The Impact of Physical Activity on Parkinson's Disease: A Comprehensive Review

Yash A. Gooty

ABSTRACT

Parkinson's Disease (PD) is the second most common neurodegenerative disease in the world, currently affecting over 8 million people. It is associated with complications in dopamine function, resulting in both motor and nonmotor symptoms. Currently, the main ways of treatment are through medication. However, patient improvement is often limited due to an increase in tolerance. Physical training has been shown to improve both motor and nonmotor symptoms, specifically around gait, balance, and general quality of life. Exercise has been correlated with improved signaling and release of dopamine in PD patients, which positions it to be a powerful therapeutic avenue. This paper aims to analyze the positive effects that aerobic exercise, strength training, stretching, and various other disciplines have on symptoms of PD, as well as examine the effect of duration and intensity of all mediums of training. While distinct types of exercise improve the health and symptoms of PD in patients, more research into combinatorial exercise plans is necessary. Combinatorial exercise plans offer increased safety and better cognitive involvement, which is notably lacking in current pharmacological treatments.

INTRODUCTION

PD is a progressive neurodegenerative disease characterized by both motor and nonmotor symptoms. Risk factors for PD are both genetic and environmental. PD is extra prevalent in adults 60 years or older and has a higher occurrence in men than in women [1]. Motor symptoms include tremors, rigidity, bradykinesia, and postural instability. Nonmotor symptoms consist of cognitive decline, mood disorders, and sleep disturbances [2]. All these symptoms cause independence and quality of life to plummet for affected individuals. Disease severity is commonly evaluated using the Unified Parkinson's Disease Rating Scale (UPDRS), which assesses both motor and nonmotor symptoms to provide a comprehensive measure of disease impact, where a lower score indicates improvement in motor ability. Despite the understanding of pathophysiology increasing, effective treatment strategies remain limited. New research into other mechanisms of PD (e.g. neuroinflammation, decreased mitochondrial function, oxidative stress), has found many current treatments do not address these potential mechanisms. Common pharmacological treatments of dopamine supplementation have many issues, such as increasing tolerance that limits improvement in patients. Medication only serves to ease current symptoms

rather than stop or slow disease progression [2]. Because of these limitations, alternative treatments have been investigated as potential therapies for the treatment of PD.

Exercise has the capacity to improve a wide range of motor and nonmotor symptoms, due to its hypothesized impact on the dopaminergic system [3]. Exercise programs can also be tailored to an individual's requirements and needs. The many types of training, including aerobic, muscular strength, flexibility, and various other mediums provide avenues for combinatorial exercise. More research needs to be done on the benefits of combinatorial exercise regimes, as many hypothesize that combining different exercise modalities may optimize improvements in motor function, cognitive performance, and quality of life. These programs may offer enhanced safety and greater cognitive benefits than current pharmacological plans [4]. This paper aims to explore the effects of various exercise modalities on PD, with a focus on how different types, durations, and intensities of exercise affect the severity of the disease. This review also identifies gaps in current understanding and identifies potential exercise interventions that maximize therapeutic benefit for individuals with PD.

1. AEROBIC EXERCISE

Aerobic exercise has emerged as one of the most effective non-pharmacological interventions for managing and treating PD, targeting both motor and non-motor symptoms [2]. Motor symptoms such as bradykinesia, rigidity, tremor, and postural instability are common and are the basis for PD severity [5]. Aerobic exercise is a type of physical activity that involves constant rhythmic movements used to increase cardiovascular health [6]. It primarily relies on aerobic respiration, where oxygen is used to produce energy for the body in the form of ATP. Aerobic exercise is particularly beneficial for cardiovascular health, as it helps strengthen the heart, improve lung function, and boost circulation. VO_2 peak, a measure of the maximum amount of oxygen an individual can utilize during intense exercise, is often used to gauge aerobic fitness levels and track improvements from training programs. Aerobic exercise has also been shown to improve mood, cognitive function, and overall energy levels [6]. It is widely recommended for individuals looking to enhance their physical fitness, as well as those with chronic conditions such as heart disease, diabetes, and PD. Various forms of aerobic exercise have been studied in PD populations, as these activities offer flexibility in intensity and duration, and can be tailored to individual fitness levels, making them accessible to a large population of patients ranging from early-stage to more advanced PD [4].

1.1 Types of Aerobic Exercise

Stationary cycling has drawn significant attention in research for its safe and easy usage in improving motor and

cognitive functions. Uygur et al. (2020) demonstrates that high-speed, low-resistance cycling can improve disease severity, balance, functional mobility, and cognitive function in individuals with mild to moderate PD [7]. After a stationary cycling regime of six weeks, motor severity measured by UPDRS was decreased, and cognitive ability, tested by serial reaction time, was found to improve by 13.1% [7]. This kind of exercise is especially appealing because its low-impact nature reduces strain on joints, while the high-repetition movements provide consistent sensory and motor stimulation. This is critical for promoting neuroplasticity, which refers to the ability of the brain to reorganize and form new neural connections, and reinforcing motor skill learning.

Treadmill walking and body-weight-supported treadmill training (BWSTT) are other commonly used aerobic exercises in the treatment of PD. Postural instability is a common motor symptom in patients with PD, and BWSTT aims to eliminate this caveat. Treadmill use enables controlled exercise intensity and precise monitoring of gait performance, while body-weight-supported treadmill training assists individuals with severe balance impairments or postural instability by partially supporting their body weight: 20% in this study [8]. This enables patients with more severe disabilities to engage in higher-intensity exercise without the risk of falling, thus enhancing motor performance and gait without compromising safety. These kinds of interventions can make aerobic exercises a more realistic avenue for PD patients.

Aquatic exercise has also been recommended for PD patients due to its low impact, which reduces joint stress and allows for freedom of movement. Water-based exercises can improve overall cardiovascular fitness while also enhancing flexibility, balance, and strength, especially in individuals who find land-based exercises challenging [9]. In the following study, participants found a 4.5-point decrease in their UPDRS-III scores, showing a significant decrease in motor symptoms of PD [9]. Aquatic therapy offers an alternative that can be beneficial for PD patients, who are generally older with joint problems. Carroll et al. found that participants enjoyed the aquatic exercise immensely, having a 100% attendance rate for the study and 90% saying they would continue their water aerobics after [9]. This clearly shows the feasibility and attractiveness of water-based exercise for PD patients.

In brief, these aerobic exercises offer many options tailored to the diverse needs of individuals with PD. Cycling and treadmill walking emphasize controlled, repetitive motions that enhance neuroplasticity and improve balance, gait, and cognitive functions, and aquatic therapy provides a gentler, low-impact environment that is particularly suitable for patients with joint or mobility issues. Aerobic exercise has

shown potential in improving motor symptoms such as gait instability and rigidity, while also providing promising avenues for supporting overall physical and mental well-being in individuals with PD.

1.2 Effects of Aerobic Exercise on Symptoms

Aerobic exercise has shown significant benefits for both motor and non-motor symptoms in PD. Studies have consistently shown that aerobic exercise improves motor performance by increasing functional mobility and balance. For instance, a 12-week intervention involving stationary cycling resulted in significant improvements in gait and motor function, in terms of both walking speed and stride length [10]. Aerobic capacity, measured in VO_2 peak, increased in the cycling group. This suggests that engaging in constant motor activities can lead to benefits that translate into daily life.

In addition to motor symptoms, PD patients experience cognitive dysfunction, depression, anxiety, and sleep disorders, all of which massively impact a patient's quality of life [2]. Aerobic exercise has positive effects on these non-motor symptoms of PD, by improving mood through the regulation of neurotransmitter systems (including dopamine, serotonin, and endorphins), which are often dysregulated in PD patients [11]. However, not all aerobic exercise regimes result in improvements in motor symptoms of PD patients. A study analyzing the benefits of aerobic exercise did not find any notable changes in non-motor symptoms [4]. The study incorporated both higher-intensity treadmill and lower-intensity treadmill exercise and found no significant improvement in symptoms such as depression and fatigue in either regime. Additional research into the specifics of aerobic exercise would help clarify these differing findings and provide more definitive conclusions on the effects of aerobic exercise on non-motor symptoms of PD.

Cognitive function is another non-motor symptom that benefits heavily from aerobic exercise. Impaired decision-making, memory problems, and gaps in attention are frequent in PD patients and are linked to both dopaminergic and non-dopaminergic pathways [3]. Aerobic exercise has been shown to enhance cognitive performance by increasing brain-derived neurotrophic factor (BDNF) levels, promoting synaptic plasticity and neurogenesis [12].

Aerobic exercise is a highly effective non-pharmacological intervention for managing both motor and non-motor symptoms in PD. It improves motor function by enhancing mobility, gait, and balance through repetitive activities like cycling, which mimic everyday movements [10]. Though the benefits for non-motor symptoms such as mood and cognition are still debated, aerobic exercise has shown promise in

improving cognitive function by increasing BDNF levels [12]. The overall impact of aerobic exercise on motor function and cognitive health makes it a critical component of disease management in PD. As more research addresses these nuances, it will help refine aerobic exercise interventions and further establish their role in managing the disease.

1.3 Mechanisms of Aerobic Exercise

The beneficial effects of aerobic exercise on motor and non-motor symptoms in PD are caused by several mechanisms. One of the primary mechanisms is neuroplasticity. Aerobic exercise results in changes in brain structure and function by promoting the release of biomolecules, such as BDNF, glial cell line-derived neurotrophic factor (GDNF), and insulin-like growth factor 1 (IGF-1) [12]. These molecules play a critical role in supporting neurons, promoting synaptic plasticity, and the formation of new neurons, particularly in regions affected by PD (such as the basal ganglia and motor cortex) [12]. In the 2016 meta-analysis, various forms of aerobic exercise were found to increase BDNF, including stationary cycling and treadmill training. Over different practices of aerobic exercise, the study found a standard effect size of 2.06 for exercise benefits on BDNF, showing a significant correlation. The UPDRS motor examination scores showed a mean difference of -5.33, indicating a clinically significant improvement in PD motor symptoms aligning with increases in BDNF [12].

Dopaminergic modulation is another key mechanism through which aerobic exercise exerts its effects. In PD, the progressive degeneration of dopaminergic neurons in the substantia nigra leads to dopamine depletion in the striatum, which is directly linked to many observed motor symptoms [3]. Aerobic exercise increases dopamine receptor sensitivity and enhances dopamine release, compensating for the loss of dopaminergic neurons. This is done by increasing the expression of D2 and D3 dopamine receptors in the striatum as well as enhancing activity in the mesolimbic pathway, a pathway responsible for reward and motivation. This improved dopaminergic function helps alleviate motor symptoms, including bradykinesia and rigidity, while also positively affecting non-motor symptoms like mood and cognition [3].

Aerobic exercise has also been found to regulate neuroinflammation, a process that is increasingly recognized as contributing to PD pathology. Chronic neuroinflammation makes neuronal degeneration worse, particularly in dopaminergic pathways. Aerobic exercise is able to lower levels of pro-inflammatory cytokines, such as TNF-α and IL-6 found in the blood [13]. Physical activity is also able to modulate the activation of microglia, the primary immune cells in the brain. Through this modulation, it reduces inflammation [13].

By reducing inflammation, aerobic exercise may slow the progression of neuronal damage in PD, contributing to longer-lasting motor and cognitive function.

Lastly, mitochondrial function and oxidative stress are critical factors in the pathogenesis of PD. Aerobic exercise improves mitochondrial function and oxidative stress. Oxidative stress is defined as an imbalance between the production of reactive oxygen species (ROS) and the body's ability to counteract these compounds. ROS are typically produced during aerobic metabolism, particularly in the mitochondria during ATP production. Therefore, the greater use of mitochondria to produce ATP can increase oxidative stress if the ROS are not adequately neutralized. Exercise training activates mitochondrial biogenesis in the skeletal muscle, which then increases the overall density of the mitochondria and enhances oxidative phosphorylation capacity [14]. Physical activity not only increases the efficiency of mitochondria but the number of them as well. This occurs through retrograde signaling, where the mitochondria send signals to the nucleus once a low ATP/ADP ratio is met, which causes the nucleus to activate genes that code for the production of more mitochondria [14]. This helps mitigate oxidative damage, further protecting neurons from degeneration.

In a word, aerobic exercise offers significant benefits for individuals with PD through multiple mechanisms, including enhanced neuroplasticity, improved dopaminergic function, reduced neuroinflammation, and improved mitochondrial health. These effects contribute to notable improvements in both motor and non-motor symptoms, showing the importance of physical activity as an efficient intervention. Promoting aerobic exercise is a vital strategy in managing PD and enhancing the quality of life for afflicted individuals.

2. STRENGTH TRAINING

Strength training, also known as resistance training, is a form of exercise designed to improve muscle strength by exercising specific muscle groups against external resistance. In PD, strength training has been researched as an effective approach to treating both motor and non-motor symptoms. Progressive resistance training (PRT) is a common form of strength training used when managing PD. Studies have shown that strength training can enhance functional mobility, reduce muscle weakness, and improve overall quality of life for individuals with PD.

2.1 Types of Strength Training

PRT involves performing exercises with increasing levels of resistance as muscle strength improves. Patients perform repetitive movements until muscle fatigue, followed by rest periods before increasing the resistance [15].

The resistance is typically provided by weights, resistance bands, or body weight. This is especially helpful as different amounts and types of external resistances can be utilized depending on the patient.

In addition to PRT, high-intensity resistance training has been shown to be safe and effective for individuals with PD. While PRT typically involves varying intensity with a focus on moderate weights and high repetitions, high-intensity training involves pushing the body close to its maximum capacity, also called muscular failure, either through heavier weights or higher repetitions. It has been shown useful for improving muscle strength and walking speed, as well as reducing bradykinesia, or slowness of movement [7]. Additionally, functional strength training, such as combining resistance training with balance exercises, has been effective in reducing the risk of falls and improving postural instability in PD patients [9].

PRT and high-intensity resistance training both play crucial roles in managing motor symptoms for individuals with PD. By gradually increasing resistance, PRT improves muscle strength, endurance, and motor function, and high-intensity training targets walking speed and bradykinesia. These resistance-based approaches offer effective means of improving both physical and functional performance in PD patients.

2.2 Effects of Strength Training on Symptoms

Strength training has been shown to have significant benefits for both motor and non-motor symptoms in PD. One of the most notable motor benefits of PRT is the improvement in muscle strength. Research has demonstrated that PRT can improve muscular strength, which is beneficial for individuals experiencing muscle weakness, a common symptom of PD [15]. A 2012 study demonstrated that elbow flexion torque increased more in PD patients who engaged in progressive resistance training (PRT) compared to those participating in general activity, after approximately 12 months. Enhanced muscle strength leads to improved functional mobility, making it easier for patients to independently perform daily tasks. The mean difference in UPDRS-III between the progressive resistance exercise group and the general fitness group was -7.3 points, showing the increased movement and quality of life gained through resistance training [15].

In terms of motor symptoms, strength training has been associated with improvements in gait, balance, and functional mobility. For example, PRT has been shown to improve walking speed, reduce bradykinesia, and enhance coordination in patients with PD [4]. Additionally, studies have indicated that incorporating balance exercises into strength training routines reduces the risk of falls and postural

instability, which are significant concerns for patients with PD [5].

Beyond the motor improvements, strength training has positive effects on non-motor symptoms as well. Sleep quality is one area that has been shown to improve with resistance training, particularly in patients with moderate PD [15]. PD often causes disruptions in sleep patterns, and improving sleep through strength training can significantly enhance patients' overall quality of life. PRT has been shown to improve cardiovascular function as a side effect, which can be impaired in PD [12].

Despite these benefits, some studies suggest that PRT may not be superior to other forms of exercise or usual activities when it comes to the overall recovery of idiopathic PD symptoms [4]. The previous study suggests that PRT may be less effective than aerobic exercise in several areas. The study found minimal to no improvement in cardiovascular health for the PRT group, whereas the low-intensity treadmill group showed positive changes in cardiovascular fitness. Additionally, while the PRT group experienced gains in muscular strength, these improvements did not translate into significant gains in gait function, which are crucial for enhancing quality of life [4].

Overall, progressive resistance training offers significant benefits for managing motor symptoms in PD, particularly in improving muscle strength, balance, and functional mobility. These improvements contribute to enhanced quality of life by increasing independence in daily tasks and reducing the risk of falls. While further research is needed to explore how PRT compares with other exercise modalities, its role in addressing muscle weakness and improving overall motor function makes it a valuable component of a comprehensive treatment plan for PD patients.

2.3 Mechanisms of Strength Training

Strength training exerts its effects on motor and non-motor symptoms through several key mechanisms. Similar to aerobic exercise, resistance training promotes the release of neurotrophic factors (BDNF) resulting in synaptic strengthening in the basal ganglia and motor cortex, supporting better motor control, learning, and memory [12].

Another important mechanism is improved muscle function and endurance. As muscle strength increases through regular resistance training, patients are able to maintain better posture, improve their walking speed, and reduce bradykinesia. This increased muscle performance helps PD patients to better engage in everyday activities.

Resistance training can have beneficial effects on the dopaminergic system as well. PD is characterized by degeneration of dopamine-producing neurons in the brain, leading to negative

motor functions. Studies suggest that strength training may increase dopamine receptor sensitivity, thus improving motor function and potentially slowing down the disease's progression [16].

Resistance training has been found to regulate inflammation and oxidative stress, both of which contribute to the progression of PD. By reducing the levels of pro-inflammatory molecules, like cytokines, and increasing anti-inflammatory responses, strength training helps protect neurons from further damage [17]. Many of these responses are similar in comparison to aerobic exercise, including increased phosphorylation and retrograde signaling that calls for more mitochondria to be constructed. Improving mitochondrial function through strength training enhances energy metabolism in neurons, further protecting against oxidative stress and helping to maintain muscle and brain function in PD patients [13].

3. STRETCHING AND FLEXIBILITY

Stretching and flexibility exercises play an essential role in managing PD by addressing motor and non-motor symptoms that significantly impact daily life. These exercises can help reduce muscle stiffness and rigidity, common motor symptoms in PD, while improving joint mobility and overall flexibility [2]. Since PD progressively affects the nervous system, leading to difficulties with movement and coordination, regular stretching exercises can counteract these effects by enhancing neuromuscular function and promoting relaxation. Flexibility training also serves as an important component of rehabilitation for PD patients, helping them maintain independence and improve their quality of life.

3.1 Types of Flexibility Training

There are several types of stretching exercises commonly recommended for individuals with PD. Static stretching involves holding a muscle in a fixed position for a set period to increase the joint range of motion and relieve muscle tension. This type of stretching is particularly helpful in loosening tight muscles that contribute to poor posture and limited movement. For example, stretches targeting the hamstrings, calves, and shoulders improve walking patterns and overall mobility in key areas affected by PD [4]. Dynamic stretching, which involves continuous movement through a joint's full range of motion, is another effective method. It prepares the muscles for more strenuous activities, like aerobic or resistance training, by increasing blood flow and warming up the muscles. Tai Chi and yoga are also popular stretching practices, as they combine stretching with balance training, making them especially beneficial for improving both motor coordination and mental well-being [2].

3.2 Effects of Flexibility Training on Symptoms

One of the most significant motor benefits of stretching exercises in PD is

the improvement in joint flexibility and range of motion. As PD patients experience muscle rigidity and bradykinesia, stretching helps to reduce stiffness and enables smoother, more coordinated movement. This is crucial in improving posture and gait, both of which are often impaired in PD. Regular stretching can lead to walking patterns, greater stride length, and improved balance, reducing the risk of falls and enhancing mobility [11]. Furthermore, incorporating balance-focused exercises such as yoga and Tai Chi into a stretching routine can directly address postural instability, one of the most common motor challenges in PD.

Beyond the motor improvements, stretching exercises also offer significant benefits for non-motor symptoms. PD often leads to mental health challenges, such as depression, anxiety, and sleep disorders, which can greatly reduce the quality of life. Stretching practices like yoga, which emphasize deep breathing and relaxation techniques, have been shown to alleviate stress and improve mood by activating the parasympathetic nervous system. This system promotes a state of calm and relaxation, which can mitigate feelings of anxiety and improve emotional regulation [2]. Studies have also indicated that flexibility exercises may enhance sleep quality in PD patients. Improved relaxation from stretching before bedtime can help alleviate the discomfort and muscle tension that often interfere with sleep, allowing patients to enjoy more restful and restorative sleep [12].

3.3 Mechanisms of Flexibility Training

The mechanisms underlying the benefits of stretching exercises in PD are multifaceted. One key factor is the improvement in neuromuscular coordination and neuroplasticity. This is particularly important for individuals with PD, as the disease progressively results in diminishing abilities in controlling movement. Stretching exercises that involve dynamic motions or proprioceptive neuromuscular facilitation (PNF) have been shown to enhance motor learning and neuromuscular coordination, leading to better cognitive function and control over muscle movements [12]. Another mechanism is the reduction of muscle rigidity and joint stiffness, which occurs as muscle fibers elongate and become more elastic during stretching. This improved muscle elasticity helps reduce the tension that contributes to stiffness, allowing for greater ease of movement and less discomfort during daily tasks [7].

Moreover, stretching exercises can improve blood circulation and muscle oxygenation, both of which are vital for muscle function. Increased circulation helps deliver oxygen and nutrients to the muscles, enhancing their performance and delaying the onset of fatigue. This is especially beneficial for PD patients who may struggle with muscle weakness and reduced endurance during physical

activities [15]. Lastly, the psychological mechanisms involved in stretching, particularly in practices like yoga and Tai Chi, cannot be overlooked. The focus on mindfulness, controlled breathing, and relaxation helps reduce stress and anxiety, both of which can exacerbate PD symptoms [2]. This holistic approach to stretching provides physical and mental benefits that contribute to an overall improvement in the patient's quality of life.

4. DURATION AND INTENSITY

Research on the duration and intensity of exercise for the management of PD highlights the significant roles both factors play in determining the effectiveness of treatment interventions. While there is a consensus that both duration and intensity are important, emerging studies suggest that exercise intensity may be more critical than duration when it comes to improving motor symptoms [15]. For instance, Corcos et al. (2013) found that two years of high-intensity resistance training led to improvements in motor symptoms among PD patients, including increased muscle strength and an average improvement of 7.3 points on the UPDRS-III. Similarly, a study conducted by Ugyur et al. (2020) revealed that high-intensity cycling exercises produced better functional outcomes compared to low-intensity alternatives. The researchers emphasized the importance of pushing the body close to its muscular limits to stimulate neuroplasticity and cause recovery in motor function [7]. These findings suggest that while resistance training is an important component of PD exercise regimens, intensity also plays a crucial role in aerobic activities, reinforcing that higher levels of exertion can enhance results.

In contrast, a study on aerobic and resistance exercise by Shulman et al. (2013) concluded that there was no consistent evidence that high-intensity exercises, including PRT, are superior to other forms of physical activity in promoting overall recovery from idiopathic PD. The higher duration treadmill training group in this study demonstrated the most improvement in measures of both gait and cardiovascular fitness. This indicates that while high-intensity exercise may offer significant motor improvements, it is not the only determinant of exercise efficacy. Duration and consistency are also essential components for achieving long-term benefits, suggesting that a balanced approach may be necessary to sustain improvements without overwhelming patients, particularly those in more advanced stages of the disease.

5. INTEGRATION OF PROGRAMS

Given these nuances, practical recommendations for exercise in PD often advocate for a combination of moderate to high-intensity workouts lasting between 30 to 60 minutes, performed three to five times per week. Incorporating a diverse array of

exercises (such as aerobic, resistance, and flexibility training) can maximize benefits across both motor and non-motor symptoms. Additionally, stretching exercises that require less intensity should be included in daily routines to alleviate rigidity and enhance flexibility [11].

Many recent studies point to the benefits of combinatorial training. A study showed that two groups of stability resistance training and gait resistance training resulted in significant enhancements in balance, mobility, and gait parameters for both compared to general activity [18]. Stability resistance training demonstrated notable improvements in balance and knee extension strength, while gait resistance training led to a faster and more stable gait, shown by longer strides and improved ankle dorsiflexion [18]. These outcomes suggest that integrating different training types can effectively target various functional impairments associated with PD. Ultimately, this indicates that a combination of exercise practices can yield synergistic benefits, making it a valuable component of rehabilitation strategies for individuals with PD.

6. SAFETY

Safety and supervision are crucial in the physical activity of patients with PD, due to their risk of falls and injuries. Direct supervision allows for immediate assistance, reducing the likelihood of accidents during exercise [4]. Monitoring vital signs before, during, and after sessions helps to identify potential health issues, enabling interventions by medical professionals [4]. A controlled environment not only provides safety but also gives confidence, encouraging active participation in the exercise program.

The use of BWSTT and aquatic exercise presents a safer alternative for PD patients compared to other forms of physical activity. BWSTT minimizes fall risk by providing support that allows individuals to practice walking mechanics while reducing the impact of body weight [8]. This controlled environment creates confidence and encourages participation without the fear of falling. Similarly, aquatic exercise offers a low-impact option that reduces strain on joints while providing buoyancy and support, making it safer for individuals with movement difficulties [9]. Both modalities have been shown to improve functional outcomes while maintaining a lower risk of injury. The integration of these exercises into rehabilitation programs can help patients safely engage in physical activity, ultimately enhancing their quality of life.

Beyond exercise modalities, cognitive measures can be utilized in order to assess risk and limit major injury. The study Mak et al. (2009) highlights the significant role fear of falling (FoF) has in predicting recurring falls among patients with PD [19]. Specifically, a low Activities-specific Balance Confidence score, indicative of high FoF, emerged

as a strong predictor of future falls. This shows the necessity for comprehensive risk assessments that use not only physical issues but also psychological factors like FoF. By recognizing FoF as a modifiable risk factor, clinicians can design targeted interventions to enhance balance confidence. Integrating psychological evaluations into fall risk assessments is essential for effective fall prevention strategies in PD patients.

CONCLUSION

In conclusion, a range of exercise therapies has demonstrated therapeutic benefits for both motor and nonmotor symptoms in patients with PD. Aerobic exercise stands out as the most extensively researched intervention, showing significant positive effects on motor function, quality of life, cognition, and emotional well-being. Resistance training is another avenue for intervention, which has been proven to improve motor symptoms, specifically muscular strength, while its effect on non-motor symptoms remains under discussion. It is essential to design combinatory exercise programs that prioritize safety and address individual issues. Moreover, further large-scale clinical trials and more rigorous studies are needed to validate the use of exercise therapies in PD and to deepen our understanding of their underlying mechanisms. This research will be vital for advancing exercise therapy as a key component of PD management.

REFERENCES

[1] Ascherio A, Schwarzschild MA. The epidemiology of Parkinson's disease: risk factors and prevention. Lancet Neurol. 2016 Nov;15(12):1257-1272. doi: 10.1016/S1474-4422(16)30230-7. Epub 2016 Oct 11. PMID: 27751556.

[2] Feng YS, Yang SD, Tan ZX, Wang MM, Xing Y, Dong F, Zhang F. The benefits and mechanisms of exercise training for Parkinson's disease. Life Sci. 2020 Mar 15;245:117345. doi: 10.1016/j.lfs.2020.117345. Epub 2020 Jan 22. PMID: 31981631.

[3] Sacheli MA, Neva JL, Lakhani B, Murray DK, Vafai N, Shahinfard E, English C, McCormick S, Dinelle K, Neilson N, McKenzie J, Schulzer M, McKenzie DC, Appel-Cresswell S, McKeown MJ, Boyd LA, Sossi V, Stoessl AJ. Exercise increases caudate dopamine release and ventral striatal activation in Parkinson's disease. Mov Disord. 2019 Dec;34(12):1891-1900. doi: 10.1002/mds.27865. Epub 2019 Oct 4. PMID: 31584222.

[4] Shulman LM, Katzel LI, Ivey FM, Sorkin JD, Favors K, Anderson KE, Smith BA, Reich SG, Weiner WJ, Macko RF. Randomized clinical trial of 3 types of physical exercise for patients with Parkinson disease. JAMA Neurol. 2013 Feb;70(2):183-90. doi: 10.1001/jamaneurol.2013.646. PMID: 23128427; PMCID: PMC4574905.

[5] Schootemeijer S, van der Kolk NM, Bloem BR, de Vries NM. Current Perspectives on Aerobic Exercise in

People with Parkinson's Disease. Neurotherapeutics. 2020 Oct;17(4):1418-1433. doi: 10.1007/s13311-020-00904-8. Erratum in: Neurotherapeutics. 2022 Mar;19(2):683-685. doi: 10.1007/s13311-022-01219-6. PMID: 32808252; PMCID: PMC7851311.
[6] Fan B, Jabeen R, Bo B, Guo C, Han M, Zhang H, Cen J, Ji X, Wei J. What and How Can Physical Activity Prevention Function on Parkinson's Disease? Oxid Med Cell Longev. 2020 Feb 13;2020:4293071. doi: 10.1155/2020/4293071. PMID: 32215173; PMCID: PMC7042542.
[7] Uygur M, Bellumori M, Knight CA. Effects of a low-resistance, interval bicycling intervention in Parkinson's Disease. Physiother Theory Pract. 2017 Dec;33(12):897-904. doi: 10.1080/09593985.2017.1359868. Epub 2017 Aug 16. PMID: 28812404; PMCID: PMC6204154.
[8] Miyai I, Fujimoto Y, Ueda Y, Yamamoto H, Nozaki S, Saito T, Kang J. Treadmill training with body weight support: its effect on Parkinson's disease. Arch Phys Med Rehabil. 2000 Jul;81(7):849-52. doi: 10.1053/apmr.2000.4439. PMID: 10895994.
[9] Carroll LM, Volpe D, Morris ME, Saunders J, Clifford AM. Aquatic Exercise Therapy for People With Parkinson Disease: A Randomized Controlled Trial. Arch Phys Med Rehabil. 2017 Apr;98(4):631-638. doi: 10.1016/j.apmr.2016.12.006. Epub 2017 Jan 12. PMID: 28088380.
[10] Nadeau A, Lungu O, Duchesne C, Robillard MÈ, Bore A, Bobeuf F, Plamondon R, Lafontaine AL, Gheysen F, Bherer L, Doyon J. A 12-Week Cycling Training Regimen Improves Gait and Executive Functions Concomitantly in People with Parkinson's Disease. Front Hum Neurosci. 2017 Jan 12;10:690. doi: 10.3389/fnhum.2016.00690. PMID: 28127282; PMCID: PMC5226941.
[11] Shu HF, Yang T, Yu SX, Huang HD, Jiang LL, Gu JW, Kuang YQ. Aerobic exercise for Parkinson's disease: a systematic review and meta-analysis of randomized controlled trials. PLoS One. 2014 Jul 1;9(7):e100503. doi: 10.1371/journal.pone.0100503. PMID: 24983753; PMCID: PMC4077570.
[12] Hirsch MA, van Wegen EEH, Newman MA, Heyn PC. Exercise-induced increase in brain-derived neurotrophic factor in human Parkinson's disease: a systematic review and meta-analysis. Transl Neurodegener. 2018 Mar 20;7:7. doi: 10.1186/s40035-018-0112-1. PMID: 29568518; PMCID: PMC5859548.
[13] Henrich MT, Oertel WH, Surmeier DJ, Geibl FF. Mitochondrial dysfunction in Parkinson's disease - a key disease hallmark with therapeutic potential. Mol Neurodegener. 2023 Nov 11;18(1):83. doi: 10.1186/s13024-023-00676-7. PMID: 37951933; PMCID: PMC10640762.
[14] Hood DA, Uguccioni G, Vainshtein A, D'souza D. Mechanisms of exercise-induced mitochondrial biogenesis in skeletal muscle: implications for health and disease. Compr Physiol. 2011 Jul;1(3):1119-34. doi: 10.1002/cphy.c100074. PMID: 23733637.
[15] Corcos DM, Robichaud JA, David FJ, Leurgans SE, Vaillancourt DE, Poon C, Rafferty MR, Kohrt WM, Comella CL. A

two-year randomized controlled trial of progressive resistance exercise for Parkinson's disease. Mov Disord. 2013 Aug;28(9):1230-40. doi: 10.1002/mds.25380. Epub 2013 Mar 27. PMID: 23536417; PMCID: PMC3701730.
[16] Fisher BE, Wu AD, Salem GJ, Song J, Lin CH, Yip J, Cen S, Gordon J, Jakowec M, Petzinger G. The effect of exercise training in improving motor performance and corticomotor excitability in people with early Parkinson's disease. Arch Phys Med Rehabil. 2008 Jul;89(7):1221-9. doi: 10.1016/j.apmr.2008.01.013. Epub 2008 Jun 13. PMID: 18534554; PMCID: PMC2989816.
[17] Neufer PD, Bamman MM, Muoio DM, Bouchard C, Cooper DM, Goodpaster BH, Booth FW, Kohrt WM, Gerszten RE, Mattson MP, Hepple RT, Kraus WE, Reid MB, Bodine SC, Jakicic JM, Fleg JL, Williams JP, Joseph L, Evans M, Maruvada P, Rodgers M, Roary M, Boyce AT, Drugan JK, Koenig JI, Ingraham RH, Krotoski D, Garcia-Cazarin M, McGowan JA, Laughlin MR. Understanding the Cellular and Molecular Mechanisms of Physical Activity-Induced Health Benefits. Cell Metab. 2015 Jul 7;22(1):4-11. doi: 10.1016/j.cmet.2015.05.011. Epub 2015 Jun 11. PMID: 26073496.
[18] Biebl JT, Azqueta-Gavaldon M, Wania C, Zettl O, Woiczinski M, Bauer L, Storz C, Bötzel K, Kraft E. Resistance Training Combined with Balance or Gait Training for Patients with Parkinson's Disease: A Randomized Controlled Pilot Study. Parkinsons Dis. 2022 Oct 7;2022:9574516. doi: 10.1155/2022/9574516. PMID: 36247107; PMCID: PMC9568326.
[19] Mak MK, Pang MY. Fear of falling is independently associated with recurrent falls in patients with Parkinson's disease: a 1-year prospective study. J Neurol. 2009 Oct;256(10):1689-95. doi: 10.1007/s00415-009-5184-5. Epub 2009 May 28. PMID: 19479166.