Medical Science

Role of Exercise in Parkinson's Disease - A Review of the Literature

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ABSTRACT

Parkinson's disease (PD) progressively affects movement, with gait disturbance and impaired balance often becoming major reasons for loss of independence. Dopaminergic therapy can improve tremor, rigidity and bradykinesia, but it has a more limited effect on axial symptoms and long-term mobility decline. This makes structured exercise relevant in PD care, particularly when the aim is to preserve walking ability, postural control and everyday function. This review evaluates evidence on aerobic, resistance, balance, mind-body, combined and technology-supported exercise interventions in PD, with attention to motor outcomes and possible neuroplastic, anti-inflammatory and neuroprotective mechanisms. The PubMed search included English-language full texts, mainly randomised controlled trials, systematic reviews and meta-analyses reporting motor outcomes. Tai Chi results were strongest for balance and mobility tests, mainly BBS and TUG, with weaker evidence for improvement across the full motor spectrum. Biomarker findings were more variable. Higher BDNF or lower inflammatory markers appeared in some longer programmes, but these results mainly help frame possible mechanisms. In freezing of gait, VR and cueing studies are still hard to compare because most were small, brief and methodologically different. In practice, 150-180 minutes per week of moderate-to-vigorous, multicomponent exercise appears reasonable. The main unresolved issues are optimal dose, durability of benefit, patient selection and the practical role of telerehabilitation in advanced disease.

Keywords: Parkinson's disease, motor symptoms, physical activity, rehabilitation, virtual reality

1. INTRODUCTION

Definition of Parkinson's disease

Parkinson's disease (PD) is among the most common neurodegenerative disorders in older adults, affecting approximately 2-3 % of the population ≥ 65 years of age (Poewe et al., 2017). The clinical diagnosis is based primarily on a characteristic motor syndrome that includes resting tremor, bradykinesia, muscular rigidity, and postural instability. As the illness advances, non-motor features such as cognitive impairment, depression, sleep disturbances, and autonomic dysfunction become increasingly prominent (Kalia & Lang, 2015).

Current standards of treatment

Levodopa and other dopaminergic drugs remain central to symptomatic treatment, especially for bradykinesia, rigidity and tremor. Their effect is less reliable for later axial problems, including impaired gait, balance disturbance and loss of independence, and they do not stop disease progression (Klein & Westenberger, 2012). This is the clinical space in which physical activity has gained importance as a non-pharmacological addition to standard care (Goldman, 2014).

The role of exercise in Parkinson's disease

The main gap left by dopaminergic treatment concerns axial and functional problems. This is where aerobic exercise is most relevant: walking, stationary cycling and Nordic walking have been associated with better gait measures, postural control and motor performance, rather than with a general reversal of PD-related impairment (Blesa et al., 2015; Tansey & Romero-Ramos, 2019). Reports of better well-being and fewer falls among physically active patients are also important, but they are harder to interpret because more active patients may differ at baseline from those who exercise less (Ascherio & Schwarzschild, 2016).

Mind-body exercise: Tai Chi, Qigong, and related practices

Tai Chi seems to act mainly through balance training rather than through a broad effect on every motor symptom. In the reviewed studies, the improvement was seen chiefly in Berg Balance Scale and Timed Up and Go results. This is why the intervention is best interpreted as a balance- and mobility-oriented approach. The biological findings are more difficult to interpret. Higher BDNF and lower pro-inflammatory cytokine concentrations after longer programmes may help explain part of the clinical response, but they do not show that exercise alters the disease process itself. For virtual-reality training and cueing systems, freezing of gait remains the most relevant target. At this stage, the main problem is not the absence of positive results, but the limited reliability of the evidence: small groups, short observation periods and markedly different training protocols.

Neuroprotective and neuroplastic mechanisms

Exercise is also being studied for molecular and structural effects that could support clinical improvement. In patients with PD, physical activity has been associated with higher brain-derived neurotrophic factor (BDNF), better mitochondrial function, reduced neuroinflammatory activity and lower oxidative stress. These mechanisms provide a biological rationale for structured training, although they do not yet establish exercise as a stand-alone disease-modifying therapy.

2. REVIEW METHODS

The PubMed search covered randomised controlled trials, systematic reviews and meta-analyses published between January 2012 and June 2025. The search terms included "Parkinson's disease", "exercise", "physical activity", "aerobic", "resistance", "balance", "Tai Chi", "rehabilitation" and "UPDRS". Studies were excluded when they focused exclusively on non-motor outcomes, assessed non-exercise interventions or were not available as full-text English-language articles. The study identification, screening, eligibility assessment and inclusion process is presented in Figure 1.

3. RESULTS AND DISCUSSION

Regular physical activity is one of the few non-pharmacological strategies repeatedly studied as an adjunct to PD treatment. The most consistent findings are motor and functional rather than definitive evidence of slowed disease progression. As shown in Table 1, improvements cluster around MDS-UPDRS III, gait measures, balance and functional capacity. The training setting seems less important than the content and continuity of the programme. In both supervised and home-based interventions, aerobic, resistance and balance-oriented exercise was associated mainly with better stride parameters and postural stability. These studies provide more information about gait mechanics than about later disability. Stride length and postural-stability scores were reported more often, whereas falls and independence were assessed less regularly or over too short a period (Blesa et al., 2015; Shulman et al., 2013; Shu et al., 2014).

Tai Chi deserves separate attention because its training pattern directly involves slow weight shifting, controlled movement and postural adjustment. In randomised trials, the main reported gains concerned balance and bradykinesia, while longer practice was sometimes accompanied by higher BDNF or lower inflammatory marker levels (Ni et al., 2014; Gu et al., 2021; Deuel & Seeberger, 2020). These biological changes may help explain part of the clinical response, but they do not establish causality. VR and cueing systems address a different problem: gait rhythm and freezing of gait. For VR and cueing systems, the available studies focus mainly on gait rhythm and freezing of gait, but robust clinical trials are still relatively few (Dockx et al., 2016; Mirelman et al., 2013).

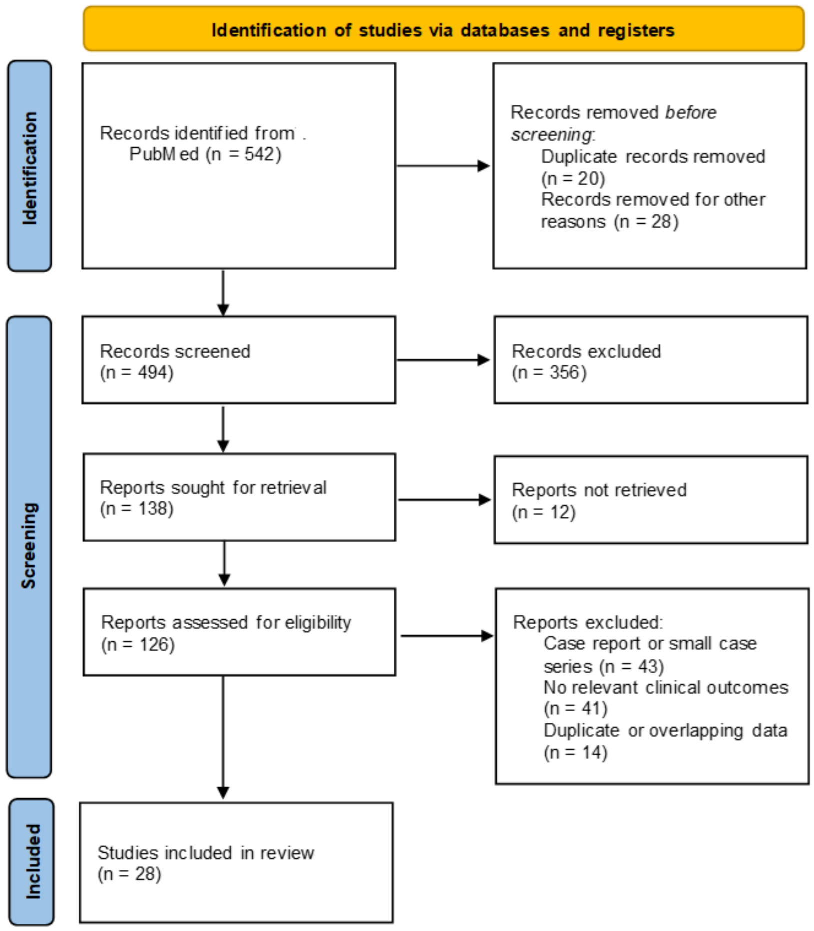

Figure 1. Flow chart for selection of articles

Several limitations make direct comparison between studies difficult. Many trials lasted only 6 to 12 weeks, so they provide little information about the persistence of training effects. Sample sizes were often small, and protocols differed in intensity, volume, supervision and combinations of exercise modalities. This heterogeneity limits attempts to define an optimal exercise dose. Non-motor symptoms are also underrepresented, despite the strong influence of depression, sleep disturbance and cognitive impairment on quality of life. Finally, patients with advanced disease, pronounced FOG or a history of deep brain stimulation are rarely included, so the results cannot be transferred to these groups without caution.

For future trials, follow-up length is probably the key limitation to address. Studies lasting 12 months or longer would make it easier to determine whether exercise produces only temporary symptomatic gains or whether the observed changes persist after the supervised intervention ends. The addition of biomarkers, including BDNF and alpha-synuclein, together with neuroimaging, could help clarify which clinical improvements are accompanied by measurable changes in neural function. Technology-based rehabilitation should also be tested in more pragmatic settings. In particular, home VR and telerehabilitation programmes need data on adherence, fall risk, tolerability and technical problems encountered by patients outside specialist centres.

These limitations do not weaken the practical role of exercise in PD care. The most defensible reason for prescribing regular, individualised training is its effect on motor performance and day-to-day mobility. Claims about disease modification should be kept separate from this clinical benefit, because they still rely mainly on biomarker findings and proposed mechanisms. Exercise is therefore best positioned as an adjunct to dopaminergic treatment and, in selected patients, surgical therapy, not as an alternative to either. The main exercise interventions and outcomes reported in the included studies are summarized in Table 1.

Table 1. Summary of exercise interventions and main outcomes in Parkinson's disease.

Intervention type	Examples	Main outcomes	Overall findings
Aerobic exercise	Treadmill, cycling, brisk walking, Nordic walking	Motor symptoms, gait, endurance, quality of life	Improved mobility, aerobic capacity and functional performance
Resistance training	Progressive strength training, lower-limb exercises	Muscle strength, balance, daily function	Improved strength and supported functional independence
Balance training	Static and dynamic balance exercises, postural training	Balance, postural stability, fall risk	Improved balance and postural control
Gait training	Treadmill training, cueing, walking tasks	Gait speed, stride length, freezing of gait	Improved selected gait parameters and walking ability
Mind–body exercise	Tai Chi, yoga, Qigong, Pilates	Balance, flexibility, well-being	Beneficial effects on balance, flexibility and quality of life
Dance-based exercise	Tango, ballroom dance, rhythmic dance	Gait, coordination, balance, participation	Improved gait, coordination and movement confidence
Technology-assisted training	Virtual reality, exergaming, wearable cueing	Gait, balance, adherence	Promising effects, but protocols were heterogeneous
Multimodal rehabilitation	Combined aerobic, resistance, balance and gait training	Global motor function, mobility, daily activities	Broad functional benefits across several domains

The available evidence supports structured physical exercise as a safe and clinically useful adjunct to pharmacotherapy in Parkinson's disease. The most reliable benefits concern motor outcomes that are directly trained: bradykinesia, gait parameters and postural stability. Longer participation may also be accompanied by higher BDNF levels and lower markers of neuroinflammation, but these biological findings should be interpreted as possible mechanisms rather than definitive proof of neuroprotection. Exercise-related benefits may involve overlapping mechanisms, including reduced oxidative stress, increased neurotrophin signalling, motor network reorganisation and improved cerebral microcirculation.

For clinical practice, a weekly target of about 150-180 minutes of moderate-to-vigorous activity is a reasonable starting point, especially when the programme combines aerobic, resistance, balance and flexibility components. The expected benefit is mainly functional: better motor performance, safer mobility and, in many patients, improved quality of life. For freezing of gait, VR-based training and cueing systems are useful areas of development, but the present data are still not strong enough to define which patients benefit most, how long the effect lasts, or how these tools should be incorporated into routine rehabilitation.

The main gaps now concern durability of benefit, standardisation of exercise dose and access for patients with advanced disease. Longer follow-up, common outcome measures and pragmatic telerehabilitation studies would make future recommendations more precise. Until such data are available, clinicians can reasonably prescribe personalised, multi-component exercise programmes as part of routine Parkinson's care.

Pathogenesis and Motor Manifestations of Parkinson's Disease

Etiopathogenesis

PD is a progressive central nervous system neurodegenerative disease, the primary pathogenesis of which is the progressive loss of dopaminergic neurons in the substantia nigra pars compacta. This process leads to dopamine loss, mainly in the caudate nucleus, and putamen, impairment of the functional balance of basal ganglia motor circuits, and aggravation of the typical motor symptoms of PD (Poewe et al., 2017; Kalia & Lang, 2015).

At the molecular level, oxidative stress and dysfunction of mitochondrial respiratory complex I play a vital role - excessive production of reactive oxygen species damages proteins, lipids, and mitochondrial DNA, thereby triggering degenerative processes (Blesa et al., 2015). The accumulation of misfolded α-synuclein further amplifies this phenomenon, the principal constituent of Lewy bodies, which is pathognomonic for PD. Point mutations or multiplications of the SNCA gene accelerate α-synuclein aggregation. At the same time, prion-like cell-to-cell spread of the protein underlies the rostro-caudal pattern of pathological progression (Burke et al., 2008).

Another important factor is a genetic predisposition, such as mutations in LRRK2, PARK2 (parkin), PINK1 and DJ-1, that impair mitochondrial repair abilities, and vesicular transport, rendering neurons more vulnerable to oxidative stress (Klein & Westenberger, 2012). Environmental factors compound the risk - especially chronic exposure to complex-I-inhibiting pesticides and herbicides, whereas cigarette smoking and caffeine intake appear to exert a protective effect (Goldman, 2014).

Evidence supports the critical importance of immunology: the brains of PD patients exhibit chronic microglial activation, and elevated levels of pro-inflammatory cytokines. Moreover, immunological research has identified autoreactive T cells that recognise α-synuclein peptides (Tansey & Romero-Ramos, 2019). This type of neuroinflammation not only persists alongside oxidative damage but also accelerates the deposition of pathological protein species.

In practical terms, these mechanisms affect the same motor pathway. Oxidative stress, α-synuclein misfolding, mitochondrial dysfunction, immune activation and genetic vulnerability gradually reduce the population of dopaminergic neurons in the substantia nigra. As striatal dopamine decreases, basal ganglia motor circuits become less stable, leading to the characteristic motor manifestations of Parkinson’s disease (Poewe et al., 2017; Kalia & Lang, 2015).

Motor abnormalities

The earliest motor symptoms are often subtle and may precede a formal diagnosis of Parkinson's disease by several years. The primary clinical manifestation remains bradykinesia - a slowness, and decrement in movement amplitude or speed which, according to MDS criteria, is the sine qua non for establishing the diagnosis (Postuma et al., 2015; Porciuncula et al., 2025). In reality, patients exhibit prolonged execution of routine tasks, reduced gestures, and "masked face expression". Also typical is muscular rigidity, a non-yielding resistance to passive movement of the limbs, which often occurs with the so-called cog wheel phenomenon; constant tone in rest, and on movement causes pain and loss of range of movement (Kalia & Lang, 2015). The third foundation of the symptom complex is that resting tremor at 4-6 Hz is most common in the distal upper limbs, aggravated by stress or fatigue; however, it is absent in approximately a third of patients and is often considered the most problematic.

With increases in neurodegeneration, gait, and balance disorders develop - steps become shorter, shoulders become less mobile, the trunk becomes stooped, and a small group of patients has a freezing of gait (FOG). Postural instability accompanies these issues, significantly predisposing to falls, and to the inability to control oneself. The progressive worsening of these manifestations, and the increasingly unpredictable response to levodopa in advanced stages highlight the need for early implementation of complementary therapeutic strategies, mainly targeted physiotherapy and structured exercise programmes that can limit disability and enhance quality of life.

Clinical evaluation of motor symptoms

The instruments most used to evaluate motor impairment are:

- MDS-UPDRS (part III) - motor examination section of the Unified Parkinson's Disease Rating Scale (Goetz et al., 2008),
- TUG (Timed Up and Go Test) - assessment of functional mobility,
- BBS (Berg Balance Scale) - a quantitative measure of balance,
- Hoehn and Yahr scale - five-stage classification of Parkinson's disease severity.

Impact of motor symptoms on quality of life

The motor manifestations significantly reduce the quality of life of patients by reducing their self-containment and mobility, exposing them to falls and caregiver dependence. Consequently, comprehensive management must extend beyond pharmacotherapy to include non-pharmacological strategies - most notably physical activity and exercise programmes (Van Nimwegen et al., 2013; Shulman et al., 2013).

Types of Physical Exercise Used in Patients with Parkinson's Disease

Clinical studies indicate that different forms of physical activity can improve motor manifestations of Parkinson's disease. The broadest benefit is usually seen when endurance, resistance and balance exercises are combined with mind-body practices, because each modality targets a different limitation: cardiorespiratory capacity, muscle strength, postural control or movement coordination.

Aerobic exercise

Aerobic training in PD usually involves brisk walking, stationary cycling, Nordic walking or dance. In most protocols, patients train three to five times per week for 30-60 minutes at moderate-to-vigorous intensity. The expected effects are not limited to fitness. Studies report changes in bradykinesia, gait speed and stride length, with Shu et al. showing lower UPDRS-III scores after regular aerobic exercise (Shu et al., 2014). Home programmes can be useful, but their effectiveness depends on adherence, appropriate intensity and safe progression rather than the absence of supervision itself.

Resistance training

Resistance training uses machines, elastic bands, free weights or body weight to strengthen the limbs and trunk. In PD, the clinical target is not only muscle force but also safer transfers, better postural responses and lower fall risk. In the trial by Shulman et al., progressive resistance training improved UPDRS III to a degree similar to aerobic exercise, although the two modalities probably act through partly different functional pathways (Shulman et al., 2013).

Balance and coordination training

Balance and gait disorders are among the most common practical problems in PD. Targeted programmes therefore use static and dynamic balance tasks, proprioceptive exercises, unstable surfaces and visual or auditory cues. These interventions are most relevant for TUG, BBS and FOG-related outcomes, where better rhythm and confidence during walking may matter as much as the numerical change in a test score (Shu et al., 2014).

Mind-body exercise

Mind-body practices such as Tai Chi, Qigong and yoga combine slow movement, breathing control and focused attention. Their value in PD is mainly related to balance, postural transitions and movement fluidity. Randomised trials report improvements in MDS-UPDRS III, BBS and TUG scores after Tai Chi practice (Li et al., 2012; Ni et al., 2014). In longer interventions, changes in BDNF and other neurotrophic markers have also been described, but these findings are better interpreted as possible biological correlates of training rather than direct proof of neuroplastic recovery (Gu et al., 2021; Deuel & Seeberger, 2020).

Combined Training

Multicomponent programmes may be useful because they address several functional deficits at the same time. A typical 12-week protocol with 60-minute sessions three times per week can combine brisk walking, strengthening and flexibility work. In this model, the advantage is not that one modality is superior, but that gait, strength, balance and daily function are trained within the same programme. Such interventions appear to be well tolerated and may produce broader functional gains than single-modality exercise (Shulman et al., 2013).

Modern Technologies

Technology-based rehabilitation should be discussed mainly in relation to the physiotherapy task it supports. In the case of VR, the main advantage is that gait and balance exercises can be performed in a controlled visual environment, with feedback given during the task rather than only after it. In VR studies, balance and walking distance were the outcomes most often showing improvement. Some treadmill-plus-VR protocols also recorded fewer unexplained falls than conventional treadmill training, although the comparison is limited by the specific patient groups and study designs used in these trials (Dockx et al., 2016; Mirelman et al., 2013). Among the 27 trials included in a recent meta-analysis, post-intervention results did not suggest an immediate loss of all gains after VR-based training. The clearest residual effects concerned balance and walking speed. This observation is clinically relevant, but it should be interpreted with caution because the studies differed in training duration, outcome assessment and follow-up timing, making it difficult to define a reliable period of benefit in everyday rehabilitation practice (De Natale et al., 2025).

Robot-assisted gait trainers, including the Lokomat (R), are usually studied as an addition to standard rehabilitation rather than as stand-alone treatment. In a 2024 review of 14 RCTs, this approach was associated with better walking speed, endurance and Timed Up and Go Test performance (Jiang et al., 2024). Wearable cueing systems are used more specifically for gait rhythm and freezing episodes. DeFOG is an example of this approach: the sensor produced an acoustic cue only when freezing of gait was detected. In the 63-patient study, freezing severity was reduced by about half, and the effect was observed in both medication-OFF and medication-ON states

(Zoetewei et al., 2024). Q-Walk addressed the same problem with a different form of cueing - tested whether portable visual cueing could replace floor stripes during physiotherapy. Patients used laser-projecting shoes during ten 90-minute sessions added to standard therapy. The main result: stride length and balance noted no improvement to conventional stripe-based training, but patients found the shoes easier to use at home and more motivating (Bartolo et al., 2024). Cueing is no longer limited to therapist-controlled rehabilitation sessions. The unresolved issue is how well such devices work during unsupervised daily walking, where adherence, incorrect cue delivery, comfort and fall risk may be as important as short-term changes in gait parameters.

In technology-assisted rehabilitation, the device itself is not the main issue. Its value depends on whether it helps the patient complete enough safe, repeated practice during the week. This is particularly important outside specialist centres, where supervision is limited and problems such as fatigue, poor adherence or fall risk may reduce the real training dose.

A single exercise type rarely matches the full motor profile of PD. Endurance training is most useful when gait capacity and fatigue are the main concerns, whereas resistance exercises are more relevant for weakness, transfers and rising from a chair. Balance work has a different target: postural control and fall prevention. Mind-body exercises add slower, coordinated movement, which may be helpful when patients struggle with rhythm, stability or movement fluidity. Programmes continued for at least 12 weeks tend to show clearer functional change than very short interventions, but the reviewed studies still differ too much to define one optimal training dose.

Biological Mechanisms Underpinning the Benefits of Physical Activity in Parkinson's Disease

The clinical effects of exercise in PD are usually explained through several overlapping mechanisms rather than a single pathway. The main proposed processes are reduced oxidative stress, changes in neurotrophic signalling, reorganisation of motor networks and improved cerebral perfusion. The strength of evidence differs between these mechanisms, so mechanistic findings should be treated as supportive explanations for clinical improvement rather than as definitive proof of neuroprotection.

Neuroprotection and Reduction of Oxidative Stress

Endurance and resistance training reduce reactive oxygen species production and increase antioxidant activity, mainly superoxide dismutase and catalase. In studies and clinics, this limits lipid peroxidation in dopaminergic neurons of the substantia nigra (Goldman, 2014; Blesa et al., 2015). Exercise has also been associated with lower central levels of pro-inflammatory cytokines, including TNF-alpha and IL-1beta - a possible link between physical training and slower neurodegenerative stress (Tansey & Romero-Ramos, 2019).

Enhanced Neuroplasticity

The neurotrophin pathway is relevant because it offers a biological explanation for some training-related motor changes. BDNF, NGF and GDNF are involved in dopaminergic neuron maintenance and synaptic signalling, so changes in these markers after exercise may help explain part of the clinical response (Gu et al., 2021; Deuel & Seeberger, 2020). In long-term Tai Chi studies, imaging findings have included differences in grey matter volume within the precentral gyrus and basal ganglia, both of which are important for postural control. These results are interesting, but they remain difficult to compare across studies because the training protocols, imaging techniques and timing of assessment were not uniform (Gu et al., 2021).

Functional Reorganisation of Motor Networks

Aerobic and mind-body training may affect cortico-striatal circuits involved in motor control. Functional MRI studies reported stronger connectivity between the motor cortex, thalamus and cerebellum after exercise, which could represent a compensatory response to impaired striatal function. This mechanism fits with the reduction of bradykinesia reported in some clinical studies, but it is still difficult to link a given connectivity change with the motor response of an individual patient (Shu et al., 2014; Deuel & Seeberger, 2020).
Improved Cerebral Perfusion and Angiogenesis

Endurance training influence cerebral perfusion by promoting angiogenic signalling in cortical and basal ganglia networks. Improved perfusion may be relevant mainly because dopaminergic pathways have high metabolic demands and are sensitive to impaired energy supply. This vascular effect should be treated as one possible contributor to better motor performance, not as an alternative to dopaminergic therapy (Frazzitta et al., 2015). One proposed pathway involves muscle-derived lactate entering the brain and stimulating HCAR1 on perivascular cells, followed by increased VEGF-A activity and capillary sprouting (Morland et al., 2017). In animal models, four weeks of moderate treadmill exercise restored striatal microvascular density and dopaminergic neurons (Al-Jarrah et al., 2010). Human evidence is still inconseqent. In one cohort of patients with mild PD, 24 weeks of cycling coincided with an increase in cerebrospinal-fluid VEGF; gait speed improved and MDS-UPDRS III scores decreased in the same participants. This finding keeps angiogenesis in the discussion of possible mechanisms, but it does not show that the VEGF change caused the motor improvement (Luthra et al., 2025). The main unresolved questions are whether the VEGF change is reproducible, what training intensity is required and whether improved vascular support has any measurable effect on levodopa response in routine care.

Influence on Biomechanical Gait Parameters

Cueing and VR-based programmes improve gait by changing how patients use external sensory information during walking. Visual, auditory or haptic cues help regulate step timing and stride length, which is particularly relevant in freezing of gait (Dockx et al., 2016; Mirelman et al., 2013). Wearable systems such as DeFOG and laser-projecting shoes enable ambulatory treatment. Daily use, accuracy of cue delivery, comfort, adherence and fall risk are likely to determine whether short-term gait gains become significant improvement in real-world (Zoetewei et al., 2024; Bartolo et al., 2024).

4. CONCLUSION

Structured, individualised exercise should be considered an important adjunct to pharmacological treatment in Parkinson's disease. The reviewed evidence supports its role in improving motor function, gait and postural control, while its potential neuroprotective or disease-modifying effects require confirmation in longer and better-standardised studies.

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Informed consent

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Ethical approval

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Conflict of interest

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Data and materials availability

All data associated with this study will be available based on the reasonable request to corresponding author.

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