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Effect of Tele-rehabilitation on balance in individuals with Parkinson.

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ABSTRACT

Background: Parkinson's disease (PD) is a chronic, progressive neurodegenerative disorder that affects approximately 1% of individuals over the age of 60. In addition to its cardinal motor symptoms—bradykinesia, rigidity, tremors, and postural instability—balance impairments are a leading cause of falls, injuries, and decreased independence. Up to 60% of individuals with PD experience falls annually, and many have recurrent episodes, significantly impacting quality of life and caregiver burden.

Objective: This narrative review aims to examine the effectiveness of tele-rehabilitation in addressing balance impairments among individuals with Parkinson's disease. It also explores the underlying mechanisms, benefits, limitations, and future directions of tele-rehabilitation within neurological care.

Methods: Relevant literature from PubMed, Cochrane, and Scopus was reviewed, including randomized controlled trials, systematic reviews, and clinical guidelines focusing on tele-rehabilitation, balance training, and neuroplasticity in PD. The review highlights both technological platforms and clinical applications relevant to remote rehabilitation delivery. Traditional physiotherapy interventions, such as gait training, strength exercises, and cueing strategies, have been shown to improve balance in PD but are limited by access, transportation, and physical disability. Tele-rehabilitation overcomes these barriers by offering home-based, digitally guided therapy through video conferencing, virtual reality, and wearable sensor technologies. Evidence suggests that tele-rehabilitation yields comparable improvements in postural control and motor outcomes, primarily through mechanisms of neuroplasticity, repetitive task training, and enhanced patient engagement. It also allows for continuous remote monitoring and personalized feedback, increasing adherence and promoting functional autonomy.

Conclusion: Tele-rehabilitation is an effective, accessible, and scalable model for delivering balance-focused interventions to people with Parkinson's disease. While the evidence supports its clinical utility, broader implementation requires addressing challenges related to digital access, standardization of treatment protocols, and safety monitoring. Future research should aim to refine tele-rehabilitation frameworks and integrate AI-powered personalization to optimize outcomes in this vulnerable population.

Keyword: Parkinson's Disease, Remote Rehabilitation, Telehealth,

1. Introduction

Parkinson's disease (PD) is a chronic, progressive neurodegenerative disorder that primarily affects motor function. Its hallmark symptoms include resting tremors, bradykinesia, rigidity, and postural instability, all of which progressively deteriorate over time. As the disease advances, the neural control of balance becomes increasingly impaired, leading to greater instability and higher fall risk. Falls are a significant concern, with approximately 60% of individuals with PD experiencing at least one fall annually, and many experiencing

recurrent episodes. This leads to increased morbidity, reduced independence, and substantial caregiver burden (1,2).

Conventional rehabilitation programs play a pivotal role in the multidisciplinary care of PD. Physiotherapy remains a central intervention, targeting balance, mobility, and posture through a combination of strength training, gait exercises, flexibility work, and postural alignment. These interventions are typically delivered in outpatient clinics or specialized centers. However, access to such services is often compromised by multiple barriers, including reduced mobility, lack of transportation, cost, and geographical disparities. This is particularly problematic for individuals living in rural or underserved communities (3,4).

To address these challenges, tele-rehabilitation has emerged as an innovative and increasingly viable solution. Defined as the remote provision of rehabilitation services using digital platforms and communication technologies, tele-rehabilitation allows patients to receive expert guidance and monitoring from their homes. It supports both real-time and asynchronous formats, and can incorporate video conferencing, wearable sensors, mobile applications, and virtual reality. Emerging studies suggest that tele-rehabilitation can achieve comparable improvements in balance and motor function to traditional face-to-face therapy, making it a compelling alternative or adjunct in the management of PD (5,6).

2. Material and methods

A comprehensive literature search was conducted to identify studies examining the effect of tele-rehabilitation on balance in individuals with Parkinson's disease. The search was carried out across four electronic databases: PubMed, Cochrane Library, Scopus, and Web of Science. The search strategy used the Boolean combination: Parkins* AND ("telerehabilitation" OR "tele-rehabilitation" OR "virtual rehabilitation" OR "remote physiotherapy" OR "remote therapy" OR "online physiotherapy" OR "e-therapy") AND ("balance" OR "postural control" OR "postural stability"). Filters were applied to include only studies published in English between January 2000 and April 2025. This narrative review included prospective observational studies, clinical trials (both randomized and non-randomized), and systematic reviews. Titles and abstracts were initially screened for relevance, followed by full-text review to determine eligibility. Additionally, the reference lists of included studies were manually searched to identify any further relevant publications.

Pathophysiology of Parkinson's Disease and Its Impact on Balance

Parkinson's disease (PD) primarily results from the progressive degeneration of dopaminergic neurons in the substantia nigra pars compacta, leading to striatal dopamine deficiency (7). This depletion disrupts basal ganglia circuitry, impairing motor control and initiating hallmark PD symptoms such as bradykinesia, rigidity, and resting tremor (8). The basal ganglia, particularly the internal globus pallidus and subthalamic nucleus, play essential roles in modulating gait and postural stability (9). Disruption in these circuits contributes directly to impaired balance and increased fall risk in PD patients (10).

Postural instability in PD is multifactorial, involving both motor and non-motor components (11). Abnormalities in anticipatory postural adjustments, which normally precede voluntary movements to maintain equilibrium, are commonly observed in PD and contribute to instability during walking or turning (12). Moreover, deficits in reactive postural control — the body's ability to respond to external perturbations — are also prevalent and associated with fall risk (13). These deficits can occur even in the early stages of PD and tend to worsen with disease progression (14).

Beyond motor symptoms, cognitive impairments such as slowed processing speed, impaired attention, and executive dysfunction further compromise balance and mobility in PD (15). These cognitive deficits interfere with dual-tasking — a key factor in safe ambulation — making patients more susceptible to instability during routine activities (16). Dysfunction in the cholinergic system, particularly degeneration of the pedunculopontine nucleus, may also contribute to gait disturbances and falls in PD (17). Such neurochemical changes underscore the complexity of balance dysfunction in this population (18).

Additionally, sensory integration deficits, including impaired proprioception and visual-vestibular processing, are implicated in poor balance control in PD (19). Individuals with PD often have delayed or inaccurate sensory feedback, which hampers the central nervous system's ability to maintain posture (20). Musculoskeletal rigidity and reduced range of motion in the trunk and lower limbs further contribute to poor postural alignment and sway (21). These factors collectively diminish the ability of individuals with PD to perform safe and coordinated movements, increasing the likelihood of falls (22).

Traditional Rehabilitation Approaches for Balance in Parkinson's

Physiotherapy remains a core component in the multidisciplinary management of Parkinson's disease (PD), with a primary goal of improving gait, balance, and mobility (23). Among the most widely used techniques are balance training, gait re-education, resistance exercises, and cueing strategies that promote motor learning and

neuroplasticity (24). These interventions aim to compensate for motor deficits, enhance motor planning, and minimize fall risk (25).

Balance-specific training typically involves static and dynamic postural exercises designed to improve stability during daily tasks (26). Tai Chi, for example, has shown promise in enhancing postural control and reducing fall frequency in individuals with mild to moderate PD (27). Similarly, dance-based therapy and treadmill training have been effective in improving gait symmetry and dynamic balance (28).

The success of these traditional programs often depends on intensity, frequency, and individualized tailoring to the patient's needs and disease stage (29). However, access to in-person physiotherapy may be constrained by physical disability, geographic location, and cost, leading to suboptimal rehabilitation engagement (30). As a result, alternative models of delivering therapy are increasingly explored to maintain continuity and effectiveness of care (31).

Results

What is Tele-rehabilitation?

Tele-rehabilitation refers to the use of telecommunication technologies to deliver rehabilitation services remotely, enabling patient-provider interaction without the need for physical presence (32). It encompasses real-time video conferencing, mobile health applications, and virtual reality systems that allow therapists to assess and guide patients in performing therapeutic exercises from home (33). In neurological rehabilitation, including Parkinson's disease, tele-rehabilitation offers a scalable and flexible solution that can improve adherence and accessibility (34). The approach also allows for continuous monitoring, remote feedback, and structured exercise protocols that are crucial in chronic progressive diseases like PD (35).

Evidence of Tele-rehabilitation in Parkinson's Disease

Recent clinical trials and pilot studies have evaluated the effectiveness of tele-rehabilitation for improving motor function and balance in individuals with Parkinson's disease (PD) (5). Gandolfi et al. conducted a multicenter randomized controlled trial using virtual reality-based tele-rehabilitation and found significant improvements in balance scores compared to standard care (6). Similarly, Cikajlo et al. demonstrated that home-based telerehabilitation using biofeedback-enhanced tasks resulted in superior postural control and functional mobility in PD patients compared to conventional therapy (36). However, both studies were limited by relatively small sample sizes, absence of long-term follow-up, and potential selection bias, as participants were often motivated and technologically adept, which may not represent the general PD population.

Meta-analyses and systematic reviews lend support to these findings. A systematic review by Goodwin et al. and a Cochrane review by Laver et al. concluded that tele-rehabilitation is not inferior to in-person interventions in improving mobility and balance in neurological populations, including those with PD (32, 37). However, critical analysis reveals notable inconsistencies across included studies. Many lacked blinding of participants and outcome assessors, increasing the risk of performance and detection bias. Furthermore, considerable heterogeneity in intervention types (e.g., duration, technology used, supervision level), outcome measures (e.g., BBS, TUG, 6MWT), and population characteristics (e.g., PD severity, comorbidities) complicates the synthesis of findings and weakens the strength of recommendations.

Additionally, mobile health (mHealth) technologies and wearable sensors are increasingly being incorporated into PD rehabilitation frameworks. These include step counters, inertial sensors, and smartphone-based applications capable of tracking gait speed, postural sway, and medication adherence (38). They offer the potential for real-time monitoring and adaptive feedback, which may enhance engagement and individualize interventions (39). Nevertheless, these technologies present practical challenges: older adults with PD may face barriers related to digital literacy, technological accessibility, or cognitive impairment, all of which can affect adherence and the reliability of collected data. Moreover, not all studies adequately report on technical failures, dropout rates, or user experience, which are essential for assessing feasibility in real-world settings.

Overall, while the evidence increasingly supports the clinical viability of tele-rehabilitation in PD care, many studies fall short in methodological rigor, particularly in randomization processes, assessor blinding, and follow-up assessment. Larger, multicenter randomized trials with standardized protocols, consistent outcome measures, and diverse populations are required to fully validate the long-term effectiveness, cost-efficiency, and patient satisfaction associated with tele-rehabilitation modalities in Parkinson's disease.

Mechanisms by Which Tele-rehabilitation Improves Balance

Tele-rehabilitation enhances balance in PD patients by promoting neuroplasticity through repetitive, task-specific training, even in remote settings (40). Regular engagement in virtual balance exercises stimulates cortical and subcortical motor pathways, potentially preserving functional connectivity despite ongoing neurodegeneration (41). Moreover, visual and auditory feedback delivered through virtual platforms strengthens sensorimotor

integration, which is critical for postural control and dynamic balance in individuals with Parkinson's disease (42).

Several studies have investigated these mechanisms using virtual reality or interactive biofeedback systems. For instance, Gandolfi et al. demonstrated improved balance outcomes following a VR-based tele-rehabilitation protocol; however, the study lacked blinding of outcome assessors and used a relatively short intervention period, raising concerns about long-term sustainability. Similarly, the study by Cikajlo et al. incorporated biofeedback through remote platforms but included a small, non-randomized sample, which limits external validity. These design flaws, including small sample sizes and insufficient follow-up, restrict our ability to draw robust conclusions about the durability and generalizability of these neural adaptations.

Another key mechanism is the psychological impact of structured tele-rehabilitation on patient motivation and confidence (43). Several observational studies and small trials have suggested that the ability to perform guided exercises from home reduces anxiety related to mobility limitations and fear of falling (44). This perceived safety, along with consistent therapist interaction, has been linked to improved exercise adherence and enhanced self-efficacy. Nevertheless, many of these studies did not control for confounding variables such as baseline anxiety levels, caregiver support, or prior technology use. Furthermore, few trials systematically measured psychological outcomes alongside physical balance metrics, which presents a missed opportunity for understanding the holistic impact of tele-rehabilitation.

Overall, while the underlying mechanisms proposed are physiologically plausible and supported by preliminary evidence, many studies suffer from limited methodological rigor. To establish causal pathways, future trials should incorporate standardized neurophysiological measures (e.g., fMRI, posturography), validated psychological scales, and robust study designs with control groups, blinded assessment, and adequate sample sizes.

Discussion

Benefits and Limitations of Tele-rehabilitation

Tele-rehabilitation offers substantial benefits, especially in improving access to care for individuals in rural or underserved areas (46). It allows patients to participate in consistent therapy sessions without transportation burdens, thus enhancing continuity of care (47). Furthermore, tele-rehabilitation platforms can be customized for individual needs and disease stages, offering flexibility in intervention design (48).

Another advantage is cost-effectiveness, with several studies reporting reduced healthcare utilization and improved efficiency with remote delivery models (49). Patients also report high satisfaction with tele-rehabilitation programs, citing convenience, real-time interaction, and comfort of home environments (47). These elements make tele-rehabilitation an attractive alternative, particularly for those with advanced disease or logistical constraints.

However, limitations exist, including technological barriers such as limited internet access, low digital literacy, and lack of appropriate devices for some populations (47). Additionally, not all motor symptoms can be adequately assessed or treated remotely, and safety concerns may arise during unsupervised exercises (49). These challenges highlight the need for hybrid models and proper patient selection to optimize tele-rehabilitation outcomes (48).

Challenges and Future Directions

While tele-rehabilitation shows promise, several critical challenges remain. These include the lack of standardized intervention protocols, limited integration into existing healthcare infrastructures, and insufficient training for both clinicians and patients in using digital platforms effectively (48). Many current studies differ widely in terms of duration, frequency, type of technology used, and outcome measures, making cross-study comparisons and meta-analyses difficult. Moreover, few trials have evaluated the long-term sustainability of balance improvements or addressed whether observed benefits translate into reduced fall incidence or hospitalization.

Another significant gap is the underrepresentation of older adults with cognitive impairments or limited digital literacy, who may be least likely to access and benefit from tele-rehabilitation. Studies often recruit highly motivated participants with adequate technological access and support, which may not reflect the broader Parkinson's disease population. Additionally, very few investigations include cost-effectiveness analyses, which are crucial for policymakers considering widespread implementation of tele-rehabilitation services.

Future research should prioritize the development of standardized, replicable tele-rehabilitation protocols, including dosage guidelines and technology specifications. Long-term randomized controlled trials with diverse participant populations are needed to assess durability of outcomes, adherence over time, and real-world impact

on fall rates and quality of life. Furthermore, the integration of artificial intelligence (AI) and machine learning into tele-rehabilitation platforms could enable personalized feedback loops, optimizing exercise programs in real-time based on patient performance and symptoms. Research into AI-driven interventions, along with clinician and patient usability studies, will be essential for ensuring that tele-rehabilitation systems are not only effective but also scalable and accessible.

Conclusion

Tele-rehabilitation represents a promising and increasingly essential approach to managing balance impairments in individuals with Parkinson's disease. By leveraging digital platforms, it offers flexible, scalable, and patient-centered interventions that are comparable in effectiveness to traditional in-person therapies. Beyond improving motor outcomes, tele-rehabilitation enhances accessibility, supports long-term adherence, and empowers patients to take an active role in their care. While current evidence supports its clinical potential, future efforts should address technological barriers, standardize intervention protocols, and explore long-term outcomes to optimize its integration into routine neurological rehabilitation.

Tables and graphs

Table 1: Characteristics of Included studies

Study ID	Study Design	Intervention Details	Disease	Outcomes Measured	Conclusion
Hall et al., 2025	Scoping review	Various digital health technologies including smartphones, video conferencing, virtual physical therapy, telecoaching, and apps	Parkinson's Disease	Self-efficacy, Falls Efficacy Scale, Exercise Self-efficacy, Physical Activity Assessment	Mixed findings; 5 of 11 studies showed statistically significant improvement in self-efficacy. Multimodal DHTs focusing on physical activity and fall prevention showed promise.
Cikajlo et al., 2012	Pilot clinical trial	Virtual reality-based balance training via dynamic standing frame in hospital and home settings with telerehabilitation	Stroke	Berg Balance Scale (BBS), Timed Up and Go (TUG), 10-m walk test, stance time	Telerehabilitation using VR significantly improved balance and gait outcomes; outcomes comparable to in-clinic therapy.
Goodwin et al., 2008	Systematic review and meta-analysis	Various exercise interventions (group/individual, physiotherapist-led, etc.) for PD patients	Parkinson's Disease	Balance, gait speed, strength, physical function, QoL	Exercise was beneficial for physical function, strength, balance and gait in PD patients; insufficient evidence for falls and depression reduction.
Laver et al., 2020	Systematic review (Cochrane Review)	Telerehabilitation vs. in-person rehab or usual care; various technologies including video calls, remote exercise, cognitive rehab	Stroke	Activities of Daily Living (ADL), Balance, Upper Limb Function, Depression, QoL	No significant difference between telerehabilitation and in-person/usual care; not inferior and may be cost-saving. Low-to-moderate quality evidence.
Cottrell et al., 2016	Systematic review and meta-analysis	Real-time telerehabilitation for musculoskeletal conditions using video conferencing and remote supervision	Musculoskeletal conditions	Physical function, Pain	Telerehabilitation is effective and comparable to standard care. Addition to usual care shows stronger benefits; stand-alone is equivalent to in-person

					therapy.
Espay et al., 2016	Expert consensus review	Use of wearable technologies and sensors for motor and non-motor monitoring in PD	Parkinson's Disease	Motor symptoms, gait, tremor, balance, non-motor outcomes like fatigue and depression	Wearable tech offers personalized care and improved monitoring. Barriers include compatibility, adherence, and meaningful clinical integration. Standardization is needed.

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