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DETERMINATION OF ACHILLES TENDON SLACK LENGTH USING SUPERSONIC SHEAR IMAGING

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SUMMARY

Passive mechanical properties of the musculo-articular complex are classically studied using passive torque-angle curves. However, the mechanical properties of each structure of this musculo-articular complex (e.g., muscle, tendon) cannot be dissociated from this relationship. We recently showed that supersonic shear imaging is able to accurately quantify muscle shear elastic modulus of one muscle (Gastrocnemius medialis - GM) during passive stretching. This study aimed to determine the slack length of achilles tendon (AT) during passive stretching and to compare it with the slack length of the GM. Relationships between shear elastic modulus and ankle joint angle were characterized for each structure (i.e., GM and AT) at both knee angles (i.e., 0° and 90° of knee flexion). With the knee fully extended, the slack length of AT occurred significantly earlier than that for the GM ($42.6 \pm 2.6^\circ$ vs. $23.5 \pm 5.4^\circ$ of plantarflexion; $p < 0.001$). For 90° of knee flexion, the slack length of AT occurred also earlier ($43.4 \pm 2.4^\circ$ vs. $14.6 \pm 8.5^\circ$ of plantar flexion; $p < 0.001$). This significant earlier rise in passive tension observed in AT is particularly unexpected. That suggests the potential involvement of monoarticular structures (e.g., soleus, fascia or pulley) prematurely under tension, generating an increase in passive tension within the AT. Further studies are required to better explain this result.

INTRODUCTION

Passive torque-angle curves are classically used to assess mechanical properties of the passive musculo-articular complex and study acute or chronic process such as stretching [1], muscle damage [2] or spasticity [3]. In some of these studies, passive torque-angle curves were used to assess mechanical properties of the passive musculo-articular complex. However, the passive joint moment is influenced by all structures crossing the joint (muscles, tendons, skin, articular structures) [4], preventing to characterize the behaviour of each structure (e.g., muscle, tendon) independently. To overcome this limitation, elastographic methods can be used to determine the local mechanical properties (i.e., shear elastic modulus) of soft tissues by measuring the propagation velocity of shear waves. We recently showed that an ultrasound shear wave

elastographic technique (supersonic shear imaging, SSI) is able to accurately quantify shear elastic modulus of a targeted muscle during passive stretching [5]. Thus, the slack length of various muscles crossing the joint can be determined [5,6], providing crucial information for both biomechanical models and clinical practice [7,8]. The aim of the present study was to extend these previous observations made on Gastrocnemius medialis (GM) to Achilles tendon (AT). We characterized the slack length of AT and we compared it with that of GM.

METHODS

Subjects. Nine healthy males volunteered to participate in the study (age: 22.6 ± 1.8 year; height: 176.9 ± 4.2 cm; weight: 74.1 ± 7.1 ; mean \pm standard deviation).

Ergometer. An isokinetic dynamometer (Biodex 3 medical, Shirley, NY, USA) was used to measure ankle angle, joint angular velocity, and torque during passive ankle dorsiflexions.

Electromyography (EMG). Surface EMG activity of the GM and soleus were recorded throughout the passive stretching cycles to ensure that no undesirable activation occurred during passive stretching.

Elastography. An Aixplorer ultrasound scanner (version 4.2; Supersonic Imagine, Aix-en-Provence, France), coupled with a linear transducer array (4–15 MHz, SuperLinear 15-4, Vermon, Tours, France) was used in supersonic shear imaging mode (musculo-skeletal preset) as previously described [9,10,11]. For each passive stretching cycle the probe was held manually by an experienced examiner and was orientated perpendicularly to the skin and parallel to the muscle fascicles or tendon fibers.

Protocol. Subjects were tested at 0° and 90° of knee angle (0° = knee fully extended) in a random order. Their right foot was attached securely to the foot plate of the dynamometer and the ankle joint aligned with the axis of the dynamometer. Then, for each knee angle, participants performed 4 slow passive loading cycles (i.e., $1^\circ \cdot s^{-1}$ and $2^\circ \cdot s^{-1}$ for the AT and GM recording, respectively) between 50° (0°: foot perpendicular to the leg) of plantarflexion and 80% of the maximal range of motion in dorsiflexion [5]. During these stretching cycles the ultrasound probe was placed in a random order on either GM or AT. For each

probe location the stretching cycle was tested twice to assess the repeatability of the measurements. For each trial, the slack length was visually detected by an experienced examiner [6].

Statistical analysis. A two-way ANOVA with repeated measures and Scheffe's post-hoc test were performed to compare the slack length of GM and AT at both knee angles (i.e., 0° and 90°). The standard error of measurement (SEM) was calculated between the two trials to assess the reliability of the determined slack length [12].

RESULTS AND DISCUSSION

Typical examples of echographic images and of the shear elastic modulus-angle relationship are depicted Fig.1. As previously described in the literature [5,6], the change in muscles shear elastic modulus during passive stretching was exponential.

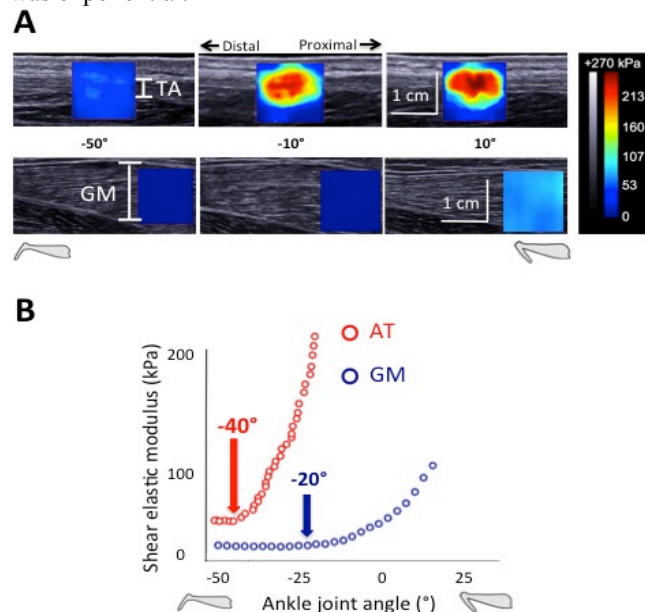


Figure 1: A- Typical examples of shear elastic modulus measurement at -50°, -10° and 10° of ankle joint angle (0° foot perpendicular to the leg) obtained with the leg perpendicular to shank. The colored region represents the shear elasticity map with the scale to the right of the figure. B- Typical example of shear elastic modulus - ankle joint angle relationship for gastrocnemius medialis (GM) and achilles tendon (AT).

The within-session repeatability of the slack length obtained at both knee angles was good (i.e., $SEM_{GM} = 1.75^\circ$; $SEM_{AT} = 1.79^\circ$). For 90° of knee flexion, the slack length of GM and AT were obtained at ankle angles of $-14.6 \pm 8.5^\circ$ and $-43.4 \pm 2.4^\circ$, respectively. ANOVA revealed significant main effects of knee angle ($p=0.027$) and structures (i.e., GM and AT; $p<0.001$), and a significant knee angle \times structure interaction ($p=0.001$). The slack length of GM when the knee was fully extended ($-23.5 \pm 5.4^\circ$) appeared at a significantly more plantarflexed angle than when the knee was flexed at 90° ($-14.6 \pm 8.5^\circ$) ($p=0.001$). This result is in accordance with our previous study [5] and can be explained by the fact that the GM is bi-articular. In addition, slack length values were close to those reported by Maïsetti et al. [5] for the GM (i.e., $-20 \pm 4^\circ$, with the knee fully

extended). The angle at the slack length of the AT was not significantly different between both knee angles ($-42.6 \pm 2.6^\circ$ with the knee fully extended vs. $-43.4 \pm 2.4^\circ$ with the knee at 90°, $p>0.05$). Finally, the slack length of the GM was obtained at a significantly lower plantarflexed angle than AT, for both knee angles ($p<0.0001$), with a mean difference of $23.9 \pm 7.6^\circ$.

Since fascicles, aponeurosis and free tendon are classically considered as in-series, a similar slack length was expected for these structures. Therefore, the difference in slack length between GM and AT was unexpected. This difference might be explained by monoarticular structures such as the soleus. Unfortunately, the probe associated to the current version of the ultrasound scanner did not allow us to get reliable measurement of shear elastic modulus in soleus. Note that the shorter slack length of the AT compared to GM could also be explained by fascia or pulleys that maybe stretched before muscle fascicles. Further studies are required to corroborate this last hypothesis.

CONCLUSION

Using SSI, the slack length of both GM and AT can be precisely characterized. More precisely, for both knee angles, the slack length of AT occurred significantly earlier than that for the GM. This unexpected result suggests the potential involvement of monoarticular structures (e.g., soleus, fascia or pulley) stretched before GM fascicles, generating a premature increase in passive tension within the AT.

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