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Review Article

Clinical and etiological findings of musculotendinous injuries after physical exercise

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ABSTRACT

The pathogenesis of sports injuries is complex and difficult to identify clearly. Recent theories bring to light new mechanisms related to the production of muscle pain and tendinopathies. The accumulation of lactate can cause fatigue and muscle pain. Apparently, the lactate anion is an excellent fuel for myocardial fibre. Its accumulation of lactic acid after performing intense physical exercise can prevent the excitability of the sarcolemma induced by the increase in the concentration of the interstitial potassium ion. The identification of sports and physical activity that can cause damage to our body has become necessary, due to the increase in the incidence of joint injuries generated by physical activity in people who routinely practice exercise and in athletes, in order to prevent future injuries. Articles related to the different mechanisms involved in the different musculoskeletal injuries related to the practice of exercise have been selected.

Keywords: Sport muscle injury, Musculofascial injury, Pathogenesis, Stress tendinopathy

INTRODUCTION

Different types of prolonged physical exercise are beneficial to health through different mechanisms. Muscle contraction during exercise causes muscle remodelling and increases blood flow at this level. This increase in the speed of flow through the vessels during physical effort stimulates neovascular development to increase muscle needs. Blood vessels enlarge by stimulating the vascular endothelium through the direct participation of nitric oxide.[1] The favorable effect of physical activity is well known from several studies. Hotta et al mention that repeated stretching of muscle fibers after exercise generates a benefit to the vascularization of muscle tissue. They found that stretching practiced daily increases local blood flow through vasodilation, generating angiogenesis.[2]

Other research teams led by Behnke conclude that the reduction in exercise capacity in older adults is due to decreased blood flow at the level of skeletal muscle, however vascularization in adults can improve with the help of physical activity.[3] Despite all the benefits shown during sports practice, this should be done in an appropriate environment and following a program in order to avoid injuries characteristic of each type of sports activity. It is necessary to have knowledge of the pathogenetic mechanism of muscle injuries in order to achieve optimal management.[4] Physical activity with

excessive load on the musculoskeletal tissues can cause injuries that have been grouped into 3 categories myofascial, myotendinous and muscular. Myofascial injuries are located at the level of the fascia in the epimysium and its deep branches, perimysium and endomysium, but they can also affect the insertions between the fascial connective tissues and the muscles. Myotendinous injuries affect both tendons, proximal and distal, or the tendon insertions of the muscles. Muscular injuries are located at a distance from the fascia and tendons and strictly affect the muscle fibers. The location of the injury is important for a correct diagnosis and adequate therapeutic management.[4]

According to their etiology, injuries associated with sports practices can be traumatic or due to overuse. Regardless of their etiology, sports injuries require medical attention, including surgical interventions followed by long-term medical recovery. The prevention of sports injuries is the fundamental objective of this research, due to the high cost of recovery, poor sports performance, intense pain and direct impact on quality of life are its main causes.[5]

It is a descriptive-exploratory study type of bibliographic review. The literature search period is from 2000 to 2024 in electronic databases such as PUBMED, ELSEVIER, and Web of Science. The keywords used in the MesH search were sport muscle injury; musculofascial injury, pathogenesis; stress tendinopathy. Inclusion criteria include search terms, level of evidence, summaries and keywords, exclusion criteria: not related to the topic, outside the year limit, not available. They will be classified by year, type of study and level of evidence. For eligibility, a critical reading is carried out, level of evidence, documents available for analysis and according to the topic. A total of 30 sources were obtained for analysis and synthesis.

Beneficial effects of exercise on the cardiovascular level

Exercise consists of physical activity performed intentionally. This is done with the aim of improving physical abilities, where activities such as high-intensity aerobic training or resistance training stand out.[6] Evidence demonstrates the primary and secondary protective role of exercise, which improves with regular practice. This habit reduces the risk of developing cardiovascular diseases (CVD), diabetes, high blood pressure and obesity. According to data from the World Health Organization (WHO), adequate adherence to the habit of exercise reduces mortality by approximately 30% due to CVD and 29% due to all associated pathologies.[7]

Cells and tissues undergo adaptations secondary to exercise. It causes an increase in mitochondrial biogenesis at the level of adipocytes, muscular myocytosis (skeletal and cardiac), and an increase in aerobic respiration in the tissues. As an effect, the supply of oxygen in the body is increased due to vasodilation and angiogenesis. Another effect is anti-inflammatory, which is evident in the long term and is inversely related to CVD and obesity.[8] Figure 1 demonstrates how exercise influences the cardiovascular system.

Effect on blood vessels

Exercise produces an increase in cardiac output, due to the increase in systolic volume and tachycardia. Initially, this, together with the transient increase in peripheral vascular resistance, causes an increase in mean arterial pressure (MAP), but in the long term, a reduction in MAP occurs and is associated with a decrease in heart failure events.[9,10] The causal mechanism of this is due to the systemic reduction of systemic vascular resistance secondary to performing exercise 3 to 5 times a week. In addition to this, there is the release of metabolites such as nitric oxide and prostacyclin from the vascular endothelium, which cause vasodilation by the relaxing action of smooth muscle. Exercise also increases the expression of endothelial nitric oxide synthase (eNOS), which has a hypotensive effect.[9,10]

During exercise, angiogenic stimuli are produced. Vascular endothelial growth factor (VEGF) is produced, which causes the development of blood vessels (angiogenesis). Another factor that promotes angiogenesis is angiostatin and platelet factor 4 (PF-4). Constant exercise produces a decrease in angiostatic factors, promoting angiogenesis.[11,12]

Endothelial cells depend on glycolysis. The lack of mitochondria limits glycolysis, which decreases the angiogenesis process. The role of these mechanisms is based on the production of lactate, which plays an important role in angiogenesis. This can be produced by endothelial cells or can come from other muscle cells to promote vascular neoformation.[13]

Mitochondria

Exercise increases the volume and functional capacity of mitochondria. This increases ATP production in skeletal muscle. This can be evidenced using biomarkers such as: the number of mtDNA copies normalized to nuclear DNA, the percentage of RNA-seq reads mapped to the mitochondrial genome, and the content of cardiolipins.[14] There are signaling pathways that confer changes to cellular processes that cause tissue adaptation through endocrine signaling. These pathways are the phosphatidylinositol 3-kinase-protein kinase B (PI3K-Akt) pathway and transcriptional regulators such as peroxisome proliferator-activated receptor gamma coactivator 1-alpha (PGC-1α) and sirtuin 1 (SIRT1), among others.[15]

MECHANISM THAT PRODUCES AN INCREASE IN MUSCLE PAIN AFTER ECCENTRIC EXERCISE

Delayed onset muscle soreness (DOMS) experienced after exercise, especially in activities involving eccentric

contractions, is due to a series of complex pathophysiological mechanisms that interact with each other.[16] During exercise, muscle fibers suffer micro-injuries due to significant mechanical tension in the contractile structures (sarcomeres), where the muscle lengthens under tension. This causes the rupture of muscle fibers, alteration of the Z-line, and irritation of the muscle fascia. Although this damage can be beneficial in the long term, it causes pain in the short term (between 24 and 72 hours) and is more evident in muscles that are not accustomed to the load.[2,20]

Following muscle damage, the inflammatory response is activated in the body, which includes the release of various inflammatory mediators such as cytokines (Interleukins IL-1β, IL-6) and tumor necrosis factor alpha (TNFα), as well as prostaglandins. These mediators increase the permeability of blood vessels and attract immune cells to the affected area, sensitizing nerve endings and intensifying the perception of pain.[16,18]

Although this process is crucial for tissue repair, it can also prolong the sensation of pain. Calcium also plays an important role in the initiation of these inflammatory alterations. Additionally, there is an increase in the release of the enzyme creatine kinase and myoglobin (which transports oxygen in muscles). These indicators reflect the magnitude of the damage and correlate with the intensity of the pain experienced.[16,17]

Intense exercise involves an increase in energy metabolism, resulting in the accumulation of metabolic products such as lactate, lactic acid, and protons. Although these are not the primary cause of pain, their accumulation can contribute to the irritation of nociceptors and interfere with the normal function of muscle cells, exacerbating damage and inflammation. Similarly, there is an increase in the production of reactive oxygen species (ROS), which generate oxidative stress in muscle cells. This stress can damage cell membranes and contribute to inflammation, exacerbating the sensation of pain.[16]

Damage to muscle structures can compromise the ability of fibers to carry out muscle contraction effectively. Muscles with a fusiform architecture, such as the biceps, are more sensitive to damage than those with a multipennate architecture, such as the quadriceps.

Additionally, type II muscle fibers are more prone to damage during eccentric exercise compared to type I fibers, which can affect the intensity of the pain. This translates into a decrease in strength and an increase in muscle stiffness, contributing to the sensation of pain and weakness.[17,18]

After exercise, the recovery process involves the repair of micro-injuries and the restoration of homeostatic balance. However, if the damage is significant, there may be a process of regeneration that includes fibrosis and alterations in the structure of the muscle tissue, which can prolong the sensation of pain and affect muscle function in the long term.[16]

DOMS is the result of a combination of muscle damage, inflammation, accumulation of metabolites, and biochemical changes, all of which can vary in their impact depending on the type of exercise performed and the individual's physical condition. These mechanisms are complex and interrelated, making the experience of muscle pain unique for each person.[17]

Prevalence of extramuscular connective tissue damage

Extramuscular connective tissue injuries are surprisingly common, especially in sports. Recent studies have shed light on fascia's dynamic role in muscle mechanics, showing its ability to contract and redistribute external forces. When these forces exceed what the fascia can handle, injuries like tears and degeneration occur, often at the muscle-tendon junction or between muscle fibers and surrounding connective tissues such as the endomysium and epimysium. These myofascial injuries frequently go hand-in-hand with muscle strains, underscoring the intricate relationship between fascia and muscle fibers in injury patterns.[20,23]

In high-impact sports like football and sprinting, damage to extramuscular connective tissue is a crucial yet often overlooked aspect of muscle strain injuries. Research shows that when muscles are strained, surrounding structures like tendons and fascia also take a hit, particularly where muscles and tendons meet. The upper portion of tendons and nearby connective tissues are more prone to strain injuries, making high-speed activities particularly risky.[23,24]

Fatigue plays a significant role in the increasing prevalence of extramuscular connective tissue injuries. As athletes tire, their coordination and biomechanics change, putting extra stress on muscles and associated connective tissues. This makes managing fatigue crucial for injury prevention.[20] The body's inflammatory response following a muscle strain can also lead to connective tissue damage. Fibrinogen deposits in injured tissues often trigger inflammation that, if unchecked, can cause scarring and ongoing inflammation. This can slow healing and increase the risk of long-term connective tissue damage.[23]

The high recurrence rates of muscle strain injuries are partly due to incomplete healing of both muscle fibers and connective tissues. This partial recovery leaves athletes vulnerable to re-injury. To break this cycle, rehabilitation programs need to focus on restoring both muscle and connective tissue health, ensuring a more complete recovery and reducing the risk of future injuries.[23,24]

Tissue injuries in injuries due to muscle strain

Athletes often experience muscle strain injuries ranging from mild to severe, with the myotendinous junction being

particularly vulnerable to rupture due to excessive stretching of muscle fibers. These injuries commonly occur during high-intensity sports that involve eccentric contractions and mechanical overload.[20]

Repeated stress on muscles and their connective tissues can lead to ongoing issues such as tendinopathies and delayed onset muscle soreness, as well as inflammation and scarring. Fatigue plays a significant role in increasing the risk of muscle strains by impairing neuromuscular control. This further complicates the relationship between connective tissue damage and muscle strain injuries.[21]

Inflammation is a key factor in the progression of tissue damage following muscle strain. While prolonged inflammation is necessary for repair, it can also hinder the healing process and promote excessive scarring. This highlights the importance of maintaining a balanced inflammatory response to ensure proper tissue regeneration.[23,24] Effective rehabilitation strategies must address both muscle fibers and connective tissues involved in strain injuries. By targeting both tissue types appropriately, healthcare professionals can reduce the risk of reinjury and promote long-term recovery.[21,22]

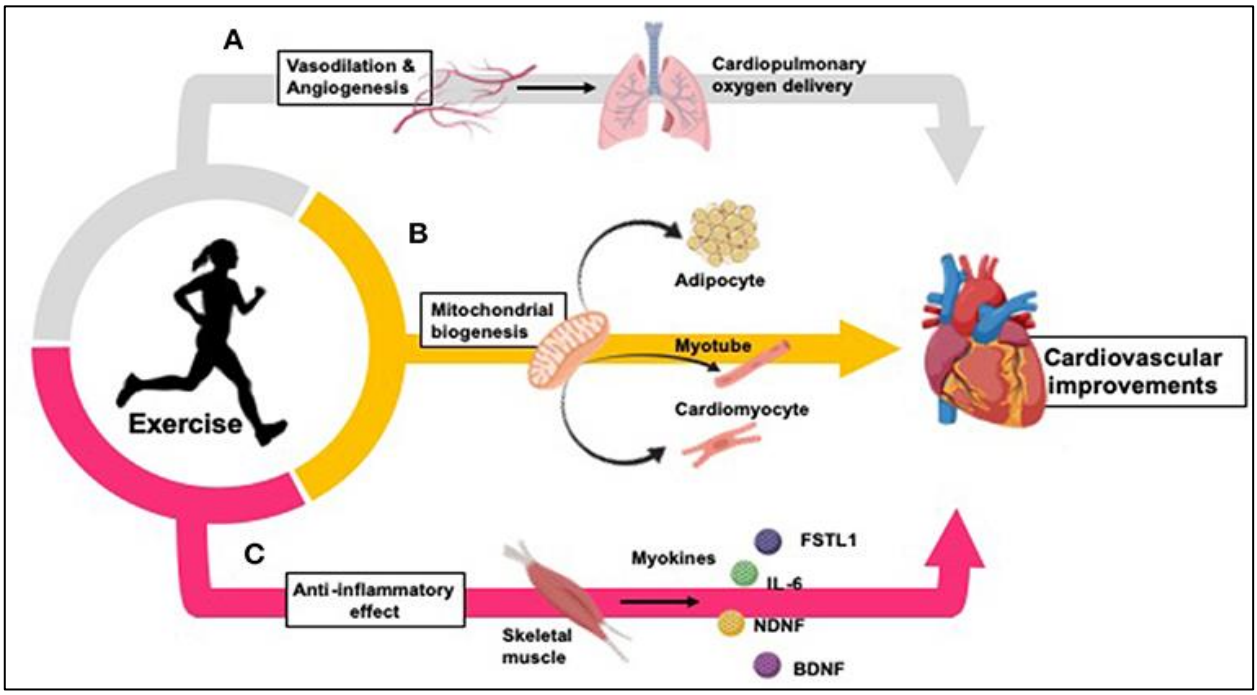

Figure 1: Effects of exercise on cardiovascular level.

DISCUSSION

Pathophysiology of muscle pain and tendinopathy after exercise

It's important to understand that muscles and fascia are interconnected and work together to facilitate body movement. Therefore, when a muscle is injured, the fascia is often injured as well. The most susceptible area lies between the muscle fibers and the fibrous connective tissue. There are various mechanisms and theories regarding the causes of pain.[24]Delayed Onset Muscle Soreness (DOMS) refers to the onset of pain 1-3 days after engaging in high-intensity muscle activity. This pain is primarily attributed to injury and pain in the fascia, rather than in the muscle itself.[24] There are several theories on the pathophysiology of DOMS, but the most widely accepted is that type III afferent nerves are activated by inflammation associated with intramuscular swelling, due to pressure on mechanosensitive receptors.[25] Lactic acid (found in the body as lactate) is produced by muscles at all times, both at rest and during exertion, with the amount depending on the level of effort. Lactate breaks down into H+ ions and lactate anions, which increase the release of potassium ions from the muscles, contributing to muscle fatigue.[24] The local inflammatory response in muscle injuries is mediated by the enzyme C-C motif chemokine ligand 2 (CCL2) and its receptor C-C chemokine receptor type 2 (CCR2). These activate and modulate macrophages and other inflammatory cells to repair tissues after ischemia occurs.

Macrophages release cytokines that sensitize nociceptors (pain receptors), stimulating the release of substance P (a neuropeptide involved in pain transmission). This process reduces muscle strength and stimulates fibroblasts to produce collagen. Excessive collagen production can result in fibrosis and scar tissue formation, leading to pain and stiffness.[24] Skeletal muscle healing involves three phases: destruction, repair, and remodeling. Destruction begins with the formation of a hematoma between ruptured muscle fibers and the proliferation of inflammatory cells in the injured area. Repair and remodeling involve the

phagocytosis of necrotic tissue, the generation of new scar tissue, and the formation of new blood vessels, all of which are vital to the muscle healing process.[26]

Inflammatory tendinopathy occurs 3-7 days after an injury and is caused by overuse of tendinous fibers, leading to small tears due to the reduced diameter and density of collagen fibers. (1) In Histological studies have shown that the initial inflammatory response is driven by macrophages and proinflammatory cytokines. This is followed by a fibrinous exudate with proliferating fibroblasts that produce collagen and alter tendon structure, resulting in scarring in different portions of the tendon and the presence of neovascularization.[26]

Lactate production mechanisms and the relationship with fatigue during exercise

The primary fuel sources for muscles during exercise are glycogen, glucose, and free fatty acids. During high-intensity exercise, anaerobic metabolism primarily relies on glucose and glycogen. As these stores deplete, fatigue sets in.[28] Anaerobic glycolysis consists of the breakdown of glucose for energy. Under aerobic conditions, glucose is converted into pyruvate and enters the Krebs cycle. However, during intense exercise, pyruvate is converted to lactate by the enzyme lactate dehydrogenase (LDH).[28]

Muscles constantly produce lactate, which, in low amounts, is metabolized by the liver (through the Cori cycle), myocardium, and kidneys to produce energy (glucose). In higher concentrations, lactate causes reduced muscle endurance. A well-supported theory suggests that lactate accumulation lowers intracellular pH due to excess hydrogen ions (H+), which inhibits calcium metabolism in the sarcoplasmic reticulum and decreases sensitivity to contractile filaments. This, along with the release of potassium (K+) from skeletal muscles, impairs muscle fiber excitability and accelerates fatigue.[29]

Another theory points to muscle fatigue caused by phosphocreatine depletion and the accumulation of inorganic phosphate, a by-product of phosphocreatine and ATP hydrolysis. This theory is supported by improved performance in athletes who supplement with creatine.[30]

CONCLUSION

The benefits of physical education and sport are indisputable. This work allows a search of updated literature in a single work, which is essential for all sports medicine professionals. Muscle contractions during exercise are favorable to angiogenesis, which supports the properties of skeletal muscle. Exercise requires a coordinated program to prevent possible traumatic and overuse injuries. The pathogenesis of these injuries is complex and not fully known. The studies carried out to identify the pathogenetic chains involved in sports injuries are useful to guide the diagnosis, the establishment of new directions for therapeutic management and the recovery of functional capacity.

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