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Nutritional and Lifestyle Approaches to Sarcopenia: Age-Specific Insights and the Role of Plant vs. Animal-Based Diets

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Abstract

Sarcopenia is a progressive condition involving the slow loss of skeletal muscle mass, strength, and overall physical capability. While it was once viewed as an unavoidable part of getting older, it is now seen as a complex disorder influenced by factors such as lifestyle, nutrition, chronic diseases, and inflammation. The impact of sarcopenia goes far beyond muscle health, playing a significant role in the development of osteoporosis, metabolic disorders and cardiovascular conditions. These connections show how serious sarcopenia is, not only for individual health but also for public health systems worldwide. Studies indicate that about 10% of people between the ages of 60 and 69 are affected by sarcopenia, and this figure rises to roughly 40% for those aged 80 and above. Research also shows that noticeable changes in muscle tissue generally begin around the age of 50. People typically lose 1% to 2% of their muscle mass annually, while their muscle strength decreases even more quickly, by 1.5 to 5%. These modifications emphasise how critical it is to identify sarcopenia early and act before the illness causes more significant health problems. This essay discusses several methods to diagnose sarcopenia, including basic physical performance tests like walking speed or chair-rise ease or the use of instruments such as handgrip dynamometers are frequently adopted to measure muscle strength. Additionally, imaging techniques such as dual-energy X-ray absorptiometry (DXA) and bioelectrical impedance analysis can provide more precise data about muscle mass.

Specifically, management strategies primarily emphasize combining resistance training with a healthy diet, particularly by increasing protein intake. While consuming enough protein is essential for maintaining muscle, eating a high-protein diet without exercise is insufficient and may even be harmful. Excessive protein intake can increase the risk of heart and kidney problems if it is not incorporated into a balanced health plan. Therefore, a comprehensive approach that mixes physical activity with mindful eating to prevent and manage sarcopenia. This essay also explores plant-based and animal-based protein sources. Animal proteins typically provide a complete set of amino acids essential for muscle development, but a well-planned plant-based diet can also effectively support muscle health. By incorporating a variety of foods such as legumes, soy products, and whole grains, individuals can obtain all the essential amino acids needed to maintain muscle mass, demonstrating that both dietary approaches, when properly managed, can contribute to the prevention of sarcopenia.

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Introduction:

Definition of sarcopenia

Conventionally, as people grow older, significant changes take place in their bodies, and one of these striking changes might be the development of sarcopenia which is described as a skeletal muscle disorder that frequently occurs during the lifespan by advancing age which means losing muscle mass, strength and physical function [1]. To begin with, coined within the late 1980s, the term "sarcopenia" is derived from the Greek words sarx (flesh) and penia (loss), reflecting the central clinical sign of the condition, loss of muscle tissue. Although at first related to ageing, sarcopenia is presently recognised as a complex and multifactorial condition that can influence people at different life stages. Although initially associated with ageing, sarcopenia is now recognised as a complex and multifactorial condition that can affect individuals at various stages of life. It is a reversible disorder influenced by a wide range of biological, behavioural, and environmental factors [1].

Modern definitions emphasise that sarcopenia encompasses not only the loss of muscle quantity but also a decline in muscle quality, meaning that muscles become less efficient even if their mass appears relatively preserved [1]. Therefore, diagnosing sarcopenia requires careful assessment of strength (typically handgrip strength), muscle mass (using imaging tools like DEXA), and physical performance (such as gait speed) [2].

Diseases associated with sarcopenia

Sarcopenia does not occur in isolation. It is frequently a key element of broader health conditions such as frailty and cachexia, and it is associated with chronic illnesses including type 2 diabetes, chronic obstructive pulmonary disease (COPD), cancer, chronic kidney disease, and heart failure [3]. In many cases, sarcopenia is not only a consequence of these diseases but also a contributing factor that can accelerate their progression. For instance, in diabetes, insulin resistance can interfere with the body's ability to build and maintain muscle, leading to an accelerated loss of muscle mass [4].

The inflammation often accompanies chronic diseases and promotes muscle breakdown, further speeding up physical decline. Importantly, sarcopenia significantly increases the probability of adverse outcomes such as hospitalisation, falls, fractures, and even death. A meta-analysis by Beaudart and colleagues in 2017 confirmed that sarcopenia is independently associated with an increased risk of mortality across various settings and populations [5].

Age-Group Prevalence

The main cause of sarcopenia is ageing. According to population studies, between 5% and 13% of adults between the ages of 60 and 70 have sarcopenia, and among those over 80, the prevalence rises dramatically to 11% to 50% [6]. Depending on the populations studied and the diagnostic criteria applied, the prevalence varies. Despite having lower baseline muscle mass, women experience more gradual declines in muscle mass than men, who typically have higher muscle mass but lose it more quickly [7].

Some factors increase the possibility of developing sarcopenia earlier than expected, including a sedentary lifestyle, malnutrition, chronic diseases, smoking, and hormonal changes such as decreased testosterone and estrogen levels [1]. Ethnic differences have also been observed, suggesting that genetic, lifestyle, and environmental factors all contribute to sarcopenia risk [8].

Solutions: The Role of Exercise and Nutrition in Managing Sarcopenia

Managing sarcopenia primarily relies on two key strategies: regular physical activity and proper nutrition. These approaches work together to help the body build muscle, enhance physical performance, and lower the chances of falls, weakness, and disability. Although medications like myostatin blockers or hormone treatments are being explored as possible options, they are not yet proven or widely used [1]. For now, the most effective and research-backed methods to slow or reverse age-related muscle loss and weakness are lifestyle changes, especially strength training paired with adequate protein consumption [10].

Dietary Protein and Nutritional Interventions

As people get older, their bodies experience a reduced ability to use dietary protein effectively for muscle building, a condition known as anabolic resistance. This means older adults require higher amounts of protein to preserve or increase muscle mass. Experts recommend that older adults consume between 1.0 and 1.5 grams of protein per kilogram of body weight per day, which is notably higher than the 0.8 grams recommended for the general population [16]. Although the total amount of protein we eat matters, how we spread it out during the day, along with the quality of that protein, is just as important for keeping muscles healthy [17]. Proteins that are rich in the amino acid leucine are especially helpful because leucine acts as a powerful trigger for muscle growth [18]. Among protein sources, whey protein is particularly effective. It's rich in leucine and digests quickly, which makes it a significant choice to recover the body after a workout [19]. In addition to protein, several other nutrients are essential for muscle

health. For instance, Vitamin D [20] and omega-3 [21]. However, it's important to understand that nutrition alone is not enough. The greatest improvements in muscle strength and growth are seen when a well-balanced diet is combined with regular physical activity, particularly resistance training [22][23].

Research has found that supplementing with protein alone, without the addition of exercise, produces minimal or no meaningful gains in muscle mass or strength [22].

Additionally, consuming large amounts of protein in the absence of physical activity, particularly in individuals with health issues like kidney problems, may lead to negative outcomes. Depending on the protein source, consuming large amounts of protein over time can strain kidney function or cause cardiovascular issues. For this reason, nutrition plans must be carefully tailored to individual needs, balanced, and ideally combined with regular exercise [24]. On the other hand, resistance training not only supports muscle growth but also boosts nervous system function, balance, and joint stability, key elements in preventing falls and maintaining independence. As such, the most effective approach to treating sarcopenia involves a combination of targeted nutrition and consistent physical activity [25].

Vegan vs. Animal-Based Diets: Implications for Muscle Health

As nutrition plays a bigger role in dealing with sarcopenia, the protein sources are also important. Proteins aren't all the same, in fact they differ in how many essential amino acids they offer, how well our bodies can digest them, and how good they are at helping build muscle. This makes it important to look at the differences between plant-based and animal-based proteins. Animal proteins, such as those found in meat, dairy, eggs, and fish, are considered complete proteins because they provide all nine essential amino acids in the right proportions for human needs and they are also easily digested and absorbed [26].

On the other hand, one or more essential amino acids are frequently lacking in plant-based proteins. Plus, plants contain things like phytic acid and fibre, which can make protein harder for our bodies to break down [17]. New research shows that a carefully planned vegan diet, especially one that includes plant protein supplements or extra amino acids, can help older adults maintain muscle [27]. That said, when people follow vegan and omnivorous diets, both do resistance training, those eating animal protein usually gain a bit more muscle or strength, but the differences aren't huge [28].

It's important to mention that plant-based diets offer additional advantages, particularly for older adults. Diets centred around nutritious plant-based foods—such as whole grains, fruits, vegetables, nuts, and legumes- have been linked to lower levels of inflammation, enhanced heart health, and improved regulation of blood sugar [29].

Resistance Training and Physical Activity

Of all the methods available, resistance training (RT) stands out as the most effective non-drug option for treating sarcopenia. It promotes muscle growth by waking up satellite cells and triggering the muscle-building process through physical stress [11]. Research indicates that older adults who participate in progressive resistance training for at least 12 weeks see clear improvements in muscle strength, size, and overall physical ability [12]. These benefits extend even to frail seniors and those in care facilities, as long as the training is supervised and structured [13]. Cardiovascular exercises like walking, biking, and swimming are excellent for maintaining heart health, but they're not particularly effective at preserving muscle mass. but still, they play an important role in enhancing overall physical fitness. Experts generally recommend incorporating a variety of workouts, including strength, balance, and endurance training, for the most comprehensive benefits [14]. It's also crucial to recognise that the effectiveness of any exercise program depends on factors like its intensity, frequency, and the individual's level of commitment. This is why personalised fitness plans are so essential in clinical and healthcare settings [15].

This thesis explores how nutrition and exercise work together to prevent and manage sarcopenia in older adults. It highlights the limits of diet alone, the benefits of combining it with resistance training, and compares vegan and animal-based diets. The goal is to offer practical strategies to reduce sarcopenia through personalised plans.

Chapter 1: Understanding Sarcopenia

1.1 Definition and Diagnostic Criteria

Definition: Sarcopenia is broadly defined as the age-related loss of skeletal muscle mass and function (strength and performance). In practical terms, it is a progressive and generalised skeletal muscle disorder associated with increased likelihood of adverse outcomes such as falls, fractures, physical disability, and even mortality [30]. The condition was first described in the context of ageing, but it is now recognised that sarcopenia can also occur secondary to chronic diseases or lifestyle factors at younger ages. In 2016, the medical community formally acknowledged sarcopenia as an independent condition by assigning it an ICD-10-CM disease code (M62.84), classifying it as a muscle disease. This recognition marked an important milestone, spurring greater clinical attention to diagnosis and management [31].

Clinical Diagnosis (EWGSOP2): The current gold-standard diagnostic framework comes from the European Working Group on Sarcopenia in Older People's 2018 consensus (EWGSOP2). EWGSOP2 defines sarcopenia as a muscle disease (muscle failure) rooted in lifelong adverse muscle changes. Notably, EWGSOP2 emphasises low muscle strength as the primary criterion for sarcopenia, rather than muscle mass alone [1]. Muscle strength (typically measured by handgrip or chair-stand tests) has proven to be the most reliable and clinically relevant measure of muscle function decline. According to EWGSOP2, diagnosis involves three key criteria:

Low muscle strength - e.g. weak grip strength or poor performance on a chair-rise test. This is the key characteristic of sarcopenia; if low strength is detected, probable sarcopenia is diagnosed [1].

Low muscle quantity or quality - reduced muscle mass (measured by DXA or BIA scans for lean mass, or imaging like CT/MRI for muscle cross-sectional area or fatty infiltration) or poor muscle quality. Demonstrating low muscle quantity/quality confirms the diagnosis of sarcopenia (when criterion 1 is already met) [1].

Low physical performance - impaired physical function, typically assessed by slow gait speed (e.g. walking speed <0.8 m/s), poor score on the Short Physical Performance Battery (SPPB), long time on the Timed-Up-and-Go (TUG) test, or other measures of functional mobility. If an individual with confirmed sarcopenia also has low physical performance, they are classified as having severe sarcopenia [1].

EWGSOP2's algorithm thus follows a logical flow: first, identify cases with weak muscle strength (suggesting probable sarcopenia), then confirm sarcopenia by measuring muscle mass, and finally grade its severity by checking physical performance. This approach differs from earlier definitions that required low muscle mass as an initial step. The updated focus reflects evidence that strength loss is more predictive of poor outcomes than mass alone [1].

Table 1.1 summarises the operational criteria from EWGSOP2
Source: [1]

Criterion	Measurement (examples)	EWGSOP2 Interpretation
1. Low muscle *strength*	Handgrip dynamometry, chair-stand test	If low → Probable sarcopenia.
2. Low muscle *quantity* or *quality*	Appendicular lean mass by DXA or BIA; muscle imaging (CT/MRI) for area or fat infiltration	Confirms diagnosis (with low strength).
3. Low physical *performance*	Gait speed, SPPB score, TUG test, 400 m walk time	Indicates Severe sarcopenia (if criteria 1 + 2 also exist).

In medical practice, identifying sarcopenia often begins with straightforward screening tools. One commonly recommended method is the SARC-F questionnaire, which helps spot individuals experiencing issues like muscle weakness, slowed movement, or trouble with daily activities. If patients screen positive for symptoms or have known risk factors, they should undergo more detailed assessments, like grip strength, muscle mass, and physical performance tests. These evaluations help doctors confirm a diagnosis of sarcopenia, determine how advanced it is, and decide on the best treatment approach. Notably, early detection of sarcopenia, even when it is only considered "probable", is helpful because it allows for early interventions that can avoid serious consequences [1].

1.2 Prevalence

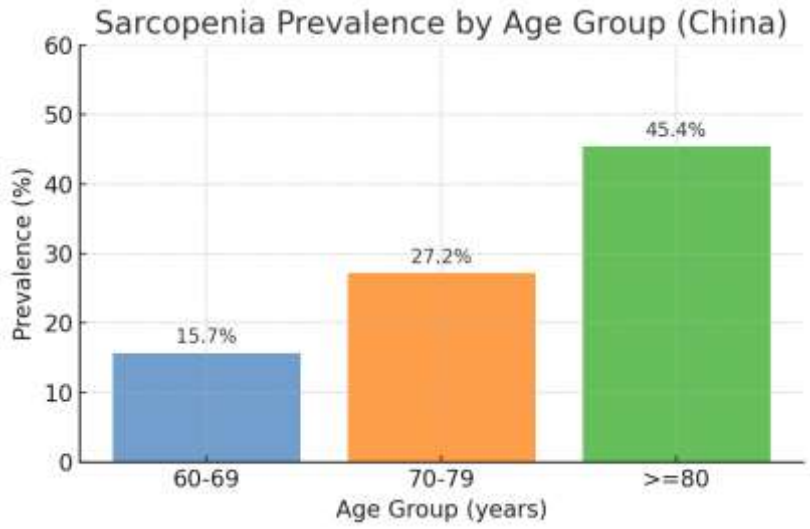
Sarcopenia is frequently seen in older adults, although the exact rates differ based on the group studied and the criteria used for diagnosis. A recent global systematic review and meta-analysis, which included data from over 690,000 people, reported that the prevalence of sarcopenia in individuals aged 60 and above generally ranged from about 10% to 27%. This variability is largely due to different diagnostic cut-offs and tools across studies. Nonetheless, it is clear that

a substantial minority of elders are affected worldwide. In fact, by some estimates, about 10–16% of seniors globally suffer from sarcopenia significant enough to impact their quality of life. The prevalence of severe sarcopenia (the most advanced stage) is lower and reported to be around 2–9% in older populations [32].

Sarcopenia has been reported across all parts of the world, although how common it is can differ from one region to another. For instance, one study using the EWGSOP criteria found the highest prevalence in Oceania and the lowest in Europe. These differences between countries may be due to factors like genetics, lifestyle habits, and research methods, but they also emphasise that sarcopenia is a widespread concern linked to ageing. Crucially, prevalence rises dramatically with advancing age. Figure 1.1 illustrates an example from a large Chinese study: in adults 60–69 years old, about 15–20% had sarcopenia, whereas nearly half of those over 80 years old were affected. Women and men are both susceptible, though some studies find men have higher sarcopenia rates when using newer criteria (EWGSOP2), while others find women are slightly more affected, depending on the definition. The risk clearly accelerates in the eighth decade of life and beyond [32][33].

Figure 1.1: Sarcopenia prevalence by age group in China.

Source: [32]



Although sarcopenia is primarily associated with older age, growing research reveals that it can also impact younger adults and even children under certain medical circumstances. This type, known as secondary sarcopenia, doesn't stem from ageing itself but instead results from chronic health conditions, inflammation, extended periods of inactivity, poor nutrition, or hormonal problems. It has been observed in populations with cancer, chronic kidney disease, HIV, and those undergoing long-term corticosteroid therapy. However, extensive research is still limited;

several case reports and studies have highlighted significant muscle loss in these individuals, often causing physical challenges similar to those experienced by the elderly [34].
In children, sarcopenia is extremely rare and not formally recognised as a medical diagnosis. However, muscle wasting has been reported in kids with inherited muscle disorders, cancer, or severe malnutrition. These findings have started conversations about the importance of managing muscle health early in life, especially for children with chronic illnesses. Although we don't yet have solid numbers on how common this is, these insights emphasise that sarcopenia isn't only a problem for older adults; identifying it in younger people may help lead to earlier treatment and more effective care strategies [35][36].

1.3 Risk Factors and Pathophysiological Mechanisms of Sarcopenia

Sarcopenia is a complex condition influenced by both external risk factors and internal biological changes. Although ageing is the main factor that can't be changed, since muscle loss and weakening happen even in healthy older adults, the speed and severity of sarcopenia are shaped by a range of other factors, including lifestyle choices, metabolic health, hormone levels, inflammation, and nervous system function [37].

Physical inactivity (sedentary lifestyle):
Muscles start to shrink when they aren't used frequently. In contrast, staying active postpones the development of sarcopenia. It's well known that a sedentary lifestyle increases risk because muscles require ongoing stimulation to preserve their size and strength. Extended periods of immobility or bed rest, such as after an illness or injury, can lead to rapid and substantial muscle loss in older adults, accelerating the progression of sarcopenia [37][38].

Insufficient nutrition and malnutrition:
A diet lacking in protein or calories disrupts the body's ability to build and maintain muscle mass. Long-term undernutrition leads to muscle loss, also makes it worse, and it is often seen in frail individuals with sarcopenia. Shortages of essential vitamins like D and B12 may further contribute to the problem. Older adults who lose weight unintentionally or experience a reduced appetite, commonly referred to as the "anorexia of ageing", are especially at risk. Protein-energy malnutrition is both a cause and a consequence of sarcopenia, setting off a damaging cycle [39].

Chronic illnesses and multimorbidity:

A wide range of chronic conditions can lead to muscle wasting. Diseases that affect major organs, such as heart failure, chronic obstructive pulmonary disease (COPD), chronic kidney disease, liver cirrhosis, and cancer, often cause inflammation and functional decline, both of which contribute to sarcopenia. for example, in liver cirrhosis, impaired ammonia metabolism, decreased protein production by the liver, and limited availability of anabolic hormones like IGF-1 work together to significantly weaken the body's ability to preserve muscle mass.. As a result, sarcopenia is both a frequent and serious issue for people with this condition [40]. Diabetes is another key factor in the development of sarcopenia, largely because of insulin resistance. This condition reduces the ability of skeletal muscles to activate crucial muscle-building pathways, such as PI3K/Akt/mTOR, resulting in lower muscle protein synthesis and increased protein breakdown over time. In older adults, insulin resistance is strongly linked to both loss of muscle mass and deterioration in muscle quality, speeding up sarcopenia, even when there's no clear sign of malnutrition or physical inactivity [41]. When several chronic conditions, such as liver disease, diabetes, and heart or lung issues, occur together, the risk and impact of sarcopenia rise dramatically. Studies show that this combination not only accelerates muscle loss but also makes treatment more difficult [40][41].

Hormonal and Metabolic Dysregulation:

Important hormones that support muscle, such as growth hormone (GH), testosterone, and IGF-1, significantly decrease in levels as people age. These hormones are vital for promoting muscle protein synthesis and supporting neuromuscular function. They also activate critical molecular pathways such as the IGF-1/Akt/mTOR cascade, which help muscles grow and repair. When these hormone levels decline, it results in what is known as the "endocrinopathy of ageing." In this state, older muscles become less responsive to anabolic signals like dietary protein and physical activity—a condition known as anabolic resistance [42]. At the same time, getting older is linked to an increase in catabolic hormones like cortisol and myostatin. Myostatin, a member of the TGF-β family, is a powerful blocker of muscle growth. When there's too much of it, it can hinder the activation of satellite cells and boost muscle breakdown, both of which play a role in the muscle loss associated with sarcopenia. When cortisol is chronically high due to stress or illness, it encourages muscle breakdown through the activation of the ubiquitin–proteasome system, further tipping the balance towards muscle degradation [42]. In addition to changes in anabolic and catabolic hormones, ageing also disrupts thyroid hormone levels and reduces insulin sensitivity in muscle tissue. These disruptions weaken metabolism and glucose processing in muscle that both are vital for maintaining muscle mass. As a result, sarcopenia

patients experience worsening muscle loss as their muscles receive less energy and weaker growth signals. In postmenopausal women, declining estrogen levels cause changes in body composition, such as increased abdominal fat and reduced physical activity, which can indirectly weaken muscle quality and function. While estrogen doesn't act on skeletal muscle as directly as testosterone does, its loss has been linked to poorer mitochondrial function, higher levels of oxidative stress, and more inflammation, all of which can accelerate the progression of sarcopenia [42].

Inflammation and Immunosenescence:

chronic, low-level inflammation, often known as "inflammaging", plays a major role in how sarcopenia starts and gets worse over time. Ageing is associated with increased circulating levels of pro-inflammatory cytokines such as tumour necrosis factor-alpha (TNF-α), interleukin-6 (IL-6), and C-reactive protein (CRP). These substances disrupt the natural balance in our muscles by speeding up the breakdown process through systems like the ubiquitin–proteasome pathway, while also blocking important growth signals from pathways such as IGF-1, Akt, mTOR. In addition, ongoing inflammation disrupts the environment that muscle stem cells need to function properly. This makes it harder for them to activate and repair damaged muscle, often weakening the muscle's ability to recover and grow. Over time, this chronic inflammation gradually breaks down the structure and function of muscle fibres. The article points out that this damage doesn't just happen throughout the body; it also takes place right inside the muscle tissue, making problems like mitochondrial damage, oxidative stress, and cell death even worse. On top of that, ageing weakens the immune system, a process called immunosenescence, which makes it harder for the body to keep inflammation in check. This creates a nonstop, out-of-balance inflammatory state that keeps telling the muscles to break down, without giving them the time or support they need to recover. together, inflammaging and immunosenescence create an internal environment that promotes muscle loss over muscle building. Tackling this low-level inflammation with anti-inflammatory foods, regular physical activity, or new treatments that help manage immune responses could be a promising way to slow down or lessen the effects of sarcopenia [43].

Neuromuscular Degeneration:

During ageing, the neuromuscular system starts to deteriorate due to a decline in both the number of motor neurons and the structural integrity of the neuromuscular junction (NMJ). Even when total muscle mass does not seem to have decreased significantly, this causes noticeable muscle dysfunction. The deterioration begins with the remodelling of motor units, a

process that becomes less efficient over time. Loss of motor neurons, particularly those that control fast-twitch (type II) muscle fibres, leads to denervation of many muscle fibres. Although some fibres may get reinnervated, this process is often slow or incomplete, causing those fibres to shrink or even die, especially those crucial for strength [44].

At the same time, the NMJ itself undergoes visible structural changes, including the breakdown of acetylcholine receptor (AChR) clusters, shallower folds on the postsynaptic side, and thinning of the presynaptic area. These changes disrupt communication between nerves and muscles, slowing down muscle activation and impairing coordination and control. Interestingly, these functional issues can arise even when muscle size remains relatively intact, emphasising that muscle efficiency matters as much as muscle quantity [45].

Adding to the problem is the increase in oxidative stress that comes with ageing. Faulty mitochondria produce more reactive oxygen species (ROS), which harm both nerve and muscle cells, destabilising the NMJ and interfering with signal transmission. Mitochondrial issues also hamper calcium balance and energy supply, which further diminishes muscle responsiveness to nerve signals [44][45].

Impaired Regeneration and Satellite Cell Decline:

Another factor in ageing is the loss of responsiveness in satellite cells, which are the muscle's resident stem cells responsible for regeneration. The number of satellite cells declines, and their ability to activate gets blocked by increased levels of transforming growth factor-beta (TGF-β), reduced insulin-like growth factor-1 (IGF-1), and rising oxidative stress. As a result, when muscles get injured or aren't used for a while, they don't heal or regenerate as effectively, which plays a big role in the gradual worsening of sarcopenia.

Recent research indicates that ageing changes the satellite cell niche, the surrounding environment where these cells reside. Higher levels of inflammatory molecules and fibrosis-related signals disrupt the satellite cells' ability to refresh themselves and grow into new muscle cells. Over time, some of these cells can become aged or stop working correctly, producing fewer of the key repair proteins like Pax7 and MyoD—both essential for getting muscle regeneration started [46].

In addition, the balance between inactive (quiescent), active, and committed satellite cells become disturbed in aging muscle, leading to a gradual depletion of these crucial regenerative cells. Factors such as changes in gene regulation (epigenetics), problems in mitochondria, and ongoing low-level inflammation further weaken their function. Altogether, these changes lead to poorer muscle adaptation, slower healing after injury, and a steady loss of muscle fibres [47].

Mitochondrial Dysfunction and Oxidative Stress:

One of the main causes of sarcopenia is mitochondrial issues that arise with ageing. Older adults produce fewer new mitochondria, their cells generate energy (ATP) less efficiently, and they create more harmful molecules known as reactive oxygen species (ROS) [48]. This creates an "energy crisis" in muscle fibres, weakening their ability to contract and making fatigue set in faster. Faulty mitochondria not only reduce energy but also produce too much ROS, which damages important parts of the cell, like proteins, fats, and both mitochondrial and nuclear DNA [49].

All this damage from oxidative stress speeds up the breakdown of muscle proteins, blocks the body's ability to repair muscle, and contributes to muscle shrinking and cell death. On top of that, ROS disrupts how mitochondria function and renew themselves, mainly through broken fusion and fission processes, which hurts their quality and ability to adapt. Research shows that this drop in mitochondrial health is a key reason why older adults lose muscle mass and strength over time [48].

The constant reshaping of the mitochondrial network is essential for keeping muscles strong and healthy. Romanello and Sandri (2021) highlight that when mitochondrial quality control systems fail, muscle flexibility suffers, and sarcopenia progresses faster [50]. They also highlight that when mitophagy, the body's way of clearing out damaged mitochondria, doesn't work properly, these broken parts pile up and add even more stress to the cells. The upside is that this damage isn't necessarily permanent. Making healthy lifestyle choices, especially sticking to regular aerobic and strength training workouts, has been shown to improve how mitochondria function, help the body better manage oxidative stress, and bring back the balance between damage and repair. It's a strong reminder of just how powerful physical activity can be in protecting against mitochondrial problems and slowing down the effects of sarcopenia [50].

Lifestyle and Environmental Contributors:

Lifestyle choices that can be changed play a big role in how sarcopenia starts and progresses. Things like poor nutrition, not getting enough exercise, drinking too much alcohol, and smoking can all lead to a drop in muscle mass and strength, making sarcopenia more likely. Eating poorly can result in inadequate protein intake, which is necessary to maintain muscle strength, while physical inactivity leads to muscle weakening and atrophy. On top of that, outside factors like low income, depression, or feeling socially isolated can also raise the risk of sarcopenia. These challenges often cause people to move less and eat poorly, which ends up making the situation

even worse. As mentioned before, making healthier lifestyle choices, like eating a balanced diet and staying physically active, can go a long way in lowering the risk and effects of sarcopenia [51]. These problems don't work separately, they're all linked and tend to make each other worse. For example, when mitochondria aren't functioning well, they can set off more oxidative stress and inflammation. That ongoing inflammation can then mess with hormone signals and hold back the muscle's ability to repair itself by shutting down satellite cell activity. Nerve loss can also lead to oxidative stress in muscle. Because of this, sarcopenia is best understood as a condition of fast-tracked muscle ageing, driven by several harmful factors working together [47][52]. Scientists are still working to untangle these complex interactions and find treatments. So far, exercise stands out as the most effective way to fight back—it increases muscle-building hormones, improves mitochondrial health, cuts down inflammation, boosts nerve signals to muscles, and helps satellite cells do their job. Gaining a deeper understanding of how sarcopenia works is key to developing medications, like myostatin blockers, hormone therapies, or anti-inflammatories, that could one day work alongside exercise and good nutrition to protect muscle health as we age [47][52].

1.4 Stages of Sarcopenia

In clinical settings, sarcopenia is usually categorized into different levels of severity to help guide treatment decisions. According to the EWGSOP2 guidelines, there's a staging system based on the criteria mentioned earlier in Section 1.1. The stages include probable, confirmed, and severe sarcopenia.

Probable Sarcopenia: This stage is identified when someone shows signs of reduced muscle strength (meeting Criterion 1). For example, an older adult with a handgrip strength below the standard cut-off, less than 27 kg for men or 16 kg for women, or someone who needs to use their arms to get up from a chair, would fall into this category. At this point, their muscle mass might still be within a normal range, but they're noticeably weaker than expected for their age. Probable sarcopenia should be taken seriously and acted on right away, ideally with strength training and better protein intake. Even without full confirmation, low muscle strength on its own raises the risk of falls and disability, and it signals the need for further tests to check muscle mass [1].

Confirmed Sarcopenia: This stage is diagnosed when a person has both weak muscle strength and noticeable loss in muscle mass or quality (meeting Criteria 1 and 2). Doctors typically

confirm this using tests like DXA scans or bio-impedance analysis, which measure the amount of lean muscle in the arms and legs. If the results fall below the cut-off, less than 7.0 kg/m² for men or 5.5 kg/m² for women, based on EWGSOP2 guidelines, it confirms the condition. In a clinical setting, doctors might also confirm it by noticing obvious muscle loss during a physical exam or through imaging [1].

At this point, the person fully fits the definition of sarcopenia, they have both muscle weakness and a measurable loss in muscle quantity or quality. This is when sarcopenia becomes a formal diagnosis (with the medical code ICD-10 M62.84), and a full treatment plan should be put into action. Confirmed sarcopenia reflects a moderate level of severity, and it means the patient is at greater risk of falling, losing physical function, and facing other health issues, so active treatment is essential [1].

Severe Sarcopenia: This is the most advanced stage and is diagnosed when all three criteria are present, meaning the person not only has weak muscles and low muscle mass, but also shows poor physical performance (meeting Criteria 1, 2, and 3). Signs of low physical performance might include walking slower than 0.8 meters per second in a 4-meter walk test, scoring 8 or lower on the SPPB, or taking more than 20 seconds to complete the Timed-Up-and-Go test [1].

At this stage, muscle loss and weakness are clearly affecting everyday life. The person might walk slowly, fall more often, or struggle with tasks like climbing stairs. People with severe sarcopenia are often frail and may need help with daily activities. This stage comes with the highest risk of serious problems, like fractures from falls, losing the ability to live independently, or needing to be hospitalised. Treating severe sarcopenia involves more than just exercise and a healthy diet. it often requires physical therapy to help with balance and coordination, fall prevention strategies, and sometimes mobility aids like walkers or canes. What really separates confirmed sarcopenia from the severe stage is how well a person can function in everyday life, not just their muscle mass measurements. It’s a clear reminder that sarcopenia isn’t only about numbers, it’s about how it affects a person’s ability to move, stay independent, and maintain quality of life [1].

It’s important to understand that these stages of sarcopenia exist on a spectrum—if nothing is done to stop it, a person can move from probable to confirmed to severe sarcopenia over time. This staging system helps guide treatment decisions. For example, someone with probable sarcopenia should get further testing and start preventive steps. Someone with confirmed sarcopenia may need more focused strength training and possibly medical treatment. For those

with severe sarcopenia, care might include fall prevention strategies and even support from a caregiver. The EWGSOP2 framework has become widely used in both research and clinical settings because it's practical and closely linked to patient outcomes. Studies show that people in the severe stage face the highest risk of disability and death. Those in the confirmed stage face a moderate risk, while people with only probable sarcopenia, who have low strength but not yet muscle loss, are still at higher risk than their peers, but they often have a good chance of recovering if they get timely help [1].

Chapter 2: Health and Functional Impacts of Sarcopenia

2.1 Effects on Physical Function, Independence, and Quality of Life

As muscles weaken, even basic activities like climbing stairs, getting up from a chair, or carrying groceries can become challenging [53]. Studies have found that older adults may become dependent on others if their muscle mass or function declines alone. One major study found that people with lower muscle mass were about 1.65 times more likely to become dependent, while those with weaker grip strength faced approximately 6.2 times higher odds of losing their independence later in life [54]. People with sarcopenia often face challenges in performing everyday tasks such as cooking or cleaning and may require assistance or assistive devices to maintain their independence. These limitations affect not only their physical capabilities but also their confidence and sense of autonomy. Many may avoid physically demanding activities or movement out of fear of exhaustion or injury. The decline in physical function caused by sarcopenia has cascading effects on quality of life. As muscle strength and endurance decrease, individuals often withdraw from social and recreational activities they once enjoyed, which can lead to social isolation and psychological distress [55]. In fact, studies show that health-related quality of life (HRQoL) is noticeably worse in those with sarcopenia compared to those without it. A 2023 review of 43 studies revealed that older adults with sarcopenia scored about 0.8 standard deviations lower on general quality of life measures [55]. The biggest drop is seen in the physical health area, which includes issues like pain, tiredness, and physical limitations. But the effects aren't only physical; research also shows that sarcopenia can hurt mental health and reduce social involvement. One Australian study found that it was linked to poorer psychological quality of life [56]. Other reports indicate that muscle loss can harm body image and self-esteem, while limited mobility reduces chances for social interaction and engagement with the community [56]. Over time, these problems can lead to a noticeable drop in how satisfied people feel with their lives. Staying physically capable and enjoying a good quality of life later in life both depend greatly on keeping our skeletal muscles

strong and healthy. Approaches like resistance training, which helps improve muscle strength, have been shown to ease some of the challenges by enhancing mobility, boosting confidence, and restoring a sense of control. Ultimately, the muscle loss caused by sarcopenia chips away at older adults' independence and affects many aspects of their well-being, making daily movement harder and impacting their mental and social lives too [56].

2.2 Associated Health Risks (e.g., Falls, Frailty)

Apart from impairing daily functioning, sarcopenia is associated with numerous severe health issues in the elderly population. One of the most concerning is the higher risk of falls and the injuries that can follow. As muscle mass and strength decline, balance can become unsteady, walking speed slows, and coordination worsens, factors that all increase the chances of falling [57][58]. A recent meta-analysis of 10 cohort studies, involving more than 10,000 older adults, found that people with sarcopenia had roughly 1.7 times the risk of falling [59]. In practical terms, that means a significantly greater chance of falling, a leading cause of injury and health decline in older adults, often resulting in fractures to the hip, wrist, or spine. Sarcopenia frequently occurs alongside osteoporosis, in a condition known as "osteosarcopenia", and the combination of the two greatly raises the risk of bone fractures from minor incidents [58][60]. When muscles are weak, they provide less protection in the event of a stumble, and fragile bones are more prone to breaking on impact, making for a risky combination. Strong evidence shows that sarcopenia significantly raises the risk of fractures. One expert report concluded that there is a high level of evidence that older adults with sarcopenia are much more likely to suffer from osteoporotic fractures than their peers. Even when a fall doesn't lead to a fracture, it can still result in a fear of falling and a loss of confidence. This often causes people to become less active, which only speeds up physical decline, creating a harmful cycle [58][60]. Another important connection is the link between sarcopenia and frailty, a condition in older adults marked by increased vulnerability. Frailty is characterised by multiple system impairments, such as weakness, slowed movement, fatigue, and weight loss, and is recognised as one of the major challenges in geriatric care, much like sarcopenia. These two conditions are closely related: sarcopenia is believed to play a key role in physical frailty, since muscle weakness and slowness are central to how frailty is defined [53]. Population studies show a strong overlap between them, with many frail seniors also meeting the criteria for sarcopenia, and vice versa [56]. They share similar risk factors like chronic inflammation, poor nutrition, and inactivity, and both are associated with serious outcomes, including disability and hospitalisation [53].

While sarcopenia focuses specifically on the loss of muscle mass and function, frailty refers more broadly to a general decline in the body's resilience. Still, low muscle strength is often the strongest signal that someone is becoming frail. Clinically, an older adult with sarcopenia is much more likely to develop frailty, and someone who is already frail often has underlying sarcopenia contributing to their weakness. When both conditions are present, the risks increase: studies have shown that people with both sarcopenia and frailty are more likely to experience falls, lose independence, and need long-term care than those with just one of the conditions [53][61]. They also tend to have a harder time recovering from illnesses or surgeries. Spotting sarcopenia early on could help identify those at higher risk for frailty, giving healthcare providers the chance to step in with treatments like exercise and nutrition plans to help slow that decline [53].

Notably, sarcopenia is associated not only with poor health outcomes but also with an increased risk of death. A range of long-term studies across various populations has shown that sarcopenia independently raises the likelihood of dying from any cause in older adults [58]. In fact, a meta-analysis in 2017 combined data from over 7,000 seniors found that those with sarcopenia had a 60% higher risk of death during the study period compared to individuals without the condition (with a pooled hazard ratio of approximately 1.60). The risk of mortality is even greater in more advanced cases of sarcopenia or over shorter follow-up periods, indicating that its effects can be both immediate and long-lasting [62]. The mechanisms underpinning this increased mortality are multifactorial: sarcopenia can worsen outcomes of other diseases (e.g. by increasing post-operative complications and impairing immunity), it contributes to falls and fractures, which can be fatal, and it often coexists with other geriatric syndromes that carry mortality risks (frailty, malnutrition). Even after controlling for age, comorbidities, and other risk factors, muscle weakness remains a significant predictor of mortality in most studies. In short, preserving muscle health is essential not only for quality of life but also for longevity [63].

Table 2.1 summarizes several major health and functional outcomes associated with sarcopenia, underlining its broad impact on older adults' health.

Table 2.1. Key adverse outcomes associated with sarcopenia in older adults.

outcome	Impact/Risk in Sarcopenia
Physical independence	Substantially reduced. Older adults with sarcopenia have higher odds of future disability and loss of independence; e.g. low muscle mass confers ~1.65× higher odds and low muscle strength ~6.2× higher odds of losing independence compared to normal [54]
Falls	Greatly increased risk. Sarcopenic individuals have ~1.7× higher odds of experiencing falls than non-sarcopenic peers, due to impaired balance and muscle weakness [59].
Fractures	Elevated risk of fragility fractures. Weakened muscles and coexisting bone loss lead to significantly higher rates of osteoporotic fractures in sarcopenic older adults [58]
Frailty	High overlap and synergism. Sarcopenia contributes to frailty; both conditions together predict markedly higher rates of falls, disability, and hospitalization than either alone [53].
Quality of Life (QoL)	Notably impaired. Sarcopenic older adults report lower HRQoL, especially in physical domains, with on average ~0.5–0.8 standard deviation worse scores vs. non-sarcopenic adults [55][56].
Mortality	Increased mortality risk. Sarcopenia is associated with ~1.5–2 fold higher risk of all-cause mortality in older populations. making it an independent predictor of reduced survival. [58][62]

Sarcopenia places a significant financial strain on both healthcare systems and families. Elderly individuals affected by this condition often experience increased hospitalization rates, extended recovery periods, and a heightened need for long-term care. These outcomes translate into increased healthcare expenditures and indirect costs, including lost productivity and caregiver strain. Public health models suggest that even modest reductions in sarcopenia prevalence could yield major cost savings, emphasizing the importance of early detection and prevention [5].

Chapter 3: Nutrition and Exercise Interventions for Sarcopenia

3.1 Nutritional Strategies for Muscle Maintenance

Maintaining muscle mass and function in individuals with sarcopenia relies heavily on proper nutrition. Insufficient dietary intake, especially protein, leads to muscle loss [64]. As people age, they experience anabolic resistance, which is a reduced ability to build muscle in response to protein consumption. As a result, older adults require a higher protein intake than younger individuals to effectively maintain muscle mass [65]. important dietary factors include total macronutrient intake (especially protein), protein quality, distribution, and timing of protein ingestion, and overall diet quality. Recent studies emphasize that increasing protein intake, together with sufficient calorie consumption and vital nutrients like vitamin D, can greatly improve sarcopenia outcomes, particularly when coupled with regular physical activity [64][66]. Whereas the general Recommended Dietary Allowance (RDA) for protein is 0.8 g per kilogram of body weight per day, this level is now considered insufficient for older adults [65]. Experts consistently recommend higher protein intakes in older populations, on the order of 1.0–1.2 g/kg/day or more, to overcome anabolic resistance and support muscle mass [65][67]. In practical terms, an older adult weighing 70 kg might aim for roughly 70–84 g of protein per day (significantly above the 56 g implied by the 0.8 g/kg RDA). Such intake levels have been associated with better maintenance of lean mass and strength in ageing individuals [64].

The amount of protein consumed per meal, as well as the timing of its intake, both play an important role in muscle health. Rather than concentrating protein intake in a single meal, it is more effective to distribute it evenly throughout the day. Studies suggest that older adults can get the most benefit from about 25 to 30 grams of protein per meal (roughly 0.4 grams per kilogram of body weight) to support muscle protein synthesis (MPS), which is the process of building muscle [66]. Each meal should also contain around 2 to 3 grams of leucine, which is a key amino acid that plays a major role in kickstarting muscle protein synthesis. It signals the body to start muscle protein synthesis by activating the mTORC1 pathway [65]. Older adults can typically get this amount of leucine from 25 to 30 grams of high-quality protein. Having protein shortly after exercising can give muscles an extra boost. Experts recommend eating a high-protein meal or taking a protein supplement of about 20 grams soon after workout. This helps the body take advantage of the heightened muscle-building response that comes with exercise [67]. Aligning protein intake with physical activity and ensuring each meal contains adequate protein can enhance muscle repair and growth. Adequate total energy intake is also necessary. Older adults in a calorie deficit or with poor appetite (common with ageing) may

continue to lose weight, including muscle mass, despite high protein percentages in the diet. In essence, “food first” approaches are promoted: a balanced diet rich in protein and nutrients, rather than reliance on pharmacological aids, is the frontline defence against sarcopenia [67].

While ensuring adequate protein is crucial for older adults to counter sarcopenia, it’s also key to be aware of the risks of regularly eating much more than what the body needs, like consistently going over 2.0 grams per kilogram of body weight per day. One potential concern is kidney health. In people with healthy kidneys, eating a high-protein diet causes an increase in glomerular filtration rate (GFR), which is a normal response by the body. So far, research hasn’t shown that this leads to long-term kidney damage in individuals with normal renal function [68]. However, the kidneys do experience a higher workload and metabolic byproduct load under such diets. In people with reduced renal reserve or at risk of chronic kidney disease (CKD), an excessive protein intake may accelerate renal decline [69]. For example, one 11-year cohort study found that women with mild renal insufficiency who habitually ate a high-protein diet had a faster loss of kidney function than those with lower protein intakes [69]. High protein intakes, especially from animal sources, can affect how the kidneys handle minerals and acid. excessive protein in the diet boosts acid production, which causes the body to pull calcium from the bones to neutralise the acid. This can lead to more calcium in the urine, a condition known as hypercalciuria. Along with the higher purine content in meat, this process helps explain why diets very high in animal protein are linked to a greater risk of developing kidney stones, both uric acid and calcium-based types [69].

Another area of concern is bone health. Diets extremely high in protein have been thought to affect calcium balance and bone turnover due to their acid load. A high intake of animal protein generates a greater net acid load, which the body buffers in part by mobilizing alkaline minerals from bone, potentially increasing calcium losses. Short-term metabolic studies support this effect: increasing protein from moderate to very high levels induces significant hypercalciuria and a decrease in calcium retention [69]. Concurrently, biomarkers of bone resorption rise on high-protein diets (e.g. urinary N-telopeptide was elevated with intakes ~140 g/day vs. Lower protein intake has been linked to reduced calcium loss in urine, which suggests that some of the extra calcium excreted on high-protein diets may come from bone breakdown [69]. This raised concerns that eating too much protein over time could harm bone mineral density (BMD) or increase the risk of fractures. Early studies supported this idea, showing that diets high in animal protein—especially those lacking enough fruits and vegetables to balance out the acid—were associated with greater bone loss and more fractures. For example, women who ate more than 95 grams of protein per day and frequently consumed red meat had higher rates of forearm bone loss and fractures than those who ate less than 68 grams [69]. However, newer research offers

a more balanced view. Protein are an important part of bone structure, and getting enough of it helps maintain muscle mass, which in turn supports and protects bone health. When calcium and alkalizing foods are sufficient, higher protein intakes do not appear to harm BMD and may even be beneficial for older adults. A dose–response meta-analysis of cohort studies reported that individuals with higher protein diets had a significantly lower risk of hip fracture (approximately 11% reduced risk compared to lower protein intake) [70]. This suggests that, beyond a certain point, protein's skeletal benefits plateau and can shift toward risk only if accompanied by nutritional imbalances (e.g. low calcium or micronutrients). The impact of consuming a high-protein diet on heart health can differ significantly depending on the kind of protein consumed. Saturated fats and sodium, which are known to contribute to heart disease, are more common in diets high in animal proteins, particularly red and processed meats. Research has shown that individuals who consume more red and processed meats are at a greater risk for coronary heart disease and high blood pressure, partly because of these added components. In contrast, protein-heavy diets that emphasise plant-based sources like legumes and nuts are generally higher in healthy fats and dietary fiber, and are associated with better cardiovascular and metabolic outcomes. According to one review by Delimaris (2013), "high-protein/high-meat diets" may increase the risk of heart disease because they are also high in cholesterol and saturated fat. These findings suggest that too much animal protein might promote heart disease through effects on fats and inflammation [69]. Therefore, it is generally not recommended to consume more than 2 grams of protein per kilogram of body weight per day, as this may put stress on kidneys, bones, and heart in addition to offering little benefit for muscle growth. Selecting high-quality sources of protein, such as plant, dairy, and lean meats, and balancing all meals with lots of vegetables and whole grains will help older people get the most out of protein without the risks [69][71].

3.2 Protein Quality: Animal vs. Plant Sources

Not all proteins are equal in their ability to support muscle maintenance. Protein quality is determined by amino acid composition (especially the content of essential amino acids, EAAs, such as leucine) and digestibility/bioavailability. High-quality proteins provide all EAAs in sufficient quantities and are easily digested, thereby strongly stimulating muscle protein synthesis. Proteins derived from animals, such as dairy, meat, and eggs, are typically regarded as complete and high in quality [65]. They give the body all the essential amino acids in the proper amounts, so no amino acid is lacking. Most animal proteins score well on the Digestible Indispensable Amino Acid Score (DIAAS), often exceeding 100, which signals excellent protein quality and no amino acid deficiencies [72]. On the other hand, many plant-based

proteins are considered incomplete because they lack sufficient amounts of one or more essential amino acids. For instance, legumes are typically low in methionine, while grains are often low in lysine. This can lead to lower DIAAS scores for individual plant foods. In addition, the amino acid composition of plant proteins tends to vary more, and they are generally less digestible [72]. Animal proteins tend to have a higher percentage of leucine compared to plant proteins [73]. According to a recent analysis, isolated animal proteins contained about 8.8% leucine by weight, while plant protein isolates averaged around 7.1%, although this can vary quite a bit depending on the plant source. For instance, whey (a dairy protein) is especially leucine-rich (~10–11% leucine) and is renowned for stimulating muscle synthesis; whole egg protein is also high-quality (~9% leucine) and complete [73]. Among plants, soy protein isolate is one of the higher-quality sources (~8% leucine) and contains all EAAs, making it comparable to some animal proteins. Other plant proteins may have more pronounced limitations: e.g. wheat or hemp protein have low lysine and a leucine content around only ~5–6%, classifying them as lower quality proteins for muscle building [73]. On the other hand, corn protein has a high leucine percentage (~13% of protein) but is very low in lysine, illustrating that a single quality metric like leucine content does not alone guarantee overall protein quality [73].

Even with these differences in protein quality, older adults don't have to rely on animal products to meet their protein needs. A well-planned plant-based diet can still support muscle health. By pairing complementary plant proteins, it's possible to get all the essential amino acids. Eating a slightly higher total amount of plant protein can also help make up for the lower quality per gram. That said, recent research cautions that strictly vegan diets may pose challenges for some seniors: a vegan diet tends to increase the risk of inadequate protein intake in older adults [65][74]. Research on how different protein sources affect muscle health has shown mixed results. A systematic review found that animal protein might have a slight edge over lower-quality plant proteins when it comes to preserving muscle mass. However, when high-quality plant proteins like soy were used, the difference was minimal [75]. Generally, both animal and plant proteins can be part of a healthy diet aimed at preventing or managing sarcopenia. Making sure plant-based diets are adequate in protein and high in essential amino acids is crucial. Protein-fortified foods or supplements, such as soy or pea protein shakes, and selecting plant sources that are high in leucine, like soy, pea, or corn, especially when combined with other proteins, are useful tactics for people who primarily consume plant proteins [65].

Table 1. Comparison of protein sources (animal vs. plant) and their quality for muscle maintenance:

Source: [65][73]

Protein source	Type	Leucine Content (% of protein)	Protein Quality & EAA Completenes
Whey protein (dairy	Animal	High (~10–11% leucine)	Excellent quality (complete amino acid profile; DIAAS ≥100). Rich in EAAs (e.g. high leucine) for robust MPS stimulation.
Egg	Animal	Moderate-High (~9% leucine)	Excellent quality (complete protein; DIAAS ≥100). Contains all EAAs in optimal ratios for humans.
Soy protein isolate	Plant	Moderate (~8% leucine)	High quality among plant proteins (complete EAA profile; DIAAS ~88). Comparable to animal protein in supporting MPS when consumed in sufficient quantity.
Hemp protein	Plant	Low (~5% leucine)	Low quality if alone (incomplete – limiting in lysine; DIAAS <75). Requires combination with other proteins to meet EAA needs.
Corn protein	Plant	Very High (~13% leucine)	Incomplete (limiting in lysine) despite high leucine. Not fully adequate alone; should be paired with lysine-rich proteins (e.g. legumes).

Note: DIAAS = Digestible Indispensable Amino Acid Score (scores ≥100 indicate "excellent" protein quality). EAA = essential amino acid; MPS = muscle protein synthesis.

Plant-Based Protein Sources and Strategies for Older Adults with Sarcopenia

There are numerous vegan protein options available that offer ample protein along with other essential nutrients [76]:

Soy and Soy Products: Soybeans and soy-derived foods (tofu, tempeh, edamame) are rich in high-quality protein. Notably, soy protein contains all essential amino acids in adequate amounts, making it one of the few plant proteins with "excellent" protein quality comparable to animal proteins. For example, the digestible indispensable amino acid score (DIAAS) of tofu

has been reported around 97 (on a scale where ≥100 is equivalent to high-quality milk protein), highlighting soy's completeness. Soy foods are also relatively high in leucine – the key amino acid for muscle protein synthesis – compared to other plant proteins, which is advantageous for older adults aiming to stimulate muscle growth [65].

Legumes (beans, lentils, chickpeas): They are key protein sources in vegan diets and are particularly advantageous for older adults. They are packed with protein, fibre, and vital micronutrients [77]. These legumes are especially rich in lysine but generally lower in methionine, which pairs well with grains to form a complete amino acid profile. In terms of protein quality, most legumes have moderate DIAAS ratings, for instance, pea protein scores around 83. But their overall nutritional value is greatly enhanced when combined with other plant-based foods [65].

Grains and Pseudocereals: Whole grains such as brown rice and whole wheat, together with pseudocereals like quinoa, amaranth, and buckwheat, provide additional protein in plant-based diets. While most grains are low in lysine, certain pseudocereals, such as quinoa and amaranth, are considered complete proteins, delivering all essential amino acids in sufficient amounts. These pseudocereals meet adult essential amino acid (EAA) needs and have higher amino acid levels than standard grains. Though they may not achieve the highest protein quality ratings found in animal proteins, they are valuable for increasing dietary variety and can be effectively combined with legumes to enhance overall protein quality [65].

Other Protein Sources: Seitan, also known as wheat gluten, is a protein-packed meat alternative, offering about 25 grams of protein per 100 grams [78]. But on its own, it's not a complete protein, it's low in lysine, which gives it a relatively low protein quality score (DIAAS of around 28). It's a good idea to pair seitan with lysine-rich foods like edamame or black beans to utilise seitan's protein density, especially for older adults. This combination helps create a more balanced amino acid profile [65].

Nuts and seeds such as almonds, peanuts, chia seeds, and hemp seeds also also provide protein along with healthy fats. While they're a bit lower in lysine and threonine, they still add valuable protein when eaten with grains and legumes [65].

Because most plant proteins (except soy, potato, and a few others) are incomplete (lacking or low in one or more essential amino acids), combining different plant foods is key to ensuring a complete amino acid profile. This concept of complementary proteins involves eating foods with complementary amino acid strengths so that one source makes up for what another lacks

[65]. A classic example is combining grains and legumes: grains (e.g. rice, wheat) tend to be low in lysine but high in methionine, whereas legumes (e.g. beans, lentils) are high in lysine and low in methionine [65]. When consumed together in a meal, for instance, rice with beans[65], or whole-grain bread with peanut butter [79], the composite protein can provide all essential amino acids in sufficient quantities. For example, a food blend of pea (legume), wheat (grain), and potato has a DIAAS of 100 (complete protein), whereas each alone has a lower score. While it's not necessary to combine complementary proteins in every single meal, including a variety throughout the day works well. Still, pairing them in the same meal can be helpful, especially for seniors with smaller appetites, because it means they don't need to eat as much of each food to meet their nutritional needs [79].

While animal-based proteins tend to be higher in leucine (around 8–9% of their protein content), plant-based sources typically have a bit less (around 6–8%, depending on the food) [65]. On a vegan diet, it's possible to hit the target of around 2.5 grams of leucine per meal by opting for larger portions or selecting foods that are higher in protein. For example, a meal with 30 grams of protein from soy, like a big serving of tofu or a soy protein shake, usually contains about that much leucine. Similarly, a well-portioned dish made with lentils or beans, quinoa, and vegetables can offer 25 to 30 grams of protein, though older adults might need to eat a fairly large amount of food to reach that level [80].

To help meet protein and leucine needs without animal products, several strategies are recommended:

Use of Plant Protein Isolates and Concentrates:

Using plant-based protein powders, like soy protein isolate, pea protein, or blended vegan powders, is a convenient way to boost protein intake. These powders are made by extracting and concentrating protein from plant foods, resulting in products that are about 80–90% protein by weight. They're typically just as digestible as animal proteins and can be easily mixed into smoothies, oatmeal, or other dishes. One of the key benefits is that many vegan protein supplements combine different plant sources, such as pea and rice, to form a complete amino acid profile [73][76]. This approach mirrors the idea of complementary proteins, offering a more balanced range of essential amino acids than any single plant source on its own. For older adults with sarcopenia, who may find it hard to eat large meals, a plant protein shake can be an efficient way to get 20 to 30 grams of protein (including roughly 2 to 3 grams of leucine) in a small, easy-to-consume serving [80].

Fortified Foods and Leucine Supplementation:

Due to a lack of some amino acids in plants, adding specific amino acids to plant-based foods is a practical way to enhance the protein quality of a vegan diet, and can greatly increase their capacity to promote muscle growth [81][82]. For instance, adding extra L-leucine to a meal or supplement can help meet the threshold needed to trigger muscle protein synthesis, without needing to increase the total amount of protein consumed. Likewise, incorporating lysine or methionine into foods that are low in these nutrients, like fortified cereals or plant-based meat products, can help create a more balanced amino acid profile [82]. Some plant-based milks and breakfast cereals are already fortified with added protein or amino acids, making them convenient and beneficial options [76]. Additionally, specialised supplements such as leucine-enriched essential amino acid (EAA) blends have been studied for their role in managing sarcopenia. Research has shown that taking free leucine or EAA supplements with meals can enhance the muscle-building response in older adults, especially when the meal is lower in protein [76][83]. However, it's important to remember that leucine alone isn't a magic fix. It works best when combined with an overall balanced intake of protein and other nutrients [84].

Slightly Higher Protein Targets:

Slightly increasing protein intake can be a smart move for vegan older adults, since plant proteins tend to have a lower quality per gram compared to animal proteins. Nutrition experts suggest that those following a fully plant-based diet aim for about 30% more protein to make up for lower digestibility and amino acid availability. For instance, while an older adult eating an omnivorous diet might need around 1.2 grams of protein per kilogram of body weight each day to support muscle health, a vegan older adult might need closer to 1.3 to 1.5 grams per kilogram to see similar results [65].

This higher intake helps compensate for the fact that each gram of plant protein may be a bit less efficient in stimulating muscle protein synthesis (MPS). The good news is, research shows that when total protein intake is high enough and distributed through the day, people eating plant-based proteins can achieve muscle outcomes that are very close to those on diets with animal proteins. With careful planning and a focus on obtaining all essential amino acids, the type of protein—plant versus animal—becomes less important than ensuring adequate overall protein intake [76].

Besides protein, researchers have looked into a number of other nutrients and supplements that might help slow down muscle loss that comes with ageing. Vitamin D has attracted a lot of interest because it plays a role in muscle function through its interaction with muscle cells,

affecting things like how muscles rebuild, energy production in the cells, and ageing at the cellular level. People with low vitamin D levels often have less muscle and weaker performance [85]. Still, studies testing vitamin D supplements in older adults who live on their own have shown mixed results. When vitamin D levels are already normal, taking more doesn't usually lead to noticeable improvements in muscle strength or physical function [86].

Omega-3 fats, especially EPA and DHA, have also been highlighted for their muscle-protecting and inflammation-fighting properties. These healthy fats may reduce pathways that lead to muscle breakdown and help improve how cells create energy. Some research and summaries of multiple studies suggest that taking at least 2 grams per day of these omega-3s might slightly increase muscle mass and strength in older adults. However, larger and longer studies are still needed to see if these benefits truly hold up over time [85].

Creatine monohydrate is another well-researched supplement that can help muscles perform better during workouts by increasing their energy reserves. Studies show that when people add creatine to their strength-training routine, they usually gain more muscle and strength than with exercise alone. This is probably because creatine supports muscle repair and energy processes and may also help reduce muscle breakdown [87].

Antioxidant vitamins like C and E are also being looked at for their possible role in fighting the oxidative stress that may speed up age-related muscle loss. Higher amounts of these vitamins in the diet or blood have been linked to stronger muscles and better physical function. However, the outcomes of studies in which participants received large dosages of these vitamins have not been compelling. In fact, some research suggests that taking too many antioxidants might actually interfere with muscle growth from exercise [85].

Micronutrients that aid in maintaining nerve and muscle function, especially vitamin B12 and magnesium, are vital for the health of older adults. Vitamin B12 is important for keeping motor neurons healthy and supporting muscle metabolism. When B12 levels are low, it’s been linked to decreased muscle mass, weaker strength, and reduced physical ability in seniors. In fact, a long-term study found that older women who didn’t get enough B12 were more likely to develop sarcopenia over a two-year span, so it highlights how important this vitamin is [88].

Magnesium is just as vital, playing a central role in how muscles contract and how the body produces energy. Research has shown that older adults with lower magnesium intake often have weaker muscles and lower muscle quality [89]. A recent review even pointed to magnesium as one of the most consistently connected minerals to better muscle mass, stronger grip, and improved physical performance in ageing individuals [90]. During ageing for supporting muscle health, it’s important to make sure they’re getting enough of these nutrients, especially those on plant-based diets, who might be more prone to falling short on vitamin B12, vitamin

D, and creatine. A well-rounded diet or targeted supplements, when necessary, can work alongside higher protein intake to help maintain strength, mobility, and muscle mass over time [65].

3.3 Exercise Interventions for Sarcopenia

Another fundamental way to manage sarcopenia is physical activity, particularly resistance-based training [64]. Although ageing and inactivity lead to muscle deterioration, exercise helps counteract or even reverse this by promoting muscle growth, enhancing neuromuscular coordination, and boosting overall physical performance. Global guidelines for sarcopenia consistently endorse exercise as the primary treatment to build muscle mass, increase strength, and improve functional abilities [64][66]. This section explores the most effective types of exercise for combating sarcopenia, their physiological benefits, suggested routines for older adults, and the typical obstacles that may hinder participation in exercise among this group.

Resistance Training

Resistance (strength) training is widely regarded as a key strategy for managing sarcopenia due to its strong impact on muscle mass and strength [91]. Progressive resistance exercises help combat the natural loss of muscle fibres that comes with aging by promoting muscle growth and improving neuromuscular function. Leading guidelines, such as those from the International Conference on Sarcopenia and Frailty Research, recommend resistance training as the primary treatment for older adults dealing with or at risk of sarcopenia, often paired with sufficient protein intake to aid muscle building [91]. Recent reviews show that resistance training significantly boosts muscle strength and lean body mass in older adults, including those with chronic illnesses such as secondary sarcopenia [92]. Interestingly, strength improvements usually occur before noticeable muscle growth, and gains in mobility, like walking speed or the ability to stand from a chair, may require a longer commitment or a combination of exercise types [93]. Exercise plans for older adults should be personalised for maximum benefit, but they typically follow research-backed recommendations for frequency, intensity, and volume:

Frequency: Older adults are advised to perform resistance training at least twice a week, with rest days in between to allow for muscle recovery. Most effective programs include 2–3 sessions weekly over a period of three months or more to see noticeable progress. Being

consistent is essential because a lack of activity can reduce the benefits of training. Therefore, it's recommended to continue exercising even after completing an initial program [66].

Intensity: Beginners or individuals with frailty should start at a moderate intensity—around 50% of their one-repetition maximum (1RM)—and gradually increase to a moderate-to-high intensity (about 60–80% 1RM), based on their tolerance [66]. This progressive approach follows the overload principle, which ensures that muscles keep adapting as strength builds. Training within the 60–80% 1RM range (which feels like a 5 to 8 out of 10 effort) is generally effective for improving strength in older adults. For those capable of more intense efforts, lifting heavier loads (>80% 1RM) with fewer repetitions can lead to greater gains in muscle size and strength. Alternatively, using lighter weights (<50% 1RM) with more repetitions can enhance muscular endurance. While both methods are beneficial, research shows that heavier resistance training produces more significant improvements in muscle mass and power [66][91].

Volume (Sets/Repetitions): A standard resistance training program for older adults usually consists of 1 to 4 sets of 8 to 15 repetitions per exercise, focusing on the major muscle groups in both the upper and lower body. Compound, multi-joint exercises—such as leg presses, chest presses, rows, and squats—are especially beneficial because they activate larger muscle areas. Each workout often includes around 8 to 10 different exercises to provide a full-body stimulus. In the early stages, using lighter weights with more repetitions (e.g., 15 reps at 50% of one-rep max) can help build endurance and ensure proper technique. As strength increases, the weight can be increased to encourage even more strength development while the number of repetitions is decreased to the 8–12 range. Rest periods of 1 to 3 minutes between sets are commonly recommended to ensure adequate recovery, especially when working at higher intensities [66].

Progression and Safety: To keep improving, progressive overload should be applied —this means increasing the weight (typically by about 5%) once a set becomes easy at the target rep range. To lower the risk of injury, proper form and supervision are crucial, especially for beginners or fragile older adults. With appropriate guidance, even individuals in their 80s and 90s can safely perform strength exercises and make meaningful improvements in muscle strength and daily function [66]. Modifications like using resistance machines, resistance bands, or chair-assisted movements can help those with joint issues or balance limitations get started safely. over time, gradually moving to free weights or heavier resistance can bring even better results. In fact, research shows that traditional weight training often leads to more strength gains than using resistance bands [92]. If someone has joint pain or orthopaedic problems and can't manage heavy lifting, low-load blood flow restriction training is an option. This technique uses

very light weights (about 20–30% of max) while gently limiting blood flow to the working muscles. It's been found to help build strength and muscle without the strain of heavy loads. Still, it's important to do this under the supervision of a trained professional [66].

Power Training: In addition to traditional slow-velocity strength training, older adults are increasingly turning to power training, which uses lighter to moderate weights to perform movements more quickly. This is because muscle power, or the ability to produce force rapidly, tends to decline faster with age than overall strength. This decline affects everyday tasks like preventing a fall or getting up from a chair. Training that focuses on speed, such as quickly but safely standing up from a squat or rapidly lifting a weight, can specifically enhance muscle power. Research indicates that, compared to conventional strength training, high-speed power exercises may lead to greater improvements in functional abilities like timed chair stands, stair climbing, and balance. Therefore, once a foundational level of strength is in place, adding some faster-paced movements (with lighter weights to ensure proper form) can be especially beneficial for improving everyday physical function [94].

A comprehensive network meta-analysis from 2023 even found that routines mixing resistance training with balance or aerobic exercises worked better than those relying on aerobic workouts or nutrition alone. These findings highlight how essential resistance training is for staying strong and independent with age, while other forms of exercise offer added benefits for endurance and stability, rounding out a well-balanced approach to aging healthfully [93].

Aerobic and Other Exercises

While resistance training is vital for maintaining muscle health, aerobic exercise and other types of physical activity offer important complementary benefits for preventing and managing sarcopenia. Although aerobic (endurance) exercise alone typically doesn't result in major increases in muscle mass, it can boost cardiovascular fitness, enhance muscle oxygen uptake, and promote fat metabolism. For older adults dealing with sarcopenia, incorporating aerobic training can enhance overall functional ability and improve performance in everyday activities that require ongoing effort. For example, aerobic fitness can help reduce tiredness during activities like walking or climbing stairs, and it can also increase exercise tolerance, making it easier for individuals to take part in more intense resistance training or enjoy recreational physical activities [66]. Endurance exercise leads to changes in skeletal muscle that work in harmony with strength improvements. It boosts mitochondrial function and increases the number of capillaries in muscle fibres, which enhances muscle endurance and helps reduce

fatigue. Aerobic exercise also improves body composition by lowering fat levels, including fat that may build up in muscles, thereby enhancing muscle quality. Just as importantly, regular aerobic activity promotes cardiovascular and metabolic health by reducing heart disease risk factors, improving how the body responds to insulin, and increasing blood circulation. These combined effects create a more favourable internal environment that may help slow down the progression of sarcopenia [66]. Research also shows that high-intensity interval training (HIIT), when customised to suit an individual's fitness level, can significantly increase fitness in older adults. One study found that HIIT improved insulin sensitivity, aerobic fitness, and even lean muscle mass in older individuals, partly by activating genes that support mitochondrial function. These insights emphasise that ageing muscles still have a strong ability to adapt to endurance training [66].

For older adults, including those with sarcopenia, general guidelines recommend getting 150 to 300 minutes of moderate-intensity aerobic exercise per week, or 75 to 150 minutes of vigorous activity, or a mix of both [95]. This typically works out to about 30 minutes of moderate exercise on most days. Specifically for sarcopenia, an expert panel recently suggested aiming for about 30 minutes of aerobic activity a day, at least three times a week, over a period of three to five months to see meaningful improvements [66]. The choice can be based on personal preference and physical ability, with options such as brisk walking, biking, swimming, water aerobics, dancing, or group fitness classes. It's advisable to begin with shorter, lower-intensity sessions for beginners or people with lower fitness levels, such as walking slowly for ten to fifteen minutes, and then progressively increasing the length and intensity [66]. Exercise intensity can be monitored by heart rate or how hard the effort feels. A good starting point might be around 40% of one's maximum heart rate (a light effort), with a gradual build-up to 50–70% (moderate intensity) over time [66]. If they're able, older adults can also benefit from adding some higher-intensity intervals, over 70% of max heart rate, under proper supervision to encourage greater cardiovascular and muscular gains. The most important principle is slow, steady progress, ensuring that endurance increases without causing too much fatigue or increasing the risk of injury [66].

Aerobic training not only enhances endurance and heart health but also works best when combined with resistance training, according to clinical evidence. A meta-analysis of 42 randomised controlled trials found that combining resistance and aerobic exercises, often along with balance training, resulted in greater improvements in physical performance (like walking speed and the ability to rise from a chair) and quality of life compared to resistance training alone [93]. Aerobic exercise essentially 'primes' the body by strengthening the heart and improving oxygen delivery, which helps individuals train their muscles more effectively and

stay active longer during the day [95]. Additionally, endurance activities burn calories and assist in managing body weight, which can indirectly support sarcopenia management by reducing inflammation linked to obesity and minimising stress on the joints during movement. Beyond aerobic workouts, several additional forms of exercise play a key role in managing sarcopenia, especially in improving functional abilities that go beyond just muscle strength [93].

Balance and Stability Training:

Sarcopenia is strongly associated with reduced balance and an increased risk of falls, so balance exercises should be combined with fitness routines for older adults [66]. Engaging in activities that challenge balance and coordination, such as standing on one leg, tandem walking (walking heel-to-toe in a straight line), walking backwards, or practising structured exercises like Tai Chi, should be done at least two to three times per week. In fact, some experts recommend doing balance exercises at least three times a week to effectively lower fall risk in people with sarcopenia [66]. These exercises usually involve slow, deliberate movements and can be included in a warm-up or cool-down routine. Tai Chi and yoga, for instance, have been shown to improve balance and body awareness in older adults, while also increasing flexibility and leg strength. Good balance can build confidence in movement, encouraging seniors to stay active without fear. In fact, a randomised study found that individuals aged 80 to 99 who participated in a 12-week program combining balance and resistance exercises experienced significant gains in their ability to live independently, as measured by their daily activity scores. Although balance exercises don’t directly increase muscle mass, they are essential for enhancing the real-world effectiveness of both strength and aerobic training [66].

Flexibility and Mobility:

It is a key for older adults to maintain full joint range of motion, good posture, and the ability to perform everyday actions like bending or reaching. Stretching keeps their joints and connective tissues in good condition, which makes movement easier, even though it doesn't directly increase muscle mass or strength. Experts generally suggest that older adults stretch at least twice a week, focusing on big muscle groups like the calves, hamstrings, hips, chest, and shoulders [96]. A typical stretch lasts about 20 to 30 seconds and should be repeated 2 to 4 times for each muscle group, ideally after warming up a bit or at the end of a workout when their muscles are already warm. Regular stretching can help reduce stiffness, improve posture (for example, tight chest muscles and weak upper-back muscles often contribute to a hunched posture in some seniors), and may even help prevent injuries during other exercises. Programs that blend balance and flexibility, like senior-friendly yoga or Pilates, can also strengthen their

core and improve their sense of balance, which helps prevent falls and keeps them moving more confidently day to day [96].

Functional and Neuromotor Exercises:

These exercises are designed to mimic daily activities to improve agility, coordination, and reaction time [93]. For instance, doing sit-to-stand exercises helps practice getting up from a chair, step-ups are similar to climbing stairs, carrying groceries mimics walking with weight, and navigating obstacles boosts the ability to move through spaces. This kind of workout blends strength, balance, and cardio in a way that directly benefits daily life [93]. Neuromotor exercises, sometimes referred to as motor skill training, engage the brain and body. They include activities like navigating around cones, catching a ball, or dual-task exercises that combine physical and cognitive elements [97]. Doing functional exercises once or twice a week can help older adults apply their strength and cardio improvements to better handle daily tasks (Activities of Daily Living (ADLs)), which is a major goal in managing sarcopenia. In fact, exercise programs that combine strength, endurance, and functional mobility exercises have been shown to improve overall physical performance in older adults who are frail [93].

The best approach to managing sarcopenia is to incorporate a variety of physical activities into a well-rounded exercise program. Resistance training is at the core because it helps build muscle strength and mass. However, other forms of exercise also play key roles: aerobic workouts improve stamina and heart health, balance exercises help prevent falls, flexibility routines keep joints moving freely, and functional training supports the ability to handle everyday tasks. combining these different types of exercise makes workouts more interesting, also helps keep older adults motivated to stick with them over time [66]. A varied routine can target many aspects of fitness, which can lead to better overall independence. Plus, these programs can be customized to fit individual needs—for example, someone might begin with gentle aerobics and seated strength training, then move on to more active forms like walking or standing exercises as they grow more confident. The main takeaway from recent research is that doing some form of physical activity is far better than doing none at all. The most effective exercise plan is one that an older adult can do safely, enjoys, and is willing to keep up with. All areas—strength, endurance, balance, and flexibility—play a part in helping maintain function and avoid the decline that comes with sarcopenia [66].

3.4 Barriers to Physical Activity in Older Adults:

Although exercise is widely known to help fight sarcopenia, many older adults still struggle to stay active. To create effective ways to support seniors in starting and sticking with exercise routines, it's important to understand what's getting in the way. These challenges are often complex, involving physical health issues, psychological obstacles, lack of social support, and environmental factors [98].

Common barriers include:

Health-related challenges:

Ongoing medical issues and physical limitations are some of the main reasons older adults avoid exercise. Being active can be difficult for people with conditions like arthritis, mobility issues, heart or lung disease-related breathing issues, and simply feeling exhausted. For those already dealing with sarcopenia, these challenges are even more intense. Joint pain or the fear of making an existing problem, like osteoporosis or a past injury, worse can stop someone from trying strength exercises [98]. Many older adults also worry about falling, especially if they feel unsteady or don't have someone around to help. These fears are understandable and can seriously affect a person's confidence in exercising. In fact, a study found that frail seniors often see themselves as "unable" to exercise because of things like arthritis, vision problems, or recent health setbacks. And for those juggling multiple health conditions, it can be even harder to find the energy or manage exercise around complex medication routines [98].

Psychological and motivational barriers:

Staying motivated is key to keeping up with exercise, but many older adults struggle with this. According to one survey, almost half of the participants said that their inability to stay active was due to a lack of motivation or simply a sense of laziness [99]. Some people don't like exercising or think that "muscle loss is just a natural part of ageing, so what's the point?" Others might feel anxious or lack confidence, especially if they've never had a regular workout routine. The idea of going to a gym or not knowing where to start can be overwhelming and lead to putting it off. Mental health factors like forgetfulness or depression can also sap the drive to be active. What someone believes really matters. If they think exercise won't help or feel they're simply too old or weak, they're unlikely to try. Tackling these mental roadblocks often involves educating people about the real benefits of exercise and helping them have good, confidence-building experiences with physical activity [99].

Social support and societal barriers:

Whether or not older adults have support from family, friends, or healthcare professionals can make a big difference in their willingness to exercise. Many seniors are more likely to stay active if someone encourages them or joins in. On the flip side, a lack of support, like having no workout partner or family members who worry and discourage activity, can be a major obstacle [98]. But social connections can also be a big help. Group classes designed for older adults often work well because they mix exercise with socialising, turning it into an enjoyable community event. Cultural attitudes matter too. In some cultures, especially among older women, going to the gym or exercising in public might feel inappropriate or unfamiliar [99]. They may not have many active older role models to look up to, which can make it harder to imagine themselves being physically active. Another obstacle is the role of healthcare providers; when physicians or physiotherapists don't bring up the importance of exercise or offer clear guidance, it can leave seniors feeling uncertain or unsupported in getting started [98][99].

Environmental and logistical barriers:

Everyday challenges can make it tough for older adults to stay active. Something as simple as not having easy access to a nearby gym, community centre, or safe park can be a real barrier. And for those who don't drive or have limited transportation, even getting to a fitness class can feel like an impossible task. Weather can also be a major hurdle. If it's too hot, cold, or rainy, going outside to exercise becomes difficult, especially for those who rely on walking as their main form of activity. Safety is another big concern. If the neighbourhood has heavy traffic, uneven sidewalks, or isn't considered safe, people are understandably hesitant to go out for a walk or jog. Then there's the cost of joining a gym or buying equipment isn't always affordable, and not everyone has space at home to work out comfortably [99]. Time can still be a significant barrier to physical activity for older adults, even in retirement. Although retirement is often assumed to bring more free time, many older adults report that their days are filled with other commitments, routines, or competing priorities. In some cases, physical activity is simply not viewed as urgent or necessary compared to other daily tasks. Additionally, the perception of being too busy—even when time is technically available—can lead to low prioritization of exercise. This highlights the importance of addressing not only time availability, but also how older adults value and structure their time throughout the day [100]. It's important to understand that these barriers don't exist in isolation. They often overlap and feed into each other. For example, someone dealing with pain or low energy from health problems might also feel

unmotivated or find exercise unpleasant. If they also lack support or don't know how to exercise safely, it becomes even harder to get started. The result is a vicious cycle: physical inactivity can worsen health and further decrease confidence and motivation, leading to greater sarcopenia and frailty [98].

Addressing barriers:

An evidence-based approach to overcoming these obstacles involves a combination of education, support, and environmental modifications. Studies indicate that older adults are willing to engage in exercise if barriers are reduced and appropriate support is provided [98]. Some effective strategies include:

Tailoring Programs:

Exercise routines for older adults should be designed with common health concerns in mind. For people with arthritis or balance problems, chair-based or low-impact options are a great way to start. These programs can start gently and become more challenging as a person's confidence and ability grow. Because each activity is tailored to the individual's health and physical condition, this individualised approach helps reduce the fear of injury [101].

Professional Guidance and Education:

Having trained professionals, like physiotherapists or certified senior fitness trainers, lead sessions or offer one-on-one support can make a big difference. They help ensure exercises are done safely and correctly, which builds trust and reduces the chance of injury. Education is just as important. When older adults understand how exercise strengthens their muscles, helps them stay independent, and that it's never too late to start, they're often more motivated. Breaking down myths about aging and showing how resistance training can improve daily life really helps. Setting personal goals and tracking progress—like walking farther or getting stronger—can also encourage people to stick with it [98].

Social and Motivational Supports:

Incorporating social aspects into physical activity can turn it from a task into a fun experience. Participating in group workouts, joining walking clubs, or partnering with a workout buddy of a similar age can foster a sense of community and accountability. Older adults often feel motivated by not wanting to disappoint their peers or simply enjoying conversations before and after the sessions. Support from family is also important – teaching family members to support rather than hinder physical activity (like assisting an elderly relative in getting to a class or

exercising together) can help eliminate obstacles. Furthermore, healthcare professionals should promote exercise: a clear recommendation from a doctor to "stay active to maintain muscle strength" can reinforce the value of exercise and encourage action. Programs tailored for older adults (such as Senior Fitness classes or walking groups in malls) help create a friendly environment where it's normal to see peers staying active [102].

Environmental and Policy Interventions: Communities can help eliminate environmental obstacles by providing safe and accessible areas where older adults can stay active. This might involve keeping sidewalks in good condition, placing benches along walking routes for resting, offering indoor spaces for exercise during extreme weather, and potentially subsidizing programs to lower financial barriers. In some areas, local governments provide free or low-cost fitness classes for seniors at community centers, making physical activity more affordable and reachable. On a personal level, having basic workout gear at home—like resistance bands or light weights—and instructions on using them can support those who have difficulty getting out. Within the home, breaking up long periods of sitting—such as getting up to walk around each hour—can help address the issue of being too sedentary. Time-saving techniques, like incorporating movement into everyday tasks (e.g., stretching during TV shows or doing sit-to-stands after meals), can help manage the common excuse of not having enough time [103].
Therefore, there are actual obstacles to physical activity among older adults, but they can be overcome. Recognising challenges such as health issues, fear, limited knowledge, and environmental hurdles, targeted interventions can be developed to address these specific problems. Overcoming inactivity is particularly important for people with sarcopenia or frailty, as they stand to benefit the most from regular exercise in terms of maintaining their independence. Fortunately, both research and real-world experiences show that older adults are often open to participating in physical activity when they receive the right kind of support, when the exercises are safe, easy to access, and viewed as meaningful. Overcoming these obstacles plays a vital role in managing sarcopenia, allowing more seniors to engage in the types of activities that support muscle health. As part of a thorough plan to prevent or treat sarcopenia, healthcare providers and caregivers should identify and address each person’s specific barriers to being active, working together to create an environment where exercise is both practical and enjoyable for older individuals [98].

3.5 Synergistic Effects of Nutrition and Exercise

Addressing sarcopenia is more effective when targeted nutrition is paired with exercise rather than using either method on its own. An expanding body of research indicates that older adults see greater enhancements in muscle strength, size, and functional ability when nutritional interventions support their exercise routines [104][105]. For example, a randomized trial with older women suffering from sarcopenia compared different groups: those undergoing resistance training combined with essential amino acids (EAA), those doing exercise alone, those receiving nutrition alone, and a control group. Meaningful gains in leg muscle mass, walking speed, and particularly knee extension strength (about a 9% increase) were observed only in the group receiving both exercise and amino acids. The researchers concluded that this combined strategy was superior in improving muscle strength, mass, and overall functional performance [104]. Further support for this dual approach comes from several meta-analyses. A 2022 network meta-analysis determined that interventions combining physical activity with nutritional supplementation were the most effective at improving muscle-related outcomes in individuals with sarcopenia, outperforming exercise-only strategies [105]. Likewise, another meta-analysis of 12 clinical trials concluded that resistance training, when paired with nutritional supplements—particularly protein and vitamin D—resulted in more pronounced gains in grip strength and walking speed compared to resistance training alone [106]. In addition, the absence of adequate nutrition during exercise can hinder muscle development in older adults. In one investigation, frail older adults participated in a 24-week resistance training regimen. Those who incorporated additional protein into their diet saw a gain of roughly 1.3 kilograms in lean muscle mass. In contrast, individuals who exercised without any nutritional supplementation experienced no notable increase in muscle mass. The study's authors stressed the importance of dietary protein as a vital element in facilitating muscle development during physical training in this age group [22]. These results show that nutrition and exercise when are used together can be more effectively counteract the age-associated phenomenon known as 'anabolic resistance' by delivering both the necessary exercise stimulus and the nutritional building blocks and signals essential for muscle development [22][107].

Carbohydrates: Glycogen Replenishment and Anabolic Energy

Although protein often takes the spotlight in discussions about sarcopenia, getting enough carbohydrates is a vital , and sometimes overlooked , part of the nutrition and exercise equation for older adults. Carbs are the body’s main energy source during high-intensity and resistance

training, and eating them after exercise is crucial for restoring muscle glycogen. In older adults, low glycogen levels can quickly sap energy, limit workout intensity, and lead to quicker fatigue. Research shows that how much glycogen people have after training plays a major role in how well they can perform during their next session. Especially when recovery time is short, their carbohydrate intake largely determines how fully their muscles can refuel and how ready they will be to go again. For older adults with sarcopenia who often engage in functional training or physical therapy, eating a carb-rich recovery meal can significantly boost workout performance and help maintain consistency [108].

Carbohydrates also support muscle growth by supplying the energy needed for the body's anabolic, or muscle-building, processes. Building muscle requires a lot of energy, and when that energy is lacking, the body may start burning amino acids for fuel instead of using them to build muscle tissue. Getting enough carbs helps preserve protein so it can be used for muscle repair and growth. Plus, eating carbs stimulates insulin production, and insulin, when combined with protein, creates a strong muscle-building environment. Insulin is a powerful hormone that reduces muscle breakdown and helps shuttle amino acids into muscle cells. In younger people, adding a lot of carbs to a protein-rich meal might not further boost muscle protein synthesis (MPS) if the protein alone is already doing the job. However, for older adults, who often have reduced insulin sensitivity, eating carbs with protein can make a real difference [109]. Insulin doesn't just help move nutrients into muscle after exercise, it also protects muscle from breaking down. From a practical standpoint, older adults should include some carbohydrates in their post-workout nutrition, like fruit, whole grains, or even a simple carb source in a recovery drink with protein. This combination helps create the energy- and insulin-rich environment the body needs to build muscle effectively. In fact, research underscores that having enough energy (especially from carbs) and insulin is just as important as protein and exercise when it comes to building and maintaining muscle [107].

Dietary Fats: Hormonal Support, Membrane Health, and Inflammation Modulation

Another essential macronutrient in the synergy equation is dietary fat. It plays a key role in maintaining hormonal balance, supporting cell function, and managing inflammation, which are critical for muscle preservation. Regarding fat consumption and anabolic hormones, it's crucial to remember that lipids and cholesterol are the source of many hormones involved in muscle regulation. Testosterone is a prime example that it's an anabolic hormone made from cholesterol that's vital for muscle protein synthesis and maintenance. In muscle tissue, testosterone not only boosts protein synthesis but also reduces protein breakdown [107]. A diet

that's too low in fat or cholesterol, especially for older adults, may hinder the body's natural production of testosterone and similar hormones. Studies in middle-aged men show that reducing dietary fat, particularly saturated and monounsaturated fats, can lead to a drop in testosterone levels, while moderate intake of quality fats supports healthier hormone profiles [110]. This means that for older men and women, getting enough fat in the diet is important to sustain hormone production, which in turn affects how well they adapt to strength training. Supporting testosterone levels is essential to enhancing the muscle's response to resistance exercise. It's also why nutrition and training complement each other so well: resistance workouts can temporarily raise testosterone in muscles, and with enough nutritional support, fats for hormone production, protein for muscle repair, these hormonal changes can lead to greater muscle growth [107] [110].

Beyond hormones, fatty acids – especially polyunsaturated fats – are integral to muscle cell membrane composition and function. Omega-3 fats like EPA and DHA, which are long-chain fatty acids, become part of cell membranes, helping to improve their fluidity and making cell signalling more efficient. By improving the health of muscle cell membranes, insulin sensitivity may increase, allowing muscles to take in nutrients more effectively. In addition, these fatty acids act as the foundation for eicosanoids — anti-inflammatory compounds that help fight off the persistent, low-level inflammation often present in older adults [21].

This highlights another key role of dietary fat: managing inflammation. Sarcopenia is frequently associated with elevated levels of inflammatory markers such as IL-6 and TNF-α, which speed up the breakdown of muscle protein and also disrupt the body's capacity to generate new muscle. Both nutrition and exercise have the power to influence this inflammatory state [111]. Regular resistance training helps reduce the persistent inflammation tied to ageing, and diets rich in unsaturated fats, such as those following a Mediterranean-style approach with olive oil, nuts, and fatty fish, have strong anti-inflammatory effects. These strategies can become even more effective when used together [112]. Older adults participated in a 12-week strength training program in a clinical trial; some were given an omega-3-rich supplement (ALA), while others were not. The group that took ALA experienced a significant drop in IL-6 levels and a clear increase in thigh muscle size, improvements that weren't observed in the non-supplement group. This indicates that an anti-inflammatory diet may enhance the muscle-building benefits of exercise by minimising inflammation-related damage. A significant finding of that study is that healthy fats and nutrient-dense foods help reduce chronic inflammation while improving the environment for muscle growth and repair, although specifics such as gender differences still require further research [112]. Ultimately, eating enough high-quality fats supports the hormonal and cellular systems that drive muscle development, while also defending against

muscle loss from inflammation. When this is combined with resistance training, which itself boosts muscle-building hormones and releases anti-inflammatory molecules, the result is a powerful, synergistic approach to preserving and strengthening muscle in older adults [112].

Hormonal and Molecular Responses to Nutrition+Exercise Synergy

At the physiological level, combining nutrition and exercise activates hormonal and molecular pathways that work together to fight sarcopenia. Resistance training acts as a powerful trigger for muscle growth by turning on mTOR and other pathways tied to hypertrophy, and it also has an impact on the endocrine system. In younger individuals, it was once believed that the spikes in anabolic hormones like testosterone and growth hormone right after exercise were the main drivers of muscle gain [107]. However, newer research points to local muscle factors as the dominant force. That said, in older adults, the overall hormonal environment still matters a lot for building muscle. Growth hormone, IGF-1, and testosterone levels decrease with age, but catabolic influences tend to increase. This balance can be shifted through a mix of exercise and nutrition. Resistance training, when done consistently over time, raises IGF-1 levels inside the muscle and boosts how sensitive muscles are to hormones such as insulin. On the nutrition side, eating carbs and protein triggers insulin release and supplies amino acids that activate mTOR and kickstart muscle protein synthesis. Insulin and amino acids work best when combined; insulin enhances protein synthesis when amino acids are present, and also cuts down on protein breakdown. This double action magnifies the muscle's response to the signals triggered by exercise. A review on anabolic resistance notes that gaining muscle isn't just about exercise and amino acids; it also depends on energy levels, hormone availability, and how well blood is flowing through muscle tissue [107]. These factors all improve when exercise and nutrition are used together. During a workout, blood flow to muscles increases significantly, and if nutrients are circulating in the blood at that time, the muscles are ready to absorb them.

That's why eating protein and other nutrients close to workout time can greatly enhance muscle protein synthesis in both young and older adults. Studies consistently show that combining resistance training with essential amino acid intake results in more muscle growth than either approach on its own, across all age groups. In practical terms, exercise delivers the stimulus and boosts circulation, while nutrition supplies the raw materials and hormonal support, together, they create the optimal hormonal and molecular environment for building muscle [113]. A clear example of hormonal synergy is insulin-like growth factor 1 (IGF-1), which gets a boost from both resistance training and protein intake. Exercise stimulates IGF-1 production in the muscles, and following it up with amino acids or protein further activates the IGF-

1/Akt/mTOR pathway, which drives protein synthesis [107]. Testosterone functions in a similar manner, its impact is heightened when paired with good nutrition. Studies now show that testosterone plays a vital role in promoting muscle growth following resistance training by increasing satellite cell activity and stimulating the mTOR pathway [113].

But for testosterone to work optimally and to aid muscle repair, the body needs enough dietary fat and protein. This is where nutrition becomes essential, supplying the body with the necessary building blocks so hormones like IGF-1, insulin, and testosterone can effectively stimulate muscle growth [110]. This becomes especially crucial for older adults, who often experience lower levels or reduced sensitivity to anabolic hormones. For them, combining a structured resistance training routine with smart dietary strategies, such as consuming more protein and ensuring enough calories and fat to support hormone production, can either raise hormone levels or make them function better [107]. Over time, this integrated approach can help shift the hormonal and molecular environment back toward muscle growth or at least help preserve existing muscle [107][113].

Nutrient Timing:

When it comes to achieving synergy in fitness, timing plays a key role. The idea of an 'anabolic window of opportunity' suggests that muscles are especially receptive to nutrients right after exercise. While newer research shows that this window is longer and more flexible than the old 30-minute rule, getting protein and carbohydrates soon after a workout still matters, especially for older adults. As we get older, our muscles become less responsive to nutrients, making it even more important to eat regularly and at the right times to benefit from exercise fully [114]. During the 48 hours following a workout, muscles are busy repairing and building. However, the benefits of training may be diminished if people skip meals for an extended period of time during this window. For example, if an elderly person works out in the afternoon and then skips dinner, the prolonged overnight fast may cause more muscle breakdown than muscle growth, On the other hand, eating protein every few waking hours and having a meal that contains both carbohydrates and protein shortly after exercise promotes muscle growth and recovery during this crucial time [114].

Exercise creates a favourable environment for nutrient absorption. Even in the absence of insulin, muscle contraction improves glucose absorption by increasing blood flow and activating GLUT4 transporters. Muscles also become more insulin-sensitive after exercise, which means that post-meal insulin can carry nutrients into muscle cells more efficientl. Eating the right kind of nutrition at night—like a protein high in casein—on training days can also

prevent overnight muscle loss, making the most of the extended muscle-building window that ageing bodies experience [114].

Chapter 4: Practical Applications

4.1 Personalised Approaches to Diet and Fitness

Older adults dealing with sarcopenia see the best results when their nutrition and exercise plans are tailored to their specific needs, preferences, and health conditions. A generic, one-size-fits-all approach often misses the mark because seniors vary widely in their lifestyles, medical histories, and physical abilities. Personalised meal plans are particularly important. According to research, tailoring calorie and protein intake to a person's specific profile can improve results, particularly for those who are malnourished or already losing muscle [115].

Exercise routines should also be personalised. Expert recommendations emphasise the need to factor in a person’s health status, such as how advanced their sarcopenia is, as well as what types of physical activity they enjoy and can safely perform. This might mean tweaking the type, intensity, and frequency of exercises to fit their situation. In practical terms, this means that when designing a plan, consideration should be given to factors such as appetite, dental health, other medical conditions, and general physical ability. Helping older adults maintain their strength, mobility, and quality of life will be more successful with a more customised approach [66].

Appetite and Dietary Tolerance:

Many older adults naturally experience a reduced appetite, often referred to as the 'anorexia of ageing'. which can make it challenging to eat enough food [116]. This issue can be further complicated by medications or health conditions like depression, leading to lower intake of calories and protein. So it’s so important to create personalised nutrition plans that focus on smaller, more calorie- and protein-packed meals and snacks, offering plenty of nourishment without requiring large portions.

Interestingly, increasing protein intake to around 1.2 grams per kilogram of body weight doesn’t appear to curb appetite in older adults, so it’s a safe and effective strategy for supporting their nutritional needs. A six-month study showed that bumping protein intake from the usual 0.8 to 1.2 g/kg/day didn’t negatively affect appetite or oral health [117]. This means that with the right support, older adults can safely follow a higher-protein diet.

Dietitians can feel confident in recommending more protein for those with sarcopenia, while keeping an eye on how full patients feel and any digestive discomfort. The type and texture of protein also matter. For individuals with dental issues or trouble chewing, softer protein options—like dairy, eggs, tofu, or ground and slow-cooked meats—are excellent choices.
Nearly half of the people over 75 have lost many of their natural teeth and may use dentures or have no teeth at all. This makes chewing and swallowing difficult. Poor oral health has been linked to lower protein and vegetable intake, while good dental health is associated with better nutrition. A well-personalised nutrition plan should always consider dental status. Offering tender foods, soft fish, or blended protein smoothies can ensure seniors get the nutrition they need, even if chewing is a challenge [118].

Comorbidities and Health Status:

Medical conditions should always shape how a diet and exercise plan is designed. For example, an older adult with diabetes may need to keep a close eye on their carbohydrate intake while still making sure they get enough protein. Someone with high blood pressure might need to watch their sodium intake, even as they include more protein-rich foods like dairy or meat in their meals. If chronic kidney disease is present, a high-protein diet might not be safe. But unless the kidney function is seriously compromised, most older adults with long-term illnesses can handle 1.2 to 1.5 grams of protein per kilogram of body weight per day—much more than the standard 0.8 g/kg often recommended for younger people [119]. This higher protein level is especially helpful for seniors with sarcopenia, particularly after an illness or hospital stay, as long as their kidneys are working properly.To keep things safe and effective, it’s important to take a personalised approach—this means checking in with their doctor and reviewing lab results to determine the right protein intake for their specific situation. Other health issues, like arthritis or heart disease, can also shape the best kind of exercise. For example, someone with osteoarthritis might find water aerobics more comfortable than jogging, while someone with balance problems could benefit from seated or supported movements [119].

Physical Capacity and Preferences:

Different older adults are affected by sarcopenia; some may still be able to manage moderate exercise at the gym, while others may be more fragile and require a more gentle, rehabilitation-focused approach. Therefore, exercise plans should include a variety of strength training, cardiovascular, balance, and flexibility exercises, all of which should be customised to the individual's present level of ability [64][66]. For someone with a significant weakness, starting with light resistance exercises, like using resistance bands or body weight, can help build

strength safely without risking injury. when they are stronger than before, the intensity can be gradually increased to build muscle and improve function. It's important to focus on activities and the person's interests. An older adult who doesn't like the gym may be more likely to stick with a walking group or dance class, while someone else might thrive with a structured weight-training routine. Personalising the activity to match someone's preferences and abilities not only makes the plan safer, it also makes it more enjoyable and sustainable over time [66].

Key Considerations for Personalisation:

It's critical to use the appropriate tools and strategies to comprehend each person's specific needs when developing diet and exercise plans for older adults. Regular sarcopenia screening, whether in a community or clinic setting, is an excellent place to start [120]. This helps determine how serious the condition is and sets the stage for appropriate goals. Nutritional screening is just as important. Tools like the Mini Nutritional Assessment can uncover issues such as unintentional weight loss, low appetite, or specific nutrient gaps. This allows care teams to tailor interventions—like recommending calorie-dense supplements for weight loss or increasing protein intake if muscle mass is low.

Working with specialists is also key. Meeting with a dietitian can help develop a nutrition plan that fits the individual's preferences, cultural background, and tolerance for different foods. Also physical therapists or exercise professionals can design movement routines that match a person's ability. If balance is an issue, the focus might be on preventing falls. If certain muscles are weak, resistance training can be customized to build them up. And personalization doesn't stop after the first plan is made—it's a continuous process. If someone feels too tired, the schedule can be adjusted. If appetite drops or a supplement causes digestive issues, the meal plan can be changed. Ongoing tweaks help ensure that the program continues to meet the person's needs over time [121]. Innovative opportunities for individualised care are being made possible by new technologies. For instance, 3D food printing is a potential method of producing personalised meals for elderly people with particular dietary requirements. This innovation makes it possible to produce foods with customised nutrient content and modified textures, making meals more appealing and easier to eat, especially for those who need soft or pureed foods.

For instance, an older adult dealing with both sarcopenia and swallowing difficulties (dysphagia) might benefit from high-protein meals made through 3D printing that are also easy to chew and swallow [122]. In the realm of physical activity, virtual reality and interactive video game systems are being tested as fun and engaging ways for seniors to exercise. These tools may help boost motivation and make it easier to stick with a fitness routine. Although these

technologies are still under study, they highlight a broader truth: personalising care sometimes means thinking outside the box. Whether it's through tailored meals or creative ways to stay active, the goal is to meet each person's unique needs [123].

Ultimately, personalised plans treat older adults as individuals with their own set of challenges, like low appetite, dental issues, or chronic health conditions, and their own strengths, such as motivation, family support, and personal goals. These factors all come together to shape the most effective approach for managing sarcopenia [124].

4.2 Weekly Meal Plans

This section offers two sample 7-day meal plans designed for older adults with sarcopenia to support the practical application of nutritional guidelines. One plan includes a variety of protein sources, including both animal-based (like poultry, fish, eggs, and dairy) and plant-based proteins (such as legumes, soy, and nuts). The second plan is completely vegan. Both are structured to meet the higher protein needs of this age group. The average daily protein intake is 90–100 grams (approximately 1.3 g/kg/day) for a person weighing 75 kg, which supports both muscle maintenance and potential muscle gain. An essential goal of these plans is to spread protein intake evenly across all meals, rather than concentrating it at dinner [119].

The meals are nutrient-rich, supplying enough carbohydrates for energy and a wide variety of fruits and vegetables for essential vitamins, minerals, and fibre. Practical considerations are also included, such as providing easy-to-chew protein options and adding flavour with herbs and spices (to prevent older adults' decreased taste sensitivity) [119]. Convenience is also a key factor: meals are simple to prepare, can often be made ahead, and leftovers are sometimes reused to cut down on daily cooking [125].

Sample 7-Day Meal Plan – Mixed Protein Sources (Animal + Plant):

This meal plan blends lean animal proteins with plant-based ones to ensure a complete amino acid profile. Each day is carefully structured based on evidence-based guidelines to help older adults meet their protein goals with an even distribution across meals [16][125][126][127][128][129][130].

Day 1:

Breakfast: Oatmeal prepared with milk, topped with crushed walnuts, banana and low-fat Greek yogurt.

Lunch: Grilled chicken breast (served in a smaller portion for easier chewing) served over quinoa and steamed vegetables.
Afternoon snack: Low-fat Greek yogurt with 1 tbsp chia seeds and honey
Dinner: Oven-baked salmon fillet with mashed sweet potatoes and sautéed spinach
Evening Snack (before bed): Warm milk or a small protein shake before bed to boost protein intake and aid overnight muscle protein synthesis.

Day 2 (Resistance exercise day):
Breakfast: Veggie omelette with cheese and whole-grain toast.
Lunch: Lean ground turkey stew with beans and mixed vegetables, served with brown rice.
Post-exercise Snack: Whey protein shake with banana
Dinner: Lentil soup (soft texture, high in protein) with green salad and cottage cheese.
Evening Snack: Warm milk or low-fat Greek yogurt before bed

Day 3:
Breakfast: Low-fat Greek yogurt parfait layered with berries and oats.
Lunch: Tuna pasta (using canned tuna for softness) on whole-grain pasta with tomato puree and olives, side of rainbow salad
Afternoon snack: A handful of almonds and a piece of fruit
Dinner: Tofu salad: cooked tofu, vegetables and boiled chickpeas
Evening snack: a tablespoon of peanut butter or a cup of milk

Day 4 (Resistance exercise day):
Breakfast: Protein-enriched oat pancakes (made with added whey or pea protein in the batter) topped with berries.
Lunch: Chickpea and chicken curry (soft texture, rich in protein and fibre) served with basmati rice.
Post-exercise snack: 4 egg whites and 1 small boiled potato
Dinner: Baked cod with lemon, served alongside lentil puree and cooked broccoli
Evening snack: milk or yogurt

Day 5:
Breakfast: Scrambled eggs with sautéed mushrooms and spinach, plus a glass of fortified orange juice (vitamin D and calcium).

Lunch: Beef and barley soup (beef chunks slow-cooked until tender for easy chewing) with a side of Greek yogurt tzatziki and pita
Evening snack: Healthy milkshake: 1 cup low-fat milk, 1 tbsp peanut butter, 1 banana
Dinner: Grilled shrimp and tofu skewers with quinoa tabbouleh
Evening snack: Low-fat milk and 1 tsp chocolate powder

Day 6 (Resistance exercise day):
Breakfast: Smoothie made with milk, Greek yogurt, banana, and peanut butter (easy to consume for those with a low morning appetite)
Lunch: Egg salad sandwich (1 egg and 2 egg whites mashed plus yogurt-based sauce) with avocado, tomato and lettuce on high-fibre bread.
Post-exercise snack: Enriched-protein chocolate milk
Dinner: Roasted chicken thigh with a side of mixed beans and green leafy vegetable salad.
Evening snack: low-fat cheese cubes and some whole-grain crackers

Day 7:
Breakfast: Steel-cut oats cooked in milk, topped with cinnamon, nut butter and diced apple.
Lunch: Salmon and bean salad
Afternoon snack: peanut butter, honey on a slice of whole grain bread.
Dinner: chicken and vegetable soup
Evening Snack: Yogurt and a sprinkle of soy protein isolate.

The mixed-protein plan meets the target protein intake while incorporating a variety of foods to ensure adequate micronutrient coverage. High-leucine foods like dairy, whey, eggs, and fish are essential [119]. The plan also highlights calcium- and vitamin D-rich options such as dairy, fortified juices, and fish, supporting both bone strength and muscle function [64]. Importantly, protein is distributed evenly throughout meals and snacks. On Days 2, 4 and 6 post-workout snacks illustrate the concept of nutritional timing: eating protein and a bit of carbs shortly after resistance training helps the body recover and build muscle. The plan also ensures hydration and fibre intake through items like soups, smoothies, fruits, and vegetables, which support digestion, which is important for seniors, because dehydration and constipation can affect appetite and nutrient uptake [125]. The plan is flexible; meals and their amount can be tailored to personal requirements and preferences, for instance, replacing salmon with canned mackerel if needed for taste or budget.

Sample 7-Day Meal Plan – Fully Vegan

This plant-based plan is designed based on evidence-based guidelines for older adults who follow a vegan diet or prefer to avoid animal products. It emphasises high-protein plant foods and complementary proteins to ensure all essential amino acids are provided. Total protein is kept high (~1.2–1.5 g/kg/day) through generous portions of legumes, soy products, nuts, and seeds, and some use of fortified plant-based protein foods [131][132][133][134].

Day 1:

Breakfast: Silken tofu scramble with turmeric, mixed with soft sautéed veggies, plus whole-grain toast topped with peanut butter.

Lunch: Cooked red lentil dahl (18 g protein per bowl) served with quinoa.

Afternoon snack: Soy yogurt,1 tbsp hemp seeds and berries

Dinner: Stir-fried tempeh (fermented soy, easier to digest) with broccoli, carrots, and brown rice.

Evening snack (before bed): Soy yogurt with almonds (boost protein intake and aid overnight muscle protein synthesis)

Day 2 (Resistance exercise day):

Breakfast: Oatmeal made with fortified soy milk (higher protein than almond milk) and chopped nuts, plus a scoop of pea protein blended in.

Lunch: Whole-wheat spaghetti with lentil Bolognese (using lentils and mushrooms instead of meat) and a sprinkle of nutritional yeast (adds B12 and protein).

Post-exercise Snack: Smoothie with pea protein powder, banana, and cocoa

Dinner: Black bean and sweet potato chili (soft texture, high fiber) with a side of cornbread (the beans provide ~15 g protein per bowl; combining grains and legumes yields complete protein).

Evening snack: Vegan protein shake: Soy/pea base protein and fortified oat milk

Day 3:

Breakfast: Chickpea flour pancakes (socca), topped with a berry compote and almond butter.

Lunch: Hummus and grilled vegetable wrap: Whole-grain wrap with chickpea hummus, grilled zucchini, peppers, and spinach. Accompanied by a cup of lentil soup.

Afternoon snack: A small bowl of edamame (green soybeans, ~11 g protein per cup).

Dinner: Vegan bean curry with tofu cubes, served over millet or rice (Mixed beans provide lysine, rice provides methionine for complementarity).

Evening snack: a cup of fortified soy milk

Day 4 (Resistance exercise day):

Breakfast: Smoothie bowl with blended silken tofu, frozen berries, and fortified soy milk. Topped with walnuts, pumpkin seeds and granola

Lunch: Split pea soup with diced carrots and potatoes. Side of whole-grain crackers with sunflower seed spread.

Post-exercise snack: Vegan protein bar or homemade energy balls made from dates, oats, and pea protein.

Dinner: Baked seitan cutlets (wheat gluten-based protein, very high protein ~25 g per serving) with mushroom gravy, served alongside mashed cauliflower and peas.

Evening snack: Soy yogurt and 1 tbsp hemp seeds

Day 5:

Breakfast: Overnight oats soaked in fortified soy milk with chia seeds (chia adds protein and omega-3) and topped with chopped apricots and almonds.

Lunch: Tofu stir-fry with cashews and mixed vegetables, served with buckwheat noodles.

Afternoon Snack: Tahini (sesame seed butter) (or peanut butter) spread on apple slices

Dinner: Quinoa and chickpea salad with chopped cucumber, olive oil, lemon, and parsley.

Evening snack: Fortified oat milk with 1 tsp cocoa powder

Day 6 (Resistance exercise day):

Breakfast: Buckwheat groats porridge cooked in fortified oat milk, topped with flaxseeds and blueberries.

Lunch: Veggie burger (made from black beans and quinoa) on a whole-grain bun with lettuce and tomato, served with a side of quinoa tabbouleh and steamed green beans.

Post-exercise snack: Vgena soy protein isolate shake and 1 banana

Dinner: Vegan Greek-style salad with marinated tofu “feta” cubes, black olives, tomato, cucumber, and chickpeas on lettuce.

Evening snack: A small serving of coconut-based yogurt with added pea protein

Day 7:

Breakfast: High-protein chia pudding (chia seeds soaked in fortified soy milk overnight) topped with sliced banana and a spoon of peanut butter.

Lunch: Tofu and vegetable stir-fry noodles: soft rice noodles with crumbled tofu, bean sprouts, and scallions in a light sauce.
Afternoon snack: Seitan slice with avocado spread on whole grain toast
Dinner: Chickpea and eggplant stew (Middle Eastern style with tomatoes and spices), served with a side of couscous; spinach salad with orange slices and almonds.
Evening snack: Soy yogurt and 1 tbsp granola.

Soy-based foods, such as tofu, tempeh, edamame, and soy milk are high in protein and contain all the essential amino acids like animal products. Legumes such as lentils, beans, chickpeas, and split peas appear in at least two meals daily and are often paired with grains like rice, quinoa, and whole-grain breads to create complete protein profiles. To increase protein intake without significantly increasing food volume, breakfasts or snacks often incorporate pea or soy protein powder. The plan also highlights important micronutrients: fortified plant-based milks and nutritional yeast provide vitamin B12, vitamin D, and calcium—nutrients commonly lacking in vegan diets but essential for bone and muscle health. Iron and zinc are sourced from legumes, nuts, seeds, and leafy greens, and their absorption is enhanced by pairing them with vitamin C-rich fruits like citrus and berries. Protein is distributed evenly across meals, with each providing approximately 20–30 grams to optimize muscle protein synthesis [119]. On days involving physical activity, a protein snack is included, following the same principle as mixed diets, consuming protein soon after exercise supports muscle recovery [125]. The plan also considers ease of consumption for older adults by recommending softer foods such as soups, stews, and porridges. To help prevent unintended weight loss, calorie-dense healthy fats like nut butters, olive oil, and avocado are added to meals. Smoothies are offered as a convenient option for those with lower appetites, allowing for easy consumption of calories and nutrients.

Conclusion:

Sarcopenia is a major and multifaceted issue that arises with aging, involving the steady decline of muscle mass, strength, and physical ability. This thesis has explored what causes sarcopenia, its effects on health, and how it can be addressed, especially through nutrition and regular physical activity. These two factors, when combined, show promising results in managing the condition. The research reviewed makes it clear that sarcopenia doesn't have to be a guaranteed part of growing older. With the right approach, it can be prevented, and in some cases, even improved, through early and consistent intervention [1].

sarcopenia results from a complicated mix of factors involving muscles, nerves, metabolism, and hormones at a biological level. The loss of muscle happens when the body's processes that build muscle (anabolic) are outweighed by those that break it down (catabolic). This imbalance is worsened by inflammation, oxidative stress, problems in the cell's energy centers (mitochondria), and the body's reduced ability to handle insulin. On top of these internal issues, lifestyle and environmental factors—like a poor diet, lack of exercise, ongoing health conditions, and financial or social hardships—also play a big role in the development and progression of sarcopenia [1].

sarcopenia significantly raises the probability of frailty, falls, bone fractures, and hospital admissions, and it's also linked to a higher risk of death. people living with sarcopenia often struggle with reduced mobility, persistent tiredness, and a gradual loss of their ability to live independently. From a public health perspectiv, sarcopenia places a heavy financial burden on healthcare systems and long-term care services, especially in societies where the population is aging quickly [135]. As mentioned in this thesis, consuming enough protein is key to both preventing and managing sarcopenia. According to current recommendations, older adults should aim to consume between 1.0 and 1.2 grams of protein per kilogram of body weight each day. Those who are frail or recovering from illness may need even more to support muscle maintenance and recovery [16]. How protein is spread out throughout the day also matters. Eating about 25 to 30 grams of protein at each meal has been shown to be the most effective way to support muscle building and maintenance [126].

Even though animal-based proteins offer higher biological value and more leucine, carefully planned vegan diets can still promote muscle health by combining foods like legumes and grains and incorporating fortified products or supplements [127].Nutrients like vitamin D, omega-3 fatty acids, and antioxidants can help improve muscle function and lower inflammation. These nutrients are often lacking in older adults and may be added through

supplements to boost the effectiveness of dietary strategies [130].Resistance training is considered the most effective physical approach to combat sarcopenia, as it greatly enhances muscle strength, walking speed, and overall physical function. Performing resistance exercises regularly, around 2 to 3 times per week, delivers the anabolic stimulus necessary to help prevent muscle loss [136]. Cardiovascular health and stamina are boosted by aerobic exercise, while activities that enhance balance and flexibility help lower the risk of falls and increase mobility [25]. The main goal is to design varied, individualized exercise programs that older adults can follow safely and consistently over time.

Crucially, combining nutrition and physical activity yields greater overall benefits. Research indicates that using protein supplements alongside resistance training results in more significant gains in lean muscle and strength than using either approach on its own [137].

The anabolic effect of protein is stronger when consumed around workout times, as exercise increases the muscle's responsiveness to dietary amino acids. This supports the idea of merging diet and exercise into well-rounded, customized treatment approaches.

On a practical level, the thesis outlines weekly meal plans and lifestyle tactics suited for older adults. These include protein-rich diets featuring both animal and plant-based foods, or entirely plant-based options. Easy-to-make snacks and meals after exercise were also developed to help maintain steady protein intake. To put these strategies into action in clinical or community environments, it's vital to offer tailored guidance, organized resistance training programs, and informative outreach [126].

Although evidence is increasing, obstacles persist. A standardized definition or diagnostic criteria for sarcopenia is still lacking, making it difficult to compare studies and create consistent treatments [6]. More long-term, diverse, and carefully controlled research is necessary to fine-tune best practices, assess new supplements, and design affordable, widely usable solutions. To conclude, sarcopenia is a modifiable risk factor that contributes to loss of function in older adults. Tackling it demands a thorough, research-based strategy that includes focused nutrition, consistent exercise, and public health initiatives. Redirecting medical and policy efforts toward prevention and healthier living can help older adults maintain independence and quality of life for longer [128].

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