Original article

Triceps surae elasticity modulus measured by shear wave elastography is not correlated to the plantar flexion torque

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Summary

Background: **Supersonic Shear Imaging (SSI) is a technique which analyses quantitatively the tissue properties in real time. The relation between joint torque and Young's modulus (E) of the agonist muscles is important for obtaining stratification values and ranges of normality. The aim of this study was to evaluate the intra and intersessions reliability of the E values of the Achilles tendon and medial gastrocnemius muscle, bilaterally, during rest, and correlate them with the isometric plantarflexion peak torque.**

Methods: **Shear modulus maps were acquired bilaterally in Achilles tendon (AT) and medial gastrocnemius (MG) muscle of 24 healthy male volunteers. Two 5-second plantarflexion maximal voluntary contractions were performed with a 40-seconds interval and correlated with E values.**

Results: **a good intrasession reliability (intraclass correlation coefficient- ICC= 0.821- 0.986) and a weak Pearson's correlation was found between E values and peak torque (r= 0.022 to -0.202) for both limbs (P > .05).**

Conclusion: **E values cannot be predictive of the triceps surae force production in untrained men. It could be helpful, otherwise, to monitor a chronic strength adaptation after an exercise intervention or rehabilitation program.**

Level of evidence: IIb, individual cohort study.

KEY WORDS: Achilles tendon, medial gastrocnemius muscle, ultrasound, Young's modulus.

Introduction

Elastography is a technique that evaluates the elasticity of biological tissue non-invasively. Quasi-static and dynamic elastographic methods can allow early diagnosis, quantification of lesion stages and biomechanical behavior analysis of the muscles and tendons[1-4]. Among the dynamic elastographic methods, Supersonic Shear Imaging (SSI) provides a quantitative estimate of the tissue properties in real time[4]. The shear modulus is the mechanical parameter related to the propagation of the shear wave in the medium. In purely elastic and soft tissues, shear modulus is associated to Young's modulus (E) which represents the degree of rigidity of the investigated medium.

During isometric conditions, such as maximal and submaximal contractions, muscle elasticity changes. For example, the isometric torque of the intrinsic muscles of the hand were correlated with E ($r^2 = 0.98 \pm 0.01$)[5]. In addition, comparing to the resting condition, there was a significant E increasing during contraction for the soleus and medial gastrocnemius[6], brachial biceps[7] and abductor of the little finger muscles[8]. The E values returns to basal when the stimulus ceases.

The E parameter was measured in the Achilles tendon (AT) of controls and athletes of various modalities such as ski jumping, runners and water polo, in order to study the chronic mechanical adaptation of this tissue to high tension demands. Although the anatomic cross-sectional area of the AT was larger in runners than water polo athletes, E values and isometric plantarflexion torque remained similar for the different groups, even if the relation between then was not investigated[9]. The medial gastrocnemius (MG) muscle and AT E were compared between genders and age (17-63 years) resulting in similar values for MG[10].

The relation between joint torque and E of the agonist muscles is important for obtaining stratification values and ranges of normality. Suydam et al.[11] used this approach and did not verify correlation between the isometric plantarflexion torque and the E of the AT measured at rest with different elastographic method (transient elastography). The same relation concerning the gastrocnemius muscle elasticity and plantar flexion torque is not available at the moment.

Another important issue is the reliability of the E values. Most of the available data refers to intrasession measures and are satisfactory: r= 0.978[7], r= 0.942-0.970[12], 0.882-0.970[13]. On the other hand, intersession measures are less available[7] generally result in lower reliability probably because both methodological and physiological variations.

The aim of this study was to evaluate the intra and intersession reliability of the E values of the Achilles tendon and medial gastrocnemius muscle, bilaterally, during rest, and correlate them with the isometric plantarflexion peak torque of a group of healthy young individuals.

Materials and methods

Subjects

This study was developed at the Laboratory of Biomechanics of the Alberto Luiz Coimbra Institute for Graduate Studies and Engineering Research at UFRJ (COPPE / UFRJ). The sample consisted of a single group of 24 healthy male volunteers (28 ± 2 years, 88.4 ± 11.4 kg, and 1.80 ± 0.08 m). The study was approved by the Ethics Committee of the University Hospital Clementino Fraga Filho (HUCFF/UFRJ) under protocol no. 127/13 and no. 570.945, according to ethical standards of Padulo et al.[14]. The subjects signed the informed consent form.

The subjects were tested twice, with one-week interval. An anamnesis was performed, containing personal data, anthropometric data and history of lesions. They were instructed not to perform heavy training between sessions. The exclusion criteria were any report of pain, myotendinous lesion or previous surgery in the structures of interest.

Shear modulus maps

AIXPLORER (v.9, Supersonic Image, Aix-en-Provence, France) was used for the shear modulus maps acquisition with two linear transducers operating in the frequencies of 4-15 MHz and 2-10 MHz. For an isotropic and purely elastic medium, the shear wave propagation velocity (C_s) and the medium density (p = 1000 kg • m^{-3} for biological tissues) are related to E values according to the equation (1):

$$E = 3 \cdot \rho \cdot (c_s^2) \quad (1)$$

The volunteers were positioned in ventral decubitus, relaxed, for the MG and AT images acquisition (Fig. 1). Images were acquired bilaterally and twice for each structure by single ultrasound experienced operator. First, the transducer was longitudinally positioned over the AT (Fig. 1 a), observing the proximal AT insertion at the right side of the rectangle map (region of interest). Subsequently, the transducer was positioned over the MG muscle, longitudinally to the limb (Fig. 1 b), in the region of 30% of the proximal leg length (distance between the fibular head and lateral malleolus). The gel (Ultrex-gel, Farmative Industry and Trade Ltda., Brazil) was used for acoustic coupling on the surface of the skin. A total of 16 images was obtained for each subject (two for each structure, bilaterally, two session days visits).

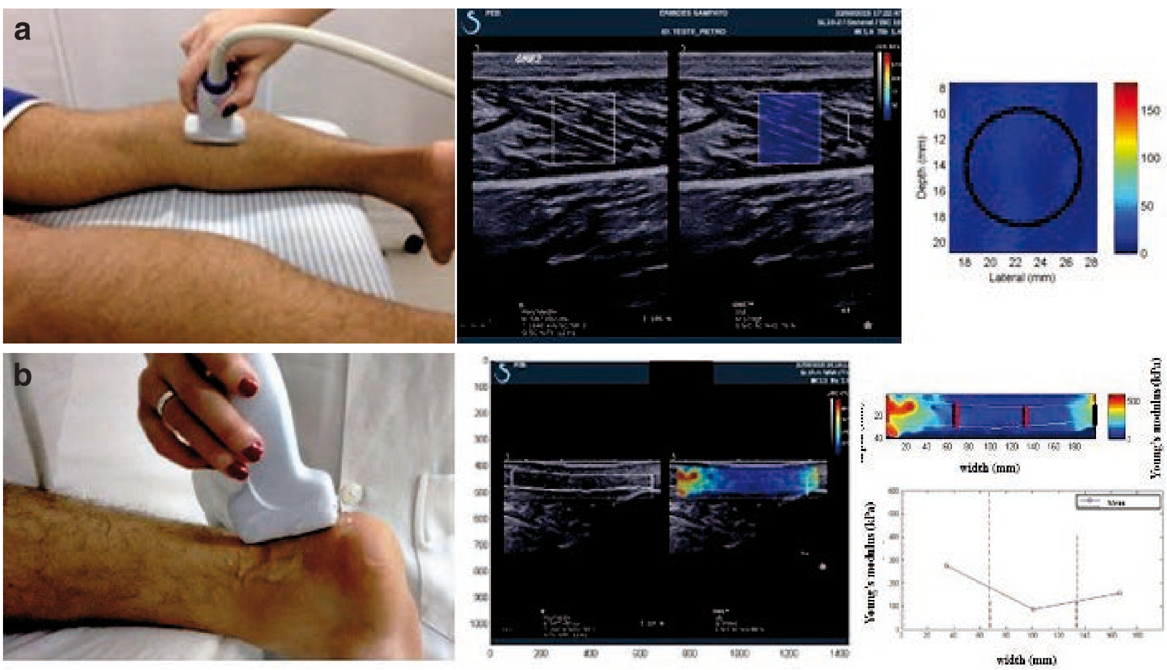

Figure 1 a, b. Transducer orientation for the acquisition of mode-B image and shear modulus maps of the medial gastrocnemius muscle (a) and Achilles tendon (b).

For the elastographic mode it was selected the musculoskeletal (MSK) or tendon presets, with scales ranging from 0-300 kPa and 0-800 kPa, respectively. A square area of approximately 1.00 cm side for the muscle and a rectangle of 1 x 4 cm for tendon were selected for the elastographic color mapping (Fig. 1). The shear modulus maps were captured after 10 seconds to guarantee the map stabilization.
Mean E values were calculated with a Matlab R2013a routine (MathWorks, Natick, MA, USA), developed in our lab, using the dicom image exported from the equipment. For MG analysis, it was considered a circular area with a diameter of 9 mm (Fig. 1 a). For the tendon, a polygon was selected, according to the tendon limits (Fig. 1 b). The central area of the polygon was used for comparison between individuals.

Plantarflexion torque

The isometric plantarflexion torque was tested with the isokinetic dynamometer (Biodex System 4 Pro, New York, USA). Subjects seated on the dynamometer chair, with 90° of hip flexion, full knee extension (avoiding hyperextension) and ankle at 90° (neutral position) fixed on the foot platform. After protocol familiarization, two 5-second maximal voluntary contractions (MVC) were performed with a 40-seconds interval. The maximum torque reached in each session was considered for analysis.
The entire protocol was repeated in a second session, with a maximum interval of one week.

Statistical analysis

The normality of E values and isometric torque was analyzed by Shapiro-Wilk test. The paired t-test was used to compare the E values and the isometric torque between the left and right sides. Pearson's correlation was used to compare the mean intra and intersession E values and the isometric plantarflexion torque. The reliability of the data was analyzed by coefficient of variation (CV), CV = (standard deviation/ mean) x 100%, and the intraclass correlation coefficient (ICC) and interpreted as follows: below 0.499 as poor, 0.500 to 0.699 as moderate, 0.700 to 0.899 as good and 0.900 to 1.000 as excellent[15]. The significance level (P) was set at 0.05. The statistical packages were SPSS 20 (IBM SPSS Statistcs Viewer, Armonk, NY, USA), STATISTICA 10 (StatSoft Inc. Tulsa, Ok, USA) and GraphPadPrism 5.0 (Graphpad Software Inc., USA).

Results

ICC ranged from 0.423 to 0.923 (Tab. I) with a good intrasession reliability and poor to moderate for intersession. CV ranged 23 - 25 % for AT and 20.95 - 17.29% for MG. There was no significant difference between the E of AT and MG and peak torque between the left and right sides, P > .05 (Tab. I).
Figure 2 show the correlation between Young's modulus (E) and peak torque for AT and MG muscle and peak torque between both limbs.

Discussion

There was a satisfactory reliability of the Young's modulus measures for AT and MG muscle. The intrasession ICC was higher than ICC intersession for both structures analyzed (Tab. I), a trend also observed by others with B-mode US images[16,17] and possibly explained by biological variations or individual demands during the time elapsed between the tests (one week), added to methodological issues as probe positioning and pressure. A minimal manual pressure was applied on the individual's skin. The CV

Table I. Reliability and mean (SD) of the Young's modulus and peak torque of the plantarflexion.

	E (kPa)						**Peak torque (N.m)**		
	L AT	**R AT**	**P**	**L MG**	**R MG**	**P**	**R**	**L**	**P**
Mean (SD)	357.20 (129.70)	386.10 (105.50)	.621	13.84 (2.90)	12.78 (2.21)	.103	130 (33.99)	136 (32.33)	.080
CV (%)	23	25	-	20.95	17.29	-	-	-	-
ICC intrasession	0.932	0.821	-	0.982	0.986	-	-	-	-
ICC intersessions	0.423	0.602	-	0.739	0.614	-	-	-	-

Abbreviation: LAT, left Achilles tendon; RAT, right Achilles tendon; LMG, left medial gastrocnemius; RMG, right medial gastrocnemius; R, right and L, left. P, significance level < .05.

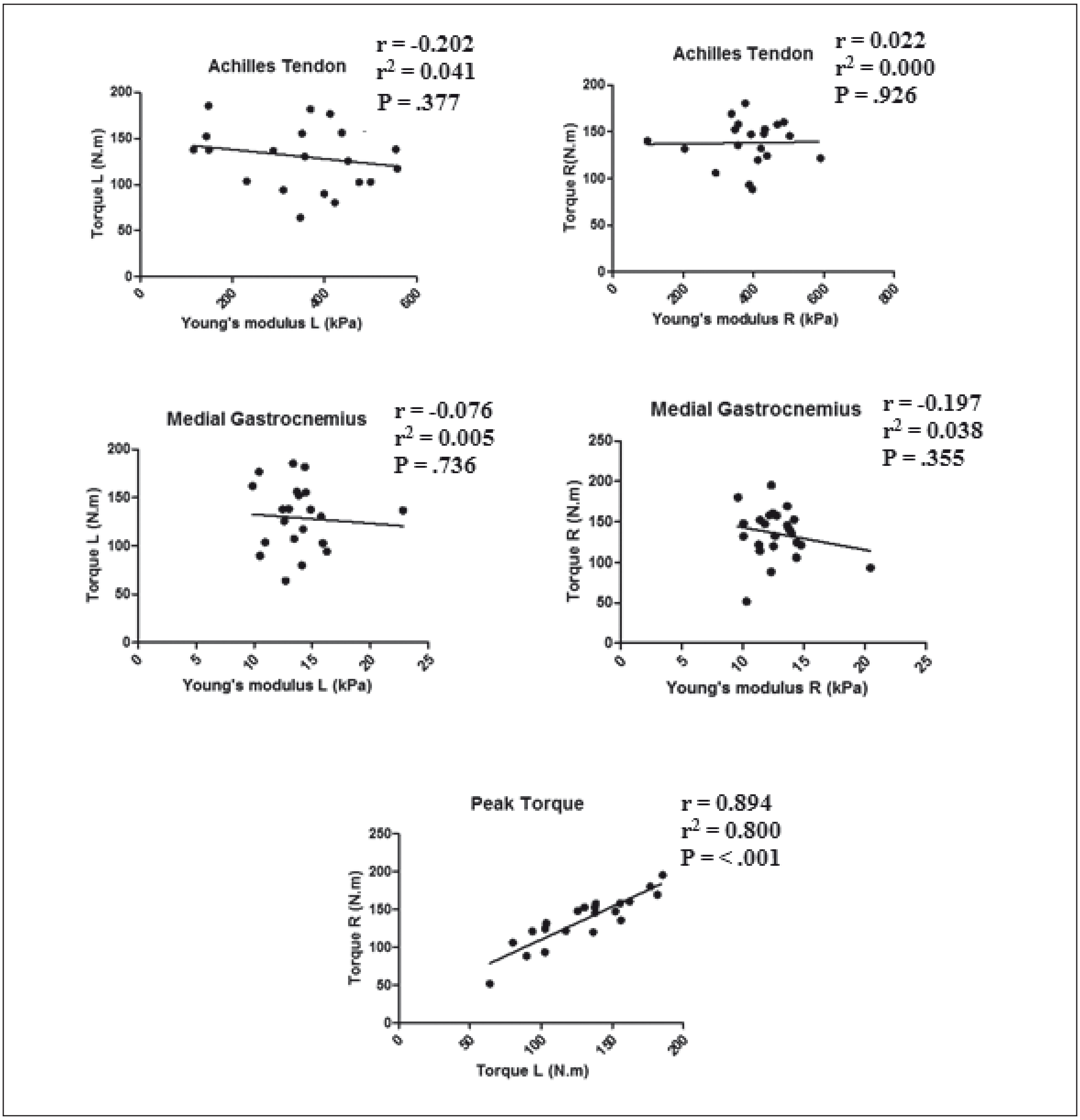

Figure 2. Correlation between the isometric plantarflexion torque and the Young's modulus of the Achilles tendon and medial gastrocnemius muscle for the left (L) and right (R) sides.

values were higher for AT (23 to 25%) compared to MG (17.29 to 20.25%), corroborating with the study by Chino and Takahashi[18] who observed values of 19.4% for MG and 22.3% for AT. The higher CV values and lowers ICCs for AT can be explained by the increasing shear wave propagation velocity (greater stiffness) through this tissue, generating a greater variability of the data. In addition, thin structures such as the tendon and blood vessels may favor the appearance of other distinct waves, such as the guided wave[19] which are not related to the elasticity of the medium. A recent methodological study on this phenomenon related to the Achilles tendon tissue *in vivo* demonstrated good correlation (r = 0.84) between the parameter given by the SSI equipment and the same parameter accounted for the guide waves[20].

The elasticity values obtained in this study are useful for stratification of a sample formed by health and young men. Other studies analyzed the same structures in a heterogeneous sample (127 healthy volunteers from 17-63 years old)[10]. The mean E values for the MG and AT were 11.10 ± 4.10 kPa and 74.40 ± 45.70 kPa, respectively. The AT E was larger in men than in women. There was no significant correlation between age (up to 63) and E for all structures[10].

Laterality had no impact on E values, confirming others for AT for untrained subjects[11]. However, other Authors found higher E values of the non-dominate side of athletes from asymmetric modalities with weight discharges over the non-dominant limb[21].

There is a weak correlation between the elasticity of the AT and MG and the isometric plantarflexion torque for both sides, indicating that the mechanical characteristics of the tissue at rest cannot predict the force generation capacity of the muscle-tendon unit. The same conclusion was reported by Suydam et al.[11] justifying that the SSI analysis is restricted to the area observed on images, disregarding the contribution of other tissues such as aponeurosis. Nevertheless, the main cause of this lack of relation is probably the neural component of the force production. The force production during MVC has a temporal relation between the frequency rate[22] and type of motor units recruited[23, 24]. Other parameters such as synergism of the agonist muscles and co-activation of the antagonists contribute to the total MVC torque production[25].

A good relation can be seen between E and muscle isometric contraction measured simultaneously for the intrinsic hand muscles (r^2 = 0.98 ± 0.01)[5]. This protocol is not viable at the moment for AT as values of E saturates the scale of the equipment.

A limitation of this study was the non-differentiation of the previous physical activity level of the subjects, which increases the heterogeneity of the group. Future studies will be performed comparing specific groups such as different sports modalities, level of training and injury. Other limitation was the impossibility of generalization of results to females or other age range. At end, the dominant leg side was not correlated to Young's modulus.

Conclusions

This study showed good reliability for intersession E measures while only medium for intrasession. Non-significant correlations were found between the Achilles tendon and MG muscle E values at rest with the maximal plantarflexion torque. E values taken at rest, are representative of the area investigated and cannot be predictive of the triceps surae force production in untrained men. It could be helpful, otherwise, to monitor a chronic strength adaptation after an exercise intervention or rehabilitation program. This is an open field for future studies.

Conflict of interest

No other relationships/conditions/circumstances that present potential conflict of interest.

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