Expert Opinion on Management Advancements in Sarcopenia: From Muscle Wasting to Recovery

Article *in* Journal of the Association of Physicians of India · June 2025

DOI: 10.59556/japi.73.1031

REVIEW ARTICLE

Expert Opinion on Management Advancements in Sarcopenia: From Muscle Wasting to Recovery

Sanjay Kalra[1], AK Das[2], Narendra Kotwal[3], Lakshmi Nagendra[4*], Rashi Agrawal[5], Ganesh HK[6], Sambit Das[7], Arun Kumar Singh[8], Nitin Kapoor[9], Atul Dhingra[10], Abhilasha Jain[11], Sourabh Sharma[12], Vinod Gupta[13], Suneet Kumar Verma[14], Hanjabam Barun Sharma[15], Ram Prabhoo[16], Naresh Shetty[17], Sameer Muchhala[18], Nimitha Pinto[19]

Received: 17 April 2025; *Accepted:* 06 May 2025

Abstract

Sarcopenia, an age-related condition marked by the decline of skeletal muscle mass, strength, and function, often leads to loss of function, disability, and diminished quality of life (QoL) in the elderly population. Despite its growing prevalence, sarcopenia is frequently underdiagnosed and inadequately managed. Timely detection and appropriate interventions are crucial to slowing disease progression and minimizing associated risks. As standardized guidelines and individualized management plans are necessary to improve clinical outcomes, this consensus paper presents expert insights into advancements in sarcopenia management, including diagnostic criteria and therapeutic interventions, and the need for personalized screening tools for Indian demographics. Furthermore, experts emphasized the importance of a multimodal approach, integrating resistance exercise, nutritional optimization, and emerging pharmacological therapies for effective sarcopenia treatment. The role of anabolic agents such as nandrolone decanoate in muscle preservation is explored, alongside considerations for patient selection and safety. This paper underscores the importance of a patient-centered approach, which addresses both functional recovery and overall well-being of individuals at risk or diagnosed with sarcopenia.

Journal of The Association of Physicians of India (2025): 10.59556/japi.73.1031

Introduction

Sarcopenia is a generalized and progressive skeletal muscle disorder characterized by a reduction in muscle mass, a decline in muscle strength, and impaired physical performance. It has been consistently linked with diminished quality of life (QoL), owing to its association with adverse health outcomes, including functional impairment, elevated risk of disability, and heightened likelihood of falls.[1] These consequences not only restrict daily activities but also contribute to psychological distress, such as depression and anxiety, further exacerbating the decline in overall well-being.[2]

According to epidemiological studies, approximately 10–16% of the elderly population is affected by sarcopenia globally,[3] with an even higher prevalence observed in individuals with certain medical conditions. For instance, individuals with diabetes exhibit a prevalence of 18%, while those with unresectable esophageal cancer may have rates as high as 66%.[4] A multicountry study, including India, reported the global prevalence of sarcopenia to be 15.2%.[5] In community settings, prevalence rates of sarcopenia are reported at 11% and 9% for men and women, respectively. Residents in nursing homes demonstrate significantly higher incidences (51% in men, 31% in women) of sarcopenia. Among hospitalized individuals, sarcopenia affects 23% of men and 24% of women. Regional variations are notable, with research from East Asia indicating prevalence rates of 40.3% in men and 41.3% in women in Korea, while studies in India and other regions reveal substantial variability. These differences highlight the influence of geographic, demographic, and healthcare-related factors on sarcopenia prevalence.[6]

The disorder's underlying mechanisms involve a dynamic interplay of molecular, cellular, and systemic processes, necessitating a standardized approach to diagnosis and management.[7] Several key elements play an important role in the pathophysiology of sarcopenia, such as those shown in Figure 1.[8]

Despite its substantial health implications, sarcopenia remains underdiagnosed and undertreated.[9] Meanwhile, emerging anabolic therapies have demonstrated promise, with 8–10% muscle mass gains within 3 months. The enhanced understanding of the molecular mechanisms and cellular pathophysiology of sarcopenia has facilitated the development of targeted interventions, such as pharmacological strategies, nutritional optimization, and exercise-based interventions.[10]

However, despite extensive research, uncertainties persist regarding the epidemiological characteristics, risk

[1]Treasurer, International Society of Endocrinology (ISE); Vice President, South Asian Obesity Forum (SOF); Bharti Hospital, Karnal, Haryana; [2]Dean Academic, Mahatma Gandhi Medical College and Research Institute, Sri Balaji Vidyapeeth, Puducherry; [3]Director, Department of Endocrinology, Paras Hospitals, Panchkula, Haryana; [4]Head of Department and Associate Professor, Department of Endocrinology, JSS Medical College, JSS Academy of Higher Education and Research, Mysuru, Karnataka; [5]Consultant, Department of Endocrinology, Kokilaben Dhirubhai Ambani Hospital, Navi Mumbai, Maharashtra; [6]Consultant Endocrinologist, Maithri Clinic, Mangalore, Karnataka; [7]Professor and Head, Department of Endocrinology, Kalinga Institute of Medical Sciences, KIIT DU, Bhubaneswar, Odisha; [8]Director, Department of Endocrinology, Metro Heart Institute with Multispecialty, Faridabad, Haryana; [9]Head of Department, Professor, and Consultant, Department of Endocrinology, Diabetes and Metabolism, Christian Medical College, Vellore, Tamil Nadu, India; Non-communicable Disease Unit, Baker Heart and Diabetes Institute, Melbourne, Victoria, Australia; [10]Associate Professor, Department of Medicine, Dr SS Tantia Medical College Hospital & Research Centre, Sri Ganganagar, Rajasthan; [11]Consultant, Department of Endocrinology, Jain Hospital, Kaithal, Haryana; [12]Assistant Professor, Department of Nephrology, VMMC & Safdarjung Hospital, New Delhi; [13]Senior Medical Officer, Deen Dayal Upadhyay Zonal Hospital, Shimla, Himachal Pradesh; [14]Consultant, Department of Internal Medicine, Alchemist Hospital, Panchkula, Haryana; Sparsh Clinic, Zirakpur, Punjab; [15]Assistant Professor, Department of Physiology, Institute of Medical Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh; [16]Head, Department of Orthopedics, Mukund Hospital; Wadia Hospital, Mumbai, Maharashtra; [17]Chief Executive Officer, Department of Orthopedics, Akash Institute of Medical Sciences & Research Centre, Bengaluru, Karnataka; [18]General Manager; [19]Manager, Medical Affairs, Zydus Healthcare Limited, Mumbai, Maharashtra, India; *Corresponding Author

How to cite this article: Kalra S, Das A, Kotwal N, *et al.* Expert Opinion on Management Advancements in Sarcopenia: From Muscle Wasting to Recovery. J Assoc Physicians India 2025;73(6):50–60.

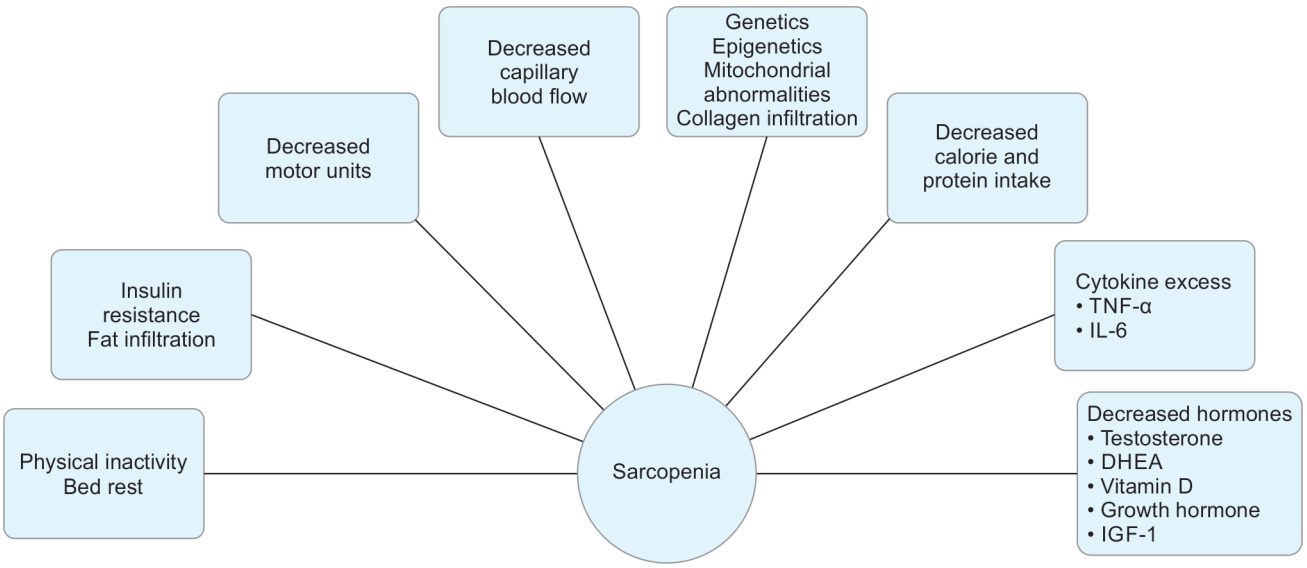

Fig. 1: Factors involved in the pathophysiology of sarcopenia

factors, and complications of sarcopenia. Additionally, the inconsistent application of effective treatments across clinical settings underscores the urgent need for standardized guidelines.[11] Therefore, establishing a consensus on diagnostic criteria and treatment protocols is crucial for early identification, risk stratification, and the development of an optimal individualized therapeutic strategy.

Methodology

The DELPHI method was utilized to develop comprehensive recommendations for sarcopenia, covering screening, diagnosis, and management, including both pharmacological and nonpharmacological interventions.[12] The DELPHI technique is a structured method widely used to gather important information on scientific topics. It is based on the assumption that opinions from expert panels are generally more accurate and unbiased than those from individuals.

This methodology was conducted in three rounds. In the first round, the core group of experts framed the questionnaire after a thorough literature review of articles published up to 2024, using databases such as PubMed, Scopus, and Web of Science (WoS). The search was conducted using the following keywords: Sarcopenia, Muscle strength, Muscle wasting, Anabolic steroids, Testosterone regimen, Nandrolone decanoate, Resistance exercise, Multimodal treatment, Screening recommendations, etc. Additionally, the reference list of all the selected studies was also analyzed. Studies in any language were included.

In the second round, the developed questionnaire was distributed to 17 physicians from India. In the third round, modifications were made to certain statements to better align with the management of sarcopenia in the Indian subpopulation, incorporating feedback from experts in the previous round. The revised statements were then shared virtually with the physicians for further approval.

The final consensus statements and manuscript were formulated based on expert discussions and insights shared during the meeting. To ensure accuracy and relevance, the experts reviewed the manuscript before its publication (Fig. 2).

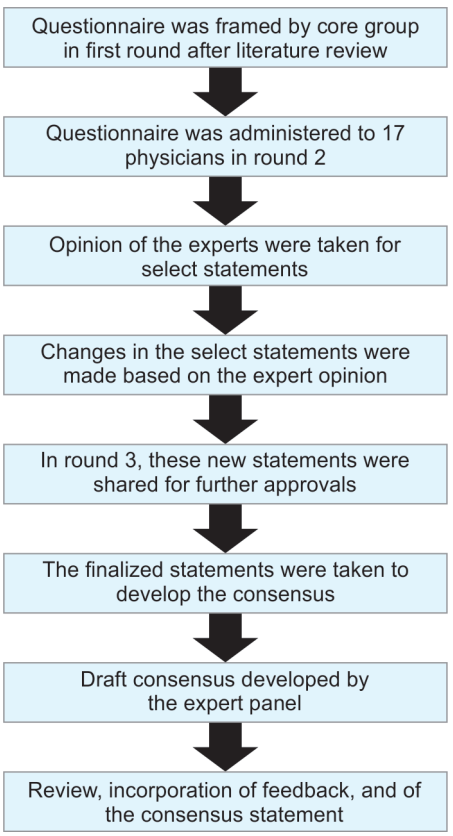

Fig. 2: The DELPHI methodology followed for framing the consensus statement

Results and Discussion

Challenges to Sarcopenia Diagnosis

Even with its high prevalence and significant negative outcomes, a standardized operational definition for the condition remained elusive. To address this gap, three consensus papers were published in 2010 under the guidance of different expert groups: the European Working Group on Sarcopenia in Older People (EWGSOP), the European Society for Clinical Nutrition and Metabolism Special Interest Groups (ESPEN-SIG), and the International Working Group on Sarcopenia (IWGS).

Each group provided a definition of sarcopenia:

- As per EWGSOP, sarcopenia is defined by reduced skeletal muscle mass along with either decreased muscle strength [e.g., handgrip strength (HGS)] or impaired muscle performance (e.g., walking speed or muscle power). If all three conditions were met, the diagnosis was classified as severe sarcopenia.
- ESPEN-SIG identified sarcopenia based on reduced skeletal muscle mass and muscle strength, suggesting that walking speed could serve as an assessment tool.
- As per IWGS, sarcopenia encompasses reduced muscle mass and muscle

function, which could be assessed through walking speed. Additionally, it noted that sarcopenia could occur either independently due to loss of muscle mass or along with increased fat mass.[13]

Among these definitions, the EWGSOP approach stands out by differentiating between muscle strength and muscle performance, allowing a wider range of classification, and providing criteria for identifying severe sarcopenia.

The EWGSOP guidelines published in 2010 introduced a staging system for sarcopenia:

- Presarcopenia: Reduced muscle mass without significantly affecting muscle strength or physical performance, identifiable only through precise muscle mass measurement techniques.
- Sarcopenia: Marked by reduced muscle mass combined with either low muscle strength or poor physical performance.
- Severe sarcopenia: Diagnosis is confirmed when an individual exhibits all three key indicators: decreased muscle mass, diminished strength, and impaired physical performance.[7]

The diagnosis of sarcopenia can be determined through specific assessments[14–16]:

- In individuals over 65 years, sarcopenia is measured by walking speed. Muscle mass should be evaluated if the walking speed is below 0.8 m/s in a 4-m walking test. Low muscle mass is defined as a skeletal muscle index below two standard deviations (SD) from the mean of a young, healthy population (<7.23 kg/m^2 in men and <5.67 kg/m^2 in women), typically measured using dual-energy X-ray absorptiometry (DEXA).[15]
- If walking speed exceeds 0.8 m/s, HGS should be tested. Muscle mass should be analyzed if grip strength is below 30 kg in men and 20 kg in women.[16]

As these definitions were formulated based on Western populations, adaptations are needed for the Indian population because of differences in physical composition, nutritional intake, and lifestyle. Multiple Indian studies highlight:

- Lower baseline muscle mass among Indian adults compared to Western populations.[17]
- Higher prevalence of vitamin D deficiency and inadequate protein intake, particularly in vegetarian populations.[18]
- Earlier onset of muscle loss due to metabolic disorders such as diabetes and obesity, which are highly prevalent in India.[19]

Expert opinion

- Sarcopenia can be determined by the occurrence of any two among these three characteristic features: reduced muscle function, muscle strength, and muscle mass, measured using metrics such as grip strength, walking speed, or chair stand tests, lean mass percentage, and appendicular skeletal muscle index (ASMI).

Causes of Sarcopenia

Sarcopenia is categorized as primary (age-related) without any identifiable cause apart from aging itself. In contrast, secondary sarcopenia occurs when additional contributing factors are present.[14] One such factor is obesity, which shares a bidirectional relationship with sarcopenia. Similar to obesity, decreased muscle strength in sarcopenia is associated with functional impairment, lower QoL, and an increased likelihood of adverse health events, often resulting in hospitalization and a greater financial burden on healthcare systems.[20] Additionally, a 2022 meta-analysis highlights that sarcopenia significantly increases the risk of mortality.[21]

The intersection of the aging and obesity epidemics has led to the emergence of sarcopenic obesity, a condition characterized by accelerated muscle loss alongside excess body fat. This combination appears to have a compounding effect, amplifying the risks tied to either condition alone.[22]

Newer antiobesity medications (AOMs), particularly those targeting incretin pathways, have demonstrated the potential to achieve over 20% weight loss. However, clinical trials evaluating their efficacy and safety have primarily focused on younger populations. Even studies that include older adults often fail to clearly define participants' age distribution. When prescribing AOMs to older adults, careful consideration is needed regarding polypharmacy, drug interactions, and potential side effects—either directly due to the medication itself or indirectly due to rapid and sustained weight loss. Nonetheless, recent findings suggest that fast weight loss does not necessarily increase the risk of muscle mass reduction compared to gradual weight loss.[20]

In most older adults, sarcopenia arises from multiple contributing factors, making it difficult to categorize individuals as having purely primary or secondary sarcopenia. The resulting muscle loss and diminished strength lead to a progressive decline in mobility, increasing frailty, and reducing physiological resilience.[14] This contributes to reduced physical activity, which further accelerates muscle wasting, creating a vicious cycle that exacerbates sarcopenic progression.[14,23]

Expert opinion

- Sarcopenia is a multifactorial syndrome that may be primary or secondary and can be influenced by factors such as the use of AOMs.

Screening for Sarcopenia

Sarcopenia often remains undiagnosed, as routine screening is not widely implemented due to the absence of highly precise screening tools. Instead, a case-finding approach is recommended, where individuals are assessed for sarcopenia if they report relevant symptoms or exhibit multiple risk factors.[24]

The key risk factors contributing to sarcopenia are categorized[4] in Table 1.

A task force from the International Conference on Frailty and Sarcopenia Research

Table 1: Risk factors for sarcopenia

Category	*Risk factors*
Nutritional factors	• Inadequate protein intake • Low overall energy intake • Deficiency in essential micronutrients • Gastrointestinal disorders leading to malabsorption • Anorexia due to aging or dental/oral health issues
Physical inactivity	• Prolonged bed rest, immobility, or deconditioning • Sedentary lifestyle and low levels of physical activity
Underlying medical conditions	• Musculoskeletal disorders (e.g., osteoporosis, arthritis) • Neurological conditions (e.g., Parkinson's disease, stroke) • Chronic illnesses (e.g., heart failure, chronic obstructive pulmonary disease) • Metabolic disorders (e.g., diabetes, obesity) • Endocrine imbalances (e.g., androgen deprivation) • Liver and kidney dysfunction • Cancer and related cachexia
Iatrogenic factors	• Hospitalization and prolonged medical interventions • Medication-related muscle loss

(ICFSR) has emphasized the importance of opportunistic screening for sarcopenia during routine health checkups, such as annual medical assessments or flu vaccination visits. Regular screening is recommended due to several key factors. All elderly individuals are at risk of developing sarcopenia, especially those with low physical activity levels. The condition is highly prevalent among the elderly population, regardless of demographic differences. Moreover, sarcopenia may be transient in its early stages, meaning that timely intervention can help prevent its progression and reduce associated health risks.[25]

Expert opinion

- Sarcopenia must be screened for in high-risk individuals, especially community-dwelling older adults, persons living with obesity and/or diabetes, postmenopausal women, patients hospitalized for >1 week, and immobilized patients.
- Sarcopenia must be screened for in high-risk individuals, such as those with chronic medical, surgical, or orthopedic ailments.

In general, sarcopenia can significantly impact the ability of older adults to perform routine daily activities. Early identification through screening, followed by a comprehensive evaluation, can significantly enhance detection rates while saving time and effort. Timely intervention in cases of possible sarcopenia can help prevent further progression, ultimately improving the QoL.[14]

From a diagnostic standpoint, reductions in grip strength due to aging can begin as early as the fifth decade of life. However, a decline in muscle mass does not always indicate sarcopenia. Research from the UK examining grip strength across various life stages identifies three distinct phases: a rise to peak strength in early adulthood, a period of stability during midlife, and a decline thereafter.[26] While some individuals may experience a significant decline in muscle function and muscle mass, they may not necessarily meet the diagnostic criteria for sarcopenia when assessed objectively. This underscores a limitation in population-based comparisons, as individuals vary in baseline muscle mass and function owing to factors such as genetics, lifestyle, and chronic diseases.[24] Additionally, acute illnesses and prolonged bed rest can accelerate muscle loss.[27]

Diagnosing sarcopenia based on a single time point may overlook individuals experiencing significant relative declines. Serial measurements, tailored to the clinical scenario, are more effective in identifying true sarcopenia cases. In acute sarcopenia—defined as incident sarcopenia within 6 months—repeat assessments may be needed as frequently as 1 week apart, whereas in stable conditions, annual evaluations alongside routine health checks, such as blood pressure monitoring, may be sufficient.[28]

Expert opinion

- Sarcopenia screening typically begins at 50–60 years, but early screening starting at 30–40 years in high-risk individuals is crucial, as earlier interventions can lead to better functional outcomes.

Need for Indian Screening Tool

Currently, sarcopenia screening typically occurs at a single time point using binary questions to identify signs or symptoms, such as frequent falls, generalized weakness, slow gait, difficulty getting up from a chair, unintended weight loss, or muscle wasting.[29] However, cases of sarcopenia may go undiagnosed if healthcare professionals do not specifically raise these questions. At present, there is no universally accepted standard for early sarcopenia screening. Commonly used methods, such as SARC-F in addition to calf circumference (SARC-CalF), gait speed (GS), body mass index (BMI), and ultrasound (US), are often employed in epidemiological studies and clinical practice. However, the cutoff points for these tests, established by large datasets from various sarcopenic working groups, may not be appropriate for specific populations. Therefore, it is crucial to develop region-specific cutoff points based on the unique demographics of a given population.[24]

For instance, the SARCO-CUBES study published in 2020 highlighted lower muscle strength and muscle mass in Indian population compared to Western populations. The study found that using Western cutoffs for sarcopenia in India may not be accurate. The study defined low muscle strength and muscle mass using HGS and ASMI, with specific thresholds for low muscle strength and muscle mass based on a SD derived from the mean value of a young reference cohort (20–39 years). For physical performance, a GS of ≤0.8 m/s indicated poor physical performance. The study revealed that muscle strength and mass peaked in the third and fourth decades of life, and sarcopenia was more prevalent when using European cutoffs. It was also found that factors such as serum testosterone positively predicted muscle strength and muscle mass in males.[30]

The lack of normative data on parameters to define cutoffs for muscle strength, quantity, and performance among Indians makes sarcopenia diagnosis particularly challenging.[30,31] Utilizing Western data for Indian populations can lead to inaccurate estimates of the prevalence of sarcopenia, either overestimating or underestimating the burden of the condition. Hence, there is a pressing need for simple, cost-effective screening tools tailored to the Indian context or studies to develop region-specific cutoff points for existing tools.[31]

Expert opinion

- There is a need for the development of an Indian sarcopenia severity scoring tool to enable patient stratification based on sarcopenia severity and syndromic presentation. Once available, such a tool could be incorporated into routine analysis, akin to blood pressure measurements, to facilitate a more tailored and effective management approach.

Multimodal Management of Sarcopenia

Management of sarcopenia requires a holistic approach that integrates physical, nutritional, pharmacological, and psychosocial therapies to optimize outcomes. Physical interventions, such as resistance exercises, have been proven to stimulate the synthesis of muscle protein and improve strength in older adults.[32] Nutritional support, particularly increased protein intake of 1.2–1.5 gm/kg/day, along with supplementation with vitamin D, omega-3 fatty acids, and creatine, is vital to preserving muscle and its function.[24] Pharmacological therapies, including hormone therapy or selective androgen receptor modulators (SARMs), are also explored to support muscle health in severe cases of sarcopenia.[33]

However, a purely physical approach may not address the broader impacts of sarcopenia, such as psychological distress, social isolation, and loss of independence. A holistic approach must include psychosocial support, encouraging patient motivation, adherence to exercise regimens, and improving QoL.[25] The social and spiritual aspects of care are essential to ensure patients are not only treated physically but are also supported emotionally, socially, and mentally. This comprehensive strategy ensures better outcomes, enhances functional recovery, and helps prevent further disability.[24,32]

Expert opinion

- A multimodal approach that combines resistance exercise, nutritional support, and appropriate pharmacologic therapy is recommended as the cornerstone of sarcopenia management.
- Sarcopenia management should be holistic, incorporating physical, nutritional, and pharmacological approaches while also addressing psychological, social, and spiritual factors to improve patient motivation and QoL.

Protein Intake

Ensuring adequate protein intake in elderly population presents a significant challenge due to several factors, including age-related appetite reduction, anabolic resistance, meal distribution patterns, and the molecular composition of protein sources.[34] The PROT-AGE study group recommends a daily protein intake of 1.0–1.2 gm/kg body weight, with 25–30 gm of protein in every meal of the day, i.e., breakfast, lunch, and dinner, to effectively stimulate the synthesis of muscle protein.[32] Similarly, Bauer et al. suggest higher protein intake (1.2 gm/kg body weight daily), either through food intake or supplementation, to counteract the diminished synthesis of muscle protein and the reduced inhibition of muscle catabolism after meals. For frail elderly individuals or those with acute or chronic illnesses, an even higher intake of 1.2–1.5 gm/kg body weight per day is advised.[32,35]

Certain protein sources, such as whey protein, are considered to be more effective in promoting muscle protein synthesis in aging muscles due to their rapid digestion, absorption, and high leucine content. Leucine, an essential amino acid, plays a crucial role in stimulating muscle growth, with a recommended intake of 2.5 gm per day. Additionally, branched-chain amino acids (BCAAs) have been shown to enhance appetite and support muscle protein synthesis.[34]

Concerns regarding high protein intake in the elderly population are largely unfounded, except in cases of advanced renal disease (estimated glomerular filtration rate <30 mL/min), where protein restriction may be necessary to slow disease progression.[34] According to the European Society for Clinical and Economic Aspects of Osteoporosis, Osteoarthritis, and Musculoskeletal Diseases (ESCEO), a high-quality protein diet is essential for maintaining overall health in older individuals.[36]

Beyond protein intake, other nutrients contribute to preserving muscle mass and function.[37] The Italian Study Group on Healthy Aging by Nutraceuticals and Dietary Supplements (HANDS) emphasizes the significance of beta-alanine, calcium, creatine, and vitamin D in maintaining muscle health during aging.[38] Beta-alanine supplementation (3.2 gm per day for 12 weeks) has been shown to improve endurance, while calcium intake (1 gm per day for 24 weeks) enhances muscle mass and muscle strength when given with protein and vitamin D, particularly in the postexercise recovery phase.[34]

Creatine supplementation (5 gm per day for 12 weeks), when combined with resistance training, has been shown to increase both muscle mass and strength.[36] Although not regularly advised, creatine can be adjunctively prescribed along with resistance training to counteract sarcopenia and muscle atrophy directly through anabolic and anticatabolic pathways,[39] resulting in increased lean muscle mass and muscle strength in aging adults.[40] Studies have shown that creatine supplementation preserves muscle fractional synthetic rate and reduces leucine oxidation and the rate of leucine appearance in plasma.[39] It can also be advised for patients diagnosed with osteoporosis, osteosarcopenia, sarcopenic obesity, physical frailty, and cachexia, owing to its favorable effects on aging muscles, bone and fat mass, muscle, and bone strength (Fig. 3).[41]

As creatine supplementation has no adverse effect on kidney or liver function,[40] it may be beneficial for individuals with chronic conditions such as chronic kidney disease (CKD), diabetes, cardiovascular diseases (CVD), nonalcoholic fatty liver disease (NAFLD), and nonalcoholic steatohepatitis (NASH). Beyond its known effects on muscle health, creatine has demonstrated a range of direct and indirect cellular benefits, including protection against ischemic and oxidative damage, reduction of inflammatory markers, and antiapoptotic effects. Additionally, it exhibits antidiabetic and lipid-lowering properties while also modulating the immune system and supporting intestinal health.[42]

In addition, β-hydroxy β-methylbutyrate (HMB), a leucine-derived metabolite, has shown potential in preserving muscle mass, though its effects on muscle strength and physical performance remain variable across studies. HMB is thought to stimulate muscle protein synthesis while mitigating muscle breakdown through its anti-inflammatory effects. Other nutritional interventions, including BCAA supplementation, have been associated with improved muscle function *via* the mTORC1 (mammalian target of rapamycin complex 1) signaling pathway, reduced inflammation, and enhanced muscle regeneration.[43]

Expert opinion

- Dietary protein intake in older adults with sarcopenia should be 1.2–1.5 gm/kg body weight per day, or 1 gm/kg per day for CKD patients with sarcopenia, including high-quality proteins from animal to plant sources, along with essential amino acid supplementation such as BCAAs or HMB, as part of a balanced diet.

Vitamin D and Calcium Supplementations[34]

Vitamin D receptor (VDR) expression declines in various tissues, including skeletal muscle, and older adults are commonly affected by vitamin D deficiency.[44] Prolonged deficiency leads to muscle atrophy, weakness, and a reduction in type II muscle fibers, contributing to inactivity, increased fall risk, and frailty. However, the effectiveness of supplementation with vitamin D in preventing muscle-wasting conditions remains debated.

Some meta-analyses indicate a dose-dependent relationship, with cholecalciferol supplementation improving muscle strength, particularly in the quadriceps and in individuals with severe deficiency. It has been observed that supplementing with 800–1000 IU of vitamin D daily leads to better muscle strength and balance in older adults. Furthermore, combining vitamin D with calcium appears to enhance muscle strength, balance, and GS more effectively than either nutrient alone.

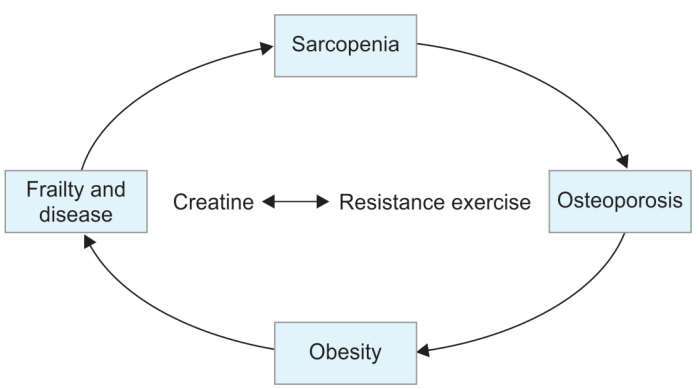

Fig. 3: Potential effect of creatine

Vitamin D supplementation also seems to amplify the benefits of resistance exercise and nutraceutical intake, as demonstrated in studies reporting increased muscle mass and strength in sarcopenic individuals.

Expert opinion

- Vitamin D and calcium supplementation should be ensured to optimize levels.

Secondary Sarcopenia or Sarcopenia with Comorbidities

In contrast to primary (or age-related) sarcopenia, sarcopenia occurring secondary to a systemic disease, with or without the addition of aging, especially certain conditions that may lead to inflammatory processes such as malignancy or organ failure, is categorized as secondary sarcopenia.[45] It can be determined by malnutrition, inactivity, drugs, and certain medical treatments. Cachexia, a kind of secondary sarcopenia, is normally caused by severe muscle-wasting conditions such as cancer, heart failure, cardiomyopathy, and end-stage renal disease.[46]

Studies have also shown that obesity and diabetes promote low-grade chronic inflammation (inflammaging), characterized by increased pro-inflammatory cytokines [interleukin-6 (IL-6), tumor necrosis factor-alpha (TNF-α)], leading to muscle catabolism and impaired anabolism.[7] Additionally, diabetes impairs glucose uptake in skeletal muscle, contributing to reduced protein synthesis and accelerated muscle breakdown, increasing the risk of sarcopenia.[47] CKD induces protein-energy wasting and metabolic acidosis, promoting muscle degradation. In contrast, cardiovascular disease reduces peripheral perfusion, impairing oxygen and nutrient delivery to muscles, thereby worsening muscle weakness and functional decline.[48]

Hence, it can be advised that correcting or managing the underlying condition, such as correcting vitamin D deficiency, optimizing glycemic control, and managing inflammatory status, may reverse or slow the progression of sarcopenia.[49]

Expert opinion

- Coexisting conditions such as obesity, diabetes, CKD, and cardiovascular disease should be managed, as they may exacerbate sarcopenia or complicate treatment.
- Addressing the underlying cause of secondary sarcopenia, if identified, is essential.

Pharmacological Interventions

Pharmacological treatments for sarcopenia are underutilized because of concerns about side effects and long-term efficacy. Anabolic agents, including testosterone, dehydroepiandrosterone (DHEA), and anabolic steroids, have been shown to improve muscle mass and strength; however, their use is constrained by potential risks such as prostate cancer in men, virilization in women, and cardiovascular complications.

Selective androgen receptor modulators offer a promising alternative by selectively binding to target androgen receptors in muscle and bone, thereby reducing activation in other tissues. SARMs such as enobosarm (GTx-024), GSK2881078, RAD140, and S-23, when tested in clinical trials, have demonstrated increased muscle strength and lean body mass. However, they are not yet FDA-approved, and concerns about lipid profile alterations and liver enzyme elevations remain. Myostatin inhibitors, such as apitegromab, bimagrumab, domagrozumab, and taldefgrobep alfa, work by blocking myostatin, a negative regulator of muscle growth. These agents have shown potential for improving muscle mass and function, but they remain experimental, with further research needed to confirm their long-term safety and efficacy. Growth hormone (GH) therapy, which stimulates insulin-like growth factor-1 (IGF-1) production and muscle protein synthesis, has also been explored for sarcopenia. Clinical trials with MK-677, a GH secretagogue, have shown increased lean body mass and functional improvements. However, GH therapy carries risks such as retention of fluids, joint pain, and elevated risks of diabetes and cardiovascular conditions.[50]

Other potential treatments under investigation include angiotensin-converting enzyme inhibitors, eicosapentaenoic acid, and cachexia-targeting agents such as MT-102. While pharmacological options for sarcopenia are expanding, none are currently FDA-approved, and further studies are required to establish safe and effective therapeutic strategies.[51]

Expert opinion

- Pharmacological treatments for sarcopenia are currently underutilized in clinical settings because of concerns about side effects and long-term efficacy.

Anabolic Steroids in Sarcopenia Management

Although exercise programs and nutritional support are well-established interventions for managing sarcopenia, their implementation can be challenging, particularly in frail, polymorbid elderly patients.[52] As an alternative, various pharmacological agents have been explored for potential therapeutic use. However, the US Food and Drug Administration (FDA) or the European Medicines Agency (EMA) has not approved any drug for sarcopenia treatment.[53]

Currently, anabolic steroids, including testosterone therapy and its synthetic derivatives such as nandrolone decanoate, are the only pharmacological options available for sarcopenia management.[54] The use of these agents is limited by adverse effects, such as a higher risk of prostate cancer in men, virilization in women, and an increased likelihood of cardiovascular complications.[55]

Hence, anabolic drugs should only be administered under clinical supervision. Regular monitoring ensures that benefits outweigh risks and that therapy is adjusted as needed to optimize safety and efficacy.[53]

Expert opinion

- The administration of anabolic drugs, supervised in a clinical setting, is an effective pharmacological approach to managing sarcopenia.

Nandrolone Decanoate

Nandrolone decanoate is a 17α-alkylated modified androgen analog of testosterone, which can be considered for use in such patients. Compared to testosterone propionate, it exhibits strong anabolic effects while having relatively weak androgenic effects, with potency ratios ranging from 3.29 to 4.92 (anabolic) and 0.31 to 0.41 (androgenic). Among anabolic–androgenic steroids (AAS), nandrolone esters are believed to offer the highest anabolic-to-androgenic effect ratio. This reduced androgenicity is attributed to the inactivation of nandrolone by 5α-reductase, which converts it into 5α-dihydronandrolone, a low-affinity androgen receptor ligand. Consequently, this transformation is associated with a lower incidence and severity of side effects.[56]

Additionally, research has highlighted the benefits of nandrolone decanoate, including its role in promoting tissue growth, preserving muscle strength and mass, and supporting bone health.[56] AAS has also been observed to enhance exercise tolerance by improving muscle resistance to overload, decreasing muscle fiber damage, and increasing protein synthesis during recovery phase.[57]

Expert opinion

- Anabolic steroids such as nandrolone decanoate may be considered as an adjunct for individuals with sarcopenia who do not respond adequately to conventional treatment.
- Nandrolone decanoate could be considered as a first-line treatment for individuals with severe symptoms and signs of sarcopenia.

Particularly, it is a promising pharmacological option for elderly patients with sarcopenia due to its superior anabolic-to-androgenic ratio compared to testosterone. With a myotropic ratio of approximately 11:1 vs testosterone's 1:1, nandrolone decanoate effectively promotes muscle growth while reducing the risk of androgen-related side effects such as virilization. This favorable profile makes it a safer alternative for individuals requiring muscle preservation and strength enhancement.

One of the key mechanisms is its ability to stimulate myogenic progenitor cell differentiation, a crucial process in muscle regeneration. It upregulates MyoD and Numb, essential regulators of muscle development, and triggers the calcineurin–NFAT signaling pathway, which is integral to muscle growth. These effects contribute to improved muscle mass and function in elderly patients with sarcopenia, which, in turn, helps reduce joint pain.[56]

Darracott et al. observed that patients with patellofemoral pain syndrome experienced clinical symptom improvement and increased patellar bone density after 6 weeks of weekly intramuscular nandrolone decanoate injections.[58] A 2019 pilot study by Tatem et al. demonstrated that nandrolone significantly reduced joint pain, as measured by the Rheumatoid Arthritis Pain Scale (RAPS), with >50% of patients noting a decrease in discomfort. Many participants also experienced a reduced need for chronic pain medications, including long-term narcotics, which is particularly relevant given concerns surrounding opioid dependency.

It also enhances IGF-1 signaling, increasing local levels of this growth factor to support skeletal muscle hypertrophy. Even when IGF-1 receptors are inhibited, nandrolone decanoate continues to drive muscle growth, emphasizing its significant involvement in androgen-facilitated muscle fiber hypertrophy.[59]

This was corroborated by a preclinical study that demonstrated nandrolone decanoate's impact on muscle repair and the expression of myogenic regulatory factors in cryoinjured rat skeletal muscle. In the study, adult male Wistar rats were assigned to four groups, with one cryoinjured group treated with nandrolone decanoate and one noninjured group receiving the same treatment. The results revealed a marked increase in MyoD mRNA after 7 days and myogenin mRNA after 21 days in the cryoinjured group. Morphological analysis showed no edema or myonecrosis after 7 days and no edema or inflammatory infiltration after 14 days. Additionally, the nandrolone decanoate-treated group displayed an earlier emergence of new muscle fibers. Thus, the use of the anabolic steroid nandrolone decanoate seems to have beneficial effects on the resolution of the inflammatory process and the repair of muscle tissue.[60]

Overall, nandrolone decanoate has shown therapeutic potential in managing chronic muscle-wasting conditions such as chronic obstructive pulmonary disease (COPD), dialysis-dependent CKD, and acquired immunodeficiency syndrome (AIDS), further reinforcing its applicability in sarcopenia treatment. Moreover, its lower androgenicity compared to testosterone reduces the risk of adverse effects such as prostate enlargement and cardiovascular complications, making it a more suitable option for elderly patients.[61]

Expert opinion

- Nandrolone decanoate is a suitable pharmacological treatment for elderly patients with sarcopenia, given its higher myotropic-to-androgenic ratio compared to testosterone.

Uses of Nandrolone Decanoate in Other Conditions

Osteopenia/Osteoporosis

Osteoporosis and sarcopenia are two interrelated age-associated conditions that significantly impact health and QoL, especially among older adults. While osteoporosis is associated with decreased bone density and structural breakdown, leading to greater fracture risk, sarcopenia is characterized by the gradual loss of muscle mass, strength, and function.[62] These conditions often coexist, exacerbating each other's effects and creating a cycle of bone and muscle deterioration. The combined effects of low bone density and muscle weakness elevate the risk of falls, fractures, and overall functional decline.[63]

Research has demonstrated that nandrolone decanoate may have a beneficial role in addressing these conditions.[64] Frisoli et al. reported a 50% reduction in fractures among postmenopausal osteoporotic women treated with nandrolone decanoate over 2 and 4 years.[65] Additionally, findings from various studies have shown significant improvements in bone health parameters following nandrolone decanoate treatment.64 Hassager et al. showed an average increase of nearly 3% in bone mineral content and thickness in the proximal forearm, while another study noted a 2.7–3.5% annual increase in forearm bone mineral content.[62] Furthermore, Frisoli et al. documented notable gains in lumbar spine (+3.4% to +3.7%), trochanteric (+4.8%), and femoral bone mineral density (+4.1% to +4.7%) over a 12–24 month period in nandrolone decanoate-treated individuals.[65]

Nandrolone decanoate has also been investigated as a therapeutic option during fracture rehabilitation, particularly in osteoporotic patients, due to the decline in anabolic stimuli associated with aging. Studies have reported that nandrolone decanoate can improve muscle strength and functional recovery among patients undergoing orthopedic procedures, such as total knee replacement (TKR). According to a randomized trial, patients receiving 50 mg nandrolone decanoate biweekly for 6 months demonstrated significant improvements in quadriceps strength and Knee Society Scores (KSS) at multiple postoperative time points. Although a reduction in bone mineral density was observed postsurgery, the change was not statistically significant. This suggests that nandrolone decanoate may help preserve musculoskeletal health.[66] A 2012 systematic review examined the use of AAS, including nandrolone decanoate, in TKR rehabilitation. While only two small randomized trials met the criteria, both showed significant improvements in quadriceps strength, Functional Independence Measure scores, and KSS at various time points. However, no significant effects were observed in hamstring strength, bone mineral density, mobility, or hospital stay duration. Notably, no adverse effects were reported, supporting the safety and potential benefits of nandrolone decanoate in post-TKR recovery.[67]

Given its anabolic properties and ability to improve functional outcomes, nandrolone decanoate may be a valuable adjunct in postfracture and postoperative rehabilitation, particularly in aging individuals with sarcopenia and osteoporosis.[63]

Expert opinion

- Nandrolone decanoate may be considered as an adjunct for persons with sarcopenia and associated osteopenia/osteoporosis.

Anemia

Androgens have long been recognized for their role in managing unexplained anemia, particularly in older adults and individuals with chronic illnesses. Since anemia and sarcopenia often coexist in aging populations, nandrolone decanoate is especially valuable in cases where conventional erythropoiesis-stimulating agents (ESAs) alone are inadequate, such as refractory and aplastic anemia.[68] Clinical evidence indicates that nandrolone decanoate can significantly enhance hemoglobin levels and hematocrit (Hct) values in anemic patients. Furthermore, its use in aplastic anemia has been shown to

stimulate erythropoiesis and reduce the need for transfusions.[56]

Nandrolone decanoate has also emerged as a potential alternative to erythropoietin (EPO) therapy in managing anemia associated with CKD, as it can increase serum EPO levels, packed cell volume, red blood cell mass, and hemoglobin concentration.[69] A 2012 meta-analysis of randomized controlled trials comparing nandrolone decanoate to EPO in CKD-related anemia found no significant difference in treatment outcomes for men over 50 years old. In all trials included in the meta-analysis, nandrolone decanoate was administered via the intramuscular route at a dose of 100–200 mg weekly for either 3 or 6 months. The authors concluded that nandrolone decanoate could serve as a cost-effective alternative to EPO, particularly in resource-limited settings.[70]

Expert opinion

- Nandrolone decanoate may be considered as an adjunct for persons with sarcopenia and associated severe anemia, including unexplained/refractory anemia, aplastic anemia, and peripheral anemia.

Hemodialysis

Several clinical trials support the use of high-dose nandrolone decanoate as an adjunct treatment for individuals with sarcopenia undergoing hemodialysis.[70]Gaughan et al. studied 19 dialysis patients with anemia randomized into two groups in a 6-month prospective trial. The first group received recombinant EPO thrice weekly for 26 weeks, while the second group received the same EPO regimen alongside 100 mg intramuscular nandrolone decanoate weekly. By the end of the study, both groups showed improvements in mean Hct, but the nandrolone decanoate group experienced a significantly higher increase (8.2% ± 4.4% vs 3.5% ± 2.8%; $p = 0.012$).[71]

Similarly, Teruel et al. conducted a prospective study to assess the effects of nandrolone decanoate in 25 male dialysis patients with anemia. The patients were administered a weekly intramuscular dose of 200 mg for 6 months, leading to significant improvements in both serum EPO and hemoglobin levels. Hemoglobin levels increased from 8 ± 0.9 gm/dL at baseline to 9.2 ± 1.3 gm/dL after 1 month ($p < 0.001$), and further to 10.7 ± 1.8 gm/dL at 6 months ($p < 0.001$).[71]

Beyond its hematological effects, nandrolone decanoate has demonstrated benefits in preserving muscle mass in hemodialysis sarcopenic patients. Johansen et al. conducted a randomized controlled trial in which hemodialysis patients were assigned to either nandrolone decanoate or a placebo, combined with lower extremity resistance exercises three times a week for 12 weeks. Patients receiving nandrolone experienced a marked increase in lean body mass and a reduction in fat mass.[72] Another randomized controlled trial in 29 hemodialysis patients showed that 6 months of treatment with nandrolone decanoate resulted in increased lean body mass, improved walking and stair-climbing performance, and a rise in serum creatinine levels compared to placebo.[73]

Expert opinion

- High doses of nandrolone may be considered as an adjunct treatment for individuals with sarcopenia undergoing hemodialysis.

Pharmacokinetics-based Regimen of Nandrolone Decanoate

Nandrolone decanoate is administered in doses ranging from 25 to 100 mg every 3 weeks, with up to five doses, depending on the clinical response and physician discretion.[74] The pharmacokinetic properties of the drug support this dosing regimen, as the drug is released slowly from the muscular depot *via* a first-order process, with a half-life of up to 7 days for the release phase. The mean half-life for the drug release from the site of injection to bloodstream is approximately 6 days.[75]

Nandrolone decanoate levels remain detectable for up to 32 days after injection, ensuring prolonged therapeutic effects. The peak concentration of nandrolone decanoate occurs between 30 and 72 hours postinjection, with C_{max} values of 2.14 ng/mL for 50 mg, 4.26 ng/mL for 100 mg, and 5.16 ng/mL for 150 mg. These findings confirm that the pharmacokinetics of nandrolone decanoate support flexible dosing intervals, with doses adjusted based on the clinical response of the patients.

A dose of 25–50 mg every 3–4 weeks is appropriate as an adjunct in a multimodal treatment approach for patients with no obvious cause requiring treatment. The 50 mg dose achieves a peak concentration of 2.14 ng/mL, which is sufficient for therapeutic efficacy while remaining within the safe pharmacokinetic range. Additionally, the half-life of nandrolone decanoate, ranging from 7.1 days at 50 mg to 11.7 days at 100 mg, allows for effective serum concentrations to be maintained over extended dosing intervals, such as every 3–4 weeks,[76] thereby ensuring consistent therapeutic effects without the need for more frequent injections.[74]

The recommended dosage when administered *via* intramuscular injection[77] (Table 2).

Expert opinion

- Nandrolone decanoate may be used in doses ranging from 25 to 100 mg every 3 weeks for up to five doses (depending on the patient's clinical response, physician's discretion).
- A standard dosage of 25–50 mg of nandrolone decanoate administered every 3–4 weeks can be utilized as an adjunctive therapy in a multimodal treatment approach for patients without an identifiable cause.

Contraindications and Precautions

Prescribing nandrolone decanoate to women may lead to virilization symptoms, such as deepened voice, hirsutism, acne, and clitoromegaly, which are often irreversible. Additionally, it might also lead to disruption in the menstrual cycle. To minimize the risk of permanent effects, discontinuation of the medication at the first signs of mild virilization is recommended. Changes in libido, either increased or decreased, have also been reported.

Nandrolone decanoate is contraindicated in patients with active or metastatic hormone-sensitive malignancies, such as prostate and breast cancer, as it may promote tumor progression. Its use is also not advised in individuals with hepatic dysfunction due to the risk of severe liver complications, including peliosis hepatis, hepatic neoplasms, and hepatocellular carcinoma, which can occur even at lower doses.[56,78]

Additionally, patients with a history of thromboembolic events, particularly those with a Hct exceeding 50%, should avoid nandrolone decanoate. The drug-induced fluid retention and erythrocytosis may elevate the risk of cardiovascular complications, including thrombosis and congestive heart failure.[79]

Table 2: Dosage recommendations based on various indications

Indications	*Dosage*
Osteoporosis	50 mg every 3 weeks
For palliative treatment of selected cases of disseminated mammary carcinoma in women	50 mg every 2–3 weeks
Adjunct to specific therapies and dietary measures in pathogenic conditions characterized by negative nitrogen balance	25–50 mg every 3 weeks

Nandrolone decanoate is strictly contraindicated during pregnancy and lactation due to its potential teratogenic effects and risks to fetal development. Furthermore, individuals with obstructive sleep apnea should not use nandrolone decanoate, as anabolic steroids may aggravate airway obstruction and impair respiratory function.[56,78–80]

Expert opinion

- Side effects of nandrolone decanoate, such as mild acne or hirsutism, are typically manageable and well tolerated in most patients.
- Nandrolone decanoate should not be used in patients with active or metastatic hormone-sensitive malignancies, such as prostate or breast cancer, hepatic dysfunction, thromboembolic events (Hct threshold 50%), pregnancy, lactation, and obstructive sleep apnea.

Anabolic Advocacy

Strict diagnostic criteria for initiating nandrolone decanoate therapy are essential to prevent inappropriate prescribing and misuse for nonmedical purposes, such as performance enhancement or cosmetic muscle growth.[81] Given its potent anabolic effects, indiscriminate use of nandrolone decanoate can result in serious complications, including cardiovascular disease, endocrine disruption, and hepatic dysfunction.[82] Ensuring that only clinically verified cases of sarcopenia receive treatment keeps therapy evidence-based and aligned with best medical practices.[83]

Accurate diagnosis not only safeguards against misuse but also optimizes patient outcomes. By restricting treatment to individuals with significant muscle loss and functional impairment, healthcare providers can develop tailored therapeutic plans that include appropriate dosing, regular monitoring, and necessary interventions to balance efficacy and safety. Clinical confirmation further supports responsible prescribing practices, mitigating the risks of dependency and long-term adverse effects while ensuring that nandrolone decanoate is used solely for its intended therapeutic purpose in sarcopenia management.[25]

Expert opinion

- Nandrolone decanoate therapy should be initiated solely in patients with sarcopenia confirmed by clinical diagnosis and/or validated diagnostic criteria, such as FNIH/EWGSOP2, using DEXA or bioelectrical impedance analysis (BIA) to avoid or discourage misuse of the drug.

Additionally, patients undergoing nandrolone decanoate therapy, like those using other anabolic steroids, must be educated on recognizing and reporting adverse events. Early identification of warning signs such as chest pain, jaundice, hormonal imbalances, or mood disturbances allows for timely medical intervention, preventing escalation into severe or irreversible conditions. Since many side effects develop gradually, patients may initially dismiss symptoms. However, prompt reporting enables healthcare providers to adjust dosages, discontinue use, or implement alternative management strategies to ensure patient safety.[56]

Beyond individual patient safety, education and awareness play a crucial role in preventing the misuse, overdose, and dependency associated with anabolic steroids. Informed patients are more likely to adhere to medical guidelines, participate in regular monitoring, and engage in shared decision-making with healthcare providers. Encouraging timely reporting of adverse effects also aligns with pharmacovigilance protocols and ethical medical practice, promoting responsible and regulated steroid use.[83]

Expert opinion

- Patients using pharmacologic agents, particularly anabolic steroids, should be educated on recognizing and reporting adverse events promptly.

Conclusion

The primary goal of nandrolone decanoate therapy should not merely be to increase muscle mass but to improve muscle strength, enhance physical performance, and boost overall QoL. While nandrolone's anabolic properties facilitate muscle hypertrophy, its most significant therapeutic benefit lies in improving functional capacity and supporting recovery in patients with muscle-wasting conditions. Chronic illnesses such as CKD, osteoporosis, HIV/AIDS-related wasting, and prolonged corticosteroid use often result in muscle weakness and mobility impairments, thereby heightening the risk of frailty, disability, and loss of independence.[84,85] By prioritizing functional improvements, nandrolone decanoate therapy can help restore strength, improve endurance, and enable patients to perform daily activities with greater ease.

Muscle hypertrophy alone does not guarantee better mobility or overall health. True therapeutic success requires improvements in neuromuscular coordination, endurance, and metabolic well-being. Emphasizing physical function ensures that nandrolone decanoate therapy delivers meaningful health outcomes, such as reducing fall risk in older adults, aiding postsurgical rehabilitation, and improving exercise tolerance in patients with chronic conditions. Additionally, optimizing QoL includes alleviating fatigue, maintaining energy levels, and enhancing overall metabolic balance, all of which are crucial for long-term disease management.[56]

Expert opinion

- The primary clinical goals of nandrolone decanoate therapy should be improving muscle strength, physical function, and QoL rather than solely increasing muscle mass.

Conflict of Interest

All authors report no competing interests.

Funding

Zydus Healthcare Limited provided a medical grant to fund the organization of an advisory board for the development of this study.

Acknowledgments

The scientific content of this publication was developed by IJCP Group with the support of an educational grant from Zydus Healthcare Limited. Ms. Priya Suhazsini provided medical writing support and editorial assistance in the preparation of the manuscript.

Orcid

Sanjay Kalra https://orcid.org/0000-0003-1308-121X
Nitin Kapoor https://orcid.org/0000-0002-9520-2072
Sourabh Sharma https://orcid.org/0000-0003-2513-5131
Nimitha Pinto https://orcid.org/0009-0003-5016-9103

References

1. Chianca V, Albano D, Messina C, et al. Sarcopenia: imaging assessment and clinical application. Abdom Radiol 2022;47(9):3205–3216.
2. Veronese N, Koyanagi A, Cereda E, et al. Sarcopenia reduces quality of life in the long-term: longitudinal analyses from the English longitudinal study of ageing. Eur Geriatr Med 2022;13(3):633–639.
3. Zhang X, Yang G, Jiang S, et al. Causal relationship between gut microbiota, metabolites, and sarcopenia: a mendelian randomization study. J Gerontol A Biol Sci Med Sci 2024;79(9):glae173.
4. Yuan S, Larsson SC. Epidemiology of sarcopenia: prevalence, risk factors, and consequences. Metabolism 2023;144:155533.
5. Xia W, Luo K, Gu Z, et al. Correlational analysis of sarcopenia and multimorbidity among older inpatients. BMC Musculoskelet Disord 2024;25(1):309.
6. Dhar M, Kapoor N, Suastika K, et al. South Asian Working Action Group on SARCOpenia (SWAG-

SARCO) – a consensus document. Osteoporos Sarcopenia 2022;8(2):35–57.
7. Marzetti E, Calvani R, Tosato M, et al. Sarcopenia: an overview. Aging Clin Exp Res 2017;29:11–17.
8. Morley JE, Baumgartner RN, Roubenoff R, et al. Sarcopenia. J Lab Clin Med 2001;137(4):231–243.
9. Papadopoulou SK. Sarcopenia: a contemporary health problem among older adult populations. Nutrients 2020;12(5):1293.
10. Bhasin S, Storer TW, Berman N, et al. The effects of supraphysiologic doses of testosterone on muscle size and strength in normal men. N Engl J Med 1996;335(1):1–7.
11. Morley JE, Anker SD, von Haehling S. Prevalence, incidence, and clinical impact of sarcopenia: facts, numbers, and epidemiology—update 2014. J Cachexia Sarcopenia Muscle 2014;5:253–259.
12. Rolland Y, Cesari M, Fielding RA, et al. Osteoporosis in frail older adults: recommendations for research from the ICFSR Task Force 2020. J Frailty Aging 2021;10(2):168–175.
13. Santilli V, Bernetti A, Mangone M, et al. Clinical definition of sarcopenia. Clin Cases Miner Bone Metab 2014;11(3):177–180.
14. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, et al. Sarcopenia: European consensus on definition and diagnosis: report of the European Working Group on sarcopenia in older people. Age Ageing 2010;39(4):412–423.
15. Muscaritoli M, Anker SD, Argilés J, et al. Consensus definition of sarcopenia, cachexia and pre-cachexia: joint document elaborated by Special Interest Groups (SIG) "cachexia-anorexia in chronic wasting diseases" and "nutrition in geriatrics." Clin Nutr 2010;29(2):154–159.
16. Rizzoli R, Reginster JY, Arnal JF, et al. Quality of life in sarcopenia and frailty. Calcif Tissue Int 2013;93:101–120.
17. Tyrovolas S, Koyanagi A, Olaya B, et al. Factors associated with skeletal muscle mass, sarcopenia, and sarcopenic obesity in older adults: a multi-continent study. J Cachexia Sarcopenia Muscle 2016;7(3):312–321.
18. Ho-Pham LT, Vu BQ, Lai TQ, et al. Vegetarianism, bone loss, fracture and vitamin D: a longitudinal study in Asian vegans and non-vegans. Eur J Clin Nutr 2012;66(1):75–82.
19. Vaish A, Vaishya R, Iyengar KP. Metabolic syndrome and its impact on bone and joint health: a comprehensive review. Apollo Med 2024:09760016241307374.
20. Boyle LD, Akbas F, Yazıcı D, et al. Pharmacotherapy for older people with obesity. Eur J Intern Med 2024;130:33–37.
21. Xu J, Wan CS, Ktoris K, et al. Sarcopenia is associated with mortality in adults: a systematic review and meta-analysis. Gerontology 2022;68(4):361–376.
22. Wannamethee SG, Atkins JL. Muscle loss and obesity: the health implications of sarcopenia and sarcopenic obesity. Proc Nutr Soc 2015;74(4):405–412.
23. Fuggle N, Shaw S, Dennison E, et al. Sarcopenia. Best Pract Res Clin Rheumatol 2017;31(2):218–242.
24. Cruz-Jentoft AJ, Sayer AA. Sarcopenia. Lancet 2019;393(10191):2636–2646.
25. Dent E, Morley JE, Cruz-Jentoft AJ, et al. International clinical practice guidelines for sarcopenia (ICFSR): screening, diagnosis and management. J Nutr Health Aging 2018;22(10):1148–1161.
26. Dodds RM, Syddall HE, Cooper R, et al. Grip strength across the life course: normative data from twelve British studies. PLoS One 2014;9(12):e113637.
27. Parry SM, Puthucheary ZA. The impact of extended bed rest on the musculoskeletal system in the critical care environment. Extrem Physiol Med 2015;4(1):16.
28. Xie WQ, Xiao GL, Hu PW, et al. Possible sarcopenia: early screening and intervention-narrative review. Ann Palliat Med 2020;9(6):4283–4293.
29. Yu SC, Khow KS, Jadczak AD, et al. Clinical screening tools for sarcopenia and its management. Curr Gerontol Geriatr Res 2016;2016(1):5978523.
30. Pal R, Aggarwal A, Singh T, et al. Diagnostic cut-offs, prevalence, and biochemical predictors of sarcopenia in healthy Indian adults: the Sarcopenia-Chandigarh Urban Bone Epidemiological Study (Sarco-CUBES). Eur Geriatr Med 2020;11:725–736.
31. Ooi H, Welch C. Obstacles to the early diagnosis and management of sarcopenia: current perspectives. Clin Interv Aging 2024 31:323–332.
32. Bauer J, Biolo G, Cederholm T, et al. Evidence-based recommendations for optimal dietary protein intake in older people: a position paper from the PROT-AGE Study Group. J Am Med Dir Assoc 2013;14(8):542–559.
33. Gattu AK, Goldman AL, Guzelce EC, et al. The anabolic applications of androgens in older adults with functional limitations. Rev Endocr Metab Disord 2022;23(6):1209–1220.
34. Iolascon G, Moretti A, De Sire A, et al. Pharmacological therapy of sarcopenia: past, present and future. Clin Cases Miner Bone Metab 2018;15(3):407–415.
35. Bauer JM, Diekmann R. Protein and older persons. Clin Geriatr Med 2015;31(3):327–338.
36. Rizzoli R, Stevenson JC, Bauer JM, et al. The role of dietary protein and vitamin D in maintaining musculoskeletal health in postmenopausal women: a consensus statement from the European Society for Clinical and Economic Aspects of Osteoporosis and Osteoarthritis (ESCEO). Maturitas 2014;79(1):122–132.
37. Cruz-Jentoft AJ, Hughes BD, Scott D, et al. Nutritional strategies for maintaining muscle mass and strength from middle age to later life: a narrative review. Maturitas 2020;132:57–64.
38. Iolascon G, Gimigliano R, Bianco M, et al. Are dietary supplements and nutraceuticals effective for musculoskeletal health and cognitive function? A scoping review. J Nutr Health Aging 2017;21(5):527–538.
39. Dolan E, Artioli GG, Pereira RM, et al. Muscular atrophy and sarcopenia in the elderly: is there a role for creatine supplementation? Biomolecules 2019;9(11):642.
40. Candow DG, Chilibeck PD, Forbes SC, et al. Creatine supplementation for older adults: focus on sarcopenia, osteoporosis, frailty and cachexia. Bone 2022;162:116467.
41. Candow DG, Forbes SC, Kirk B, et al. Current evidence and possible future applications of creatine supplementation for older adults. Nutrients 2021;13(3):745.
42. Casciola R, Leoni L, Cuffari B, et al. Creatine supplementation to improve sarcopenia in chronic liver disease: facts and perspectives. Nutrients 2023;15(4):863.
43. Cruz-Jentoft AJ. Beta-hydroxy-beta-methyl butyrate (HMB): from experimental data to clinical evidence in sarcopenia. Curr Protein Pept Sci 2018;19(7):668–672.
44. Mitchell PJ, Cooper C, Dawson-Hughes B, et al. Life-course approach to nutrition. Osteoporos Int 2015;26:2723–2742.
45. Cruz-Jentoft AJ, Bahat G, Bauer J, et al. Sarcopenia: revised European consensus on definition and diagnosis. Age Ageing 2019;48(1):16–31.
46. Tagliafico AS, Bignotti B, Torri L, et al. Sarcopenia: how to measure, when and why. Radiol Med 2022;127(3):228–237.
47. Cleasby ME, Jamieson P, Atherton PJ. Insulin resistance and sarcopenia: mechanistic links between common co-morbidities. J Endocrinol 2016;229(2):R67–R81.
48. Cheng TC, Huang SH, Kao CL, et al. Muscle wasting in chronic kidney disease: mechanism and clinical implications—a narrative review. Int J Mol Sci 2022;23(11):6047.
49. Beaudart C, McCloskey E, Bruyère O, et al. Sarcopenia in daily practice: assessment and management. BMC Geriatr 2016;16:170.
50. Sayer AA, Robinson SM, Patel HP, et al. New horizons in the pathogenesis, diagnosis and management of sarcopenia. Age Ageing 2013;42(2):145–150.
51. Jang JY, Kim D, Kim ND. Pathogenesis, intervention, and current status of drug development for sarcopenia: a review. Biomedicines 2023;11(6):1635.
52. Rolland Y, Dray C, Vellas B, et al. Current and investigational medications for the treatment of sarcopenia. Metabolism 2023;149:155597.
53. Najm A, Niculescu AG, Grumezescu AM, et al. Emerging therapeutic strategies in sarcopenia: an updated review on pathogenesis and treatment advances. Int J Mol Sci 2024;25(8):4300.
54. Morley JE. Sarcopenia: diagnosis and treatment. J Nutr Health Aging 2008;12(7):452–456.
55. Dhillon RJ, Hasni S. Pathogenesis and management of sarcopenia. Clin Geriatr Med 2017;33(1):17–26.
56. Patanè FG, Liberto A, Maria Maglitto AN, et al. Nandrolone decanoate: use, abuse and side effects. Medicina 2020;56(11):606.
57. Busardo FP, Frati P, Di Sanzo M, et al. The impact of nandrolone decanoate on the central nervous system. Curr Neuropharmacol 2015;13(1):122–131.
58. Heintjes E, Berger MY, Bierma-Zeinstra SM, et al. Pharmacotherapy for patellofemoral pain syndrome. Cochrane Database Syst Rev 2004;2004(3):CD003470.
59. Tatem AJ, Holland LC, Kovac J, et al. Nandrolone decanoate relieves joint pain in hypogonadal men: a novel prospective pilot study and review of the literature. Transl Androl Urol 2020;9(Suppl. 2):S186–S194.
60. Piovesan RF, Fernandes KP, Alves AN, et al. Effect of nandrolone decanoate on skeletal muscle repair. Int J Sports Med 2013;34(1):87–82.
61. Pan MM, Kovac JR. Beyond testosterone cypionate: evidence behind the use of nandrolone in male health and wellness. Transl Androl Urol 2016;5(2):213–219.
62. Das C, Das PP, Kambhampati SB. Sarcopenia and osteoporosis. Indian J Orthop 2023;57(Suppl. 1):33–41.
63. Reiss J, Iglseder B, Alzner R, et al. Sarcopenia and osteoporosis are interrelated in geriatric inpatients. Z Gerontol Geriatr 2019;52(7):688–693.
64. Câmara LC, Starling MA, Canvilo LM, et al. Lean body mass in osteoporotic postmenopausal women treated with nandrolone decanoate: a systematic search review. J Adv Med Med Res 2023;35(20):105–113.
65. Frisoli A Jr, Chaves PH, Pinheiro MM, et al. The effect of nandrolone decanoate on bone mineral density, muscle mass, and hemoglobin levels in elderly women with osteoporosis: a double-blind, randomized, placebo-controlled clinical trial. J Gerontol A Biol Sci Med Sci 2005;60(5):648–653.
66. Hohmann E, Tetsworth K, Hohmann S, et al. Anabolic steroids after total knee arthroplasty. A double blinded prospective pilot study. J Orthop Surg Res 2010;5:93.
67. Metcalfe D, Watts E, Masters JP, et al. Anabolic steroids in patients undergoing total knee arthroplasty. BMJ Open 2012;2(5):e001435.
68. Al-Sharefi A, Mohammed A, Abdalaziz A, et al. Androgens and anemia: current trends and future prospects. Front Endocrinol 2019;10:754.
69. Yuen MV, Gianturco SL, Pavlech LL, et al. Nandrolone Decanoate: Summary Report.
70. Adamu B, Ma'aji SM, Erwin PJ, et al. Meta-analysis of randomized controlled trials on androgens versus erythropoietin for anaemia of chronic kidney disease: implications for developing countries. Int J Nephrol 2012;2012(1):580437.
71. Snyder G, Shoskes DA. Hypogonadism and testosterone replacement therapy in end-stage renal disease (ESRD) and transplant patients. Transl Androl Urol 2016;5(6):885–889.
72. Johansen KL, Painter PL, Sakkas GK, et al. Effects of resistance exercise training and nandrolone decanoate on body composition and muscle function among patients who receive hemodialysis: a randomized, controlled trial. J Am Soc Nephrol 2006;17(8):2307–2314.
73. Garibotto G, Picciotto D, Verzola D. Testosterone deficiency, frailty and muscle wasting in CKD: a converging paradigm? Nephrol Dial Transplant 2019;34(5):723–726.
74. Nandrolone dosage guide + max dose, adjustments [Internet]. Drugs.com. Available from: https://www.drugs.com/dosage/nandrolone.html. [Last accessed March, 2025].
75. Bagchus WM, Smeets JM, Verheul HA, et al. Pharmacokinetic evaluation of three different intramuscular doses of nandrolone decanoate:

analysis of serum and urine samples in healthy men. J Clin Endocrinol Metab 2005;90(5):2624–2630.
76. Wijnand HP, Bosch AM, Donker CW. Pharmacokinetic parameters of nandrolone (19-nortestosterone) after intramuscular administration of nandrolone decanoate (Deca-Durabolin®) to healthy volunteers. Eur J Endocrinol 1985;110(3_Supplement_a):S19–S30.
77. PubChem. Nandrolone decanoate [Internet]. Available from: https://pubchem.ncbi.nlm.nih.gov/compound/Nandrolone-decanoate. [Last accessed March, 2025].
78. Drugs.com. Deca-durabolin side effects: generic name: nandrolone [Internet]. Drugs.com. Available from: https://www.drugs.com/sfx/deca-durabolin-side-effects.html. [Last accessed March, 2025].
79. Basaria S, Dobs AS. Safety and adverse effects of androgens: how to counsel patients. Mayo Clin Proc 2004;79(Suppl. 4):S25–S32.
80. Drugs.com. Androlone-D side effects: generic name: nandrolone [Internet]. Drugs.com. Available from: https://www.drugs.com/sfx/androlone-d-side-effects.html. [Last accessed March, 2025].
81. Nieschlag E, Vorona E. Mechanisms in endocrinology: medical consequences of doping with anabolic androgenic steroids: effects on reproductive functions. Eur J Endocrinol 2015;173(2):R47–R58.
82. Basaria S, Wahlstrom JT, Dobs AS. Anabolic-androgenic steroid therapy in the treatment of chronic diseases. J Clin Endocrinol Metab 2001;86(11):5108–5117.
83. Ribeiro B. Anabolic-androgenic steroid use in sports, health, and society. Med Sci Sports Exerc 2021;53(8):1778–1794.
84. Simão VA, Berloffa Belardin L, Araújo Leite GA, et al. Effects of different doses of nandrolone decanoate on estrous cycle and ovarian tissue of rats after treatment and recovery periods. Int J Exp Pathol 2015;96(5):338–349.
85. Bafunno V, Santacroce RO, Chetta M, et al. Polymorphic miRNA-mediated gene contribution to inhibitor development in haemophilia A. Haemophilia 2012;18(6):1003–1007.