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Research article

Biomechanical properties of isolated fascicles of the Iliopsoas and Achilles tendons in African American and Caucasian men

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ABSTRACT

Objectives: To investigate biomechanical properties of the Iliopsoas and Achilles tendons in young African American (AA) and Caucasian (CC) men, and attempt to clarify whether the difference in Achilles tendon ruptures between AA and CC can be explained by differences in material properties.
Methods: Tissue from 12 young males (AA, $n = 6$; CC, $n = 6$) was obtained from routine forensic autopsies. Iliopsoas and Achilles tendon samples were obtained from cadavers that were age, height and weight matched. Tendon collagen fascicles were tested micromechanically in a Deben mechanical testing rig.
Results: Peak failure stress in Iliopsoas tendon fascicles was considerably higher ($p < 0.05$) in AA (22.4 ± 7.2 MPa) than CC (6.8 ± 2.1 MPa) whereas peak strain did not differ (AA: 19.7 ± 5.2%, CC: 18.3 ± 3.5%). Likewise, Young's modulus was greater ($p < 0.05$) in AA (165.3 ± 67.3 MPa) than CC (63.6 ± 23.6 MPa). In contrast, peak failure stress in Achilles tendon fascicles was similar ($p > 0.1$) in AA (21.9 ± 9.9 MPa) and CC (28.1 ± 9.8 MPa), and peak strain did not differ ($p > 0.1$) between AA (16.3 ± 3.5%) and CC (13.8 ± 4.4%). Young's modulus was slightly greater in CC (316.8 ± 110 MPa) than AA (222.8 ± 84.6 MPa), yet not significantly ($p > 0.1$).
Conclusions: These findings indicate that Iliopsoas tendon fascicles are stronger in young AA compared to CC males, which is suggested to reflect differences in muscle mass and force generating capacity. This could not be confirmed in Achilles tendon fascicles.

1. Introduction

Stabilising structures in the lumbosacral region differ anatomically between African American (AA) and Caucasian (CC) individuals (Hanson and Magnusson, 1998). The Psoas major muscle has been reported to have a greater circumference in young AA than CC individuals (Hanson et al., 1999) and lumbopelvic ligaments differ accordingly (Hanson et al., 1998). The functional roles of these differences remain unclear. It is also well known that the rupture incidence of the Achilles tendon is higher in AA compared with CC people (Davis et al., 1999; Owens et al., 2007). The reason for this difference in rupture incidence, as well as its possible relation to mechanical tendon properties and muscle size has not yet been established. Therefore, we set out to investigate whether the biomechanical properties of Achilles and the Iliopsoas tendon fascicles differed in the same subjects, and whether the outcome could be related to difference in muscle size.

The mechanical properties of tendons are dependent on the collagen fibre diameter and orientation. The number of collagen cross-links may also influence the biomechanical properties of tendons (Kjaer, 2004). The collagen fibrils are parallel to each other, closely packed, and show a wave-like appearance due to planar undulations, so-called crimps, on a scale of several micrometers (Hulmes, 2002). Because the tendon is a multi-stranded structure made up of many partially independent fibrils and fascicles, it does not behave as a rigid structure and this property also contributes to its flexibility (Ker, 2002; Silver et al., 2003).

Although the anatomy and function of the Triceps surae and the Achilles tendon have been extensively studied (Davis et al., 1999; Fukashiro et al., 2002; McCarthy et al., 2006; Owens et al., 2007; White et al., 2007), the biomechanical function of the Iliopsoas, and specifically the Psoas major, have been debated, especially in relation to spinal stability (McGill, 2002; Richardson et al., 2004). Biomechanical analyses of the Psoas major muscle suggest that it has a minimal capability to produce movement in the lumbar spine and that the muscle contributes very little to hip flexion (Rab et al., 1977; Van Dyke et al., 1987; Bogduk et al., 1992; Santaguida and McGill, 1995). The main function of the Psoas major muscle is thus to assist the Iliacus in providing hip joint stability (Dangaria and Naesh, 1998; Yoshio et al., 2002).

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It is well established that tendons are subject to many types of injuries. Frequently, such injuries result in inflammation and degeneration or weakening of the tendon, which may eventually lead to tendon rupture (Sharma and Maffulli, 2006). A study of the passive viscoelastic properties of the Triceps surae in AA and CC athletes revealed that AA athletes had significantly greater muscle viscosity and elasticity than CC athletes, while tendon elasticity did not differ (Fukashiro et al., 2002). Moreover, the same study reported that the circumference of the Triceps surae did not differ between AA and CC subjects. To our best knowledge, only a single study presenting racial differences in the Psoas major muscle in young people has been published, concluding that the circumference was considerably greater in AA than CC individuals (Hanson et al., 1999).

Increased knowledge on muscle and tendon function and their role in stability is rapidly emerging. To clarify unanswered questions regarding the potential relationship between muscle size (and hence contractile force) and tendon biomechanical properties, the purpose of this study has been to investigate the possible differences in the biomechanical properties of isolated collagen fascicles from the Iliopsoas and the Achilles tendons in young AA and CC men. The Psoas major muscle is positively known to be larger (i.e. stronger) in AA than CC (Hanson et al., 1999), whereas the circumference of the Triceps surae has been reported not to differ between AA and CC subjects (Fukashiro et al., 2002) although the rupture incidence does differ (Davis et al., 1999; Owens et al., 2007; White et al., 2007). Therefore the Achilles and Iliopsoas tendons were selected to be biomechanically tested in this study to determine whether the tendon fascicles differed and whether any conclusions could be drawn from the results about either strength or rupture incidence.

2. Materials and methods

2.1. Harvesting of tendon samples

Two separate fascicles from each of the tendon samples (a total of 48 fascicles) were collected from cadaver material during routine forensic autopsies with approval by the local Ethics Committee obtained at the Arkansas State Crime Laboratory, Little Rock, Arkansas. The Achilles tendon samples were harvested 3–6 cm above the attachment to the calcaneus from which the fascicles were dissected. This is the typical rupture site in Achilles tendon ruptures (Kongsgaard et al., 2005). All samples were taken as soon as possible post mortem. In all instances the subjects were considered fresh; i.e. there was still rigor mortis indicating that postmortal decomposition had not yet initiated. Prior to testing, the samples were stored in −72 °C. The mechanical testing and subsequent analysis was performed at the Institute of Sports Medicine Copenhagen, Bispebjerg Hospital, Denmark.

Tendon sample collagen fascicles were carefully dissected from 12 randomly chosen young male cadavers (AA, $n = 6$; CC, $n = 6$) in routine forensic autopsies. Causes of death are not listed since the subjects had no known injury or pathology related to the studied regions. The Iliopsoas and Achilles tendon samples were obtained from the same cadavers. The ethnicity of subjects was defined by the coroner, and then by records of the Medical Examiner's office. Both authorities were unfamiliar with the study at hand and, therefore, any bias was eliminated. Age, height and weight were similar in AA and CC (Table 1).

Table 1
Age, weight and body height of subjects (mean ± SD).

	Age (yrs)	Height (cm)	Weight (kg)
AA (n = 6)	28.3 ± 10.6	173.6 ± 7.3	72.2 ± 6.3
CC (n = 6)	35.0 ± 4.0	182.0 ± 3.5	81.1 ± 7.9

2.2. Mechanical testing

Measurements were performed using a micro-tensile testing apparatus (200 N tensile stage, Petri dish version, Deben Ltd., Suffolk, UK). Dissected collagen fascicles, which had an average diameter of 0.7 mm, were prepared for mechanical testing by reducing the length to ~20 mm. The methodology has been described in detail previously (Haraldsson et al., 2005). Briefly, each 5 mm end of the fascicle was allowed to air dry at room temperature until the ends appeared pellucid while the midsection remained wrapped in PBS (0.15 M) gauze. The ends were glued with cyanoacrylate to aluminium specimen mounting plates of the rig. The fascicle was then immersed and hydrated for 20 min in PBS solution in a Petri dish where it remained during testing at 2.0 mm/min. The initial specimen testing length clamp-to-clamp was ~10 mm. The cross-sectional area was calculated based on diameters measured from stereomicroscopic images along the length of the specimen. Images were obtained while the fascicle was mounted and immersed.

2.3. Material analysis

The smallest cross-sectional area of three measurements was used for calculation of stress. Fascicle stress was calculated as the tensile force (N) divided by the cross-sectional area (mm^2) of the fascicle and reported in Pascal (N/m^2). Failure stress was defined as the highest stress measured during failure testing. The resting length (L_0) of the fascicle was defined as the length at force onset, which was obtained during slow elongation (0.5 mm/min) until the change in instantaneous passive fascicle force exceeded the mean value of the preceding 100 data points by 0.075% of peak passive force (~0.03 N). Fascicle strain was defined as ΔL divided by L_0 and was expressed as a percentage $[(\Delta L/L_0) \times 100]$. Young's tangent modulus was calculated in the linear part of the stress–strain curve. The analysis of fascicle stiffness and energy absorption was performed at 10% intervals of peak failure force. Young's modulus units were reported for the 10% interval that yielded the highest value. Energy absorption at failure was calculated by integrating the area below the length force-deformation curve from force onset (L_0) until peak force and reported as mJ/mm^2.

Differences between the groups were investigated by two-tailed independent *t*-tests. Results are reported as mean ± SD.

3. Results

3.1. Iliopsoas tendon fascicles

Peak failure stress (MPa) in Iliopsoas tendon fascicles was considerably higher in AA than in the CC ($p < 0.01$) (Fig. 1) subjects whereas fascicle strain at failure (%) was similar in both groups ($p > 0.5$) (Table 2). Young's modulus (MPa) was greater in AA than CC ($p < 0.01$). Likewise, absorbed energy was higher in AA than CC subjects ($p < 0.01$).

3.2. Achilles tendon fascicles

Peak failure stress did not differ significantly between AA and CC subjects ($p > 0.1$), and the peak strain at failure was similar between the two groups ($p > 0.1$) (Fig. 2). Likewise, Young's modulus and absorbed energy at failure were similar ($p > 0.1$) in the two groups (Table 3).