The role of muscle quality in the treatment of chronic Achilles tendon pathology

O papel da qualidade muscular no tratamento de patologia crônica do tendão de Aquiles

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Kewords:
Muscles; Achilles tendon/pathology

Descritores:
Músculos; Tendão do calcâneo/patologia

ABSTRACT

The expansion of the concepts on the fatty substitution of muscle fibers as an indicator of suffering of the human muscular units favored the emergence of new strategies for the treatment of the muscular injuries of the ankle and foot. These concepts and the new trends in the treatment of these lesions are presented in this review article.

RESUMO

A ampliação dos conceitos sobre a substituição gordurosa das fibras musculares como indicador de sofrimento das unidades musculares humanas favoreceu o surgimento de novas estratégias para o tratamento das lesões musculares do tornozelo e pé. Estes conceitos e as novas tendências de encaminhamento do tratamento destas lesões são apresentadas neste artigo de revisão.

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Conflicts of interest and source of funding:
none declared.
The authors have no conflicts of interest or funding to disclose.

Received on:
Dec 12, 2017

Accepted on:
Dec 24, 2017

INTRODUCTION

Chronic Achilles tendon (AT) disorders can be very debilitating and functionally disturbing. There are variable degrees of dysfunction present and pain accompanying the process can be more than only bothersome. Usually, in tendinopathic disease, eccentric calf training in conjunction with extracorporal shock wave therapy has shown to be a very effective way to treat the problem successfully.[(1)] When conservative measures fail, surgical treatment is warranted. However, until today, surgical solutions in the treatment of chronic AT disease have been based on the size of tendon defect.[(2)] The problem with this is, that it does not reflect the quality of muscle tissue. Therefore, this approach does not provide any information regarding the functional result.[(3-7)] The driving force to move our joints comes from the muscles. The tendons provide a functional link from muscle to bone and help to transmit all energy from one source of origin to the end organ. When treating chronic AT diseases it is important to know whether the muscle is intact or not. Thus, chronic AT diseases may be treated by addressing the tendon itself or to replace it together with a functional muscle unit.

The current article tries to provide the readers with essential information about the role of muscle quality in the assessment of surgical repair of chronic Achilles tendon disorders and to offer a base for surgical decision-making. Besides this, it can be transferred to all other chronic tendon diseases around the foot and ankle.

BRIEF OVERVIEW

Originally, the principles of tendon transfers have been introduced for the treatment of upper extremity pathologies. However, the same principles can be transferred into the lower extremity as follows:

1. Correction of contracture: maximum passive motion of all involved joints must be present before a tendon transfer procedure.
2. Adequate strength: the tendon chosen as a donor for transfer must be strong enough to perform its new function in its altered position.
3. Straight line of muscle pull: in the most effective transfer, the muscle passes in a direct line from its origin to the insertion of the substituted tendon.
4. One tendon-one function: the most effective force of amplitude is provided by a muscle motored by a single tendon.
5. Synergism: preferred, but not mandatory.
6. Expendable donor: the removal of a tendon for transfer must not result in an unacceptable loss of function.(8,9)

In recent years, attention has focused on the importance of muscle quality for a successful tendon repair and transfer.

Muscle contraction induces movements of the tendon that transmits force and energy to move the joint.(10) Some authors studied the effect of a tendon transfer and lengthening by adjusting model parameters according to surgical techniques. The geometry of the musculoskeletal system defines the moment arms and the length of the muscles and thus the lever arm of a muscle can generate at certain muscle force.(11)

There are some factors that influence the force-producing capabilities of skeletal muscle which include fibre-type distribution (slow-twitch – ST- and fast-twitch – FT-), neural variables (central drive, muscle membrane excitability, exciting-contraction coupling mechanism, metabolic capacities), and muscle architecture (especially, muscle fiber length and physiologic cross-sectional area).(12)

According to the rotator cuff surgery in the shoulder where the quality of the muscles is of great importance for the overall surgical outcome,(13-15) we may assume that any surgical procedure involving tendon transfers is associated with a more favorable outcome when the corresponding muscle presents an optimal anatomic-physiological status.(16)

The muscle and its anatomy. The pennation angle

The architectural characteristics of a muscle include the cross-sectional area (CSA), which can be further defined as either anatomical CSA (ASCA) or physiological CSA (PCSA); muscle thickness (the distance between the superficial and deep/intermediate aponeurosis); pennation angle (the angle of the fascicles relative to the tendon); fascicle angle (the angle of the fascicle onto the aponeurosis); fascicle length (the length of fascicles running between the aponeurosis/tendon); and muscle volume (the product of the length and ACSA of the skeletal tissue located within the epimysium).(12)

Because the behavior of a muscle during contraction in humans cannot be directly observed, in vivo functions of human muscles have been evaluated from joint actions, but those do not only reflect the intrinsic characteristics of muscle fibers as they are affected by anatomical factors within a muscle, and within a joint system.(10)

There are two main categories of muscle architecture that are commonly present in large muscle groups: parallel and pennate.(17) Especially in pennate muscles in which fascicles are arranged diagonally to the line of pull of the muscle it is almost impossible to describe the behavior of a muscle-tendon unit from the joint movement.(10)

Tendons may extend far into the muscle, where they are termed "central tendon." The central muscle tendon is a typical feature of pennate muscle and is a prerequisite for the synergistic action of the parallel-arranged muscle fibers. With physiological contraction, muscle fibers increase their diameter and shorten.

For each fascicle i its PA is simply calculated as

$$PA^i = \cos{-1}(\text{line of action} \cdot \text{fascicle orientation}^i)$$ (18)

The pennation angle is increased in the contracted muscle, which allows the contracted, shortened, and thickened fibers to find space next to each other.

In cases of hypertrophic muscles such as in bodybuilders, the opposite effect occurs as the pennation angle is increased forced by the hypertrophy of the fibers or in atrophied muscle, where the pennation angle is decreased.

With an increasing pennation angle, the effectiveness of each fiber to pull the tendon in the desired direction decreases with the cosine of that angle and reaches zero at 90°.[19]

In case of chronic tendon tears, the fibers suffer from atrophy and shortening and with the pathologically increased pennation angle, large gap spaces are opened between the fibers, which are filled with fat and scar tissue. This fat is along with the increased pennation angle considered a secondary sign of long-standing tendon tears.[19]

Due to the actual limitations for radiological assessments of pennation angles, an average measurement of PA for an entire muscle is assumed. However, region-specific variations of PA throughout a muscle have been described.[18]

The pathogenesis of fatty infiltration

In 1994, Goutallier et al.[13] introduced a grading system to classify the fatty degeneration of muscles after his observations in rotator cuff ruptures.

They assumed that the rupture of the shoulder cuff tendons could induce a degeneration of cuff muscles, and that rotator cuff tears might be responsible for muscular degeneration. The main consequence of fatty degeneration has been found to be loss of strength and range of motion.[13-15] Although the term degeneration might have been a good way to explain the changes within the rotator cuff muscles, it is not correct. As mentioned above the newly created spaces between the muscle fibers are filled with fat and scar tissue. Therefore, the authors change the term into fatty infiltration of the muscle.

Originally described for computer tomography (CT) scan evaluation, this classification has been adapted for magnetic resonance imaging (MRI): Grade 0 indicates no intramuscular fat; grade 1, some fatty streaks; grade 2, fat evident but less fat than muscle; grade 3, equal amounts of fat and muscle tissue; and grade 4, more fat than muscle tissue. Fatty infiltration is defined as present when equal or higher than stage 2.[13-16,20,21]

Goutallier et al.[13,15] described that fatty infiltration of the muscles was not related to aging. In shoulders free of osteoarthritis and neurologic impairments, fatty infiltration occurs only due to rotator cuff tears and it increases over time.

After successful tendon repair, fatty infiltration in the corresponding muscle showed no further noticeable increase but did not decrease either, at least during the first 4 years after surgery.[15,22] Therefore, it can be concluded that once fatty infiltration is present it can not be reversed to normal. The more a muscle gets fatty infiltrated the more it will be lost.[14,19,23]

A work published by Valderrabano et al.[24] determined the positive recovery of the posterior tibial muscle after late reconstruction following tendon rupture in stage II of posterior tibial tendon dysfunction in a fourteen-patient series. These results are contradictory to all current scientific literature and must be interpreted with a highest degree of caution.

Hoffmann et al.[16] demonstrated that edema and fatty degeneration of the soleus and gastrocnemius muscles are common in patients with AT abnormalities even in the absence of tendon tears.

Additionally, Schmid et al.[25] found substantial fatty atrophy of the *abductor digiti minimi* (ADM) muscle in up to 6% of healthy volunteers and up to 11% of patients with an association between age and degree of fatty atrophy of the ADM muscle for volunteers and for patients.

We hypothesize that similar to the rotator cuff in the shoulder the quality of the calf muscles may be an important factor for the functional results after surgical treatment of foot and ankle disorders, and therefore establishing the quality of the calf muscles may be essential for proper decision-making.[16,20]

Diagnosis tools

Imaging of muscle by CT and MRI has revealed strong associations for fatty infiltration diagnosis.[13,15,16,21]

A well-defined method of assessment must be established if muscular damage becomes a variable considered in decision-making.

Qualitative imaging of fatty infiltration by CT scans has been proven to be clinically relevant in an investigation that has remained the standard of reference to the present[13] with a good inter-observer reproducibility.

Until to date, the experience with MRI is more limited but Goutallier's grading criteria have been applied to MRI in several investigations[16,21,25] with an even better inter-observer agreement than for CT.

Cross-sectional imaging methods have the potential to demonstrate both atrophy (reduced cross-sectional area of the muscle) and fatty infiltration (streaks or regions of low density below 0 Hounsfield units on CT scans and increased signal intensity on T1-weighted MR images).[21]

We strongly believe that MRI evaluation of fatty infiltration allows a good assessment and diagnosis without body radiation.

MRI is a noninvasive image acquisition modality without radiation that also allows an accurate diagnosis of associated injuries as well as other soft tissues evaluation.

Standard sequences of magnetic resonance imaging should be acquired with a standard dedicated send-receive extremity coil for the Achilles tendon and a body array coil for the calves.

The standard sequences of MRI described by Hoffmann et al.[16] are the following: T1 (SE) sagittal, T2 (TSE) sagittal and STIR axial for Achilles tendon evaluation and T1 (TSE) axial and STIR axial for calf muscles evaluation.

The patients must be placed in supine position and the feet must be symmetrically aligned when imaging both calves at the same time.

Edema in the soleus and gastrocnemius muscles can be diagnosed when diffuse increased signal is seen on the axial STIR images compared with the anterior muscle compartment.

The Goutallier's classification system for fatty infiltration is applied to the T1-weighted MRI sequences[16] (Table 1).

Table 1. Goutallier's Classification System

Goutallier's classification system	MRI findings in muscle belly
Grade 0	No intramuscular fat
Grade 1	Some fatty streaks
Grade 2	Fat evident but less fat than muscle
Grade 3	Equal amounts of fat and muscle tissue
Grade 4	More fat than muscle tissue

The fatty degeneration diagnosis is established when fatty infiltration of the calves muscle is equal to or higher than grade 2.[13,16]

Solutions for decision making

At this point, we support an algorithm[6] for good decision-making in chronic AT disorders based on three main ideas:

1. Proper assessment of muscle quality
2. Treatment plan follows muscle integrity
3. Knowledge of what a successful tendon transfer means

The proper assessment of muscle quality will lead to a very easy question to be answer: Is the muscle intact?

An intact muscle is defined as a muscle free of fatty infiltration, which means grades 0 and 1 according to Goutallier's classification after MRI evaluation. A not intact muscle suffers from fatty infiltration, which means grade 2 or higher according to Goutallier's classification.

When the question can be answered with YES, the treatment of the AT can be done with whatever means that is available to reconstruct the tendon defect.

Currently, operative treatment selection for chronic AT disease is based on the size of tendon rupture and/or tendinopathic area.[3-7]

For small areas of Achilles tendinopathy, hyper volumetric injection of local anesthetics or a minimally invasive or endoscopic paratenon release is recommended by some authors.[26]

In cases of intermediate degenerations (from 2 to 5cm) gaps open debridement is recommended. Finally, for those cases with larger ruptures or gaps, augmentation procedures are preferred.

Autologous techniques include V-Y myotendinous flap, free tendon grafts and transfers of musculotendinous units including the peroneus brevis (PB), flexor digitorum longus (FDL), and flexor hallucis longus (FHL).

According to the algorithm based on muscle quality we should consider flaps or free tendon grafts when triceps sural quality is good and fatty infiltration is not present.

When the answer to the question is NO, the treatment plan changes considerably and requires the transfer of a musculotendinous unit. The FHL-transfer for chronic and irreparable AT disease is a very valuable option. The muscle rarely undergoes fatty infiltration, works in phase with the triceps and bears the potential to achieve excellent results.

Hahn et al.[27] reported their results in 13 patients with chronic Achilles tendinopathy (10 ruptures) who underwent augmentation with FHL transfers. The passive range of motion and isolate passive dorsal extension of the ankle joint did not differ between the operated and non-operated side. The active flexion of the first metatarsophalangeal joint (MTPJ) was significantly reduced on the operated side (6.2 degrees,

p=0.018) as well as the active plantar flexion in the first interphalangeal joint (IPJ) (30.8 degrees, p=0.002) without causing any impairment in the daily living. Isokinetic measurements for isolated plantar flexion force did not show a statistically significant difference at 120 degrees/s by at 60 degrees/s there was a significant deficit for the operated side of 35% (p=0.002).

Clinical gait analysis could not detect any visible asymmetry or limping and the patients did not describe any irregularity during normal walking.

The AOFAS Ankle-Hindfoot score improved from a preoperative average of 64 (range, 28 to 87) points to 92 points (range, 71 to 100) at the last follow-up (p=0.001).

Ten patients (77%) returned to their former level of activity despite the slight plantar flexion force deficiency in isokinetic measurements observed. Recent studies have shown comparable results.[5]

Will et al.[28] reported excellent clinical outcomes of 19 patients with chronic Achilles tendinopathy treated with single incision FHL transfer, with a mean AOFAS hindfoot function scores of 96.4±5.7 and mean AOFAS hallux function scores of 92.4±6.6. All patients could perform a double heel rise and eight of 19 (42%) patients could perform a single heel rise on the operated side.

Rahm et al.[6] reported good results of FHL transfer achieving an average strength from 75% to 81% of maximum isokinetic concentric ankle plantar flexion force, in a forty-patient series (42 ankles).

SUMMARY

When treating chronic AT disorders the main question to answer is whether the muscle unit is still intact with low degree or absence of fatty infiltration.

In case of viable muscle quality stage II or less the tendon pathology can directly be addressed by any means. However, when the muscle quality is bad or lost, the authors suggest choosing the transfer of an intact musculotendinous unit.

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