# How does aging affect muscle recovery time and are there specific nutrients that mitigate the metabolic decline associated with aging?

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**Abstract:** There have been many technological innovations that make it possible to increase the longevity of individuals and change lives. The topic of muscle deterioration and recovery weaves right into the advancing world of medicine and technology. As one ages, the body begins to deteriorate, with many parts of the body losing their full functional capacity. Many of these motor functions include a decline in strength, processing speed, and spatial awareness. As an individual ages, the time required for muscle recovery increases, but this topic is infrequently discussed by practitioners in the field. Due to this gap in knowledge, there have been many strategies brought up in recent years to try and slow down the decreasing metabolism and muscle recovery time. The goal of the paper was to find specific nutrients or food groups that mitigates the deterioration of muscle recovery time that occurs with age. Using previous experimental data and clinical trials has been important in studying the effects of aging on muscle recovery and finding an overarching solution. This paper includes results from numerous lab studies and clinical trials to conclude that aging increases oxidative stress and inflammation within the body and the solution to this is to supplement the body with nutrients that trigger an anti-inflammatory response. Effective supplements include proteins, vitamins/antioxidants, and carbohydrates that help ameliorate the slowed recovery time that occurs with aging. These findings demonstrate that it is possible to slow down what the body perceives as aging and further advance the field of medicine and technology by showing that nutrients have a greater impact than most perceive. With society's increasing interest in modern diets, a thorough understanding of nutrient supplementation and muscle physiology is crucial for creating a well-balanced nutrition that will promote muscle growth and function.

## Introduction:

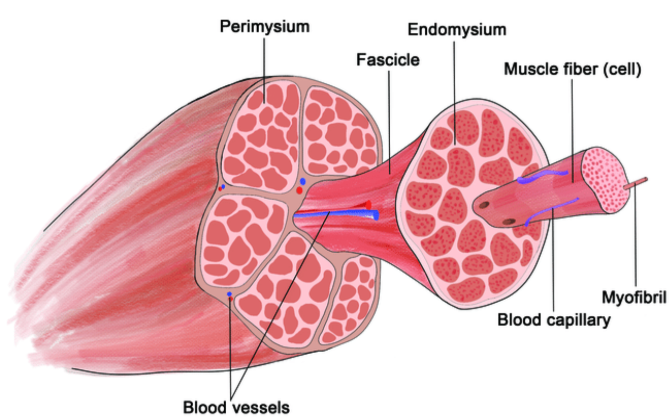
Aging, an inevitable process for human life, happens without much consideration. Every second, a transformation occurs within our body; a transformation that challenges its youthful nature. This is formally known as senescence, or aging. Aging can be categorized into different fields; it can occur through hormonal changes, cognitive changes, cellular changes, and tissue degeneration. The paper will focus mainly on tissue functional decline due to changes in the cellular level, specifically within muscle. As aging occurs in muscle tissue, the muscle recovery time increases. With this increase, the muscles experience extended fatigue and a decline in physical function. This is crucial because it can affect many factors in an individual's lifestyle. Muscle recovery time greatly impacts how much exercise and impact the body can withstand before muscle failure. Fatigue limits the body in sustained tasks, and as a person ages, the body becomes highly susceptible to poor exercise performance and decreased independence in everyday activities. Endurance is diminished, leading to the deterioration of many subsystems of the body over time. Research on aging has been focused on trying to find interventions in order to improve the well-being of older adults. Due to the increasing lifespan of many adults, the topic of aging has been a crucial area of study and a societal issue. Throughout the years, modern scientific technology has been created for many differing fields, but there is a dearth of information about the connection between nutrition and aging. Proper nutrition has already been

shown to decrease prolonged health risks and physiological changes [12]. With current technology, it is possible to find an optimized nutritional plan to help mitigate the effects of an increased muscle recovery time due to aging.
It is well known that energy is synthesized in the body, but many overlook the fact that aging also slows down this metabolic process. Many believe that targeting health benefits in certain nutrients will be a promising solution to slow the effects of aging on the metabolic process and muscle function. The goal of this paper is to incorporate information regarding specific nutrients and propose their implementation to potentially improve the muscle recovery time of aging individuals.

**Muscle Anatomy and Physiology**
Muscles are extremely vital for many important functions of everyday human health. They consist of soft tissues that are made up of intricate fibers bundled tightly together. Muscles can be categorized into three different types: skeletal (striated) muscle, cardiac muscle, and smooth muscle. Together, the muscles play an important role in crucial and basic functions of the body, which include functions which range from breathing and pumping blood, to speaking and moving. However, the three types of muscle have drastically different functions within the body. Cardiac muscles are found along the walls of the heart, whilst smooth muscles comprise other essential organs, such as the stomach and intestines. This review focuses on skeletal muscles, which are essential for movement and exercise and are affected the most by the effects of aging [1]. Skeletal muscles are striated and help with the contraction and flexion of the body, working in tandem with the tendons, ligaments, and bones.

**Figure 1**

*Striated Muscle*

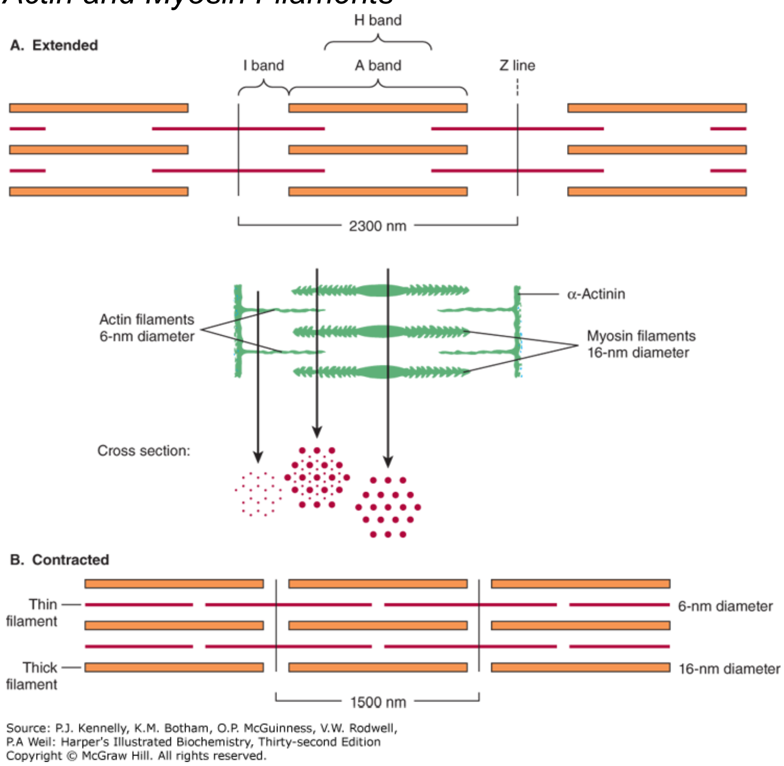



*Note.* The diagram depicts the bundled organization of the various layers of the striated muscle. From Fan, J., Abedi-Dorcheh, K., Sadat Vaziri, A., Kazemi-Aghdam, F., Rafieyan, S., Sohrabinejad, M., Ghorbani, M., Rastegar Adib, F., Ghasemi, Z., Klavins, K., & Jahed, V. (2022). A Review of Recent Advances in Natural Polymer-Based Scaffolds for Musculoskeletal Tissue Engineering. *Polymers*, *14*(10), 2097. https://doi.org/10.3390/polym14102097

As shown in Figure 1, skeletal muscle is divided into three different layers, the epimysium, perimysium, and endomysium, each of which is made up of collagen. The epimysium is the outermost layer that is bound to the tendon and surrounds the entire muscle. Within the skeletal muscle are structures called fascicles, which are wrapped by a layer called the perimysium. The fascicle consists of numerous muscle fibers, each surrounded by a connective tissue called the endomysium. The muscle fiber itself contains many cylindrical objects called myofibrils and an outer layer called the sarcolemma. On top of each muscle fiber reside satellite cells, which are very important due to the fact that they help stimulate muscle growth regeneration. The sarcolemma is the cell membrane of a muscle fiber, which is essential in maintaining the cell's internal environment.

**Figure 2**

*Actin and Myosin Filaments*




*Note.* The diagram shows the actin-myosin interaction that allows for muscle contraction and extension. From Kennelly, P. J., Botham, K. M., McGuinness, O., Rodwell, V. W., & P. Anthony Weil. (2022). *Harper's Illustrated Biochemistry, Thirty-Second Edition*. McGraw Hill Professional.

These myofibrils are also composed of multiple sarcomeres, with each sarcomere containing little threads called myofilaments. Each myofilament consists of a thick and thin filament. These thick and thin filaments are composed of proteins called myosin and actin, respectively. On a thick filament, the myosin heads bind with the actin on the thin filaments. This phenomenon induces energy release, more specifically, ATP release [2]. In the muscle, the myosin and actin protein's main function is muscle contraction and extension. As shown in Figure 2, there is a cyclic binding and unbinding of the myosin head on the actin filament that occurs, to allow for muscle contraction and extension. This process requires the use of energy in the form of ATP. Continual muscle use and repeated contraction creates lots of stress on the muscle fiber, leading to eventual microscopic tears in the muscle tissue. The experience of a higher muscle recovery time causes these microscopic tears to heal at a slower rate [3]. With this increased load on the body, it needs many body systems to work in sync. Similarly, the transfer of ATP throughout the body is also a process that requires the body to operate in unison.

**Cellular respiration**

In general, ATP is produced through cellular respiration, a mechanism in which glucose and oxygen are processed to package energy[4]. The cell undergoes glycolysis, which occurs in the cytoplasm of the cell. During this phase, one glucose molecule (6-carbon sugar) is broken down into pyruvate molecules, ATP, NAD, and $H_2O$ molecules. The pyruvate produced during this step is then used in the next step, most commonly known as the Krebs Cycle. During the Krebs Cycle, this pyruvate molecule is broken down into five separate compounds. Finally, it goes through the cycle of the electron transport chain, which produces an abundant amount of ATP molecules. This is crucial because, in comparison with glycolysis (in which one glucose produces 2 pyruvate and 2 ATP molecules), the electron transport chain produces ~28-30 ATP per glucose [5]. Going through the whole cycle of cellular respiration is important for muscle recovery because it plays a huge role in releasing contractions after exercise and other strenuous activities [4]. Moreover, a decreased efficiency of cellular respiration generates less ATP and a slower muscle recovery time, creating more stress on the muscle recovery process [69].

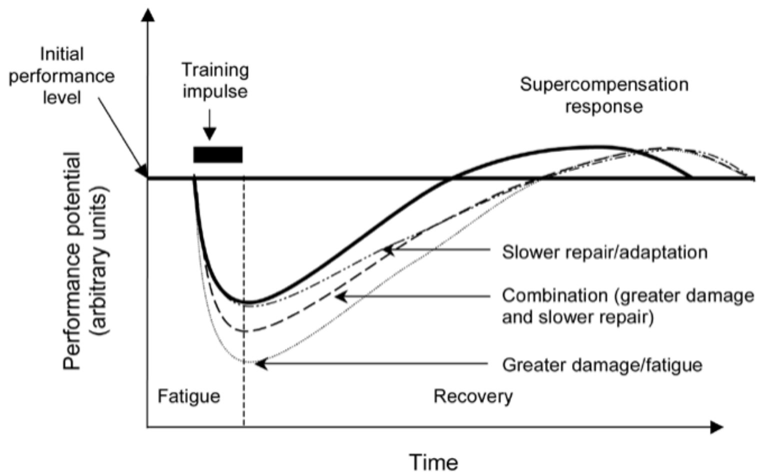
**Muscle Recovery**

Muscle recovery is the term used to describe the process in which muscles refuel and rest. Through rehydration, regeneration, and reduction of inflammation, the ultimate goal is to return to homeostasis, which is essentially how the body maintains an equilibrium [6]. There are three different categories of muscle recovery; immediate, short-term, and training recovery. Immediate recovery is the time between exertions, for example, the time between bicep curl reps and the time between the leg strides of a racer. In immediate recovery, the muscle needs to rejuvenate with ATP so the muscles have enough energy for the next stride or rep. When muscles burn ATP for energy, waste products such as lactic acid are released. In order to keep performing consistently, the body frequently tries to accelerate the removal of lactic acid.

Short-term recovery is the recovery time between sets of exercise or interval sprints. Because short-term muscle recovery is in short intervals of time, the body relies on creatine phosphate resynthesis. This resynthesis process is needed in order to regenerate ATP supply and maintain normal contractile function. During this short rest period, the body replenishes the storage of creatine phosphate in order to serve as the energy source in short vigorous activities. As shown in Figure 3, an individual has a greater muscle recovery time and a slower response time with age.

**Figure 3**

*Muscle Recovery after exercise*




*Note.* Model of time course after an exercise impulse. The bold line shows the normal model of an average adult athlete, and the dashed lines represent models for an aging athlete, experiencing slower recovery with age. From Fell, J., & Williams, A. D. (2008). The Effect of Aging on Skeletal-Muscle Recovery from Exercise: Possible Implications for Aging Athletes. *Journal of Aging and Physical Activity*, *16*(1), 97–115. https://doi.org/10.1123/japa.16.1.97

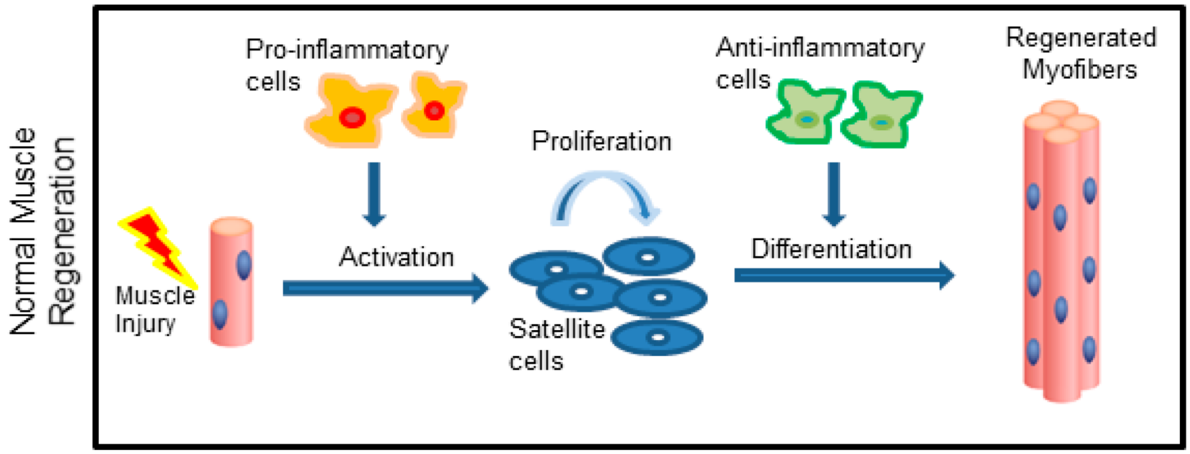
This review focuses mostly on the last type of muscle recovery, also known as training recovery. Training recovery is the time the body gets to regenerate in between separate workouts or days of physical exercise. For many athletes, this would be the period of time between their practices or competitions. One thing that is clearly seen in training recovery is muscle fatigue and inflammation [7]. To investigate recovery as a whole, knowledge of why muscle fatigue happens is vital, in order to find ways to slow it down. With muscle fatigue, the body has a decreased capacity to perform certain physical interactions and the reduction of one's muscle force. There are two different types of fatigue hypotheses, central fatigue and peripheral fatigue. The central fatigue hypothesis states that muscles have the ability to work longer, however, the central nervous system inhibits this to prevent ensuing injuries. On the other hand, peripheral fatigue declares that the homeostasis of the muscles has been disturbed, leading to the muscle not being capable of responding to the action signaled by the brain [8]. According to Roy Jentjen's study, the best explanation for peripheral fatigue is the exhaustion of muscle glucose supply and the accumulation of lactic acid. As determined before, lactic acid is a waste byproduct that causes a decrease in muscle function [9]. This response prompts the inflammation response in the body. In certain eccentric activities such as weightlifting, muscle fatigue after a few days leads to delayed onset muscle soreness (DOMS) [10]. DOMS is caused by a very intricate process that happens within the muscle fibers themselves. During exercise, when the myofibrils are stretched, some of the sarcomeres within the myofibrils don't stretch as much. As a result, the sarcomeres that are stretched the most become weak and there becomes a gap between the myofilaments. This constant overstretching causes failure of the sarcomeres to reattach, which is commonly known as "microtears". Repeated healing of microtears leads to greater muscle mass and the end of the muscle recovery process.

**Inflammatory response**

As seen in figure 4, the inflammatory response to microtears is best characterized by neutrophils, a type of immune cell, moving to the damaged area to begin the repair process and promoting healing.

**FIgure 4**

*The Inflammatory Process*




*Note.* Shows the process of muscle recovery and the different compounds essential to the process. From Ziemkiewicz, N., Hilliard, G., Pullen, N. A., & Garg, K. (2021). The Role of Innate and Adaptive Immune Cells in Skeletal Muscle Regeneration. *International Journal of Molecular Sciences*, *22*(6), 3265. https://doi.org/10.3390/ijms22063265

They do this by releasing reactive oxygen and nitrogen species.  Other inflammatory cells and factors such as lymphocytes, monocytes, and anti-inflammatory cytokines are mobilized into circulation. After roughly 24 hours, the neutrophils leave the site, and the monocytes give rise to pro-inflammatory macrophages that produce inflammatory cytokines in the muscle. The inflammatory cytokines begin to break down damaged muscle fibers, followed by many other specialized inflammatory antigens. Stem cells, such as satellite cells and fibroadipogenic progenitor cells (FAPs) proliferate, and cause the expansion of satellite cells. After a few days, the satellite cells stop expanding and retreat. The macrophages decrease, turning into anti-inflammatory macrophages, which stimulate satellite cell differentiation. These new satellite cells can help rebuild the damage done to the muscle fibers, finishing the cycle of muscle recovery [11].

**Aging**

The human body naturally seeks  but is hindered by many aspects of the aging process. Regardless of any external factors, the body's internal environment shifts in an attempt to maintain a balance known as homeostasis. For example, during intense physical activity, our body temperature rises above our normal internal temperature of 37 degrees Celsius. In order to maintain balance, the sweat glands become activated, allowing our body to cool down to normal internal temperature. Another example of homeostasis is during times of starvation, our body maintains our nutritional status by utilizing stored resources. This shows how our lives are owed to metabolic homeostasis; and although these practical functions are vital for the body to survive, it eventually fails against one thing, the progression of time. The body requires the consistency of regulatory processes to function, but aging increases turmoil and disturbances, such as a surge in heat generation and demand for oxygen refill. This begins the process of an impaired homeostasis, as the body's cell growth and energy turnover is severely hindered [12]. Furthermore, aging is also classified with the damage to macromolecules. Macromolecules are essentially the building blocks of muscles, meaning that this damage due to aging has consequences. These damages are extremely variable, from a high exposure to mitochondrial ROS to increased damage from UV radiation. This damage can interfere with cell functions such as transcription, translation, and metabolism. Macromolecular damage can also cause aging indirectly through DNA mutations. These DNA mutations can eventually lead to cell death and damaged DNA templates. When these DNA templates become damaged, their transcription is inhibited and the DNA is not able to create amino acids vital for protein synthesis [67]. The body is prone to greater damaged molecules (proteins, lipids, DNA), metabolites (reactive oxygen species), and cell damage with aging [45]. Overall, cell damage caused by free radicals is an important catalyst of aging and disease, more specifically cancer and a suppresed immune system [21].

**How does aging affect cellular respiration?**
Another theory of aging is the oxidative stress theory. With aging also comes an increase in harmful reactive oxygen species [58]. Due to the increase in reactive oxygen species, there is an imbalance between pro-oxidants and antioxidants in the body, which is a leading factor in the development of oxidative stress. This theory claims that oxygen radicals produced during the cellular respiration process damage the mitochondria, protein, and DNA, resulting in the acceleration of the aging process. In particular, the accumulation and production of oxygen radicals are directly correlated with age [68]. In cellular respiration, a vital step in the process is the electron transport chain, which produces vast amounts of ATP by creating a protein gradient. With aging in the oxidative stress theory, electrons leak during the step of transfer from NADH dehydrogenase. This leakage is caused by the inhibition of electron transport by rotenone and antimycin A, both of which block the diffusion of electrons. The restriction of electron transport by these two compounds leads to an increase in $O_2$ production from the reduction of NADH dehydrogenase [13]. Furthermore, the chemical production of oxygen radicals involves redox reactions, where a molecule either gains an electron (reduction/pro-oxidants) or loses an electron (oxidation/antioxidants). These pro-oxidants are extremely relevant because reactive oxygen species (ROS) are linked to cellular respiration [57,58]. In cellular respiration, oxygen is used by the mitochondria to produce ATP.

**Aging of muscles and the different ways it affects muscle recovery**
Aging may cause a condition called sarcopenia. Sarcopenia is defined as the loss of muscle mass during the process of aging. One considerable effect that sarcopenia has on the body is that it leads to a reduction in capillarization of the skeletal muscle, which is an effect associated with aging. This reduced capillarization leads to dysregulation in satellite cell activation and eventually hinders the muscle's ability to regenerate [14]. This is important because skeletal muscle has a significant impact on homeostasis and metabolism. The decreasing metabolisms of such muscle fibers result from declined skeletal muscle mass. This muscle loss is a result of many factors, such as protein oxidation and reduced satellite cell nourishment. Thus, aging

muscle shows an impaired response in numerous mRNAs that might negatively influence muscle growth and remodeling of the tissue [15].

**Myofilament aging**

Changes in the myofilaments of the muscle include the ability of muscle fiber activation, actin/myosin interactions, and energy production. Recent breakthroughs regarding age-induced changes in myofilaments have shown that older men and women have reduced maximal force. One such reason for this is the age-related consequence of reduced protein synthesis within the myostatin gene leading to lower myosin concentration overall. As referred to before, another consequence of aging is oxidation. More importantly in muscles, the increase of oxidation that comes with aging modifies the structure of myosin and obstructs the binding process it has with the actin filament. This is the main reason why it limits the maximum force a person can generate because there is not enough actin-myosin in a strong-binding state. The decreased number of actin-myosin clusters gives off the appearance of a weakened muscle and longer recovery times after muscle use [16].

**Satellite cells**

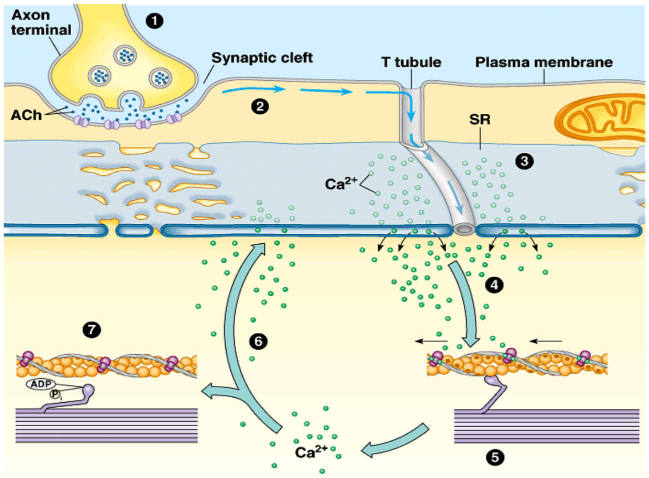
Muscle stem cells, more specifically, satellite cells, help stabilize the health of muscle regeneration and homeostasis. It has been noted that a reduction in these satellite cells are provoked with advancing age. With an aging individual, type 2 myosin-heavy fibers are the main fibers linked with satellite cells. To note, most of the motor fibers that are lost within someone aging are precisely type 2 fibers (fast twitch muscle fibers), with type 1 muscle fibers mostly being unaffected. This decline in muscle mass is also seen with a 30-40% decrease in the number of muscle fibers past the age of 30. Satellite cell activation is overseen by interleukin-6. This specific protein balances satellite cell activation during exercise and other trauma to muscle fibers. However, the advancement of age incites the breakdown of muscle through cytokine-originated proteins [17]. The lack of satellite cells directly translates to a decline in muscle regeneration [18].

**Excitation-contraction coupling**

Relating to contractions and muscle catabolism is a unique phenomenon called excitation-contraction coupling. This process triggers the muscle to contract due to the conversion of sarcolemma action potential into muscle response and a generation of force. Action potential is termed as a shift from negative to positive membrane potential, causing the sodium channels of a neuron to open and close. Excitation-contraction coupling sees a wave of action potential toward the transverse tubules until it gradually goes down into the sarcoplasm of the muscle fiber. This action potential stimulates the opening of sodium channels that are connected with calcium channels. By opening the calcium channels, calcium ions are free to bind with the troponin of the thin filament (actin). A change or mishap in any step of this process may lead to reduced force generation and muscle fiber activation. Within this procedure lies many critical elements that need to work with each other. One of these are the dihydropyridine receptors in the transverse tubule that initially cause the activation of the calcium ions. Aging causes a reduction of dihydropyridine receptors and a shortage of calcium release[19]. As stated before in the hydrolysis process, the body needs continual calcium ions and ATP present in order to repeat the process. With a shortage of calcium ions, energy can’t be provided as efficiently as possible.

**Figure 5**

*Process of Excitation-contraction coupling*




*Note.* [1] An action potential arrives at the muscle junction, diffuses and binds to its receptors on the plasma membrane, [2] the action potential travels along the sarcolemma and down the T-tubules, [3] triggers $Ca^{2+}$ release from the SR (sarcoplastic reticulum), [4] $Ca^{2+}$ binds to troponin [5] contraction occurs, [6] $Ca^{2+}$ is actively removed into the SR when the action potential ends, [7] tropomyosin blockage is restored and the muscle relaxes. From Ducreux, S. (2006). *Functional effects of mutations in the skeletal muscle ryanodine receptor type 1 (RYR1) linked to malignant hyperthermia and central core disease*. Edoc.unibas.ch. https://edoc.unibas.ch/439/

**Adipocyte infiltration**

Adipocytes are cells that store fat and the adipose tissue within the muscles are shown to increase with respect to aging. This increased muscle fat concentration is directly correlated with reduced muscle strength. Increasing the muscle fat concentration also multiples TNF-a (tumor necrosis factor-alpha) production. It has been shown that TNF-a obstructs the excitation-contraction coupling process by changing the calcium storage [20]. We already know that changing calcium levels can harm muscle recovery in many ways.

**Previous research not including nutrients**

There has been some limited previous research focused on  ways to slow down the process of aging in muscles. In a study done by Aversa *et al.* (2016), they stated that the best way to extend one's lifespan was to strengthen the immune system, mainly by preventing the influx of an aging pigment called lipofuscin [21]. In a different approach, Wu *et al.* (2022) discussed the role of regulatory T cells and provided new strategies for immunotherapy in skeletal muscle damage. One such strategy was promoting the proliferation of satellite cells and using these regulatory T cells to hasten the conversion from pro-inflammatory macrophages to anti-inflammatory macrophages. However, there was controversy surrounding the source of the regulatory T cells [22]. A more practical approach was described by Stockinger *et al.* (2017), which explained that a caloric deficit slowed the aging of muscles. More specifically, a natural phenol called resveratrol was found to preserve muscle fibers in mice. It states that resveratrol increases the number of connections between the muscle cells and promotes muscle communication [23].

**Nutrients essential to the body**

In order for the body to perform at its maximum capacity, it requires a variety of distinct nutrients. These specific nutrients consist of carbohydrates, proteins, fats, vitamins, fiber, water, and minerals [24]. Each of these has its specific functions that keep the body running smoothly. Nutrients are split into two different types, macronutrients and micronutrients. Micronutrients are what we know as vitamins and minerals. Our body demands 23 of these vitamins, including but not limited to calcium, magnesium, and vitamin C [25]. These mineral nutrients serve as catalysts for enzymes in many processes within the body. These enzymes play a key role in the digestion and absorption of foods and fluids [24]. However, these minerals and vitamins are only needed in small quantities, compared to macronutrients, such as carbohydrates, lipids, and proteins, which serve as an energy source for the body [25]. They are termed “energy-yielding”, meaning they are needed in large amounts, giving them the name “macro” [30].

**Specific nutrients can help reduce muscle recovery time**

Within all the nutrients that your body needs, there are specific nutrients that have already been shown to reduce the muscle's recovery time. When focusing on muscle recovery, it is important to understand the main causes of muscle fatigue. Any type of strenuous activity causes an increase in metabolism and increases the functionality of the exercised body part [34]. Nutrients that specifically target oxidative stress and inflammation are vital because they can help us understand how to slow down the effect of aging on muscles [35].

**Carbohydrates**

Carbohydrates are organic compounds made up of hydrogen, carbon, and oxygen molecules. Most carbohydrates are digested and absorbed, while others, such as fibers, remain in the digestive tract and provide many health benefits, such as providing the body with glucose [30]. A deficiency in dietary fiber could possibly lead to disturbances in homeostasis. Such examples of this include constipation, colon cancer, and cardiovascular diseases [29]. Carbohydrates are necessary for the body because they induce blood pressure regulation and insulin resistance. They are the main energy source for many metabolic sources in the human body that are needed for daily activities and bodily functions [26]. There are three classes of carbohydrates, monosaccharides, oligosaccharides, and polysaccharides. Monosaccharides are also known as simple sugars, which include glucose and fructose. Next are oligosaccharides, which are composed of two to ten monosaccharide units connected by a glycosidic bond. Oligosaccharides include more complex sugars such as maltose, lactose, and sucrose. Lastly, polysaccharides are the most complex group of carbohydrates. They are made up of 11-10,000,000 monosaccharide units. The three most important polysaccharides that are vital to human health are starch, glycogen, and cellulose [30].

**Carbohydrate benefits regarding muscle recovery time**

Carbohydrates play an extremely important role in the reduction in muscle recovery time. In its general form, carbohydrates help optimize the restoration of muscle glycogen storage and recovery. Specifically, carbohydrate-filled foods with a moderate to high glycemic index improve muscle glycogen synthesis [26]. Adequate restoration of glycogen storage is important as it is how glucose is stored in the body for enhanced exercise performance [68]. Two studies performed by the same research group tracking mountain marathon runners found that carbohydrate supplementation positively stimulates neuromuscular recovery and reduces the decline in performance. It also showed that this supplementation improved long-term muscle recovery [63,64]. As stated already, aging decreases the efficiency of cellular respiration, making processes such as excitation-contraction coupling less powerful. Carbohydrates replenish the intermyofibrillar glycogen, counteracting the muscle impairments caused by damaged sarcoplasmic reticulum calcium ion release. The importance of carbohydrate consumption is demonstrated by to the fact that muscle contractions and ATP activation are affected by muscle damage [63,65]. Carbohydrates also work hand in hand with protein synthesis, protein degradation, and muscle protein breakdown, all of which are affected by glycogen availability. Proper carbohydrate supplementation leads to increased glycogen availability and an advantageous metabolism response concerning the listed processes [66].

**Lipids**

Like carbohydrates, there are numerous types of lipids that have varying functions in the human body. These types include cholesterol, fatty acids, triglycerides, and phospholipids. Triglycerides are the most commonly consumed type of lipid and work along with fatty acids. Triglycerides are broken down into fatty acids and are put into circulation for different functions. Some examples of these fatty acids include saturated, trans, monosaturated, and polyunsaturated fatty acids [30]. Lipids help provide fatty acids for brain development, serve as another source of energy, and are crucial for the absorption of many vitamins [27]. In the digestion process, these fatty acids provide the body with an enzyme necessary to consume omega 6 and 3 ends (their methyl functional group). Cholesterol is another type of lipid and is found in animal-based sources. Consuming cholesterol is vital in the synthesizing of hormones such as estrogen and testosterone. Phospholipids are another type of lipid that helps make up the structure of the cellular membrane and help balance substances that enter and exit the cell [30].

**Proteins**

Proteins are another form of macronutrient that is made up of amino acids connected by peptide bonds. Essentially, amino acids are carbon molecules that are attached to hydrogen groups and a side chain. The side chain is unique for every amino acid and helps defines the unique function of the protein. Amino acids are important because the body cannot synthesize them; they’re required from an external source [30]. Proteins also act as building blocks of tissues in the body. With this, they can also be used to make enzymes, hormones, and hemoglobin [28].

**The benefits of protein in muscle recovery time**

The effects of consuming protein include a drastic reduction in muscle recovery time [37]. In particular, the structure of amino acids (the building blocks of proteins) are the main reason for this reduction of muscle recovery time. Changes to the branched-chain amino acids in the bloodstream cause a difference in how it is utilized by the body, potentially affecting one's peak performance over a period of time. The protein metabolism of this leads to delayed onset muscle soreness (DOMS). The amino acids in protein are best for increasing leucine concentration in plasma. This amino acid period of permanence led to the minimization of muscle soreness, meaning muscle recovery was hastened [36]. Specifically, glutamine is a type of amino acid that promotes muscle recovery by increasing protein synthesis in the human body.

Glutamine supplementation also reduces the impact of the inflammatory response after vigorous exercises [37]. In a study done by Legault et al. (2015), they showed that glutamine reduce muscle soreness, which corresponded with a faster recovery time [38]. Another study concerning glutamine supplementation in the diet showed that after muscle damage occurred, the glutamine caused a reduction of muscle damage markers. It also led to a balance between the anabolic and catabolic hormones and maintained leukocyte cell numbers for recovery. With glutamine being the most abundant amino acid, incorporating it into one's diet will reduce the inflammation that results as a consequence of strenuous activities [39]. In Street et al. (20110 research, they showed that glutamine was important in stimulating the improvement of immune function and restoring plasma concentrations, both of which are affected by aging [44]. The best way to implement protein into your diet is at levels of 1.2-1.6 g/kg or 1.4-2.0 g/kg, according to Saracino et al. (2020) [40,65].

**Figure 6**

*Table overviewing amino acid and protein supplements*

| Nutrient source (key nutrient) | Mechanism of action | Suggested benefits |
|---|---|---|
| BCAAs (*Leucine*, *Valine*, *Isoleucine*) | Increased MPS | ↓DMG, ↓DOMS, ↑MF |
| Creatine | Anti-inflammatory properties | ↓DMG, ↓DOMS, ↓INF, ↑MF |
| HMB | Increased MPS and cellular membrane integrity | ↓DMG, ↓DOMS, ↑MF |
| L-glutamine | Anti-inflammatory properties | ↓DMG, ↓DOMS, ↑MF |
| Protein | Increased MPS | ↓DOMS, ↑MF |
| Taurine | Antioxidant properties | ↓DMG, ↓DOMS, ↑MF |

*BCAAs* branched-chain amino acids, *↓DMG* nutrient reduced indirect markers of muscle damage compared to placebo, *↓DOMS* nutrient reduced soreness and delayed-onset muscle soreness compared to placebo, *↓INF* nutrient reduced markers of inflammation compared to placebo, *HMB* β-hydroxy-β-methylbutyrate, *↑MF* nutrient improved muscle function relative to placebo

*Note.* From Harty, P. S., Cottet, M. L., Malloy, J. K., & Kerksick, C. M. (2019). Nutritional and Supplementation Strategies to Prevent and Attenuate Exercise-Induced Muscle Damage: a Brief Review. *Sports Medicine - Open*, *5*(1). https://doi.org/10.1186/s40798-018-0176-6

In this review study conducted by Harty et al. (2019) (Figure 6), they took different types of amino acid and protein supplements and found the benefits of each in muscle recovery [41]. For example, creatine possessed anti-inflammatory properties that reduced inflammatory markers that are seen with aging. Deminice et al (2013) tested 25 humans and found that creatine supplementation blocked the release of inflammation markers TNF-a, CRP, and LDH [42]. β-Hydroxy-β-Methylbutyrate, also known as HMB, can also improve recovery. It does this by increasing protein synthesis within the body and decreasing muscle protein breakdown. This supplementation slows down muscle damage and gives a quicker recovery [43]. Preceding evidence has shown that the absorption of taurine, an amino-containing sulfonic acid, improves muscle function by displaying antioxidant effects. These effects will be specified in the next section. Taurin regulates calcium homeostasis in muscle tissues and is a beneficial way to decrease oxidative stress markers [46].

**Vitamins**

In contrast to macronutrients, there are micronutrients. As stated earlier, these nutrients are needed in smaller quantities. In particular, vitamins are crucial for maintaining homeostasis and preventing many disorders. There are two main types of vitamins, fat-soluble and water-soluble [31]. Water-soluble vitamins are absorbed after digestion and transported throughout the body by proteins. Some water-soluble vitamins include the vitamin B complex (B1, B2, B3, B6, B12), biotin, and vitamin C [30]. On the other hand, fat-soluble vitamins are absorbed and transported by chylomicrons in the digestive tract, after which they are stored in lipids until needed by the body [32].

**Benefits of vitamins and antioxidants**

The use of foods containing vitamins and antioxidants to strengthen muscle recovery is an ongoing research topic. In exercise, reactive oxygen and nitrogen species are released, causing a state of oxidative stress. The use of vitamins and antioxidants helps neutralize these oxidative species and decreases susceptibility to illness [47].

**Vitamins C and E**

In particular, vitamin C, which is found in many citrus fruits, has advantageous benefits such as the regeneration of antioxidant molecules [48]. In addition to its antioxidant benefits, supplementing vitamin C has been shown to reduce damage to neutrophils (mentioned previously with muscle recovery) and result in a lessened impairment of muscle tissue [49]. Much research has come to the conclusion that the supplementation of ~1000mg/day of vitamin C is a good amount for improving and reducing muscle recovery speeds[47]. On the other hand, vitamin E supplementation has received less spotlight compared to its partner. This is due to the fact that previous research regarding vitamin E has found insignificant results regarding its positives concerning muscle recovery. For example, Jakeman *et al.,* found that there were no effects of vitamin E on muscle damage and antioxidant status [50]. However, Santos *et al.,* established that under hypoxic (low oxygen) conditions, there were greater RONS (reactive oxygen and nitrogen species). Furthermore, vitamin E supplementation in this environment lowered markers of muscle damage and inflammation [51]. As previously stated in this paper, aging increases the demand for oxygen refill. If an increasing need for oxygen is needed as one ages, vitamin E supplementation for that circumstance may be beneficial.

**Vitamin D**

Vitamin D is a secosteroid hormone that is synthesized in the skin as vitamin D3 after exposure to UV radiation. In the body, it is transformed into another form called calcitriol, which helps regulate calcium and phosphate homeostasis. It also takes part in the functionality of numerous tissues through the vitamin D receptor [52,41]. Vitamin D is extremely important for the muscle recovery process due to the fact that it helps muscle regeneration through muscle cell development and balances the immune response (particularly pro- & anti-inflammatory compounds [47]. In Zebrowska *et al.,* it was shown that participants consuming 2000 IU/day of vitamin D3 spanning 3 weeks reduced markers of muscle damage and inflammatory proteins, including interleukin-6 and tnf-a [53]. In particular, vitamin D3 supplementation thrives when sunlight-induced endogenous synthesis is reduced. This is when the body is exposed to sunlight, triggering the production of previtamin d3 [54]. A consequence of aging is a surge of heat generation required, meaning vitamin D can be used to increase the absorption of ultraviolet light from the sun, eventually slowing the aging process. Mieszkowski *et al.* (2021), studied the anti-inflammatory effects of vitamin D on the body. They found that introducing vitamin D into circulation caused a decrease in pro-inflammatory cytokines. This means that greater levels of vitamin D directly correlate to the modulation of the inflammatory response via serum marker levels [56].

**Antioxidants**

Antioxidants are chemical compounds that are seen to be extremely good for overall human health. They can be found in many fruits, vegetables, and teas. Particularly for the body, antioxidants help protect the body's macromolecules from oxidation. They do this by reducing the amount of free radicals that can severely lead to chain reactions within cells [21]. Free radicals are extremely important for the body in small concentrations; however, with the aging process, free radicals begin proliferating [58]. For example, Poon *et al.,* found that ~10,000 free radicals attack each cell per day [59]. When antioxidants are ingested by the body, it triggers an activation of electrons that sends signals to transcription factors. These specific transcription factors are those responsible for the reduction and oxidation of free radicals (specific examples include NF-kB, AP1, and P53). The transcription factors are key for repairing damaged DNA, positively influencing the immune system, and stopping the death of cells [21]. Pearson *et al.,* found that a specific type of antioxidant, resveratrol, created an overall reduction in oxidative stress and inflammation. Moreover, it changed the gene expression in muscle tissue, giving greater motor coordination and vascular function [60]. Another form of antioxidant, polyphenols, improves muscle recovery by signaling activities that regulate antioxidant response and enhance vascular function. Bowtell and Kelly (2019) determined that polyphenol supplementation suppressed oxidative stress and inflammation markers by donating an electron to oxygen radicals and reversing the oxidation process [61].

**Minerals**

Mineral is a very broad term that can be classified into major and trace minerals.. Minerals can be acquired through certain foods and are used to maintain electrolyte balance, enzymatic reactions [30], and stabilization of the body's metabolism and homeostasis [33]. Specific minerals have already been mentioned in the paper when discussing the role they have in reducing muscle recovery time.

**Conclusion**

Research has shown that aging affects muscle fibers, more specifically, striated muscles, by decreasing the effectiveness of cellular respiration and metabolic activity. Both of these have major consequences, including the decline of satellite cell regeneration which is crucial for overall muscle recovery. The decreased effectiveness of cellular respiration is extremely unfavorable because it prompts less ATP to be produced within the muscle. Additionally, decreased energy also causes a weakened inflammatory response. This, in turn, causes decreased satellite cell differentiation and leads to a slower muscle recovery time. With this slower muscle recovery, the striated muscles start to become weaker and ultimately exhibit weakened body movements and functions. This fight for the extenuation of the body's recovery time coincides with recent studies trying to explore what was once unfamiliar. Various methods to slow down the metabolic decline of our muscle fibers have shown that a balance and supplementation of certain nutrients can lead to the amelioration of one's muscle recovery time. This research paper splits these beneficial nutrients into three different categories, proteins, vitamins/antioxidants, and carbohydrates. Many of the studies analyzed in this process showed that these specific nutrients aided in the reduction of inflammation and oxidative stress within the muscle. This is important because the levels of both components are inflated with age, so reducing it is extremely important. The main takeaway of this review is that although these nutrients were extremely useful, only consistent and specific amounts of supplementation could actually help in slowing muscle recovery time. For example, most of the studies gave the subjects a set amount of supplementation for a variable amount of time, not taking into account the fact that stopping this set amount could provide no aid. By understanding all the varying aspects of aging, it is important to implement as many ways possible to treat the body to a healthier and elongated lifestyle. Educating people about the so-called "perfect" nutritional intake will help support healthy aging regardless of the increase in muscle recovery time.

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