BI-LATERAL SYMMETRY IN ACHILLES TENDON MECHANICAL PROPERTIES

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SUMMARY

The purpose of this study was to compare the mechanical properties of the human Achilles tendon between the dominant and non-dominant limbs of a group of subjects. Twenty healthy young subjects volunteered for this study. Their footedness was assessed via a questionnaire. Peak ankle-plantar flexion moments were determined using dynamometry. Ultrasound imaging was used to determine the change in Achilles tendon length, during dynamometry testing, by tracking the motion of a myotendinous junction. Tendon length was measured using ultrasound imaging, with the knee extended, ankle at 90°, and the muscles relaxed. The following measures were compared between limbs: maximum ankle plantar-flexion moment normalized by body mass, Achilles tendon length was normalized by leg length, and peak Achilles tendon strain. There were no statistically significant differences between the peak moments, tendon lengths, or peak tendon strains when comparing dominant with non-dominant legs - directional asymmetry (Table 1). In contrast all three metrics were statistically significantly different when assessed for overall asymmetry; that is comparing maximum values with minimum values. These results raise questions about the functional importance of such asymmetries, and how these asymmetries arose.

INTRODUCTION

Various aspects of human gait have been examined, and a number of these studies have identified inter-limb asymmetries. Herzog et al. [1] demonstrated asymmetry in a number of metrics determined from the ground reaction forces recorded during walking. In a similar fashion, Maupas et al. [2] showed that healthy subjects during walking demonstrated asymmetry in their knee joint kinematics. These asymmetries seem to extend to the kinematics and kinetics of running [3,4]. While these studies have demonstrated the presence of asymmetry in features of human gait they have not identified the source of this variability.

While the evidence is relatively abundant indicating asymmetries in the kinematics and kinetics of human gait there is less evidence examining the symmetry or otherwise of human limb morphology. Guichet et al. [5] estimated that at least one in 1000 has a discrepancy in the length of their legs of at least 20 mm. The detailed examination of human bones reveals morphological differences between the right and left limb bones not just in terms of length but also in terms of other bone dimensions [6]. Chhibber and Singh [7] showed that the bones of the dominant and non-dominant lower limb had different masses, they also showed statistically significant differences between the masses of the muscles of these limbs. Studies such as these suggest a mechanism for the link between gait asymmetries and musculoskeletal injuries [8].

While studies have shown asymmetries in human gait patterns and in some skeletal and muscle properties, the mechanical properties of the tendons of the dominant and non-dominant limbs has not been examined. Therefore the purpose of this study was to compare the mechanical properties of the human Achilles tendon between the dominant and non-dominant limbs of a group of subjects.

METHODS

In overview, for a group of experimental subjects their dominant limb was assessed, the length of both their Achilles tendons, the maximum isometric ankle plantar-flexion moments, and the Achilles tendon strains under these moments were determined.

All subjects gave informed consent to participate in the study which used protocols approved by the Institutional Review Board. Potential subjects were excluded if they had a history of lower body injuries. Twenty healthy young subjects, ten males and ten females, volunteered for this study (age 25.9±5.5years; height 169.6±8.3cm; mass 70.7±11.9kg). All subjects were assessed for lower limb dominance using the Waterloo Footedness Questionnaire [9].

Measurements of the Achilles tendons were made using ultrasound. The tendon was scanned using a 7.5MHz ultrasound probe (SSD-1000, Aloka, Japan) in B-mode. To enhance image quality, by decreasing echo reverberations, a stand-off pad (2cm thick and 9 cm in diameter) and a small amount of ultrasound gel were used. The ultrasound images were digitally recorded for subsequent analysis using Scion Image (NIH Image, version Beta 4.0.2, National Institutes of Health, Bethesda, MD). Prior to tendon scanning the accuracy of the ultrasound imaging and digitizing systems were estimated using a phantom (CIRS model 042). Using dimensions similar to those of the Achilles tendon points in the phantom could be measured to an accuracy of 0.1mm.

The length and maximum strain of the Achilles tendons were measured using ultrasound on both legs of all subjects. The length of the Achilles tendon was defined from its insertion point on the calcaneus to where it merges into the muscle belly. During these measures the subjects were instructed to lay prone with their knees and hips at 180° and 0° respectively. The foot of the leg being examined was flattened against a flat surface perpendicular to the subject, so the ankle joint was positioned at 90°. With the triceps surae muscles relaxed this position was used to obtain a reference length for the Achilles tendon. To obtain tendon length overlapping ultrasound images were taken from the region of the calcaneus until the myotendinous junction was reached. Using this tendon length as a reference the change in length of the Achilles tendon was determined by measuring the displacement of the myotendinous junction during a maximum effort isometric ankle plantar-flexion.

To obtain an estimate of tendon extension under maximum isometric force, the Achilles tendon was imaged during maximum plantar-flexion efforts. After a general warm-up subjects were placed in a Biodex dynamometer (Model III) with a 90° hip angle, a fully extended knee, and 90° of ankle plantar-flexion. Straps placed around the waist, chest, thigh, and foot ensured stability of the subject as well as the immobility of the ankle. The axis of the dynamometer was aligned with the ankle axis. Once correctly positioned the subjects then performed two submaximal isometric plantar-flexions for practice; after this each subject was instructed to perform three maximum isometric plantar-flexions. Subjects were allowed to rest between efforts to reduce the influence of fatigue. The trials with the greatest moment for each subject were used for analysis. The order in which the legs were tested was randomized.

All images were digitized by three trained operators. The measurements were compared between operators by assessing the intra-class correlations (ICC 2.1; [10]). The ICC for all measurements were high (ICC > 0.8), therefore to reduce random measurement noise the mean of the measurers estimates were used for all subsequent analyses.

The following measures were compared between limbs: the peak plantar-flexion moment, tendon slack length, and tendon strain due to the maximum isometric moment. These measures were compared in two ways. One method was to compare the values for the dominant legs with the values for the non-dominant legs – directional symmetry. The second method was to compare the maximum value with the minimum value – overall symmetry. The data pairs were compared using paired t-tests. Prior to this analysis data were tested for normality using the Anderson-Darling test. For summary statistics the data were normalized as follows: maximum ankle plantar-flexion moment normalized by body mass, and Achilles tendon length was normalized by leg length.

RESULTS AND DISCUSSION

Of the 20 subjects 18 were right leg dominant. There were no statistically significant differences between the peak moments, tendon lengths, or peak tendon strains when comparing dominant with non-dominant legs - directional asymmetry (Table 1). In contrast all three metrics were statistically significantly different when assessed for overall asymmetry; that is comparing maximum values with minimum values.

The results of this study are in contrast to previous observations about directional asymmetry between bones [6], and between muscles [7]. The major experimental difference between this and those studies is that the measures in this study were made in vivo. A deficiency of this study was that the gait of the subjects was not assessed so that the correlation between tendon asymmetries and gait asymmetries could not be assessed. It should also be highlighted that lower limb dominance is not as well defined as upper limb dominance.

The peak strains for the Achilles tendon measured in this study were greater than those observed in other studies [e.g., 11]. In many previous studies examining peak tendon strain in vivo measures were made with a flexed knee, which changes the length of the gastrocnemius [12], which therefore reduces the peak ankle plantar-flexion moment [13], and thus Achilles tendon strain.

CONCLUSIONS

This study examined inter-limb differences in Achilles tendon properties. It demonstrated differences between the limbs for peak plantar-flexion moment, tendon length, and peak tendon strain. These differences were not associated with limb dominance. It raises questions about the functional importance of such asymmetries, and how these asymmetries arose.

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Table 1: The mean (± standard deviation) of the normalized peak moment, Achilles tendon length, peak tendon strain, and the results of the statistical comparisons.

	Dominant Limb	Non-Dominant Limb	P value *Directional Symmetry*	P Value *Overall Symmetry*
Peak Moment (Nm/kg)	1.2 ± 0.5	1.3 ± 0.5	0.18	<0.001
Tendon Length (% leg length)	25 ± 3	25 ± 2	0.50	<0.001
Peak Strain (%)	7.9 ± 2.6	7.8 ± 2.3	0.61	<0.001