Conditioning of the Achilles tendon via ankle exercise improves correlations between sonographic measures of tendon thickness and body anthropometry

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Wearing SC, Grigg NL, Hooper SL, Smeathers JE. Conditioning of the Achilles tendon via ankle exercise improves correlations between sonographic measures of tendon thickness and body anthropometry. J Appl Physiol 110: 1384–1389, 2011. First published March 10, 2011; doi:10.1152/japplphysiol.00075.2011.—Although conditioning is routinely used in mechanical tests of tendon in vitro, previous in vivo research evaluating the influence of body anthropometry on Achilles tendon thickness has not considered its potential effects on tendon structure. This study evaluated the relationship between Achilles tendon thickness and body anthropometry in healthy adults both before and after resistive ankle plantarflexion exercise. A convenience sample of 30 healthy male adults underwent sonographic examination of the Achilles tendon in addition to standard anthropometric measures of stature and body weight. A 10–5 MHz linear array transducer was used to acquire longitudinal sonograms of the Achilles tendon, 20 mm proximal to the tendon insertion. Participants then completed a series of 90–100 repetitions) of conditioning exercises against an effective resistance between 100% and 150% body weight. Longitudinal sonograms were repeated immediately on completion of the exercise intervention, and anteroposterior Achilles tendon thickness was determined. Achilles tendon thickness was significantly reduced immediately following conditioning exercise (t = 9.71, P < 0.001), resulting in an average transverse strain of -18.8%. In contrast to preexercise measures, Achilles tendon thickness was significantly correlated with body weight (r = 0.72, P < 0.001) and to a lesser extent height (r = 0.45, P = 0.01) and body mass index (r = 0.63, P < 0.001) after exercise. Conditioning of the Achilles tendon via resistive ankle exercises induces alterations in tendon structure that substantially improve correlations between Achilles tendon thickness and body anthropometry. It is recommended that conditioning exercises, which standardize the load history of tendon, are employed before measurements of sonographic tendon thickness in vivo.

SONOGRAPHIC MEASUREMENT OF Achilles tendon thickness has been widely used as a noninvasive method for identifying local tendon pathology (26, 36) and for detecting and monitoring systemic conditions, including familial hypercholesterolemia (10, 45, 55), diabetes (1, 19), end-stage renal disease (5), inflammatory arthritis (18, 39), and Behçet’s disease (20, 40). Although thickening of the Achilles tendon is classically used as a clinical indicator of pathology, considerable variation in anteroposterior (AP) thickness of the “normal” Achilles tendon has been reported within the literature, with mean values ranging from as little as 4.2 mm to as much as 7.1 mm for healthy individuals (29, 55).

Body weight, stature, ethnicity, and habitual physical activity have all been suggested to moderate tendon size in healthy adults (7, 27, 29), and positive correlations observed among measures of tendon thickness, body weight, and stature (29, 41, 54) tend to support the concept that tendon size is largely under genetic control (14). Surprisingly, however, reported correlations between Achilles tendon size and body anthropometry are typically weak, with body weight only accounting for between 6 and 30% of the variability in Achilles tendon thickness (1, 29, 41).

Altered estrogen levels have also been mooted to influence tendon health and thickness in healthy females (8, 33), although such hormonal effects appear to be present only in physically active adults (14), indicating that physical activity may be an important determinant of tendon size. However, little is known about the adaptive response of the human Achilles tendon to physical activity. Most, but not all (25), studies have observed that habitually active individuals have larger tendons than untrained individuals (35, 42, 53). However, acute bouts of activity appear to induce the opposite effect over the short term, with a marked, although transient, decrease in sonographic thickness of the Achilles tendon reported on completion of intense resistive ankle exercise (22, 50), floor-ball (13), and walking (21). Such conditioning effects are widely reported in mechanical testing of tendon in vitro and have been suggested to reflect extrusion of fluid from the tendon core on tensile loading (24, 50). Thus Achilles tendon thickness measured immediately postconditioning is likely to be less influenced by tendon fluid and represent a more accurate index of the collagen content compared with preexercise measures of tendon thickness. However, research specifically evaluating the relationship between anthropometric parameters and Achilles tendon size, in vivo, has failed to employ preconditioning exercises to standardize the load history of tendon and, as such, is likely confounded by the transient movement of tendon fluid.

The aim of the present study, therefore, was to reevaluate the relationship between Achilles tendon thickness and anthropometric characteristics in healthy adults before and immediately after a bout of resistive ankle exercise. It was hypothesized that the relationship between Achilles tendon thickness and measures of body anthropometry would be strengthened when thickness was measured postexercise.

METHODS

A convenience sample of 30 healthy adult men was recruited from University faculty to participate in the study. Participants were non-smokers, nonmedicated, and recreationally active based on self-report. No participant reported a medical history of diabetes, inflammatory...
joint disease, familial hypercholesterolemia, or Achilles tendon pain or pathology. The study received approval from the institutional review board.

All participants reported to the laboratory (thermoneutral environment) wearing lightweight, comfortable clothing and having abstained from vigorous physical activity and consumption of alcohol in the previous 24 h. Measurements of body height (stretch stature) were made to the nearest millimeter, using a Harpenden stadiometer (Cranlea and Co., Birmingham, UK), and body weight was recorded to the nearest gram with clinical scales (Tanita, Tokyo, Japan). Body mass index (BMI) was subsequently estimated by dividing body weight (kg) by the square of body height (m).

Sonographic examination of the Achilles tendon was undertaken with a high-resolution B-mode ultrasound machine (LOGIQ BookXP, GE Healthcare) using a 10–5 MHz linear array transducer and standardized protocol (15). In accordance with previous recommendations (15), longitudinal sonograms of the Achilles tendon were acquired perpendicular to the point of maximum tendon width and encompassed the superior aspect of the calcaneus and distal Achilles tendon. Particular care was taken to position the transducer perpendicular to the tendon surface. Sonograms were acquired with the aid of an acoustic stand-off pad, while the participant was positioned prone with his ankle passively positioned at a right angle (90°) to his leg (29).

Following baseline (preexercise) sonograms, participants completed a series (90–100 repetitions) of standing ankle plantarflexion exercises in which they were required to move their foot from full ankle plantarflexion to full dorsiflexion at a rate of ~1 Hz (52). Exercises were performed against an effective resistance of between 10 and 50% of the participant’s ability to perform the exercise (52). Participants were divided by tertiles into lower (BMI < 23) and upper (BMI > 27) extremes of BMI; corresponding with “low normal weight” and “low overweight” cut-off points recommended for reporting by the World Health Organisation (World Health Organization: global database on body mass index available at: http://apps.who.int/bmi/index.jsp?introPage=intro_3.html; accessed November 20, 2010). Independent t-tests were subsequently used to compare tendon parameters of the lower and upper extremes of BMI.

RESULTS

The demographic and anthropometric characteristics of the participants are summarized in Table 1. Average anteroposterior thickness of the Achilles tendon was 4.4 mm before exercise. There were no significant correlations noted between preexercise dimensions of the Achilles tendon and anthropometric measures, including age (r = −0.07), weight (r = 0.34; Fig. 2), height (r = 0.20), and BMI (r = 0.31).

There was a significant decrease in AP tendon thickness immediately following strenuous ankle exercise (t = 9.71, P < 0.001), resulting in an average transverse strain of −18.8% (Table 1). Postexercise measures of AP tendon thickness were significantly and positively correlated with body weight (r = 0.72, P < 0.001; Fig. 3), height (r = 0.45, P = 0.01) and BMI (r = 0.63, P < 0.001) following conditioning exercises. However, postexercise Achilles tendon thickness was not correlated with age (r = 0.18).

AP tendon thickness was significantly greater in high overweight and obese participants (BMI > 27 kg/m²) both before (t = −2.38, P = 0.03) and after (t = −4.23, P = 0.001) exercise compared with the low normal and underweight subgroups (Table 2). However, the acute transverse strain response of the Achilles tendon was significantly less in the high overweight and obese subgroups (−11.5%) compared with that

Table 1. Participant characteristics and Achilles tendon thickness before and after conditioning exercise of the ankle

<table>
<thead>
<tr>
<th>Age, yr</th>
<th>Height, m</th>
<th>Weight, kg</th>
<th>BMI, kg/m²</th>
<th>Preexercise ATT, mm</th>
<th>Postexercise ATT, mm</th>
<th>True Strain, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>37 ± 13</td>
<td>1.78 ± 0.06</td>
<td>79.3 ± 14.4</td>
<td>25.0 ± 4.0</td>
<td>4.4 ± 0.5</td>
<td>3.6 ± 0.4</td>
<td>−18.8 ± 8.1</td>
</tr>
</tbody>
</table>

Values are means ± SD (n = 30 participants). BMI, body mass index; ATT, Achilles tendon thickness.
of low normal and underweight (−19.5%) groups ($t = 3.17, P = 0.008$).

**DISCUSSION**

Conditioning is routinely used in laboratory studies to standardize the load history of tendon and to reduce the variability in subsequent estimates of biomechanical properties (11, 46, 47). This creep-related phenomenon is characterized by an increase in the initial reference length of a tendon during consecutive stretch cycles to a given stress and may increase estimates of tendon strength and stiffness in vitro (11, 46, 47).

Although there is emerging evidence that conditioning may have similar effects on tendon in vivo (13, 21, 22, 30, 34, 50), the present study is the first to show that conditioning exercise improves the correlation between Achilles tendon thickness and measures of body anthropometry. These findings highlight the importance of employing conditioning in sonographic determination of Achilles tendon thickness, which is routinely used to clinically monitor local and systemic causes of tendon pathology.

The mean preexercise thickness of the Achilles tendon in the present study (4.4 mm) is consistent with the lower range of values reported within the literature (Table 3). It is noteworthy that, in contrast to earlier research regarding the sonographic appearance of the Achilles tendon, the present study did not include the paratenon within measures of tendon thickness. At rest, the average thickness of the loose connective tissue layer of the paratenon is $0.4$ mm (15), and the structure allows independent movement of the Achilles tendon, akin to the gliding function afforded by the sheath surrounding synovial tendons (37). With exercise, a marked dilation of blood vessels of the paratenon has been observed, resulting in a substantial increase in blood flow (up to sevenfold) and hypertrophy of the paratenon (4, 28). Such exercise-induced changes of the paratenon would, therefore, oppose those of the tendon proper and so mask the decrease in tendon thickness noted in the present study immediately postexercise. As advocated by Fredburg et al. (15), inclusion of the paratenon in measures of Achilles tendon thickness, therefore, is not recommended and may explain some of the discrepancies reported between studies on the effect of exercise on Achilles tendon thickness.

Acute reductions in Achilles tendon size have been previously, although not exclusively (16), observed following intense or prolonged ankle exercise (13, 21, 22, 50) and have been hypothesized to mainly reflect fluctuations in the fluid content of the tendon matrix (22, 50). In support of this concept, animal studies have observed a visible loss of water from tendon exposed to either static or cyclic loading in vitro (24). Similarly, static tensile loading has been shown to promote rapid unbinding and radial extrusion of fluid from the tendon core (23, 51). A decrease in tendon fluid content following exercise would reduce the cross-sectional area of the Achilles tendon and more accurately reflect tendon collagen content. Such a mechanism would underpin the present observation that postexercise measures of Achilles tendon thickness were significantly correlated with measures of body anthropometry, namely body weight and body height, whereas preexercise measures were not.

![Fig. 2. Scatter plot of preexercise Achilles tendon thickness and body weight.](image1)

![Fig. 3. Scatter plot of postexercise Achilles tendon thickness and body weight. Note that body weight accounted for 52% of the variability in postexercise Achilles tendon thickness, compared with just 12% of variability in preexercise measures.](image2)

**Table 2. Response of the Achilles tendon to conditioning exercise of the ankle in normal weight and overweight participants**

<table>
<thead>
<tr>
<th></th>
<th>BMI ≤ 23</th>
<th>BMI ≥ 27</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n$</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Age, yr</td>
<td>$37 ± 17$</td>
<td>$45 ± 12$</td>
</tr>
<tr>
<td>BMI, kg/m$^2$</td>
<td>$21.3 ± 1.2$</td>
<td>$30.5 ± 3.6^*$</td>
</tr>
<tr>
<td>Preexercise ATT, mm</td>
<td>$4.0 ± 0.4$</td>
<td>$4.4 ± 0.3^*$</td>
</tr>
<tr>
<td>Postexercise ATT, mm</td>
<td>$3.3 ± 0.3$</td>
<td>$4.0 ± 0.3^*$</td>
</tr>
<tr>
<td>True strain, %</td>
<td>$–19.5 ± 7.4$</td>
<td>$–11.5 ± 2.4^*$</td>
</tr>
</tbody>
</table>

Values are means ± SD. *Statistically significant difference ($P < 0.05$).
In the present investigation, conditioning of the Achilles tendon via resistive ankle exercises substantially improved the correlation between measures of tendon thickness and body anthropometry. Body weight accounted for 52% of the variability in postexercise Achilles tendon thickness compared with just 12% of variability in preexercise measures. Although these findings suggest that other factors still influence Achilles tendon size, they highlight the importance of conditioning in evaluating the sonographic thickness of the Achilles tendon and directly contrast those of previous research in which body weight accounted for only 6–30% of the variability in tendon thickness (1, 29, 41). In light of these data, it is recommended that ankle conditioning exercises be performed before sonographic determination of Achilles tendon thickness in vivo. Although such preconditioning is unlikely to influence the clinical diagnosis of tendon pathology, in which thickness measurements are typically of the order of 15–50% greater than that of healthy tendon (18–20, 26, 48), it would standardize the load history of the Achilles tendon, potentially minimize confounding effects of tendon hydration, and arguably provide a more biomechanically relevant index of tendon structure. As such, it is also recommended that bilateral preconditioning exercises be employed in unilateral cases of tendinopathy, if clinical comparisons of thickness are to be made with the asymptomatic limb.

Interestingly, the AP thickness of the Achilles tendon was significantly greater in obese individuals, confirming observations made in animal models in which a greater content and cross-linking of tendon collagen was seen in obese rodents (3). It is noteworthy, however, that in the present study the transverse strain response of the Achilles tendon in overweight and obese individuals (11.5%) was nearly half that of their lower normal weight counterparts (19.5%), suggesting that there was relatively less fluid movement in the Achilles tendon of overweight and obese individuals in response to conditioning exercise. Reduced fluid movement, in turn, may be associated with impaired passive nutritional pathways in tendon (32) and, speculatively, may contribute to the higher incidence of tendon pathology observed in overweight and obese populations (17). It is also possible, however, that overweight and obese individuals employed different movement or muscle activation patterns when performing ankle exercises compared with normal weight individuals, as has been reported during other tasks, such as the sit-to-stand maneuver (43, 44). Similarly, animal models have shown that physical activity may alter transverse strains in tendon, with a greater Poisson’s ratio (ratio of transverse to axial strain) noted in tendons of animals with low physical activity levels (38). Although all participants completed the conditioning exercises using a visibly similar protocol, lower limb kinematics and electromyography were not recorded during the performance of the conditioning exercises nor were the habitual activity levels of individuals monitored. It is unclear, therefore, whether the reduced transverse strain response observed in the obese group reflects metabolic changes associated with adiposity, different movement strategies, or altered physical activity levels. Additional research, therefore, is required to further elucidate the potential role of adiposity on the acute strain response of the Achilles tendon to conditioning exercise.

Although the spatial resolution of high-frequency ultrasound makes it an ideal method for imaging the Achilles tendon, it is also recognized that it is a highly user-dependent technique. The coefficient of variation for repeated measures of Achilles tendon thickness in the present study (2.3%), however, was small relative to the overall effect of conditioning (~18% strain). This provides further evidence that ultrasonography appears suitable for registering acute changes in the Achilles tendon due to training stimuli (6). Although the technique also allowed for precise localization of the tendon boundary, the present study did not attempt to distinguish between constituent tendinous portions arising from the soleus and gastrocnemius muscles (2). Similarly, this study determined the AP thickness of the Achilles tendon at a single site, 20 mm proximal to the calcaneal insertion. Although there is evidence that the Achilles tendon is transversely isotropic (31) and that tendon dimensions are uniform 20–50 mm from the calcaneal insertion in healthy tendon (15), there is also evidence, albeit in animal models, that the composition of the Achilles tendon may vary along its length (9) and with pathology. Thus it is unknown whether the effects of conditioning are uniform across the entire tendon structure. Further research, therefore, evaluating potential changes in mediolateral dimensions at multiple sites and in pathological tendons with varied compositional states seems warranted.

The conditioning protocol employed in the present study was sufficient to induce alterations in tendon structure. However, the relative importance of components of the loading stimulus (magnitude, frequency, and duration) to the acute response of the Achilles tendon remains unknown. Thus future research directed toward identifying an optimal loading stim-
ulus that will standardize tendon structure without inducing unnecessary muscle soreness is required. Nonetheless, the findings of the present investigation suggest that conditioning of the Achilles tendon substantially improves correlations between sonoographic measures of Achilles tendon thickness and body anthropometry.

In conclusion, conditioning of the Achilles tendon, via resistive ankle exercise, induces alterations in tendon structure that substantially improve correlations between sonoographic measures of Achilles tendon thickness and body anthropometry. Given such structural changes most likely reflect convective fluid movement within the tendon matrix, it is recommended that preconditioning exercises, which act to standardize the load history of the tendon and more accurately reflect tendon collagen, be performed before sonoographic measurements of Achilles tendon thickness in vivo.

GRANTS

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

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