A review of Parkinson's disease combined with sarcopenia in the elderly

Chenghui Zhang1，Mengqi Li1，Hong Fan\*

1School of Medicine, Shaoxing University, Shaoxing, Zhejiang 312000, P. R. China

1School of Medicine, Shaoxing University, Shaoxing, Zhejiang 312000, P. R. China

\*Corresponding Author: Hong Fan, Department of Geriatrics, Shaoxing People’s Hospital (Shaoxing Hospital of Zhejiang University), Shaoxing 312000, Zhejiang, P. R. China Tel.: +86 057588559641

Email address: fhrainbow@163.com

Abstract

Sarcopenia is an aging-associated muscle disease characterised by loss of skeletal muscle mass and strength, with or without loss of physical performance, which can increase the risk of falls, fractures, disability and death. Parkinson's disease (PD) is the second most common neurodegenerative disease and one of the diseases with the greatest increase in prevalence, disability and mortality in recent years. The occurrence of sarcopenia is more prevalent in patients with PD. In order to improve the survival status and prognosis of patients with PD combined with sarcopenia, this article reviews the progress of research related to the epidemiology, diagnostic criteria, pathogenesis, adverse outcomes, and treatment of PD combined with sarcopenia at home and abroad in recent years.

Keywords: sarcopenia; Parkinson's disease; diagnosis; pathogenesis

Introduce

Since the first definition of sarcopenia in 1988, several definitions of sarcopenia have been developed by different working groups or societies, with the most used definition being developed by the European Working Group on Sarcopenia in Older People (EWGSOP): sarcopenia is an ageing-associated muscular disease characterised by loss of skeletal muscle mass and strength with or without loss of physical performance, which can increase the fall, fracture, disability and death risk1.The increasing prevalence of sarcopenia has become a serious global public health problem, posing a serious threat to the quality of life and survival prognosis of patients. It is characterised by a loss of muscle mass and strength associated with aging and chronic diseases such as PD 1.PD is the second most common neurodegenerative disease and one of the diseases with the greatest increase in prevalence, disability and mortality in recent years 2. It is expected that by 2030, there will be approximately 5 million PD patients in China, accounting for about half of the PD patients worldwide 3. Its clinical features are characterised by motor symptoms such as bradykinesia, resting tremor, rigidity and postural instability.Motor symptoms in patients with PD can lead to a decrease in muscle strength, performance and muscle mass 4. PD is involved in the development of sarcopenia, and the clinical presentation and severity of PD is a determining factor that directly affects sarcopenia 5.

Neurodegenerative diseases and muscle loss associated with aging increase the risk of PD sarcopenia in older adults, seriously affecting their physical and psychological health. Effective screening and rational diagnosis and treatment of sarcopenia are of great significance in improving the quality of life of the elderly and alleviating the medical and economic pressure on the society. In this article, we review the progress of research on the epidemiology, diagnostic criteria, mechanisms, adverse effects and treatment of PD sarcopenia at home and abroad, with the aim of strengthening the national awareness, improving the identification, prevention and treatment capabilities, and improving the survival and prognosis of PD patients with sarcopenia.

Epidemiology of Parkinson's disease combined with sarcopenia

Currently, the overall prevalence of sarcopenia in community-dwelling populations is 10 per cent globally6. However, the prevalence of sarcopenia tends to vary according to different diagnostic criteria: the prevalence of sarcopenia in the general population according to the EWGSOP, EWGSOP2 and Asian Working Group on Sarcopenia (AWGS) classifications is 22%, 10% and 15%, respectively 7. The prevalence of sarcopenia is higher in patients with PD than in age- and sex-matched healthy elderly controls 8-10. The prevalence of sarcopenia in PD ranges from 10.9% to 31.4% 11. In PD patients, sarcopenia is significantly more prevalent in men than in women, which may be due to the fact that female PD patients exposed to the same dose of levodopa as male controls have more side effects due to low body weight, such as dyskinesia, which acts as an exercise, increases energy expenditure, and affects body composition9. However, the prevalence of sarcopenia in PD varies in different studies. According to EWGSOP2010, the prevalence of sarcopenia in PD ranges from 6-31.4% 8,9,12,13；according to AWGS2019, the prevalence of sarcopenia is 40%10. Differences between these studies may be related to diagnostic criteria, muscle mass measurement techniques, different thresholds for the muscle mass index used to define sarcopenia, and the inclusion of patients with PD with their own characteristics 14.

Diagnosis of sarcopenia

1. Main diagnostic methods

1.1 Screening

Calf circumference and the SARC-F questionnaire: Calf circumference is measured using a non-elastic band to measure the maximum circumference of the calves bilaterally, and the "finger-ring test" can be used as a valid alternative to measuring calf circumference.The SARC-F questionnaire involves five functional statuses of older adults, and the scale has low sensitivity and high specificity, which allows for the accurate identification of impaired physical function and is associated with poor clinical outcomes15. The SARC-F has the advantage of being a simple, rapid and effective screening tool that is independent of instrumentation and thresholds, and independent of age and gender differences.The addition of calf circumference to the SARC-CalF questionnaire improves the sensitivity of the SARC-F.

1.2 Muscle strength

Upper extremity grip strength has been widely recognised as an indicator of muscle strength. The most commonly used grip strength measurement is the spring-loaded grip strength device, followed by the hydraulic grip strength device. The use of two types of grip strength devices: (1) hydraulic grip strength device: take a sitting position, 90 ° elbow flexion to measure grip strength; (2) spring-loaded grip strength device: standing position, elbow extension to measure grip strength; if the elderly can not stand independently, then choose to sit to measure. Use the dominant hand or both hands respectively, maximum force isometric contraction, at least 2 tests, select the maximum reading. In addition, it is recommended to use an electronic grip strength device with a digital display to ensure the accuracy of the data.

1.3 Skeletal muscle mass

The most commonly used instruments for measuring skeletal muscle mass(SMM) are Dual Energy X-ray Absorptiometry (DXA) and Bioelectrical Impedance Analysis (BIA).BIA calculates percent body fat from electrical impedance, and its measurements are highly correlated with body water content. DXA is highly accurate, has low radiation exposure, is easy to perform, and is capable of evaluating regional distributions of fat and muscle. The multi-frequency BIA instrument is the closest to the DXA measurements of extremity SMM.So AWGS2019 recommends using either the DXA or multi-frequency BIA in combination with height correction to measur SMM. 16.

1.4 Physical function

The Simple Physical Performance Battery (SPPB), step speed, The five-repetition sit-to-stand test（5STS）, the Time-Up-Go test (TUG), and the 400m walk test were used to assess somatic function. The SPPB is a comprehensive somatic function test tool with three components: the three-posture test, including standing with feet together, standing with feet in a half tandem anteroposteriorly and anteriorly and posteriorly and standing with feet in a tandem anteriorly and posteriorly, with each posture being tested for 10s; the gait test; and the 5STS.Step speed is the simplest, quickest and safest method of assessing somatic function. TUG measures the time it takes to walk a certain distance at a normal walking speed from the start of movement, without acceleration or deceleration, and is measured at least twice, with the average speed recorded.TUG can reflect the individual's balance and walking ability. The TUG measures the time it takes for a subject to rise from a seat of about 46cm in height, complete a 3m round trip walk at the fastest and steadiest speed, and finally sit back in the chair, and the measurement is repeated at least twice, with the shortest time recorded. 400m walk can test the walking ability and endurance of the elderly. Subjects are required to complete the walk as fast as they can, with up to 2 breaks. Due to its long duration and high physical demands, it is not suitable for the elderly or frail, and is currently only used in scientific research.

2. Cutoff value for diagnosis

Currently, EWGSOP, the International Working Group on Sarcopenia (IWGS), AWGS, and Foundation for the National Institutes of Health (FNIH) have developed and recommended parameters and diagnostic cut-points for the assessment of sarcopenia that are appropriate for their own regional populations, which mainly include 3 aspects of muscle mass, muscle strength, and somatic capacity, as shown in Table 1.

Comparing AWGS2019 and AWGS2014, the diagnosis of sarcopenia has been updated in terms of grip strength and step speed thresholds. Assessment of somatic function is no longer limited to step speed, and the 5STS and SPPB can be used in place of step speed. In addition, the AWGS2019 Working Group updated the diagnostic criteria and proposed a screening programme for the community and hospitals, recommending first screening for calf circumference (< 34 cm in men and < 33 cm in women) or use of the SARC-F (≥ 4 points) or SARC-CalF (≥ 11 points) questionnaires to facilitate early identification of people at risk of sarcopenia. EWGSOP2018 and AWGS2019 differ slightly in their diagnostic strategies. The definition of sarcopenia by EWGSOP2018 1emphasises muscle strength as the primary indicator, confirms the diagnosis of sarcopenia by detecting low muscle number and mass, and identifies poorer physical performance as a marker of severe sarcopenia.AWGS2019 16 suggests that declines in both muscle strength and somatic functioning are the result of declines in muscle mass, and that they have a detrimental impact on prognosis. Therefore sarcopenia can be diagnosed whenever there is a decrease in muscle strength or function combined with a decrease in muscle mass. Severe sarcopenia is diagnosed if there is a decrease in both muscle strength and function.

Table 1 Diagnostic methods and cut-off values in the latest consensus

|  |  |  |  |
| --- | --- | --- | --- |
| Consensus | Muscle strength (grip strength: kg) | Muscle mass | Physical function |
| IWGS17 | — | DXA-ALMI：M<7.23 kg/m2，F<5.67kg/m2 | step speed＜ 1.0 m/s |
| FNIH18EWGSOP，20181  | M＜26F＜16M＜27F＜16 | DXA-ASM/BMI：M<0.789，F<0.512ALM(kg):M<19.75，F<15.02DXA-ASMI：M<7.0 kg/m2，F<6.0 kg/m2 | step speed＜ 0.8 m/s |
| step speed＜ 0.8 m/s or SPPB ≤ 8 pointsorTUG ≥ 20 s or The 400-m walk was not completed or≥ 6 min or5STS＞15 s |
| AWGS，201916 | M＜28 F＜18 | DXA-ASMI: M<7.0 kg/m2，F<5.4 kg/m2BIA-ASMI: M<7.0 kg/m2，F<5.7 kg/m2 | step speed＜ 1.0 m/s or SPPB ≤ 9 pointsor5STS＞12 s |

ASM: appendicular skeletal muscle mass; ALM: appendicular skeletal muscle mass; ASMI: appendicular skeletal muscle mass index;ALMI: appendicular skeletal muscle mass index

3. Diagnostic algorithm

 According to AWGS 2019 16, the diagnostic process of sarcopenia mainly includes two parts: community primary medical institutions and clinical medical institutions. Cases were detected by measuring calf circumference or SARC-CalF in community primary care Settings, and then evaluated by grip strength and five times sit up time. Lifestyle intervention and related health education are recommended for residents with possible sarcopenia, and referral to hospitals for diagnosis is also encouraged. In hospital and institutional diagnostic algorithms, initial evaluation is considered when a patient presents with typical symptoms of sarcopenia, such as muscle wasting, falls, and abnormal gait characterized by slow walking. Muscle strength, physical function, and appendicular skeletal muscle mass were assessed. On the basis of the diagnosis of sarcopenia, if there is a simultaneous decline in muscle strength and function, it is considered as severe sarcopenia.

Pathogenesis of Parkinson's disease with sarcopenia

1. Disruption of the neuromuscular junction

Disruption of the neuromuscular junction (NMJ) is common in several neurodegenerative diseases, including PD 19,and can induce downstream sarcopenia phenotypes, reflecting the key role of the NMJ in maintaining muscle health 20. NMJ dysfunction often precedes muscle damage and may exacerbate the postsynaptic changes in PD-related sarcopenia20. The NMJ is a plastic structure that can achieve self-repair with exercise and other interventions 21. Studies have found that exercise can maintain the plasticity of the NMJ in rodents and restore the structure and function of the NMJ in humans22. Neurotrophin and CAF22b have been implicated in NMJ disruption and muscle degeneration. Circulating levels of these biomarkers are significantly altered in the early stages of PD, while biomarker levels partially return to normal levels in patients after rehabilitation treatment 23.

 Brain-derived neurotrophic factor (BDNF) and glial cell line-derived neurotrophic factor (GDNF) are released by muscle fibers, motor neurons, and adjacent Schwann cells and are mainly used to maintain NMJ function and mediate axon sprouting and acetylcholine receptor aggregation after denervation24. Plasma BDNF and GDNF levels are low in PD patients24 , which weakens the neuroprotective ability of BDNF and GDNF and may lead to NMJ dysfunction and decreased muscle function. The loss of muscle mass and strength in the elderly is also partially attributed to the diminished protective effects of BDNF and GDNF 25. The expression of BDNF and GDNF in the tissues of PD patients has plasticity. Exercise intervention can increase plasma BDNF and GDNF levels in the elderly , thereby improving the neuroprotective ability of BDNF and GDNF26,27.

Aggrecan is a neuronal proteoglycan composed of two aggrecan fragments. C-terminal aggregation protein fragment 22 (CAF22) is one of the smaller fragments, which is a circulating biomarker of NMJ destruction and sarcopenia in the elderly 28，and is released into the blood circulation as a stable non-bioactive molecule24. The study by Karim et al.23found that patients before treatment had a significant reduction in grip strength and a significant increase in plasma CAF22 levels. Rehabilitation training can reduce plasma CAF22 levels while restoring grip strength, and promote NMJ recovery and muscle health.

2. Chronic inflammation

Chronic inflammation is considered as a potential pathological condition29. Elevated levels of circulating inflammatory mediators, including interleukin-6(IL-6) and tumor necrosis factor-α(TNF-α), were detected in both patients with early PD and those with sarcopenia. High levels of IL-6 can lead to sarcopenia30. A randomized controlled trial of 99 older adults with limited mobility identified an age-related increase in circulating IL-6 levels as a key factor in the decline in skeletal muscle strength, mass, and function31. Pelosi et al. observed the effects of high levels of IL-6 on NSE/IL-6 mice and found that IL-6 may cause muscle atrophy by promoting an increase in glycolytic metabolism32.

A meta-analysis showed that older adults with sarcopenia had higher levels of TNF-α, indicating that high levels of TNF-α were associated with an increased risk of sarcopenia33. Increased plasma concentrations of TNF-α were associated with lower muscle mass, strength, and activation of apoptosis in muscle cells. TNF-α activates local vascular endothelial cells, leading to the release of nitric oxide, which in turn increases vascular permeability and allows passage of proinflammatory cells, ultimately causing inflammation 34. TNF-α can also promote muscle atrophy by activating the nuclear factor-kB (NF-Κb) pathway, up-regulating muscle ring finger protein-1 (MuRF-1), and activating the ubiquitin-proteasome pathway 35. Pyroptosis mediated by TNF-ɑ/caspase-8/caspase-3/GSDME signaling pathway is a new mechanism for the occurrence and development of sarcopenia. Caspase-3/GSDME signaling pathway mediated pyroptosis may be a promising therapeutic target for sarcopenia 36.

3. Impaired autophagy function of muscle fibers

Impaired autophagy function of muscle fibers is the common pathophysiological mechanism of muscle fiber loss in sarcopenia and PD 13. Autophagy regulates inflammatory cytokines by inhibiting oxidative stress to maintain the normal function of muscle fiber organelles and cells 37,38. Autophagy dysfunction disrupts cellular homeostasis, impairs mitochondrial function, aggravates oxidative stress, accelerates cell senescence, and damages muscle satellite cells 39. Satellite cells are located between the basement and sarcolemmal membranes of muscle fibers in a mitotically quiescent state, and these cells are activated and proliferate in response to stimuli such as physical exercise, injury, or mechanical stress. Insulin-like growth factor-1(IGF-1) is closely related to the differentiation and proliferation of muscle satellite cells and the fusion of muscle cells 40,41. Inhibition of autophagy may reduce growth hormone receptor (GHR) and IGF-1 to inhibit satellite cell regeneration42. Oxidative stress refers to the imbalance between oxidative and antioxidant regulation. Several evidences suggest that the Kelch-like ECH-associated protein 1 (Keap1) -nuclear factor-erythroid 2-related factor 2 (Nrf2) system is closely related to oxidative stress, and its signaling is also regulated by phosphatidylinositol 3 kinase (PI3K)/protein kinase B (PKB, also known as Akt), PKC and mitogen-activated protein kinase43. Autophagy plays a protective role in oxidative stress by promoting the competitive binding of Nrf2 by p62 instead of Keap1 and inhibiting the degradation of Nrf244. Impaired autophagy leads to reduced inhibition of Nrf2 degradation, increased ROS production and oxidative stress markers. The NF-κB signaling pathway is known to promote inflammatory activation. Related studies have found that inhibition of autophagy may activate the NF-κB signaling pathway, generate the NLRP3 inflammatome, promote the expression of inflammatory factor IL-1β, inhibit the anabolic metabolism of myocytes, and induce sarcopenia45-47. FOXOs members are the most widely known transcription factors downstream of the AKT/IGF-1/ insulin pathway, and their activity can be regulated by a variety of enzymes or by transcription factors. In humans, four FOXOs have been identified, among which FOXO1 and FOXO3 are involved in muscle atrophy, regulation of autophagy gene transcription and aberrant autophagy48,49. FOXOs are induced by adenosine 5 '-monophosphP-activated protein kinase (AMPK) to translocate into the nucleus and persist in muscle atrophy50.

3. Motor neuron reduction

The effects of PD on skeletal muscle include decreased muscle strength, endurance, and muscle atrophy19. These effects can be explained in part by the death of motor neurons, and this continued denervation accelerates the onset of sarcopenia. A reduction in the number of motor neurons is a common feature of both sarcopenia and PD51. The transcription factor NF-κB is a key intracellular signaling molecule in denervation leading to muscle atrophy52. The transcription factor NF-κB is a key intracellular signaling molecule in denervation leading to muscle atrophy34. These effects can be explained in part by the death of motor neurons, and this continued denervation accelerates the onset of sarcopenia. A reduction in the number of motor neurons is a common feature of both sarcopenia and PD12. Neuronal apoptosis may be the mechanism of motor neuron reduction in PD patients with sarcopenia. The mitochondrial permeability transition pore (mPTP) is a weakly selective large conductive channel that is closed under non-stress conditions and can be triggered to open by reactive oxygen species (ROS) and Ca2+ overload produced by mitochondria. Excessive opening of mPTP results in an imbalance of mitochondrial membrane potential and subsequent release of mitochondrial contents, such as ROS and cytochrome c, into the cytoplasm, thereby initiating an apoptotic signaling cascade in motor neurons and myofibers. Activation of apoptotic signals is accompanied by DNA fragmentation and nuclear apoptosis, which eventually leads to muscle atrophy and denervation 53.

5. Brain structure and network changes

Changes in brain structure and networks play a key role in the pathophysiology of PD patients with sarcopenia. Decreased gray matter volume in specific regions of PD patients, such as the uncinate gyrus and superior temporal gyrus, is significantly associated with core muscle loss 54. The reduced size of the default mode network results in insufficient activity of the task-related network, resulting in poor motion function 54. Compared with PD patients without sarcopenia, sarcopenia showed the strongest correlation with muscle mass loss by diffusion tensor imaging (DTI), which represents white matter changes in the executive function network of PD patients with sarcopenia 55. Furthermore, reduced ASMI was associated with reduced fractional anisotropy of frontostriato-thalamic circuits in sarcopenic PD patients 55.

6.Sex hormone deficiency

PD patients with sarcopenia may be affected by the changes of sex hormones. Androgens play an important role in the maintenance of muscle mass. Low plasma testosterone levels can cause or accelerate muscle and age-related diseases. In addition to the natural decline in testosterone levels with age, abnormalities in plasma testosterone levels can be observed in endocrine diseases such as late-onset hypogonadism, decreased androgen production, and accelerated testosterone metabolism 56. However, no studies have investigated the relationship between testosterone and sarcopenia in PD patients, and future studies are needed to clarify this.

However, no studies have investigated the relationship between testosterone and sarcopenia in PD patients, and future studies are needed to clarify this57. However, no studies have investigated the relationship between testosterone and sarcopenia in PD patients, and future studies are needed to clarify this58. However, no studies have investigated the relationship between testosterone and sarcopenia in PD patients, and future studies are needed to clarify this 58 . These inflammatory factors can degrade muscle proteins and reduce the ability of adult muscles to respond to injury. Estradiol inhibits the occurrence of sarcopenia by regulating local and systemic inflammatory responses 59,60.

6. Mitochondrial dysfunction

Mitochondrial dysfunction has been demonstrated in non-neuronal tissues of PD patients, and it has been shown that mitochondrial abnormalities are more common in PD with sarcopenia than in healthy older muscles 11 . ROS includes superoxide anions, hydroxyl radicals and hydrogen peroxide, and the most important ROS production in muscle cells is located in the mitochondria. ROS causes progressive damage to key cellular macromolecules, including lipids, proteins, and DNA, thereby altering their structure and function. Denervation or NMJ degeneration significantly increases the production of peroxides in muscle mitochondria while eliminating the interaction between motor neurons and muscle, resulting in significant defects in muscle regeneration 61. Yang et al. 62 found that oxidative stress induced by α-synuclein (α-Syn) aggregation might be a new idea for muscle atrophy in PD patients. Aggregation of α-Syn results in an increased number of swollen and broken cristae structure mitochondria in intramuscular axons and NMJS. At the same time, the expression of genes related to ROS metabolism decreased, resulting in increased oxidative stress of intramuscular mitochondria. In addition, mitochondrial dysfunction may also be the result of failure of mitochondrial quality control (MQC) processes, including protease homeostasis, biogenesis, dynamics, and mitophagy 63.

Adverse outcomes

1.Fall

Falls are a serious problem in PD patients with sarcopenia. Patients with PD and sarcopenia have an increasing risk of falling compared to healthy individuals and patients with other neurological conditions such as polyneuropathy, spinal disease, and multiple sclerosis 51. Older adults taking anti-PD medications have a higher risk of exposure to fall-inducing medications. The more advanced the disease, the more drugs they need, and the less independent these patients are 51. Clinical manifestations associated with sarcopenia, such as reduced mobility, poor balance, and reduced leg muscle strength, are associated with increased risk of falls 64. Studies had shown that disease duration, freezing of gait, postural instability, non-motor symptoms, and high levodopa equivalent daily dose (LEDD) were also associated with the occurrence of falls 9,51,65. From the perspective of prognosis, compared with non-fallers, frequent fallers have a longer course of disease and worse prognosis 66. From the perspective of prognosis, compared with non-fallers, frequent fallers have a longer course of disease and worse prognosis.

2. Disability

Disability is defined as impairment in the ability to perform basic activities of daily living (ADL) and instrumental activities of daily living (IADL). Individuals with PD and sarcopenia have greater difficulty with ADL and IADL 67. Musculoskeletal conditions and motor and nonmotor symptoms of PD affect life skills, and these challenges increase with aging and neurodegenerative disease progression. Muscle strength is strongly associated with severity of PD and disability, and sarcopenia, defined using the SARC-F questionnaire, is a good predictor of disability in PD 9.

3. Fracture

 The occurrence of fractures is influenced by two main factors: on the one hand, the neuro-musculoskeletal changes accompanying PD and impaired postural stability due to reduced leg muscle strength can lead to falls, which cause traumatic injuries-fractures; on the other hand, PD and the use of levodopa increases the risk of osteoporosis 68.

4. Dysphagia

Age and disease characteristics are high risk factors for dysphagia in patients with PD, and muscle mass is lower in patients with PD compared to healthy controls and more pronounced in PD patients with dysphagia 4.Chronic denervation and reinnervation are secondary to systemic neurodegeneration, resulting in pharyngeal atrophy of the swallowing muscle in PD patients with dysphagia 69. Dysphagia can lead to inadequate drug intake, malnutrition, dehydration, and aspiration pneumonia, which is the leading causes of death in PD patients 70.

5. Loss of weight

Weight loss and reduced body mass index are common in PD patients due to altered energy expenditure, impaired homeostatic regulation, and gastrointestinal dysfunction 10. Weight loss may precede the diagnosis of PD and often worsens as the disease progresses, leading to an increased risk of malnutrition, fractures, pressure ulcers, and death 10.

Treatment of Parkinson's disease with sarcopenia

1. Non-drug treatment

* 1. Exercise therapy

Exercise is considered to be one of the most commonly used treatments to improve sarcopenia in PD patients1,71. Liver growth factor (HGF) is attached to the extracellular matrix and is released after physical activity to repair tissue damage caused by exercise and can activate muscle satellite cells. Exercise promotes the production of nitric oxide (NO) in the body, and NO is a key signal for HGF activation. Lack of exercise or disuse leads to reduced NO production, which in turn affects HGF release from the extracellular matrix, keeping muscle satellite cells in the G0 phase of the cell cycle 34. Resistance exercise has been shown to be beneficial for sarcopenia and is widely accepted by patients as a treatment 72,73. In one study, significant improvements in SMM, muscle function, and NMJ integrity index were found in PD patients after 16 weeks of resistance training. Whole-transcriptome skeletal muscle RNA sequencing of skeletal muscle of PD patients before and after resistance training found that genes related to nervous system and muscle development were significantly up-regulated, and genes negatively regulated by muscle adaptation were down-regulated 74. Exercise can stimulate the transfer of muscle mitochondria and mitochondrial DNA (mtDNA) through extracellular vesicles to repair damaged neuronal mitochondria 75. Exercise-induced autophagy is beneficial for the treatment of sarcopenia by regulating Akt/mTOR and Akt/FoxO3a signaling pathways and AMPK-mediated MQC76. In addition, the ubiquitin-proteasome system(UPS) is one of the major pathways involved in muscle protein degradation. This system plays a key role in controlling muscle fiber size. In this degradation mechanism, specific ligases bind ubiquitin to substrate proteins in order to initiate their proteolysis. Exercise can activate AMPK/PGC-1α signaling pathway and inhibit UPS damage, excessive apoptosis, autophagy defects and mitochondrial dysfunction, thereby preventing and delaying sarcopenia 77. Skeletal muscle contraction stimulates the release of BDNF and activates cyclic-AMP response element binding protein (CREB) to stimulate DNA repair 34.

1.2 Nutritional therapy

Muscle-targeting oral nutritional supplements may be an effective treatment for PD patients with sarcopenia. Muscle-targeted oral nutritional supplements are whey protein-based formulations rich in leucine and vitamin D 78. Whey protein has been shown to be a valuable source of protein by rapidly increasing plasma essential amino acid levels, thereby stimulating muscle protein synthesis 79. Whey proteins are capable of producing a variety of dipeptide and tripeptide hydrolysates, known as antisarcopenia peptides, which are more readily absorbed than free amino acids 80. They play a key role by activating the PI3K/Akt/mTOR and MAPK pathways and inhibiting the UPS and AMPK pathway, thereby promoting the synthesis and inhibiting the degradation of muscle proteins 81. Leucine has a positive effect on protein turnover in regulating skeletal muscle anabolism, protein synthesis, and autophagy 82. Leucine can stimulate muscle protein synthesis and inhibit protein degradation through mTOR signaling pathway, and further effectively improve sarcopenia 81. Vitamin D deficiency can promote the expression of related proteins and regulate the synthesis and degradation of skeletal muscle proteins. The study found that vitamin D deficiency increased protein expression of MuRF1, muscle atrophy F-box (MAFbx), and FOXO3a 83. MAFbx catalyzes protein degradation and promotes and controls protein synthesis by regulating eukaryotic initiation factor 3 (eIF3f)84. MuRF1 selectively binds to and promotes fibrin ubiquitination, thereby increasing protein degradation by the 26S proteasome 85. A pragmatic, bi-center, randomized assessor-blinded controlled trial found that consumption of a whey protein formula rich in leucine and vitamin D improved lower limb function and preserved muscle mass in patients with PD 86. In a single-center, double-blind, randomized, controlled trial, consumption of a whey protein nutritional formula rich in leucine and vitamin d improved physical function and muscle mass. 87.Therefore, it further suggests the feasibility of muscle-targeted oral nutritional supplements in the prevention and treatment of PD patients with sarcopenia.

1.3 Exercise combined with nutrition therapy

Resistance exercise combined with nutritional supplements can significantly improve patients' physical function, muscle mass and strength 16 . Taking a formula rich in leucine and vitamin D, combined with rehabilitation exercise for people with PD, improves walking distance and speed and increases muscle mass more than rehabilitation alone 86. The study found that participants who took whey protein after resistance exercise had increased muscle mass, grip strength and gait speed compared to those in any single intervention group 88. Therefore, exercise combined with nutrition therapy is superior to a single treatment in PD patients with sarcopenia.

1. Drug therapy

There are currently no specific drugs approved for the treatment of PD patients with sarcopenia 89. However, some drugs used in clinical or scientific research have been shown to benefit muscles. Therefore, we summarize the potential benefits of these drugs on muscle and provide new directions for the treatment of sarcopenia.

Inflammation plays a crucial role in the pathogenesis of PD with sarcopenia. Therefore, targeted therapy against inflammatory factors associated with sarcopenia may be an effective strategy to improve sarcopenia 89. TNF-α and IL-6 promote chronic inflammation and affect skeletal muscle capacity, which are regarded as potential therapeutic targets for sarcopenia. TNF-α inhibitor etanercept can inhibit fiber type transition, inhibit muscle loss, improve muscle function, and prolong the life span of aging mice 90,91. Patients with rheumatoid arthritis had increased skeletal muscle mass in the extremities with tocilizumab, an anti-IL-6 receptor monoclonal antibody, as compared with untreated patients 92.

Irisin is an exercise-induced polypeptide hormone secreted by muscle and produced by FNDC5 proteolysis, which is also a biomarker of sarcopenia 93. Several lines of evidence suggest that PI3K/Akt/Nrf2 is a therapeutic target for oxidation/reduction (REDOX) reactions imbalance and age-related diseases 43. Irisin protects skeletal muscle by reducing REDOX imbalance and fibrosis by regulating the PI3K/Akt signaling pathway 93. Irisin plays a neuroprotective role in PD by reducing the loss of dopaminergic neurons and promoting lysosomal degradation of pathological α-syn in PD mouse models 94. In addition, irisin triggers the expression of brain-derived neurotrophic factor, which crosses the blood-brain barrier, enhances mitochondrial biogenesis in neurons, and reduces dopaminergic loss in animal models of PD 95.

Angiogenic factor-1 (AGGF1) is a biologically active substance that stimulates the formation of new blood vessels and usually plays a role in growth, development, and repair. 96. A recent study found that intramuscular and intraperitoneal injection of recombinant AGGF1 protein can alleviate the atrophy phenotype of denervated mice. This may be due to AGGF1 may promote skeletal muscle autophagy and inhibit MuRF1 expression through AGGF1-TWEAK (tumor necrosis factor-like weak inducer of apoptosis)/Fn14-NF-κB signaling pathway. Finally, skeletal muscle atrophy was alleviated. Therefore, AGGF1 protein therapy may be a new way to treat patients with skeletal muscle atrophy 52.

Melatonin is an endogenous substance secreted by the pineal gland, which can increase autophagy through the cGAS-STING-TBK and AMPK/FoXO3a signaling pathways, thereby improving oxidative stress and inflammation 97,98. The antioxidant effect of melatonin can also be mediated by mitochondria 99. Mitochondria are an important site for ROS production, and melatonin can protect mitochondrial structure from oxidative stress by regulating glutathione peroxidase (GPx) and glutathione reductase (GRd) to maintain the reduced state of glutathione in mitochondria 100. Pax7 acetylation regulates skeletal muscle satellite cells self-renewal and muscle stem cell differentiation potential 101. Melatonin increases Paired box(Pax7) expression to accelerate skeletal muscle differentiation, thereby rapidly rescuing muscle injury102. Therefore, melatonin can be used as an important therapeutic target for muscle injury repair. In addition, in PD patients, melatonin can improve neuroinflammation by inhibiting signal transducer and activator of transcription (STAT)-related proinflammatory microglial polarization, providing neuroprotection in PD patients103. At the same time, melatonin has potential therapeutic value in improving patients' sleep104. Therefore, melatonin supplementation may have certain benefits in the treatment of PD patients with sarcopenia.

Androgen supplementation has been observed clinically to exert anabolic effects, enhance muscle strength, and increase muscle size 56. Testosterone can promote muscle fiber regeneration and repair by activating IGF-1 level in muscle satellite cells. Binding of IGF-1 to its receptor activates PI3K and Akt, which activate mammalian target of rapamycin (mTOR), thereby promoting muscle protein synthesis 81. Androgens may also maintain mitochondrial mass by inducing mitochondrial biogenesis and inhibiting autophagy. In addition, testosterone may protect the mitochondrial respiratory chain from oxidative damage and maintain normal oxidative phosphorylation function as found in a large number of animal tests 105-107. However, no studies of testosterone supplementation have specifically focused on PD patients with sarcopenia. Therefore, the efficacy and safety of supplemental testosterone therapy in PD patients with sarcopenia remain to be determined 108.

Estrogens, especially estradiol, play a key role in the protection of muscle health in older women. Postmenopausal skeletal muscle mass loss is reversible with estradiol hormone replacement therapy. At the same time, estrogen replacement therapy can also significantly increase the number of muscle satellite cells and improve motor capacity and muscle strength 58. At the same time, estrogen replacement therapy can also significantly increase the number of muscle satellite cells and improve motor capacity and muscle strength. From the genomic pathway, estrogen promotes mitochondrial biogenesis and ATP production by increasing the expression of PGC-1 and downstream target genes through estrogen receptor α (ERα) and Erβ. From non-genomic pathways, ERα and G protein-coupled estrogen receptor (GPER) enhance mitochondrial respiration and ATP production through PKA-mediated 17β-estradiol 63. However, estrogen replacement therapy has not been widely accepted as an effective treatment for PD with sarcopenia 109.

Spermidine, a naturally occurring polyamine, has received much attention due to its potential autophagy induction mechanism and is a good target for the prevention and treatment of sarcopenia 49. The researchers found that spermidine can promote autophagy through activation of the (AMPK)/p27Kip1 and SIRT1/FoXO3a pathways, inducing the proliferation of muscle satellite cells and muscle regeneration 110,111. In addition to reducing markers of oxidative damage and preserving mitochondrial function, spermidine has anti-inflammatory properties, Its anti-inflammatory properties are through inhibiting the accumulation of ROS, reducing the expression level of tumor necrosis factor-α (TNF-α), inhibiting the nuclear translocation of NF-κb p65 subunit, and inhibiting the expression of IL-18 and IL-1β112. In addition, spermidine has been found to have a potential neuroprotective effect against degenerative changes in PD through its antioxidant and anti-inflammatory properties in animal studies of PD. It rescued neurons in the substantia nigra pars compacta (SNpc) of the midbrain and striatal nerve endings while reducing oxidative stress, neuroinflammation and restoring striatal neurochemistry 113.

Conclusion

Loss of muscle mass and strength as well as neurodegenerative changes are inevitable processes during human aging. Sarcopenia and PD are common diseases in the elderly, and the combination of the two is closely related to falls, fractures, frailty, and even death. At the same time. The progressive loss of function associated with sarcopenia may ultimately contribute to the neurodegenerative process of PD. Therefore, active detection, diagnosis and appropriate management of PD with sarcopenia are essential. Early screening, detection, and treatment of sarcopenia may serve as a potential protective measure against the decline in strength and physical function that may occur in PD patients as the disease progresses. More and more experts and scholars believe that exercise and nutrition therapy are particularly important for the improvement of patients' condition and life treatment. Although a variety of drugs have been found to be beneficial in the treatment of PD with sarcopenia, there is no specific drug for the disease at present, and a variety of basic and clinical trials need to be carried out in the future.

References

1. Cruz-Jentoft AJ, Bahat G, Bauer J, et al. Sarcopenia: revised European consensus on definition and diagnosis. *Age and ageing.* 2019;48(1):16-31.

2. Dorsey ER, Elbaz A, Nichols E, et al. Global, regional, and national burden of Parkinson's disease, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. *The Lancet Neurology.* 2018;17(11):939-953.

3. Li G, Ma J, Cui S, et al. Parkinson’s Disease in China: A Forty-Year Growing Track of Bedside Work. Translational Neurodegeneration, 8, Article No. 22. In:2019.

4. Umay E, Yigman Z, Ozturk E, Gundogdu I, Koçer B. Is Dysphagia in Older Patients with Parkinson’s Disease Associated With Sarcopenia? *The journal of nutrition, health & aging.* 2021;25:742-747.

5. da Luz MCL, Bezerra GKA, Asano AGC, Chaves de Lemos MdC, Cabral PC. Determinant factors of sarcopenia in individuals with Parkinson’s disease. *Neurological Sciences.* 2021;42:979-985.

6. Shafiee G, Keshtkar A, Soltani A, Ahadi Z, Larijani B, Heshmat R. Prevalence of sarcopenia in the world: a systematic review and meta-analysis of general population studies. *Journal of Diabetes & Metabolic Disorders.* 2017;16:1-10.

7. Petermann‐Rocha F, Balntzi V, Gray SR, et al. Global prevalence of sarcopenia and severe sarcopenia: a systematic review and meta‐analysis. *Journal of cachexia, sarcopenia and muscle.* 2022;13(1):86-99.

8. Yazar T, Yazar HO, Zayimoğlu E, Çankaya S. Incidence of sarcopenia and dynapenia according to stage in patients with idiopathic Parkinson’s disease. *Neurological Sciences.* 2018;39:1415-1421.

9. Ozer FF, Akın S, Gultekin M, Zararsız GE. Sarcopenia, dynapenia, and body composition in Parkinson’s disease: are they good predictors of disability?: a case–control study. *Neurological Sciences.* 2020;41:313-320.

10. Tan AH, Hew YC, Lim S-Y, et al. Altered body composition, sarcopenia, frailty, and their clinico-biological correlates, in Parkinson's disease. *Parkinsonism & related disorders.* 2018;56:58-64.

11. Hart A, Cordova-Rivera L, Barker F, Sayer AA, Granic A, Yarnall AJ. The prevalence of sarcopenia in Parkinson’s disease and related disorders-a systematic review. *Neurological Sciences.* 2023:1-13.

12. Krenovsky J-P, Bötzel K, Ceballos-Baumann A, et al. Interrelation between sarcopenia and the number of motor neurons in patients with parkinsonian syndromes. *Gerontology.* 2020;66(4):409-415.

13. Vetrano DL, Pisciotta MS, Laudisio A, et al. Sarcopenia in Parkinson disease: comparison of different criteria and association with disease severity. *Journal of the American Medical Directors Association.* 2018;19(6):523-527.

14. Cai Y, Feng F, Wei Q, Jiang Z, Ou R, Shang H. Sarcopenia in patients with Parkinson's disease: a systematic review and meta-analysis. *Frontiers in neurology.* 2021;12:111.

15. Bahat G, Yilmaz O, Kilic C, Oren M, Karan M. Performance of SARC-F in regard to sarcopenia definitions, muscle mass and functional measures. *The journal of nutrition, health & aging.* 2018;22:898-903.

16. Chen L-K, Woo J, Assantachai P, et al. Asian Working Group for Sarcopenia: 2019 consensus update on sarcopenia diagnosis and treatment. *Journal of the American Medical Directors Association.* 2020;21(3):300-307. e302.

17. Sarcopenia IWGo. Sarcopenia: an undiagnosed condition in older adults. Current consensus definition: prevalence, etiology, and consequences. *Journal of the American Medical Directors Association.* 2011;12(4):249.

18. Studenski SA, Peters KW, Alley DE, et al. The FNIH sarcopenia project: rationale, study description, conference recommendations, and final estimates. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences.* 2014;69(5):547-558.

19. Kelly NA, Hammond KG, Bickel CS, Windham ST, Tuggle SC, Bamman MM. Effects of aging and Parkinson’s disease on motor unit remodeling: influence of resistance exercise training. *Journal of applied physiology.* 2018;124(4):888-898.

20. Bhaskaran S, Pollock N, C Macpherson P, et al. Neuron‐specific deletion of CuZnSOD leads to an advanced sarcopenic phenotype in older mice. *Aging Cell.* 2020;19(10):e13225.

21. Krause Neto W, Ciena AP, Anaruma CA, De Souza RR, Gama EF. Effects of exercise on neuromuscular junction components across age: systematic review of animal experimental studies. *BMC Research Notes.* 2015;8:1-15.

22. Kreko-Pierce T, Eaton BA. Rejuvenation of the aged neuromuscular junction by exercise. *Cell Stress.* 2018;2(2):25.

23. Karim A, Iqbal MS, Muhammad T, Qaisar R. Evaluation of sarcopenia using biomarkers of the neuromuscular junction in Parkinson’s disease. *Journal of Molecular Neuroscience.* 2022;72(4):820-829.

24. Pratt J, De Vito G, Narici M, Boreham C. Neuromuscular junction aging: a role for biomarkers and exercise. *The Journals of Gerontology: Series A.* 2021;76(4):576-585.

25. Karim A, Muhammad T, Qaisar R. Prediction of sarcopenia using multiple biomarkers of neuromuscular junction degeneration in chronic obstructive pulmonary disease. *Journal of Personalized Medicine.* 2021;11(9):919.

26. Håkansson K, Ledreux A, Daffner K, et al. BDNF responses in healthy older persons to 35 minutes of physical exercise, cognitive training, and mindfulness: associations with working memory function. *Journal of Alzheimer's Disease.* 2017;55(2):645-657.

27. Piotrowicz Z, Chalimoniuk M, Płoszczyca K K, Czuba M, Langfort J. Acute normobaric hypoxia does not affect the simultaneous exercise-induced increase in circulating BDNF and GDNF in young healthy men: A feasibility study. *PloS one.* 2019;14(10):e0224207.

28. Qaisar R, Karim A, Muhammad T. Plasma CAF22 levels as a useful predictor of muscle health in patients with chronic obstructive pulmonary disease. *Biology.* 2020;9(7):166.

29. Suzuki K. Chronic inflammation as an immunological abnormality and effectiveness of exercise. *Biomolecules.* 2019;9(6):223.

30. Wang T. Searching for the link between inflammaging and sarcopenia. *Ageing research reviews.* 2022;77:101611.

31. Grosicki GJ, Barrett BB, Englund DA, et al. Circulating interleukin-6 is associated with skeletal muscle strength, quality, and functional adaptation with exercise training in mobility-limited older adults. *The Journal of frailty & aging.* 2020;9:57-63.

32. Pelosi L, Berardinelli MG, Forcina L, et al. Sustained systemic levels of IL-6 impinge early muscle growth and induce muscle atrophy and wasting in adulthood. *Cells.* 2021;10(7):1816.

33. Picca A, Coelho-Junior HJ, Calvani R, Marzetti E, Vetrano DL. Biomarkers shared by frailty and sarcopenia in older adults: A systematic review and meta-analysis. *Ageing research reviews.* 2022;73:101530.

34. Pascual-Fernández J, Fernández-Montero A, Córdova-Martínez A, Pastor D, Martínez-Rodríguez A, Roche E. Sarcopenia: molecular pathways and potential targets for intervention. *International Journal of Molecular Sciences.* 2020;21(22):8844.

35. Giron M, Thomas M, Dardevet D, Chassard C, Savary‐Auzeloux I. Gut microbes and muscle function: can probiotics make our muscles stronger? *Journal of Cachexia, Sarcopenia and Muscle.* 2022;13(3):1460-1476.

36. Wu J, Lin S, Chen W, et al. TNF-α contributes to sarcopenia through caspase-8/caspase-3/GSDME-mediated pyroptosis. *Cell Death Discovery.* 2023;9(1):76.

37. Li J, Tian M, Hua T, et al. Combination of autophagy and NFE2L2/NRF2 activation as a treatment approach for neuropathic pain. *Autophagy.* 2021;17(12):4062-4082.

38. Li W, He P, Huang Y, et al. Selective autophagy of intracellular organelles: recent research advances. *Theranostics.* 2021;11(1):222.

39. Xie G, Jin H, Mikhail H, et al. Autophagy in sarcopenia: Possible mechanisms and novel therapies. *Biomedicine & Pharmacotherapy.* 2023;165:115147.

40. Baht GS, Bareja A, Lee DE, et al. Meteorin-like facilitates skeletal muscle repair through a Stat3/IGF-1 mechanism. *Nature metabolism.* 2020;2(3):278-289.

41. Rostami S, Salehizadeh R, Shamloo S, Fayazmilani R. The Effect of Voluntary Physical Activity in an Enriched Environment and Combined Exercise Training on the Satellite Cell Pool in Developing Rats. *Frontiers in Physiology.* 2022;13:899234.

42. Zecchini S, Giovarelli M, Perrotta C, et al. Autophagy controls neonatal myogenesis by regulating the GH-IGF1 system through a NFE2L2-and DDIT3-mediated mechanism. *Autophagy.* 2019;15(1):58-77.

43. Yu C, Xiao J-H. The Keap1-Nrf2 system: a mediator between oxidative stress and aging. *Oxidative Medicine and Cellular Longevity.* 2021;2021:1-16.

44. Kitaoka Y, Tamura Y, Takahashi K, Takeda K, Takemasa T, Hatta H. Effects of Nrf2 deficiency on mitochondrial oxidative stress in aged skeletal muscle. *Physiological reports.* 2019;7(3):e13998.

45. De Biase D, Piegari G, Prisco F, et al. Implication of the NLRP3 inflammasome in bovine age-related sarcopenia. *International Journal of Molecular Sciences.* 2021;22(7):3609.

46. Qiao L, Ma J, Zhang Z, et al. Deficient chaperone-mediated autophagy promotes inflammation and atherosclerosis. *Circulation Research.* 2021;129(12):1141-1157.

47. Eggelbusch M, Shi A, Broeksma BC, et al. The NLRP3 inflammasome contributes to inflammation‐induced morphological and metabolic alterations in skeletal muscle. *Journal of Cachexia, Sarcopenia and Muscle.* 2022;13(6):3048-3061.

48. Bhardwaj G, Penniman CM, Klaus K, et al. Transcriptomic regulation of muscle mitochondria and calcium signaling by Insulin/IGF-1 receptors depends on FoxO transcription factors. *Frontiers in physiology.* 2022;12:2536.

49. Galasso L, Cappella A, Mulè A, et al. Polyamines and Physical Activity in Musculoskeletal Diseases: A Potential Therapeutic Challenge. *International Journal of Molecular Sciences.* 2023;24(12):9798.

50. Chen W, Chen Y, Liu Y, Wang X. Autophagy in muscle regeneration: potential therapies for myopathies. *Journal of Cachexia, Sarcopenia and Muscle.* 2022;13(3):1673-1685.

51. Lima DP, de Almeida SB, Bonfadini JdC, et al. Clinical correlates of sarcopenia and falls in Parkinson’s disease. *PLoS One.* 2020;15(3):e0227238.

52. He Z, Song Q, Yu Y, et al. Protein therapy of skeletal muscle atrophy and mechanism by angiogenic factor AGGF1. *Journal of Cachexia, Sarcopenia and Muscle.* 2023;14(2):978-991.

53. Alway SE, Mohamed JS, Myers MJ. Mitochondria initiate and regulate sarcopenia. *Exercise and sport sciences reviews.* 2017;45(2):58.

54. Wu Y-N, Chen M-H, Chiang P-L, et al. Associations between brain structural damage and core muscle loss in patients with Parkinson’s disease. *Journal of Clinical Medicine.* 2020;9(1):239.

55. Lee C-Y, Chen H-L, Chen P-C, et al. Correlation between executive network integrity and sarcopenia in patients with Parkinson’s disease. *International journal of environmental research and public health.* 2019;16(24):4884.

56. Basualto-Alarcón C, Varela D, Duran J, Maass R, Estrada M. Sarcopenia and androgens: a link between pathology and treatment. *Clinical Nutrition and Aging.* 2017:239-268.

57. Yang L, Smith L, Hamer M. Gender-specific risk factors for incident sarcopenia: 8-year follow-up of the English longitudinal study of ageing. *J Epidemiol Community Health.* 2019;73(1):86-88.

58. Geraci A, Calvani R, Ferri E, Marzetti E, Arosio B, Cesari M. Sarcopenia and menopause: the role of estradiol. *Frontiers in endocrinology.* 2021;12:682012.

59. Juppi H-K, Sipilä S, Cronin NJ, et al. Role of menopausal transition and physical activity in loss of lean and muscle mass: a follow-up study in middle-aged Finnish women. *Journal of clinical medicine.* 2020;9(5):1588.

60. Spangenburg E. Estrogen Regulates the Satellite Cell Compartment in Females. 2019.

61. Xu H, Ranjit R, Richardson A, Van Remmen H. Muscle mitochondrial catalase expression prevents neuromuscular junction disruption, atrophy, and weakness in a mouse model of accelerated sarcopenia. *Journal of cachexia, sarcopenia and muscle.* 2021;12(6):1582-1596.

62. Yang Q, Wang Y, Zhao C, Pang S, Lu J, Chan P. α‐Synuclein aggregation causes muscle atrophy through neuromuscular junction degeneration. *Journal of Cachexia, Sarcopenia and Muscle.* 2023;14(1):226-242.

63. Tian X, Lou S, Shi R. From mitochondria to sarcopenia: role of 17β-estradiol and testosterone. *Frontiers in Endocrinology.* 2023;14:1156583.

64. Hrytsuliak B, Ostapiak Z, Polataiko Y, et al. Dynamics of balance indicators, activities of daily living, and quality of life of elderly suffering from Parkinson’s disease and frailty after proximal humerus fracture following physiotherapeutic functional training. *Journal of Medicine and Life.* 2022;15(1):98.

65. Henderson EJ, Morgan GS, Amin J, Gaunt DM, Ben-Shlomo Y. The minimum clinically important difference (MCID) for a falls intervention in Parkinson's: a delphi study. *Parkinsonism & related disorders.* 2019;61:106-110.

66. Farombi TH, Owolabi MO, Ogunniyi A. Falls and their associated risks in Parkinson’s disease patients in Nigeria. *Journal of movement disorders.* 2016;9(3):160.

67. Barichella M, Pinelli G, Iorio L, et al. Sarcopenia and dynapenia in patients with parkinsonism. *Journal of the American Medical Directors Association.* 2016;17(7):640-646.

68. Hulbert S, Rochester L, Nieuwboer A, et al. Staying safe”–a narrative review of falls prevention in people with Parkinson’s–“PDSAFE. *Disability and rehabilitation.* 2019;41(21):2596-2605.

69. Mu L, Sobotka S, Chen J, et al. Altered pharyngeal muscles in Parkinson disease. *Journal of Neuropathology & Experimental Neurology.* 2012;71(6):520-530.

70. Katunina E, Titova N. The epidemiology of nonmotor symptoms in Parkinson's disease (cohort and other studies). *International review of neurobiology.* 2017;133:91-110.

71. Noor H, Reid J, Slee A. Resistance exercise and nutritional interventions for augmenting sarcopenia outcomes in chronic kidney disease: a narrative review. *Journal of Cachexia, Sarcopenia and Muscle.* 2021;12(6):1621-1640.

72. Vlietstra L, Hendrickx W, Waters DL. Exercise interventions in healthy older adults with sarcopenia: a systematic review and meta‐analysis. *Australasian journal on ageing.* 2018;37(3):169-183.

73. Van Ancum JM, Meskers CG, Reijnierse EM, et al. Lack of knowledge contrasts the willingness to counteract sarcopenia among community-dwelling adults. *Journal of aging and health.* 2020;32(7-8):787-794.

74. Lavin KM, Ge Y, Sealfon SC, et al. Rehabilitative impact of exercise training on human skeletal muscle transcriptional programs in Parkinson’s disease. *Frontiers in Physiology.* 2020;11:653.

75. Burtscher J, Millet GP, Place N, Kayser B, Zanou N. The muscle-brain axis and neurodegenerative diseases: the key role of mitochondria in exercise-induced neuroprotection. *International Journal of Molecular Sciences.* 2021;22(12):6479.

76. Zeng Z, Liang J, Wu L, Zhang H, Lv J, Chen N. Exercise-induced autophagy suppresses sarcopenia through Akt/mTOR and Akt/FoxO3a signal pathways and AMPK-mediated mitochondrial quality control. *Frontiers in Physiology.* 2020;11:583478.

77. Liang J, Zhang H, Zeng Z, et al. Lifelong aerobic exercise alleviates sarcopenia by activating autophagy and inhibiting protein degradation via the AMPK/PGC-1α signaling pathway. *Metabolites.* 2021;11(5):323.

78. Cereda E, Pisati R, Rondanelli M, Caccialanza R. Whey protein, leucine-and vitamin-D-enriched oral nutritional supplementation for the treatment of sarcopenia. *Nutrients.* 2022;14(7):1524.

79. Boirie Y, Guillet C. Fast digestive proteins and sarcopenia of aging. *Current opinion in clinical nutrition and metabolic care.* 2018;21(1):37-41.

80. Lees MJ, Carson BP. The potential role of fish-derived protein hydrolysates on metabolic health, skeletal muscle mass and function in ageing. *Nutrients.* 2020;12(8):2434.

81. Zhu X, Wang J, Lu Y, et al. Potential of Food Protein-Derived Bioactive Peptides against Sarcopenia: A Comprehensive Review. *Journal of Agricultural and Food Chemistry.* 2023;71(14):5419-5437.

82. Dos Santos ALS, Anastácio LR. The impact of L-branched-chain amino acids and L-leucine on malnutrition, sarcopenia, and other outcomes in patients with chronic liver disease. *Expert Review of Gastroenterology & Hepatology.* 2021;15(2):181-194.

83. Yang A, Lv Q, Chen F, et al. The effect of vitamin D on sarcopenia depends on the level of physical activity in older adults. *Journal of cachexia, sarcopenia and muscle.* 2020;11(3):678-689.

84. Furrer R, Handschin C. Muscle wasting diseases: novel targets and treatments. *Annual review of pharmacology and toxicology.* 2019;59:315-339.

85. Polge C, Heng AE, Jarzaguet M, et al. Muscle actin is polyubiquitinylated in vitro and in vivo and targeted for breakdown by the E3 ligase MuRF1. *The FASEB Journal.* 2011;25(11):3790-3802.

86. Barichella M, Cereda E, Pinelli G, et al. Muscle-targeted nutritional support for rehabilitation in patients with parkinsonian syndrome. *Neurology.* 2019;93(5):e485-e496.

87. Rondanelli M, Cereda E, Klersy C, et al. Improving rehabilitation in sarcopenia: a randomized‐controlled trial utilizing a muscle‐targeted food for special medical purposes. *Journal of cachexia, sarcopenia and muscle.* 2020;11(6):1535-1547.

88. Mori H, Tokuda Y. Effect of whey protein supplementation after resistance exercise on the muscle mass and physical function of healthy older women: A randomized controlled trial. *Geriatrics & gerontology international.* 2018;18(9):1398-1404.

89. Liang Z, Zhang T, Liu H, et al. Inflammaging: The ground for sarcopenia? *Experimental Gerontology.* 2022:111931.

90. Dionyssiotis Y. Sarcopenia in the elderly. *European endocrinology.* 2019;15(1):13.

91. Sciorati C, Gamberale R, Monno A, et al. Pharmacological blockade of TNFα prevents sarcopenia and prolongs survival in aging mice. *Aging (Albany NY).* 2020;12(23):23497.

92. Tournadre A, Pereira B, Dutheil F, et al. Changes in body composition and metabolic profile during interleukin 6 inhibition in rheumatoid arthritis. J Cachexia Sarcopenia Muscle 8: 639–646. In:2017.

93. Wu Y, Wu Y, Yu J, et al. Irisin ameliorates D-galactose-induced skeletal muscle fibrosis via the PI3K/Akt pathway. *European Journal of Pharmacology.* 2023;939:175476.

94. Kam T-I, Park H, Chou S-C, et al. Amelioration of pathologic α-synuclein-induced Parkinson’s disease by irisin. *Proceedings of the National Academy of Sciences.* 2022;119(36):e2204835119.

95. Murphy KT, Lynch GS. Impaired skeletal muscle health in Parkinsonian syndromes: clinical implications, mechanisms and potential treatments. *Journal of Cachexia, Sarcopenia and Muscle.* 2023.

96. Da X, Li Z, Huang X, et al. AGGF1 therapy inhibits thoracic aortic aneurysms by enhancing integrin α7-mediated inhibition of TGF-β1 maturation and ERK1/2 signaling. *Nature Communications.* 2023;14(1):2265.

97. Ali T, Rahman SU, Hao Q, et al. Melatonin prevents neuroinflammation and relieves depression by attenuating autophagy impairment through FOXO3a regulation. *Journal of pineal research.* 2020;69(2):e12667.

98. Wang S, Wang L, Qin X, et al. ALDH2 contributes to melatonin-induced protection against APP/PS1 mutation-prompted cardiac anomalies through cGAS-STING-TBK1-mediated regulation of mitophagy. *Signal Transduction and Targeted Therapy.* 2020;5(1):119.

99. Feng T-Y, Li Q, Ren F, et al. Melatonin protects goat spermatogonial stem cells against oxidative damage during cryopreservation by improving antioxidant capacity and inhibiting mitochondrial apoptosis pathway. *Oxidative Medicine and Cellular Longevity.* 2020;2020.

100. Jin H, Xie W, Hu P, et al. The role of melatonin in sarcopenia: Advances and application prospects. *Experimental Gerontology.* 2021;149:111319.

101. Sincennes M-C, Brun CE, Lin AY, et al. Acetylation of PAX7 controls muscle stem cell self-renewal and differentiation potential in mice. *Nature Communications.* 2021;12(1):3253.

102. Su C-M, Tsai C-H, Chen H-T, et al. Melatonin improves muscle injury and differentiation by increasing Pax7 expression. *International Journal of Biological Sciences.* 2023;19(4):1049.

103. Li J, Liu H, Wang X, et al. Melatonin ameliorates Parkinson’s disease via regulating microglia polarization in a RORα‐dependent pathway. *npj Parkinson's Disease.* 2022;8(1):90.

104. Pérez-Lloret S, Cardinali DP. Melatonin as a chronobiotic and cytoprotective agent in Parkinson’s Disease. *Frontiers in Pharmacology.* 2021;12:650597.

105. Rossetti ML, Esser KA, Lee C, Tomko Jr RJ, Eroshkin AM, Gordon BS. Disruptions to the limb muscle core molecular clock coincide with changes in mitochondrial quality control following androgen depletion. *American Journal of Physiology-Endocrinology and Metabolism.* 2019;317(4):E631-E645.

106. Liu C, Ma J, Zhang J, et al. Testosterone deficiency caused by castration modulates mitochondrial biogenesis through the AR/PGC1α/TFAM pathway. *Frontiers in genetics.* 2019;10:505.

107. Rottenberg H, Hoek JB. The mitochondrial permeability transition: nexus of aging, disease and longevity. *Cells.* 2021;10(1):79.

108. Rolland Y, Dray C, Vellas B, Barreto PDS. Current and investigational medications for the treatment of sarcopenia. *Metabolism.* 2023:155597.

109. Li N, Wang JJ, Lu ZL, Zhu MX, Xu HX, Liu J. Protein Supplementation for the Prevention and Management of Sarcopenia in the Elderly. *Journal of Nutritional Oncology.* 2019;4(2):74-84.

110. White JP, Billin AN, Campbell ME, Russell AJ, Huffman KM, Kraus WE. The AMPK/p27Kip1 axis regulates autophagy/apoptosis decisions in aged skeletal muscle stem cells. *Stem Cell Reports.* 2018;11(2):425-439.

111. Zheng Y, Shi B, Ma M, Wu X, Lin X. The novel relationship between Sirt3 and autophagy in myocardial ischemia–reperfusion. *Journal of cellular physiology.* 2019;234(5):5488-5495.

112. Madeo F, Eisenberg T, Pietrocola F, Kroemer G. Spermidine in health and disease. *Science.* 2018;359(6374):eaan2788.

113. Sharma S, Kumar P, Deshmukh R. Neuroprotective potential of spermidine against rotenone induced Parkinson's disease in rats. *Neurochemistry International.* 2018;116:104-111.