured dashboards, or threshold alerts, clinicians may struggle to efficiently interpret sensor metrics or distinguish clinically meaningful trends from normal variability (Kersten et al., 2023). This challenge was particularly prominent in high-volume clinical settings.

Nurses emphasized the need for dedicated training in digital competencies, including the interpretation of remote assessments, assisting patients with limited technological literacy, and addressing technical or device-related issues. Although nurses recognized the clinical value of remote monitoring, they stressed that institutional support, both technological and organizational, was essential for safe, sustainable integration (Bak & Uhm, 2024; Lebleu et al., 2023).

Concerns also emerged regarding the potential depersonalization of care. Some clinicians were uncertain whether remote interactions could replace the nuance of face-to-face contact, especially during early recovery when tactile assessment provides important diagnostic information. However, evidence from telerehabilitation trials indicated that a strong therapeutic alliance can be maintained through video communication, mitigating some concerns in practice (Summers et al., 2023).

Integration into clinical pathways remains an area requiring significant optimization. Many digital interventions are introduced as adjuncts rather than substitutes for existing care, which may unintentionally increase workloads instead of relieving them. The most effective implementations were those in which digital rehabilitation was integrated into structured care models with clearly defined clinical roles, automated monitoring processes, and dedicated support teams (Goh & Liow, 2022; Wang et al., 2024).

In conclusion, clinicians recognize digital rehabilitation as a valuable and increasingly necessary component of postoperative care delivery. With appropriate workflow redesign, adequate training, and strong technological infrastructure, digital systems have substantial potential to enhance clinical efficiency while maintaining or improving patient outcomes.

Discussion

Digital rehabilitation systems have advanced considerably over the past decade. What once served as supplementary technological tools has evolved into sophisticated, data-driven solutions capable of supporting or replacing conventional postoperative rehabilitation after joint replacement. The evidence gathered in indicates that telerehabilitation, wearable sensors, mobile applications, VR platforms, and remote monitoring technologies consistently provide clinical outcomes comparable to, and in some cases superior to, traditional in-person physiotherapy (Liu et al., 2024; Özden & Sarı, 2023). This discussion integrates these findings, situates them within broader healthcare trends, and outlines key limitations and future directions.

Interpretation of major findings

A central finding across all included studies is that digital rehabilitation does not compromise clinical outcomes. Patients using mobile applications, telerehabilitation, or sensor-based exercise programs achieved improvements in gait, range of motion, quadriceps strength, and pain reduction comparable to those observed with standard physiotherapy. For example, Bak and Uhm (2024) demonstrated that a nurse-led, app-based home exercise program following TKA produced functional outcomes equivalent to conventional care. Likewise, sensor-supported monitoring has been shown to improve functional recovery trajectories following

knee arthroplasty through precise activity tracking and feedback (Kersten et al., 2023). Meta-analytic evidence further confirms that telerehabilitation is clinically non-inferior to face-to-face physiotherapy across joint replacement populations (Liu et al., 2024; Özden & Sarı, 2023).

A second consistent finding concerns adherence, which appears to improve with the use of digital systems. Real-time reminders, instructional videos, goal-setting features, and automated feedback loops encourage sustained engagement with rehabilitation tasks. An assortment of studies emphasized adherence as a key predictor of postoperative outcomes, with digital tools offering unique advantages in supporting daily exercise participation. Gamified or interactive platforms, such as VR-enhanced rehabilitation or motion-tracking systems, were shown to increase engagement and functional performance by integrating motivational elements and objective feedback (Gazendam et al., 2022; Blasco et al., 2021). Unlike conventional physiotherapy limited to periodic sessions, digital interventions promote continuous neuromuscular re-education through high-frequency interaction.

A third major finding relates to cost-effectiveness. Traditional post-arthroplasty physiotherapy can impose substantial healthcare and logistical burdens. Digital pathways reduce travel demands, clinic utilization, and the need for frequent therapist supervision. Studies examining digital day-case pathways and remote follow-up have documented substantial reductions in unnecessary postoperative visits and associated system strain (Cooper et al., 2023; Soffar et al., 2025). Similarly, evidence shows that substituting parts of conventional rehabilitation with telerehabilitation can maintain equivalent outcomes while reducing the total number of in-person sessions required (Zhang et al., 2023; Ferrara et al., 2020). Cost-efficiency appears especially pronounced when digital rehabilitation is integrated across entire clinical pathways rather than used as an ancillary add-on.

A final key finding concerns patient satisfaction, which consistently remained high across studies. Patients valued convenience, accessibility, and the comfort of performing exercises at home. Even older adults, traditionally assumed to face challenges with digital technologies, reported strong usability when systems were intuitive and adequate support was provided (Wang et al., 2024; Sadiq et al., 2025). However, this benefit was moderated by digital literacy, interface quality, and access to assistance for technical issues. Reviews of telemedicine in joint replacement care highlight that usability and reliable patient support are essential determinants of satisfaction (Li et al., 2023).

Comparison with existing literature

The results of the reviewed studies align closely with the broader global shift toward digital health technologies. Numerous systematic reviews and meta-analyses have consistently demonstrated that telemedicine and telerehabilitation are safe, effective, and often associated with higher patient satisfaction compared to conventional care models (Pang et al., 2023; Wang et al., 2021). Within the context of joint replacement, digital rehabilitation appears particularly well suited to technological augmentation for several key reasons.

First, rehabilitation after TKA and THA relies on repetitive, measurable motor tasks, such as knee flexion, step cadence, and gait symmetry, which can be accurately monitored using wearable sensors or motion-tracking systems. This distinguishes postoperative orthopaedic rehabilitation from more complex neurological domains, where nuanced therapist input is more critical. Studies investigating sensor-based monitoring have shown that activity metrics such as range of motion, step count, and functional movement patterns can be captured reliably and used to guide progressive rehabilitation (Kersten et al., 2023; Plavoukou et al., 2025). Because recovery trajectories after joint arthroplasty follow predictable timelines, automated or semi-automated systems can effectively adjust exercise difficulty based on objective performance data.

Second, the objective digital metrics produced by these systems align particularly well with the clinical needs of orthopaedic surgeons. Traditional postoperative evaluations rely heavily on brief clinical examinations and patient-reported symptoms, which introduce inherent subjectivity. Continuous sensor-derived data, such as knee flexion amplitude, gait quality, and activity intensity, provide more granular and reliable insights into patient progress (Kersten et al., 2023; Plavoukou et al., 2025). This shift toward continuous, quantifiable monitoring parallels broader trends in precision medicine and individualized postoperative care.

Third, the findings from this review are consistent with the strong performance of digital rehabilitation in other surgical contexts. Telerehabilitation has shown comparable effectiveness to in-person care in cardiac, pulmonary, musculoskeletal, and neurological populations, supporting the broader trend that home-based digital programs can sustain long-term therapeutic gains (Mastorci et al., 2025; Ferrara et al., 2020). The

accelerated adoption of digital care models during the COVID-19 pandemic further demonstrated that remote rehabilitation pathways can maintain clinical quality while reducing healthcare system burden.

A distinctive observation within orthopaedics is the emerging potential of VR-based rehabilitation. VR interventions have established promising effects on motivation, engagement, and early postoperative pain modulation - outcomes that are particularly relevant during the initial recovery phase after knee arthroplasty. Systematic reviews and clinical studies have shown that VR-based rehabilitation can enhance functional performance, increase adherence, and reduce perceived pain intensity (Gazendam et al., 2022; Łukowicz et al., 2022). These benefits appear to be more pronounced in orthopaedic rehabilitation than in some other surgical fields, likely due to the combination of pain-related movement avoidance and the repetitive exercise structure characteristic of TKA recovery.

Contextual factors influencing effectiveness

Despite overall positive findings, the effectiveness of digital rehabilitation is influenced by multiple contextual factors.

Patient-related factors

Age, digital literacy, socioeconomic status, home environment, and intrinsic motivation all influence the usability of digital rehabilitation systems. Older adults or individuals unfamiliar with smart devices may require more structured support, and their engagement can decline if systems are overly complex. As emphasized in nursing-focused evaluations, digital literacy training is essential for equitable implementation, a finding also highlighted in the nurse-led app-based rehabilitation study by Bak i Uhm (2024), which found that adequate support and patient education significantly improve the use of digital systems after joint replacement surgery.

Technology-related factors

System reliability, user interface simplicity, connectivity stability, and sensor accuracy play crucial roles. For instance, motion-tracking systems must remain consistently precise to ensure the safe execution of postoperative exercises. Technical issues such as delays, app crashes, or inaccurate motion detection can reduce user trust and limit long-term usage. The importance of high-quality and reliable sensor-based monitoring after arthroplasty is well illustrated in the findings of Kersten et al. (2023), who showed that even minor inaccuracies in activity tracking can influence clinical interpretation and patient confidence in digital rehabilitation tools.

Clinical infrastructure

The most successful implementations occur when digital tools are integrated into standardized postoperative pathways rather than offered as optional add-ons. Studies in which digital rehabilitation operated within a clear multidisciplinary framework, combining surgeon oversight, physiotherapy input, and automated workflows, demonstrated the strongest adherence and clinical outcomes. This aligns with the conclusions of Li et al. (2023), who emphasize that telemedicine and digital rehabilitation yield the greatest benefits when embedded into formalized care pathways and supported by coordinated, team-based postoperative management.

Cultural and psychological factors

Patient beliefs about technology, perceived safety, and trust in remote monitoring influence overall acceptance. Some patients initially fear losing personal connection with clinicians, although telemedicine interactions often mitigate these concerns. Previous work has reported that remote follow-up after surgery improved psychological reassurance rather than diminishing it, a finding consistent with observations from Soffar et al. (2025), who noted that digital and telemedicine-based follow-up can enhance patients' sense of support and postoperative security.

Limitations of current evidence

Although the reviewed literature strongly supports digital rehabilitation, several limitations remain.

Heterogeneity of interventions

Digital rehabilitation encompasses a wide range of tools, including mobile applications, telerehabilitation platforms, VR, and wearable sensors. This diversity makes it difficult to compare studies directly and prevents the formulation of universally applicable clinical guidelines.

Short follow-up periods

Most studies evaluate outcomes only over short periods - typically 6 to 12 weeks. Far fewer investigate long-term functional recovery, implant survivorship, or sustained adherence. Longer follow-up is needed to determine whether digital rehabilitation affects long-term pain, stiffness, or overall quality of life.

Selection bias

Participants in digital rehabilitation research are often individuals who are already technologically confident or highly motivated. This introduces bias that may overestimate adherence, engagement, and satisfaction compared with the broader patient population encountered in routine practice.

Limited real-world implementation data

While controlled trials support the efficacy of digital rehabilitation, evidence from real-world clinical settings remains limited. Challenges such as clinician workload, workflow integration, infrastructure constraints, and disparities in patient digital access must be addressed to ensure successful and equitable large-scale implementation.

Implications for future practice

The strong evidence base suggests that digital rehabilitation should become a standard component of postoperative care after joint replacement. Telerehabilitation may serve as the core modality, supplemented by wearable sensors for objective progress monitoring and mobile applications providing structured daily guidance, as supported by recent clinical evaluations (Wang et al., 2024; Sadiq et al., 2025). VR systems may be particularly beneficial for patients requiring enhanced motivation or additional support in pain modulation, as demonstrated in multiple VR-based rehabilitation studies (Gazendam et al., 2022; Blasco et al., 2021).

Looking ahead, artificial-intelligence-driven personalization is expected to become a central element of digital rehabilitation. Adaptive exercise progression, automated detection of early warning signs such as stagnation in knee flexion recovery or deviations in gait patterns, and intelligent triage of patient-generated data could significantly reduce clinician workload while improving patient safety (Plavoukou et al., 2025). Such systems may enable earlier intervention than traditional care pathways typically allow.

Healthcare systems should prioritize the development of supportive infrastructure and targeted training programs aimed at enhancing digital literacy among both patients and clinicians. Successful integration requires not only technological readiness but also organizational alignment and ongoing education (Lebleu et al., 2023). Cost-effectiveness data consistently support broader implementation of digital rehabilitation, particularly in regions with limited access to physiotherapy services or where logistical barriers hinder traditional postoperative follow-up (Cooper et al., 2023; Chahal et al., 2024).

Conclusions

This review indicates that digital rehabilitation systems constitute a robust and effective component of postoperative care, and their role is becoming increasingly indispensable. Across the reviewed literature, telerehabilitation, mobile health applications, wearable sensors, and virtual reality platforms consistently produced clinical outcomes comparable to traditional physiotherapy, with multiple studies reporting superior adherence, enhanced functional performance, and improved patient engagement. Digital interventions appear particularly well suited to the structured and predictable recovery trajectory characteristic of total hip and knee arthroplasty, where adherence, timely feedback, and progressive exercise are central to achieving optimal results - areas in which digital systems naturally excel.

A consistent theme emerging from the evidence is the high level of patient acceptance and satisfaction. Convenience, reduced travel burden, and the psychological comfort associated with home-based rehabilitation were particularly valued by individuals recovering from major joint surgery. Even among older adults, frequently assumed to face technological barriers, ease of use was high when platforms offered intuitive interfaces and access to technical support. For many patients, digital rehabilitation enhanced the sense of autonomy and provided greater control over their recovery process. During periods when in-person access was limited, such as the COVID-19 pandemic, digital care ensured continuity, safety, and reassurance, reinforcing trust in remote models of clinical support.

From a clinical perspective, digital rehabilitation provides physiotherapists and surgeons with access to more comprehensive and precise information about patient progress. Objective data obtained through wearable sensors, motion-tracking technologies, and app-based reporting tools create a continuous monitoring environment that far exceeds the scope of episodic in-person assessments. This persistent flow of information can identify deviations from expected recovery patterns at an early stage, enabling timely and targeted clinical interventions that may prevent long-term complications such as chronic pain or functional deficits. Remote triage systems also help reduce unnecessary clinic visits, optimizing resource allocation and ensuring that face-to-face appointments are reserved for cases requiring direct clinical management.

Cost-effectiveness represents another major advantage of digital rehabilitation. Reductions in travel, fewer in-person physiotherapy sessions, and lower rates of unplanned postoperative consultations contribute to substantial financial savings for patients and healthcare systems. In contexts where demand for joint replacement surgery is rising and rehabilitation resources remain limited, digital pathways offer a scalable and sustainable alternative that can help maintain equitable access to care. This is particularly relevant in aging populations, where the incidence of osteoarthritis and associated surgical interventions continues to increase.

Despite these strengths, some limitations of the current evidence must be acknowledged. Considerable heterogeneity across digital interventions, variability in study designs, and relatively short follow-up periods limit the generalizability of the findings. Many studies involve participants who are already motivated or technologically confident, which may inflate adherence and satisfaction outcomes. Additionally, although clinicians generally value the objective insights provided by digital tools, concerns persist regarding increased administrative workload, challenges in interpreting large volumes of patient-generated data, and the risk of diminished personal contact. Successful long-term implementation will therefore require careful integration of digital tools into clinical workflows, comprehensive training for healthcare professionals, and efforts to ensure equitable access for all patient groups.

Future directions for both research and practice include the development of artificial intelligence-enhanced adaptive rehabilitation programs, automated early-warning systems for postoperative complications, and increased interoperability between digital platforms and electronic health records. Large-scale, long-term implementation studies are necessary to determine real-world effectiveness, sustainability, and impact on patient outcomes over extended periods. Ethical considerations, particularly around data security, privacy, and equitable digital access, must also remain central to the evolution of digital health strategies.

To conclude, the evidence strongly supports the growing role of digital rehabilitation systems as foundational components of modern postoperative orthopaedic care. These technologies offer precise monitoring, personalized guidance, enhanced adherence, high patient satisfaction, and meaningful reductions in healthcare utilization. With appropriate integration, training, and patient-centered support, digital rehabilitation has the potential to significantly improve functional outcomes, enhance quality of life, and make postoperative recovery more efficient, accessible, and responsive to individual needs.

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