Journal of Applied Sports Science
June 2025, Volume 15, No. 1
www.jass.alexu.edu.eg

Progressive Resistance Training Counteracts Aging Physical and Hormonal Deterioration

Prof. Hamdy Abd El-Maksoud El-Gazzar (1)

(1) Prof. at Faculty of Sport Education, Alexandria University Department of Training Combat, and Individual Sports

Abstract:

One of the most striking effects of age is the involuntary loss of muscle mass, strength, endurance, and function, termed sarcopenia. Muscle mass decreases approximately 3–8% per decade after the age of 30 and this rate of decline is even higher after the age of 60

This review article focuses on the changes that occur in muscles as we age, particularly the involuntary loss of muscle mass, strength, and function, which is termed sarcopenia. It also discusses the potentially treatable causes of this condition, such as age-related endocrine and nutritional changes, and inactivity . The article emphasizes the importance of weight training at 80% of 1RM for elderly individuals to reduce or prevent these changes that can interfere with their quality of life. Cross-sectional studies comparing young adults aged 18–45 years and older adults under 65 years old show significant differences. The median values of the reported rate of muscle loss are 0.47% per year in men and 0.37% per year in women..

Keywords: *(Resistance Training, Aging, Hormonal Deterioration)*

Purpose of review:

One of the most striking effects of age is the involuntary loss of muscle mass, strength, endurance, and function, termed sarcopenia. Muscle mass decreases approximately 3–8% per decade after the age of 30 and this rate of decline is even higher after the age of 60 [33].

This review article focuses on the changes that occur in muscles as we age, particularly the involuntary loss of muscle mass, strength, and function, which is termed sarcopenia. It also discusses the potentially treatable causes of this condition, such as age-related endocrine and nutritional changes, and inactivity [33]. The article emphasizes the importance of weight training at 80% of 1RM for elderly individuals to reduce or prevent these changes that can interfere with their quality of life. Cross-sectional studies comparing young adults aged 18–45 years and older adults under 65 years old show significant differences. The median values of the reported rate of muscle loss are 0.47% per year in men and 0.37% per year in women [25].

As people age, they tend to lose muscle mass, with men experiencing more significant muscle loss compared to women. Research shows that men can lose 0.5% to 1.0% of their muscle mass every year after the age of 70, with a 4.7% decrease for men and a 3.7% decrease for women per decade compared to their peak muscle mass. This has led to the age of 70 being considered as the target age for clinical trials addressing sarcopenia. Additionally, strength tends to decrease by 10% to 15% per decade up to the age of 70, after which the decline accelerates to 25% to 40% per decade [32].

Aging brings about changes in cells, tissues, and organs. Cells become larger and less able to divide and multiply, and they may accumulate pigments and fatty substances. Additionally, waste products build up in tissues, and connective tissues become stiffer. This can make organs, blood vessels, and airways more rigid. Many tissues also experience atrophy, losing mass and becoming lumpy or more rigid. As a result of these changes, organs gradually lose function with age. Most people don't notice this loss immediately, as organs have a reserve capacity beyond what is typically needed. However, after the age of 30, an average of 1% of this reserve is lost each year. The heart, lungs, and kidneys experience the most significant declines in reserve capacity, and the extent of reserve loss varies among individuals and among different organs within the same person [24].

If enough cells decrease in size, the entire organ atrophies. This is often a normal aging change and can occur in any tissue. It is most common in skeletal muscle, the heart, the brain, and the sex organs (such as the breasts and ovaries). Bones become thinner and more likely to break with minor trauma. The cause of atrophy is unknown, but may include reduced use, decreased workload, decreased blood supply or nutrition to the cells, and reduced stimulation by nerves or hormones [2][24][26][27][34].

Aging muscle undergoes a range of changes, some of which are normal (such as age-related sarcopenia) and some of which are not (such as anorexia and cachexia syndrome linked to cancer. More precisely, sarcopenia has been defined as a relative muscle mass that is less than two standard deviations below that of a sex-matched control group that is between the ages of 18 and 40. However, the prevalence of sarcopenia varies widely, ranging from 8% to

40% [8][9][33][36]. After the age of 30, muscle mass starts to diminish at a rate of about 3-8% every decade, and after the age of 60, this rate of decline increases even further [4][5]. Elderly people's unintentional loss of muscular mass, strength, and function is a major factor to and cause of impairment [13][33].

If enough cells decrease in size, the entire organ atrophies. This is often a normal aging change and can occur in any tissue [24]. It is most common in skeletal muscle, the heart, the brain, and the sex organs such as the breasts and ovaries. Bones become thinner and more likely to break with minor trauma. The cause of atrophy is unknown, but may include reduced use, decreased workload, decreased blood supply or nutrition to the cells, and reduced stimulation by nerves or hormones. Studies indicate a strong relationship of lower extremity strength to balance and gait. The studies demon Exercise opposes the harmful effects of secondary aging by preventing the decline in mitochondrial respiration, mitigating aging-related loss of muscle mass, and enhancing insulin sensitivity. This review focuses on mechanisms by which exercise promotes "healthy aging" by inducing modifications in skeletal muscle [33].

As people age, they gradually lose muscle fibers, with about 50% of the fibers in limb muscles being lost by the age of 80. The extent of remaining fiber atrophy depends largely on a person's level of physical activity. Even "master athletes" who maintain high fitness levels throughout their lives experience a decline in performance after the age of 40, with peak performance decreasing by around 50% by the age of 80. However, well-designed and carefully administered training programs can slow down age-related muscle atrophy, weakness, and fatigue, as evidenced by the success of master athletes and previously sedentary elderly individuals who take up such programs [10].

Figure (1) Muscle cells shrink causing muscle sagging

Cells enlarge means hypertrophy that is caused by an increase of proteins in the cell membrane and cell structures, not an increase in the cell's fluid. When some cells atrophy, others may hypertrophy to make up for the loss of cell mass. While Hyperplasia is the number of cells increases. There is an increased rate of cell division. Hyperplasia usually occurs to compensate for a loss of cells. It allows some organs and tissues to regenerate, including the skin, lining of the intestines, liver, and bone marrow. The liver is especially good at regeneration. It can replace up to 70% of its structure within 2 weeks after an injury. Tissues that have limited ability to regenerate include bone, cartilage, and smooth muscle (such as the muscles around the intestines). The Dysplasia concerns the size, shape, or organization of mature cells becomes abnormal. This is also called atypical hyperplasia [2][3][4]. Dysplasia is quite common in the cells of the cervix and the lining of the respiratory tract. Neoplasia refers to the formation of tumors [27].

Sarcopenia is most often caused by the aging process. Sometime in the 30s or 40s, that starts to gradually lose strength and muscular mass. The onset of this process occurs between 65 and 80 years of age. Man could lose up to 8% of his muscle mass every ten years; however, rates might vary. Sarcopenia may be associated with the following physical aging-related changes: fewer nerve cells are used by the brain to communicate with the muscles to contract; Decreased amounts of a few hormones; including growth hormone; testosterone; and insulin-like growth factor [31].

As people age, their skeletal muscle undergoes significant changes, including a loss of muscle mass and strength known as sarcopenia [5]. This leads to reduced potential for muscle regrowth and decreased physical performance. Age-related muscle aging is also associated with impaired muscle metabolism, insulin resistance, and mitochondrial dysfunction. Muscle endurance and strength decline noticeably with aging, mainly due to decreased muscle mass and protein synthesis. Additionally, the cross-sectional area of type I and type II muscle fibers decreases and there is a shift towards a slower profile in their distribution as we age [31][36][37]

Connective tissue undergoes a shift and stiffens, causing the airways, blood arteries, and organs to become more rigid. As a result, many tissues have increased difficulty absorbing oxygen and other nutrients, and expelling carbon dioxide and other waste products due to changes in cell membranes. Additionally, many tissues experience mass loss and cells get smaller. If a sufficient number of cells shrink, the organ as a whole atrophies. This can happen in any tissue and is frequently a natural aging change. The heart, brain, skeletal muscle, and sex organs (such as the ovaries and breasts) are the areas where it occurs most frequently [21][32][33].

Muscle Fiber Type Distribution with Age:

Distribution of Muscle Fiber Type with Age Age-related variations in the distribution of muscle fibers have been found. The Krebs cycle and electron transport chain are two examples of the many mitochondria and aerobic enzymes found in type I fibers, which are small, slow-contracting, low-tension output fibers [32]. These fibers can metabolize fat for energy expenditure and have a high fatigue resistance. Larger and faster-contracting Type II fibers generate high tension output but fatigue quickly. Although the precise percentages are unknown, it is evident that as people age, the proportion of type I fibers increases relative to type II fibers Similarly, as people age, their overall muscle strength declines, which may be due to a reduction in the contribution of the fewer big type II fibers that produce tension [3][12][24][32].

Muscle Fiber Denervation:

The reasons behind the age-related increase in type I fiber composition may be due to the atrophic influence the motor nerve has on muscle fibers. It is possible that regeneration of previously damaged muscle fibers fails, but this seems unlikely. A more reasonable explanation would be a reorganization of the aging motor unit pool. About one quarter of the motor units are inactive and nonfunctional. While the number of active motor units decreases, each active motor unit pool becomes larger. The increase in the size of the active motor units may be due to new collaterals from the most active motoneurons in the type I pool branching out to the nonfunctioning fibers, which is commonly seen in nerve injury. Therefore, with age, there is less of a contribution to tension output from the higher tension type II fibers because the lower tension–output type I fibers are now more predominant. Overall, the muscle mass of the elderly is smaller and weaker because of the loss of type II fibers [1][3][5].

If enough cells decrease in size, the entire organ atrophies. This is often a normal aging change and can occur in any tissue. It is most common in skeletal muscle, the heart, the brain, and the sex organs (such as the breasts and ovaries). Bones become thinner and more likely to break with minor trauma. The cause of atrophy is unknown, but may include reduced use, decreased workload, decreased blood supply or nutrition to the cells, and reduced stimulation by nerves or hormones. Connective tissue changes, becoming stiffer. This makes the organs, blood vessels, and airways more rigid. Cell membranes change, so many tissues have more trouble getting oxygen and nutrients and removing carbon dioxide and other wastes. Many tissues lose mass. This process is called atrophy. Some tissues become lumpy (nodular) or more rigid. The trophic effect the motor neuron exerts on muscle fibers could be the cause of the age-related raise in type I fiber composition [24].

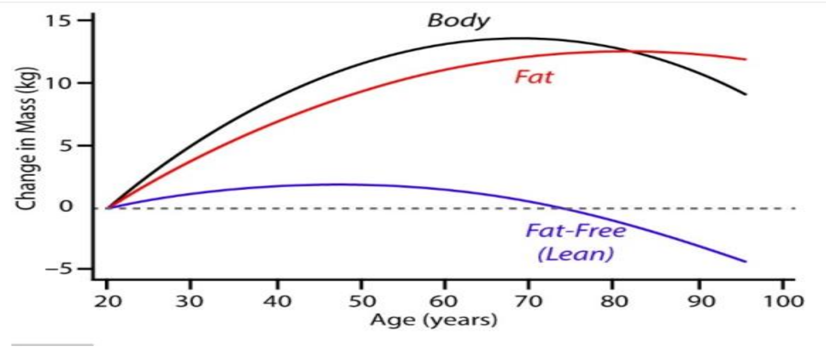
Failure of previously damaged muscle fibers to regenerate is a possibility, but it appears unlikely. A restructure of the pool of older motor units would make more sense. Approximately 25% of the motor units are not operating or functioning. Each pool of active motor units grows in size as the total number of active motor units declines [5]. The most active motor neurons in the type I pool may have produced additional collaterals that branched out to the nonfunctioning fibers, causing an increase in the size of the active motor units. This phenomenon is frequently observed in nerve damage. Issues in measuring the extent of muscle loss are influenced by availability, cost, and constraints [28]. Right now, the most used method is DXA. Although sarcopenia lacks a single, conclusive biological marker, other indicators are linked to it, such as adipokines, cytokines, antioxidants, signs of oxidative damage, and apoptosis [32].

Muscle weakness is common among the elderly and is closely associated with frailty, reduced functionality, immobility, falls, and injuries in this age group. The significant decline in skeletal muscle strength and size as people age is a complex issue, influenced partly by biological changes associated with aging, the presence of acute and chronic diseases, a sedentary lifestyle, and nutritional deficiencies, whether selective or generalized [11].

The average percentage of type I fibers was significantly higher in men, while the percentage of type IIA fibers was significantly higher in women. For men, the distribution was 58% type I, 27% type IIA, and 13% type IIB, while for women, it was 51% type I, 32% type IIA, and 15% type IIB. Additionally, the sizes of all fiber types were significantly larger in men than in women. When participants were grouped into age categories of 20, 30, 40, 50, 60, and 70 years, the fiber composition was found to be similar at different ages in both men and women, but changes in fiber sizes were observed. The study also found that 70-year-old men and women showed significantly reduced sizes of both type I and type II fibers compared to the 60-year-old group. Minor changes were observed in enzyme activities concerning age [10]. As people age, they tend to lose muscle, usually at a rate of 3% to 5% every ten years after the age of thirty. Inactive individuals experience the most significant muscle loss. Around age 60, this loss may become more apparent and accelerate. Studies indicate that between 11% and 50% of adults over 80 have sarcopenia, which can pose significant risks such as fragility, falls, broken bones, disabilities, and even death [8][10][31][33].

Both men and women experience a decline in strength, with men losing almost twice as much strength as women. Studies also indicate that Blacks experience about 28% more strength loss than whites. The annual rates of decline in leg strength were approximately three times greater than the rates of loss of leg lean mass (approximately 1% per year) for different demographic groups (references 15 and 31). Additionally, a study shows a strong relationship between lower extremity strength, balance, and gait, demonstrating an association between these functions and falls (reference 37).

Figure (2) Age-related changes in the lean mass



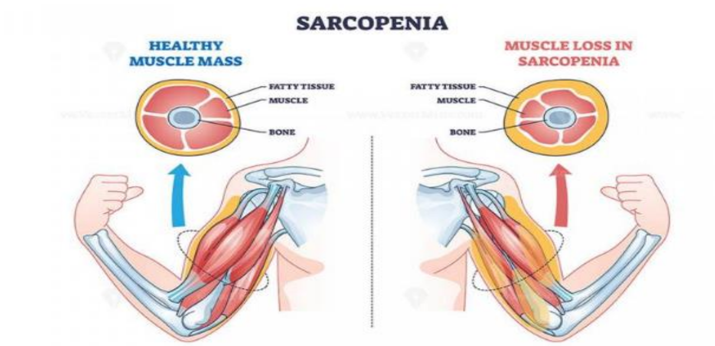
As we age, several physical changes occur that may be linked to sarcopenia. These changes include lower levels of hormones such as growth hormone, testosterone, and insulin-like growth factor. There is also a decline in nerve cells that transmit signals from the brain to the muscles to initiate movement. Additionally, there is a reduction in the body's ability to convert protein into energy and an increase in inflammation, partly due to illness. Research suggests that a quantitative loss in muscle cross-sectional area is a significant factor in the decrease in muscle strength observed with age. This, along with muscle strength at T1, accounts for 90% of the variability in strength at T2 [13]. The concentrations of dehydroepiandrosterone in the blood also decrease gradually with normal aging (adrenopause) [33].

Sarcopenia Risk Factors:

Sarcopenia is the age-related loss of muscle mass, which has a negative impact on strength, functional independence, and overall quality of life. Sarcopenia is a multifactorial condition characterized by changes in muscle morphology, protein and hormonal kinetics, oxidative stress, inflammation, physical activity, and nutrition. It is well known that resistance exercise increases aging muscle mass and strength, and these physiological adaptations from exercise may be further enhanced with certain nutritional interventions [4]. The prevalence of sarcopenia is high in the population over 65 years old and often leads to poor outcomes such as functional decline and its related consequences. Currently, there is no clear understanding of the pathophysiology of sarcopenia or precise clinical or biological markers to identify it [5]. Recent data reported include those regarding the potential role of insulin resistance in the development of sarcopenia [33].

In elderly patients, age-related changes in body composition, as well as the increased prevalence of obesity, result in a combination of excess weight and reduced muscle mass or strength, recently defined as sarcopenic obesity (SO) [39]. Sarcopenia is now recognized as a multifactorial geriatric syndrome. Cachexia has been defined as 'a complex metabolic syndrome associated with underlying illness and characterized by loss of muscle mass with or without loss of fat mass' [29]. Although many variables can lead to sarcopenia development in some individuals, age and inactivity are two important risk factors. While muscle loss starts decades before age 60, sarcopenia is uncommon before then. A poor diet, chronic illness, and inactivity are among the risk factors that older persons are likely to have in addition to the biological changes that come with aging and can lead to muscle and strength loss [7][8][31].

Figure (3) Sarcopenia with aging



In a study involving participants, it was observed that there was a significant decrease in strength over time. Specifically, the decline in leg muscle strength for men over time was found to be about 60% greater than what was estimated in an analysis of the same group at a single point in time [20]. At the cellular level, muscles experience a reduction in both cross-sectional area and fiber numbers, with type II muscle fibers being the most impacted by aging. Some loss of nerve supply to the muscle fibers may also occur. These factors combined lead to an increased percentage of type 1 fibers in older adults [22]. With aging, there is a noticeable decline in both muscle endurance and strength. The primary causes of this decline are decreased muscle mass and reduced protein synthesis. Normal aging leads to a decrease in the cross-sectional area of type I and type II fibers, as well as a shift in their relative distribution towards a slower profile. The decline in endurance may be attributed to reduced mitochondria and consequently fewer aerobic enzymes [7][17][28][32].

Since muscle is the final component of a movement, nearly every process—from supplying oxygen to the blood to supplying oxygen to working muscle—may have some role to play. While inactivity can be a precursor to strength loss, which is a hallmark of aging, the altered fiber profile skeletal muscle's remarkable adaptability is one of its best qualities [32]. Many studies show that skeletal muscle is trainable, and that older people can achieve significant gains from training, indicating that this ability to adjust to its demands lasts throughout life. For instance, people between the ages of 60 and 80 can raise their aerobic fitness by 20% to 30% with the right exercise, which is comparable to what is achieved by considerably younger people. Both peripheral muscle adaptations and central cardiovascular mechanisms contribute to the gains [19][23][30][34].

Several studies have found that high-resistance weight training can lead to notable improvements in muscle strength, size, and mobility in frail nursing home residents, even up to 96 years of age [12]. Data from these studies indicates a strong connection between lower extremity strength, balance, and walking ability, and suggests that these factors are linked to the risk of falls [38]. Research on isometric and dynamic endurance in relation to age and skeletal muscle characteristics has shown that maximum isometric and dynamic strength decrease in older age groups, while isometric and dynamic endurance remain relatively unchanged. Additionally, there are significant correlations between endurance and factors such as fiber type distribution, fiber areas, and LDH isozyme activities [23].

In a study, the effects of prolonged endurance training on maximal O2 uptake capacity (VO2max) and its determinants were examined in 11 older individuals (average age 63). The participants were assessed before training, after 6 months of low-intensity (LI) training, and after an additional 6 months of higher-intensity (HI) training. Before training, VO2max was 25.4 ml/kg/min. After LI training, it increased to 28.2 ml/kg/min (a significant difference), and after HI training, it further increased to 32.9 ml/kg/min (a significant difference), resulting in an overall increase of 30% [30]. Aerobic exercise has been shown in several studies to improve VO2max, mitochondrial density and activity, insulin sensitivity and energy expenditure in young and older individuals [33].

A study on the number of motor units in thinner muscles and the changes in the motor unit count with aging reveals that the number of motor units decreases with age, particularly after midlife. This means that elderly individuals often have less than half the number of motor units compared to when they were younger, even if they still have good strength. The cause of this decline is not fully understood, but it likely involves peripheral nerve trauma and primary neuronal cell death [3].

In a recent study, sixteen highly trained master endurance athletes, aged 59 +/- 6 years, were compared with 16 young athletes who had similar training regimens, as well as 18 untrained middle-aged men. Both groups of athletes showed significantly greater left ventricular volume and mass compared to the untrained men. There were no significant differences in percent fiber shortening or velocity of fiber shortening among the three groups. The maximum O2 uptake (VO2max) averaged 15% less in the master athletes compared to the young athletes (58.7 vs. 69 ml.kg-1.min-1) [17].

Additionally, muscle can react to resistance exercise to the fullest extent. For instance, strength gains of about 5% per day were observed in men over 66 who exercised by lifting 80% of their 1 RM (repetition maximum) for 12 weeks [20]. These results are comparable to those shown in males much younger than 66. A prominent indicator of frailty in older individuals is slower walking speed, a longer time to stand up from a sitting position, poor balance, and difficulty ascending stairs, falls, and other symptoms. Even at this advanced age, strength might be improved (in this group by 175%), as well as the cross-sectional area of the thigh muscles (by 15%), according to a resistance training program conducted on a group of participants whose age was 90 years or older [3][22].

In a separate study, twelve healthy and untrained volunteers (aged 60-72) took part in a 12-week strength training program. The program involved 8 repetitions per set, 3 sets per day, and was carried out 3 days a week, with the participants working at 80% of their one repetition maximum (1 RM) for both the extensors and flexors of both knee joints. The study observed a progressive increase in strength for both the extensors and flexors. After 12 weeks, the extensor strength had increased by 107.4% and the flexor strength had increased by 226.7%, with these differences being statistically significant. [14].

Over time, a decline in testosterone levels in males can lead to a loss of lean muscle mass and muscle strength. This can result in decreased physical activity, an increased risk of falls, depression, and other health issues such as obesity and its connection to the onset of type II diabetes. However, this trend can be slowed down or even reversed by using testosterone supplements. Hormone replacement therapy can also reverse the effects of lower estrogen levels in women, which can result in decreased activity levels. Lower estrogen levels in women can cause decreased muscle mass and weaker bones. Unfortunately, exogenous steroid therapy has more negative side effects in addition to its many positive benefits. Erythrocytosis and prostate cancer rates in males have been linked to testosterone replacement therapy [2][9][15][24].

The Hormone factor:

Aging is associated with a loss of sex hormone in both men (andropause) and women (menopause). In men, reductions in testosterone can trigger declines in muscle mass, bone mass, and in physical function. In women, the impact of the loss of sex hormones, such as estradiol, on bone is well elucidated, but evidence is limited on whether the loss of estradiol negatively affects muscle mass and physical function. The natural decrease of testosterone, a hormone that promotes muscle growth and protein synthesis, may be a factor in sarcopenia. Consider testosterone as the firewood that will help create muscle. Aging is associated with a gradual decline in circulating testosterone concentrations and decreased musculature in men. While testosterone administration is often considered when symptoms of hypogonadism are presented [9] [18][24].

Aging changes in the male reproductive system may include changes in testicular tissue, sperm production, and erectile function. These changes usually occur gradually. Aging changes in the male reproductive system occur primarily in the testes. Testicular tissue mass decreases. The level of the male sex hormone, testosterone decreases gradually. There may be problems getting an erection. This is a general slowing, instead of a complete lack of function [9].

The tubes that carry sperm may become less elastic (a process called sclerosis). The testes continue to produce sperm, but the rate of sperm cell production slows. The epididymis, seminal vesicles, and prostate gland lose some of their surface cells. But they continue to produce the fluid that helps carry sperm. The prostate gland enlarges with age as some of the prostate tissue is replaced with a scar like tissue. This condition, called benign prostatic hyperplasia (BPH), affects about 50% of men. BPH may cause problems with slowed urination and ejaculation. In both men and women, reproductive system changes are closely related to changes in the urinary system [24].

Study indicates that although testicular morphology, semen production, and fertility are maintained up to a very old age in men, there is clear evidence of decreased fecundity with advancing age and an increased risk of specific genetic disorders related to paternal age among the offspring of older men [2].

Supplemental testosterone supplementation has been proven in certain studies to increase lean body mass, or muscle, in older men, but side effects are possible. Furthermore, the FDA has not approved these supplements expressly for the purpose of helping men gain more muscle mass. Thus, progressive resistance training is the most effective way to gain muscle mass regardless of age, according to that; when strength and endurance increase, progressively increase the volume of the workouts (weight, reps, and sets). Powders can be added to a variety of meals, such as oatmeal, smoothies, and yogurt, and can provide approximately 30 g per scoop. "While food sources are the best, supplemental protein can help with consuming enough calories and protein from the regular diet [9][16].

Vitamin D may be protective for muscle loss; a more alkalinogenic diet and diets higher in the antioxidant nutrients vitamin C and vitamin E may also prevent muscle loss strength. Decreased melatonin levels may play an important role in the loss of normal sleep-wake cycles (circadian rhythms) with aging [28][35].

As people age, most hormones tend to decrease in levels, while in some cases, there may be an increase. The sensitivity of hormone receptors also decreases with age, leading to an overall loss in endocrine function, even when hormone levels do not decrease. Some age-related hormone reductions include Estrogen in women, melatonin, growth hormone, and testosterone in men. In women, estrogen levels decrease throughout menopause, while testosterone levels in men usually decline gradually over time. Reduced strength and muscular mass can result from lower growth hormone levels. Decreased levels of growth hormone may lead to decreased muscle mass and strength. Reduced melatonin levels may play an important role in the loss of normal sleep-wake cycles (circadian rhythms) with aging. It's worth noting that some age-related hormonal changes may impact the quality of life or cause bothersome symptoms, such as hot flashes [24][36].

Fortunately, recent clinical trials have shown promising results from administering SARM (endosperm) to healthy elderly men. This indicates an increase in lean body mass and physical function [38]. It's important to note that the estimated direct healthcare cost attributed to muscle loss in the United States in 2000 was approximately $18.5 billion ($10.8 billion for men, $7.7 billion for women), representing about 1.5% of total healthcare expenditures that year [21].

Recommendations:

Although decreased muscle mass is a part of aging, it is not irreversible. The best exercises to build muscle include bodyweight exercises like pushups, squats, planks, and lunges; strength training using weight machines; resistance band exercises; and weightlifting with dumbbells. Keeping the program consistent, along with gradually increasing the challenge of the routine for each major muscle group, helps gain muscle mass.

References:

1. **Aniansson A, Hedberg M, Henning GB, Grimby G.** Muscle morphology, enzymatic activity, and muscle strength in elderly men: a follow-up study. Muscle Nerve. 1986; 9:585-591.
2. **Bhasin, S., Rodrigo J., Valderrábano, , and Thiago Gagliano-Jucá,T .** Age-Related Changes in the Male Reproductive System. 2022. **https://www.ncbi.nlm.nih.gov/books/NBK278998/**
3. **Brown WF.** A method for estimating the number of motor units in the thenar muscles and the changes in motor unit count with aging. J Neurol Neurosurg Psychiatry. 1972; 35:845-852
4. **Candow DG, Forbes SC, Little JP, Cornish SM, Pinkoski C, Chilibeck PD.** Effect of nutritional interventions and resistance exercise on aging muscle mass and strength. Biogerontology. 2012; 13:345-358.
5. **Cruz-Jentoft AJ, Landi F, Topinková E, Michel JP.** Understanding sarcopenia as a geriatric syndrome. Curr Opin Clin Nutr Metab Care. 2010; 13:1-7
6. **Dillon EL, Durham WJ, Urban RJ, Sheffield-Moore M.** Hormone treatment and muscle anabolism during aging: androgens. Clin Nutr. 2010; 29:697-700
7. **Essen-Gustavsson B, Borges O.** Histochemical and metabolic characteristics of human skeletal muscle in relation to age. Acta Physiol Scand. 1986; 126:107-114
8. **Evans WJ.** Skeletal muscle loss: cachexia, sarcopenia, and inactivity. Am J Clin Nutr. 2010; 91:1123S-1127S
9. **Evans WJ, Morley JE, Argilés J, et al. Cachexia:** a new definition. Clin Nutr. 2008; 27:793-799
10. **Faulkner JA, Larkin LM, Claflin DR, Brooks SV.** Age-related changes in the structure and function of skeletal muscles. Clin Exp Pharmacol Physiol. 2007;34:1091-1096 .
11. **Fiatarone MA, Evans WJ.** The etiology and reversibilty of muscle dysfunction in the aged. J Gerontol. 1993;48:77-83
12. **Fiatarone MA, Marks EC, Ryan ND, Meredith CN, Lipsitz LA, Evans WJ.** High-intensity strength training in nonagenarians. Effects on skeletal muscle. JAMA. 1990; 263:3029-3034
13. **Frontera WR, Hughes VA, Fielding RA, Fiatarone MA, Evans WJ, Roubenoff R.** Aging of skeletal muscle: a 12-yr longitudinal study. J Appl Physiol. 2000; 88:1321-1326
14. **Frontera WR, Meredith CN, O'Reilly KP, Knuttgen HG, Evans WJ.** Strength conditioning in older men: skeletal muscle hypertrophy and improved function. J Appl Physiol. 1988; 64:1038-1044
15. **Goodpaster BH, Park SW, Harris TB, et al.** The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. J Gerontol A Biol Sci Med Sci. 2006; 61:1059-1064
16. **Harvard Health Publishing.** preserve your muscle mass. 2016. https://www.health.harvard.edu/staying-healthy/preserve-your-muscle-mass
17. **Heath GW, Hagberg JM, Ehsani AA, Holloszy JO. A physiological comparison of young and older endurance athletes. J Appl Physiol. 1981; 51:634-640.**
18. **Horstman AM, Dillon EL, Urban RJ, Sheffield-Moore M.** The role of androgens and estrogens on healthy aging and longevity. J Gerontol A Biol Sci Med Sci. 2012; 67:1140-1152
19. **How to put on muscle as you age, Piedmont, 2024. https://www.piedmont.org/living-real-change/how-to-put-on-muscle-as-you-age**
20. **Hughes VA, Frontera WR, Wood M, et al.** Longitudinal muscle strength changes in older adults: influence of muscle mass, physical activity, and health. J Gerontol A Biol Sci Med Sci. 2001; 56:B209-B217.
21. **Janssen I, Shepard DS, Katzmarzyk PT, Roubenoff R.** The health care costs of sarcopenia in the United States. J Gerontol. 2004; 52:80-85
22. **Kirkendall DT, Garrett WE., Jr.** The effects of aging and training on skeletal muscle. Am J Sports Med. 1998; 26:598-602.
23. **Larsson L, Karlsson J.** Isometric and dynamic endurance as a function of age and skeletal muscle characteristics. Acta Physiol Scand. 1978; 104:129-136.
24. **Medical Encyclopedia: Aging changes in the male reproductive system. n.d. https://medlineplus.gov/ency/article/004017.htm#:~:text=The%20tubes%20that%20carry%20sperm,fluid%20that%20helps%20carry%20sperm.**
25. **Mitchell WK, Williams J, Atherton P, Larvin M, Lund J, Narici M.** Sarcopenia, dynapenia, and the impact of advancing age on human skeletal muscle size and strength; a quantitative review. Front Physiol. 2012; 3:260.

26. **Previll LA, Heflin MT, Cohen HJ. The aging patient. In: Wing EJ, Schiffman FJ, eds.** Cecil Essentials of Medicine. 10th ed. Philadelphia, PA: Elsevier; 2022: chap 126**.**
27. **Roberts,J.** Aging changes in organs, tissue and cells. Medical Encyclopedia: 2023. https://medlineplus.gov/ency/article/004012.htm
28. **Robinson S, Cooper C, Aihie Sayer A.** Nutrition and sarcopenia: a review of the evidence and implications for preventive strategies. J Aging Res. 2012; 2012:510801.
29. **Rolland Y, Abellan van Kan GA, Gillette-Guyonnet S, Vellas B.** Cachexia vs sarcopenia. Curr Opin Clin Nutr Metab Care. 2011; 14:15-21.
30. **Seals DR, Hagberg JM, Hurley BF, Ehsani AA, Holloszy JO.** Endurance training in older men and women. I. Cardiovascular responses to exercise. J Appl Physiol. 1984; 57:1024-1029
31. **Sheikh, Z,** Sarcopenia with Aging 2024. https://www.webmd.com/healthy-aging/sarcopenia-with-aging
32. **Siparsky , P. N., Kirkendall D. T, Garrett Jr W., E.** Muscle changes in aging: understanding sarcopenia. 2014. https://pubmed.ncbi.nlm.nih.gov/24427440/
33. **Volpi, E., Nazemi, R. and Fujita S.** Muscle tissue changes with aging. 2024. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2804956/
34. **Walston JD. Common clinical sequelae of aging. In: Goldman L, Schafer Al, eds. Goldman-Cecil Medicine. 26th ed. Philadelphia, PA: Elsevier; 2020: chap 22.**
35. **Welch A. A. Nutritional influences on age-related skeletal muscle loss. Proc Nutr Soc. 2014 Feb; 73(1):16-33. www.doi.org/10.1017/S0029665113003698.**
36. **William F. Young, Jr,** Effects of Aging on the Endocrine System. MD, MSc, Mayo Clinic College of Medicine, Reviewed/Revised Apr 2022. https://www.msdmanuals.com/home/hormonal-and-metabolic-disorders/biology-of-the-endocrine-system/effects-of-aging-on-the-endocrine-system/
37. **Wolfson L, Judge J, Whipple R, King M.** Strength is a major factor in balance, gait, and the occurrence of falls. J Gerontol A Biol Sci Med Sci. 1995; 50: 64–67. **https://pubmed.ncbi.nlm.nih.gov/7493221/**
38. **Yanase T., Tanabe, M., NomiyamaT** [Transdisciplinary Approach for Sarcopenia. Appication of selective androgen receptor modulator to the therapy of sarcopenia], [Article in Japanese]. (2014). https://pubmed.ncbi.nlm.nih.gov/25266096/
39. **Zamboni M, Mazzali G, Fantin F, Rossi A, Di Francesco V. Sarcopenic obesity:** a new category of obesity in the elderly. Nutr Metab Cardiovasc Dis. 2008; 18:388-395**.**