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FLEXIBILIDADE E TENDÃO DE AQUILES: UMA BREVE REVISÃO

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Resumo: A realização de treino de flexibilidade como rotina em um programa de exercícios é importante para melhorar amplitude de movimento (ADM). Os tendões têm um impacto profundo na função geral do sistema musculoesquelético, influenciam na limitação da ADM, e sua estrutura e propriedades mecânicas podem se beneficiar de protocolos de alongamento. O uso sistemático dos membros inferiores na locomoção fez com que o tendão de Aquiles se tornasse o maior e mais forte tendão do corpo humano. Portanto, entender qual a melhor prescrição e frequência de exercício de flexibilidade para que ocasione alterações nas propriedades tendíneas é essencial para uma rotina de exercícios adequada e eficaz. Sendo assim, o objetivo dessa revisão de literatura foi organizar e discutir publicações sobre as implicações do alongamento do tríceps sural na ADM, bem como sua influência nas propriedades tendíneas. Estudos agudos mostram que tempos contínuos entre cinco e 10 minutos de alongamento estático causam diminuição da rigidez tendínea, o que não é visto em tempos intervalados inferiores a cinco minutos. Os estudos crônicos, por sua vez, também não apresentam resultados significativos na rigidez com protocolos de alongamento intervalados e estudos com protocolos contínuos não foram encontrados. Dessa forma, não é possível saber se um tempo contínuo de alongamento (superior a um minuto) ou um tempo superior a cinco minutos, intervalado, podem influenciar na rigidez tendínea.

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Palavras-chave: tendão do Calcâneo; amplitude de movimento articular; fenômenos biomecânicos.

Afiliação

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FLEXIBILITY AND ACHILLES TENDON: A BRIEF REVIEW

Abstract: Performing flexibility training in an exercise program is important to improve range of motion (ROM). Tendons have a profound impact on the general function of the musculoskeletal system, influence the limitation of ROM, and its structure and mechanical properties can benefit from stretching protocols. The systematic use of lower limbs in locomotion caused the Achilles tendon to become the largest and strongest tendon in the human body. Therefore, understanding the best prescription and frequency of flexibility exercise leads to changes in tendon properties is essential for an appropriate and effective exercise routine. Thus, the aim of this review was to organize and discuss publications about the implications of triceps surae stretching in ROM, as well as its influence on tendon properties. Acute studies show that continuous stretching times between five and 10 minutes cause decreased tendon stiffness, which is not seen in fractionated stretching times less than five minutes. Chronic studies, in turn, also don't present significant results in stiffness with fractionated times and studies with continuous times were not found. Thus, it is not possible to know if a continuous stretching time (longer than one minute) or a total time longer than five minutes but fractionated, can influence the tendon stiffness.

Key words: Achilles tendon; range of motion, articular; biomechanical phenomena

Introduction

According to the American College of Sports Medicine (2011) (ACSM)[1] it is important to perform flexibility exercises to improve joint range of motion (ROM), postural stability and balance in all age groups, especially in elderly individuals who lose ROM over time.

Optimal musculoskeletal function requires adequate maintenance of movement in all joints, and it is very clear in the literature that resistance training induces structural and mechanical changes in the muscle-tendon unit (MTU)[2]. On the other hand, the flexibility training proves to be effective in increasing ROM in several populations, but it is not yet clear what mechanical changes occur. Two theories are more widely accepted in the literature to explain these gains: theory based on sensor mechanisms (sensory) and changes in non-contractile structures (mechanical)[3]. Sensory theory has been proposed that the increased ROM is due to a modification of sensation, when it is only observable that subject's perception of the ROM final feeling occurred later after stretch application[4]. The mechanical theories include viscoelastic deformation, because the viscous behavior of MTU when they undergo stretch of sufficient magnitude and duration[4].

However, flexibility is directly influenced by the soft tissue that surrounds the joint (e.g., muscles, joint capsule, ligaments and tendons)[5]. It is know that when passive movement occurs in a joint, the tendon is responsible for part of the deformation observed in the muscle complex antagonist to the evaluated movement[6].

Tendons have a profound impact on the general function of the musculoskeletal system in its role as a force transmitter from muscle to bone. The systematic use of lower limbs in human locomotion caused the Achilles tendon to become the largest and strongest tendon in the human body[7].

The tendons, constituted by type I collagen fibers, influence the limitation of ROM and their structure and mechanical properties may benefit from stretching protocols[8], since may change in response to the frequency, duration and magnitude of activities. Thus, the use of stretching exercises is indicated to restore ROM and decrease tendon tension[5], besides contributing to injury prevention by allowing the good functioning of the entire kinetic chain of motion[9]. However, so far, few studies have directly evaluated deformations related to tendon properties during passive stretching[10-11].

Therefore, understanding the best prescription and frequency of flexibility exercise to cause changes in tendon properties are essential for a proper and effective exercise routine[12]. Thus, the aim of this literature review was to organize and discuss publications about the implications of triceps surae stretching in ROM, as well as its influence on Achilles tendon properties.

Achilles Tendon

The calcaneal tendon (Achilles tendon) is constituted of the sheaths of connective tissue of the soleus, medial and lateral gastrocnemius muscles, thus forming the triceps surae muscle group, responsible for plantar flexion of the ankle. It is the greatest and most resistant tendon in the human body, yet it is one of the most common sites of overload injury due to its susceptibility to high loads and stress during locomotion[13-14].

The triceps surae muscle group is most important for performing daily lie and sports activities due to its influence on lower limb strength and power output during locomotion[9,14]. Thus, the tendon receives significant mechanical loads for the purpose of storing and returning elastic energy, thus allowing explosive movements like running and jumping[15]. It is exposed to a considerable stress load in its role of power transmission, it is subsequently vulnerable to the development of damage induced by the load[16].

Limited dorsal flexion due to shortened triceps surae, combined with low strength, may limit an individual's ability to respond to anterior postural disturbances, and thus require more force to control the center of mass. This can prevent normal walking and cause falls in the elderly[17]. In addition, shortening of these muscles it is associated with several lower limb disorders, such as Achilles tendonitis and plantar fasciitis[18]. These factors demonstrate the importance of establishing proper stretching protocols for maintaining and/or increase angle ROM.

Mechanical Properties Of The Tendon

Skeletal muscle are composed of contractile components, the muscle fibers, and elastic components, the aponeurosis, the muscle sheaths (endomysium, perimysium and epimysium) that are constituted after the end of the muscular belly to form the tendon[19]; this set of contractile and elastic components forms the MTU[20]. The tendons, in turn, are white and flexible bands, found forming the origin and insertion of muscles with the function of transmitting muscle strength to the bone[21-22].

The tendons are also responsible for the storage and release elastic energy during joint movements, which characterizes them as a "biological spring"[11,19,23]. They are constituted by a complex extracellular matrix, composed of type I collagen and elastin, responsible for traction force, as well as blood and lymphatic vessels and nerves[22]. The collagen fibers, which form the basic unit of the tendon, come from the multiple fibrous sheaths that surround the muscle (endomysium, perimysium, epimysium and fascia) and make it a dense connective tissue structure.

These collagen fibers are grouped into fascicles, which are wrapped by the endotendon. The fascicles are then surrounded by epitendon, which is supplied by blood and lymphatic vessels and nerves; and around it is yet another sheath called paratendon[24](Figure 1).

The Achilles tendon presents this structural feature, its blood supply is carried by a branch of the posterior tibial artery that provides blood to the peritendinous tissues. The middle portion of the tendon is poorly vascularized. It also receives sensory innervations, especially branches of the sural nerve. Most of the innervations are seen in the paratendon, with little penetration into the epitendon toward the endotendon[25].

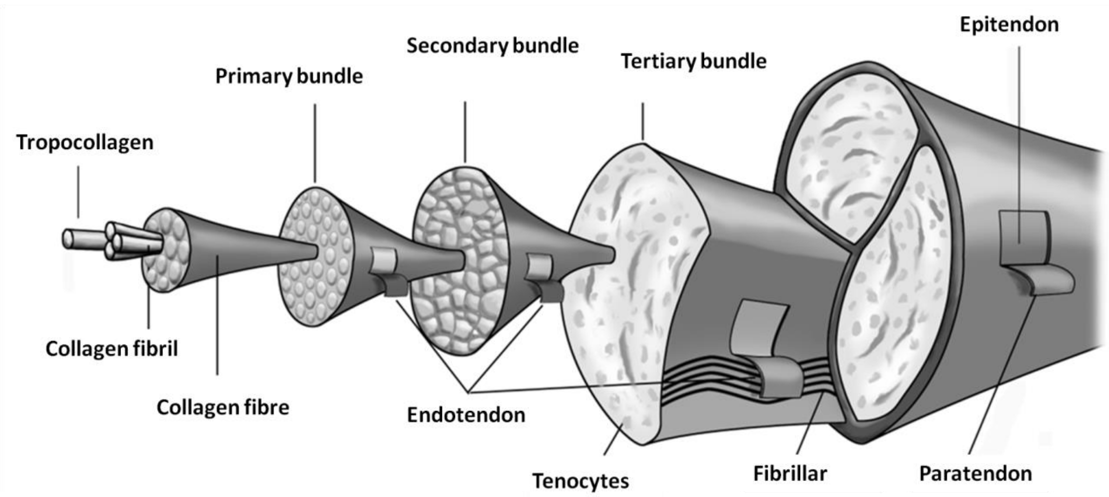

Figure 1 - Internal architecture of tendon.

When the tendons are studied, the presence of a complex mechanical behavior is observed, namely, the improved range of stretching, resulting from time and history dependent viscoelastic responses.

These responses come from collagen, which as a viscous material, provides flow resistance (e.g., its liquid content provides resistance to movement within the extracellular matrix when stress is applied to this liquid content), defined as viscosity, and affects the load-deformation curve of these tissues by applying force.

At the beginning of the load-deformation curve (Figure 2-1), the toe region is observed, that is, the collagen fibers, which at rest are wavy begin to distend when force is applied, all crimpled fibers straighten. Thus, it is known that when stress is applied, such as when the tendon is stretched, collagen fibers become aligned, causing considerable deformation without using excessive force. By maintaining the overload, after fiber rectification, the linear region or elastic phase begins, where the presented deformation increases linearly with the applied force (Figure 2-2). During this phase the tissue is able to return to its original shape upon removal of the load. In practice, the linear region can be observed when the tissue is taken to the end of its ROM and a smooth stretch is applied. The rhythm of elastic return is determined by the properties of the material, in particular the amount of viscous resistance. It is still possible to observe a yield region, or phase of plastic deformation, which occurs when the elastic limit of the material is exceeded (Figure 2-3). In the yield region the return after load elimination is limited, following a different path than the initial path traveled. Tissue may become permanently deformed due to tissue failure[26].

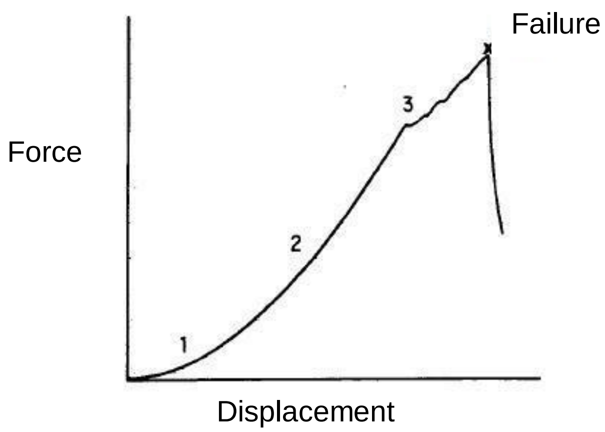

Figure 2 - Tendon load-deformation Curve. (1) toe region; (2) linear region; (3) yield region.

The return path of the load-discharge of the load-deformation curve is called hysteresis, which represents the amount of energy lost in heat during the recoil[27]. By minimizing hysteresis it is possible to increase movement efficiency.

Another aspect that is related to movement efficiency is tendon stiffness. The more complacent the tendon, the greater the ability to stretch and absorb energy. On the other hand, the stiffer a tendon, the more force it takes to increase its length, but the less muscle strength it takes to move a joint.

In turn, because they are constituted by connective tissue, the tendons have the ability to adapt to stimuli, as a result of their plasticity, thus being able to assume a new length after the removal of the initial stimulus. As such, they can benefit from stretching exercise as it leads to increased MTU extensibility and, thereby, increases ROM[8].

Stretching and Tendon

The absence of regular stretching training and the practice of sports that perform repetitive movements favor a reduction of ROM. The restriction of joint ROM) affects flexibility. This characteristic is considered an intrinsic property of body tissue that depends on the viscoelasticity of muscles, ligaments and other connective tissues, such as tendons[28].

In sports, problems involving tendons represent a large part of musculoskeletal injuries, such as tendinopathies, being a frequent cause of removal the sports field[22]. Tendinopathies occur when the tissue, on receiving the tension imposed by the movements, cannot deform in order to absorb energy, leading to the onset of micro lesions that over time result in inflammation and rupture.

Factors that are commonly associated with injuries to the musculoskeletal system are excessive stiffness, greater hysteresis, and decreased flexibility in the myotendinous complex[29]. Since stretching can improve these parameters[30], it is an exercise used to increase ROM, seeking change in viscoelastic tendon behavior[15].

Static stretching is the most commonly used method to restore or increase flexibility, and is also a therapeutic method for tendinopathy rehabilitation. It is characterized by a slow stretching in the MTU to the point of individual tolerance, maintaining tissue at the at the position of maximum length for a given time[31]. The main advantages of this method over other types of stretching are the low energy application, low risk of exceeding tissue extensibility and unlikelihood of causing pain[5,32]. Stretching only increases ROM when traction is maintained long enough time for the connective tissue to deform, the duration of stretching being directly proportional to the viscoelastic deformation capacity[8].

Although stretching is a common practice and several studies show increased ROM after its application[33-35], the evaluation of its efficacy is often restricted to joint movement[36-37], which limits knowledge regarding the mechanism that leads to this increase[9] often causing the attribution of flexibility gains only to increase the individual's tolerance to stretching[23].

Knowing that flexibility is influenced by the soft tissues surrounding the joint, e.g. muscles, joint capsule, ligaments and tendons[5], it is necessary to investigate other outcomes after stretching in order to obtain more objective information on the behavior of MTU[14,38].

Stiffness is among the outcomes that allow the assessment of muscle tendon structure behavior. The stiffness of a tissue is determined by the amount of change in the length of this structure when force is applied. The MTU stiffness, as well as muscle and Achilles tendon stiffness are calculated from mathematical formulas that include values of passive torque and myotendinous junction (MTJ) displacement. These outcomes were obtained using an isokinetic dynamometer[37,39-42] and ultrasound[8,37,40-41], respectively. These outcomes, for the ankle, are measured during passive movements of this joint between the neutral (0°) position and a maximum dorsal flexion.

Stretching with acute protocols of one to two minutes duration has not shown significant results in MTU stiffness[43], while longer times, between two and a half and three minutes, show a decrease in this stiffness[44]. In addition, studies show that, although MTU stiffness decreases immediately after static stretching at times between two and 8 minutes, this reduction is temporary, since after 20 minutes of rest the stiffness returns to basal level[38].

Hypotheses are presented to explain the mechanism responsible for this decrease in MTU stiffness induced by stretching, namely: it increases tendon compliance, that is, it decreases tendon stiffness[45]; increases length of muscle fascicle[44]; and/or alteration of intramuscular connective tissue[37].

Due to the possible interference of tendon stiffness in MTU stiffness, recent studies have begun to evaluate the effect of stretching on tendon stiffness acutely (one intervention) and chronically (after stretching protocols ranging from days to weeks).

Acute Effects

Acute studies (Table 1) show that times between five and 10 minutes of continuous static stretching cause decreased tendon stiffness measured by ultrasound[45-46]. In studies with a shorter and fractionated stretching time protocol, however, tendon stiffness does not change after stretching[9,39,47]. These results suggest that it is necessary to perform stretching for a longer time to have an effect on tendon stiffness.

Table 1 – Characterization of studies on the acute effect of passive static stretching on the mechanical properties of the Achilles tendon.

STUDY	PARTICIPANTS	STRETCHING PROTOCOL	RESULTS
Kay and Blazevich, 2009a[9]	15, male and female	3 x 1 min (rest 60s)	- No difference in tendon stiffness.
Kay, Husbands-Beasley and Blazevich, 2015[47]	17, male and female	4 x15 s	- Increased ROM. - No difference in tendon stiffness and PT. - Decreased muscle stiffness and MTU.
Konrad, Stafilidis and Tilp, 2017[39]	122, male and female	4 x 30 s (rest 20 s)	- Increased ROM. - No difference in tendon stiffness. - Decreased PT, muscle and MTU stiffness.
Kubo et al., 2001[45]	7 male	10 min	- Decreased tendon stiffness and hysteresis.
Kubo, Kanehisa and Fukunaga, 2002a[46]	8 male	5 min	- Decreased tendon stiffness and hysteresis.

d: day; s: seconds; min: minutes ROM: range of motion; PT: passive torque; MTU: muscle-tendon unit.

Long-term Effects

Studies with chronic stretching protocols have increased ROM, but there are still few studies evaluating the effects on the tendon[14,42].

Studies found in the literature (Table 2) do not present significant results regarding tendon stiffness. For example, Blazevich et al.[14] and Konrad and Tilp (2014)[41] who applied four sets of 30 seconds, with three and six-week protocols, respectively, did not observe changes in the mechanical properties of the tendon nor did Kubo, Kanehisa and Fukunaga (2002b)[48], when applying five sets of 45 seconds of stretching twice a day for approximately three weeks.

The fractionated protocols do not present an alteration in stiffness which may be due to the time of rest of the muscles between one and another stretching serie. These studies applied fractionated stretching protocols shorter than five minutes and found no change in tendon stiffness, nor did acute studies with these characteristics. Tendon stiffness decreased in acute studies with and continuously applied stretching protocols[45,48], However, no chronic studies with this type of protocol were found to evaluate whether the results are similar.

Although chronic studies found no direct alteration in tendon stiffness, they present alteration in passive torque and MTJ displacement, outcomes that influence tendon stiffness.

Besides it not being clear in the literature whether change really occurs in tendon stiffness with stretching, it is also uncertain how the stretching protocol should be applied to change this variable. This gap in the literature thus justifies the need for controlled clinical studies with chronic stretching protocols that provide the scientific basis and information regarding the forms of conduct clearly for its application in clinical practice.

Table 2 - Characterization of studies on the chronic effect of passive static stretching on the mechanical properties of the Achilles tendon.

STUDY	PARTICIPANTS	PROTOCOL	DURATION	RESULTS
Blazevich et al., 2014[14]	22 male	3 weeks, 2x/d	4 x 30 s	- Trend of the decreased MTJ displacement. - No difference in tendon stiffness and PT.
Konrad and Tilp 2014[41]	49, male and female	6 weeks, 5d/week	4 x 30 s	- Increased ROM. - Without change in structural parameters of muscle and tendon.
Kubo, Kanehisa and Fukunaga, 2002b[48]	8 male	2.86 weeks, 2x/d	5 x 45 s	- No difference in tendon stiffness. - Decreased hysteresis.
Mahieu et al., 2007[42]	96, male and female	6 weeks, Dayli	5 x 20 s	- Decreased PT. - No difference in tendon stiffness.

d: day; s: seconds; ROM: range of motion; PT: passive torque; MTJ: myotendinous junction.

Conclusion

The literature presents several types of passive static stretching protocols with positive effect the increase of ROM, but with few identified changes in the mechanical muscle-tendon properties after the interventions.

The chronic response with fractional stretching for less than five minutes seems to be similar to the acute one and does not cause changes in tendon stiffness. Thus, there are two possible hypotheses: (1) longer stretching times may be necessary to generate changes in tendon stiffness, regardless of being fractional or continuous; or (2) the fact that the protocol is continuous, which influenced tendon stiffness, and shorter times of continuous application could produce the same effect.

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