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Original Research

The Achilles Tendon in Healthy Subjects: An Anthropometric and Ultrasound Mapping Study

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A R T I C L E I N F O

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A B S T R A C T

Ultrasonography is an inexpensive, fast, and reliable imaging technique widely used to assess the Achilles tendon. Although significant data exists regarding pathologic tendon changes, ultrasound data from healthy individuals are more limited. We aimed to better characterize ultrasound Achilles tendon measurements in healthy individuals and identify important correlating factors. The information collected included patient demographics, body habitus, activity level, foot dominance, and resting ankle angle. Ultrasound analysis was performed bilaterally on the Achilles tendons of 50 subjects using a high-frequency transducer to measure tendon width, thickness, cross-sectional area, and length. Males had a significantly larger mean tendon length, width, thickness, and cross-sectional area. No statistically significant difference was found in any tendon dimension between the white and black participants. Similarly, no difference was found in any tendon parameter when comparing right versus left leg dominance. Healthy subjects had a mean ankle resting angle of 45.1° ± 24° with no statistically significant difference between right and left ankles. Considering all individuals, each tendon parameter (tendon length, width, thickness, and cross-sectional area) correlated positively with subject height, weight, tibia length, and foot size. Only the Achilles cross-sectional area correlated significantly with the activity level. The resting angle of the ankle correlated positively with both tendon length and thickness. In conclusion, we found significant variations in Achilles tendon anatomy in the healthy adult population. We have thoroughly characterized significant correlations between healthy tendon dimensions and various body habitus, activity levels, and ankle parameters. Greater knowledge of the normal Achilles tendon anatomy and characterization of its variations in the healthy population will potentially allow for better pathologic diagnosis and surgical repair.

The Achilles tendon is the strongest tendon in the human body and serves as the primary plantarflexing mechanism of the ankle. Injuries to the Achilles tendon are among the most commonly encountered in sports medicine and have been shown to have an increasing incidence, likely owing to the growing popularity of competitive and recreational sports (1–3). To properly care for this common injury, we believe that a detailed understanding of the normal Achilles tendon anatomy is needed. Therefore, effective and reliable imaging techniques are critical in the diagnosis and management of such injuries.

Ultrasonography is an accurate, inexpensive, fast, safe (no ionizing radiation), and noninvasive imaging technique that has been widely used and accepted for assessing the tendons (4–6). Additionally, it provides the ability to perform imaging during joint motion and easy contralateral side comparison. Regarding the Achilles tendon, ultrasonography has been well used in diagnosing pathologic features, including rupture, tendinosis, and tendonitis (7–9). Moreover, it has been shown to be a reproducible imaging method with good inter- and intraobserver reliability (10). The Achilles tendon is particularly amenable to ultrasound analysis because of its relatively superficial anatomic positioning (9,11). Although alterations in the cross-sectional area and thickness have been well documented in the diagnosis of Achilles tendon pathology, data regarding the anthropometric measurements with ultrasonography in healthy individuals are more limited. To the best of our knowledge, little is known about the correlation between ultrasound Achilles tendon measurements (i.e., length, width, thickness, cross-sectional area) and demographic data (e.g., race, age, gender), body habitus (e.g., height, weight, body mass index [BMI], tibia length, foot size), activity level, and foot dominance (9,12,13).

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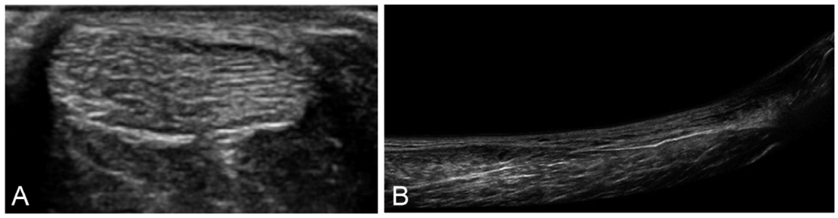

Fig. *(A)* Cross-sectional ultrasound image and *(B)* longitudinal extended field-of-view (EFOV) ultrasound image of the Achilles tendon. Tendon thickness was measured on the cross-sectional view as the maximal anteroposterior dimension, tendon width using the maximal mediolateral dimension, and cross-sectional area using the continuous trace feature. Achilles tendon length was measured on the EFOV as the distance from the musculotendinous junction of the gastrocnemius to the insertion on the calcaneus.

Additionally, the ankle resting angle is a concept that has been shown to be important by Carmont et al (14,15), in particular, regarding restoring the Achilles tendon length and tension. Pathologic features of the Achilles tendon can alter the angle at which the ankle rests; therefore, an understanding of the normal variations is particularly important. We aimed to better characterize this angle in a healthy population and determine the correlations with Achilles tendon parameters, demographic data, and body habitus.

Therefore, the purpose of the present study was to determine the resting ankle angle and perform ultrasound analysis of the Achilles tendon in a group of healthy participants to report any correlations with the demographic data, body habitus characteristics, ankle dominance, and activity level. Having a better understanding of the normal variations of Achilles tendon anatomy and resting ankle angle in a healthy population will not only enable clinicians to better diagnose tendon pathology, but it will also allow surgeons to more effectively repair tendon defects and restore normal anatomic function of the ankle joint.

Participants and Methods

The present prospective observational research study was performed by recruiting healthy subjects to participate in accordance with our institutional review board. Most of these volunteers consisted of staff and visitors to the home institution's medical center.

Inclusion Criteria

Subjects were included in the study if they met the following inclusion critera: age ≥18 years; agreed to undergo ultrasound analysis of bilateral Achilles tendons, no history of arthritic, neurologic, or vascular lower extremity pathology; and otherwise healthy and no other illnesses that prevented normal ambulation (without assistive devices).

Exclusion Criteria

Subjects were excluded from the study if they had a known history of Achilles tendon pathology, including tendon trauma, surgical repair, or a history of tendonitis within the previous 6 months. They were also excluded if they had a history of major lower extremity joint surgery, including the hip, knee, or ankle or had contraindications to ultrasonography (i.e., allergies to the ultrasound gel or skin lacerations or lesions that prevented proper ultrasound analysis of the tendon). Finally, the subjects were excluded if they had medical conditions possibly affecting the Achilles tendon, including rheumatoid arthritis, gout, psoriasis, ankylosing spondylitis, and Reiter syndrome.

Questionnaires

After the subjects provided informed consent, preliminary demographic information was collected, including age, gender, and race. To characterize the foot dominance of an individual, the subjects were asked with which leg they would prefer to kick a ball. To quantify the patient activity level, we used a validated ankle activity scale developed by Halasi et al (16). This survey provides a reliable measure of ankle-specific activity levels and has been used in multiple subsequent studies (17,18). The scaling system gauges a subject's involvement using an extensive series of activities, with calculation of a final cumulative score.

Body Habitus Measurements

The height and weight of each participant was recorded in the normal fashion, with subsequent calculation of the BMI. The foot length was obtained bilaterally by measuring the distance from the most posterior aspect of the heel to the most distal portion of the longest digit using a standard tape measure with 1-mm increments. The distance from the ridge of the medial tibial plateau to the inferior aspect of the medial malleolus was quantified as the tibia length in the present study. The resting angles of the bilateral ankles were measured using a technique similar to that described by Carmont et al (14). With subjects in the prone position and their knee flexed to 90°, they were asked to relax the ankle and foot. A standard goniometer with 1° increments was positioned with 1 arm along the length of the fibular shaft. With the axis of the goniometer placed at the tip of the distal fibula, the other arm was aligned to the head of the fifth metatarsal and the angle recorded.

Ultrasound Analysis

Ultrasound analysis was performed bilaterally on the Achilles tendons using a GE Logiq s8 ultrasound machine (GE Healthcare, Little Chalfont, UK) with a ML6-15 5- to 15-MHz linear array transducer. With subjects lying in the prone position and both feet hanging over the edge of the examination bed, the transducer was placed transversely to the tendon to obtain a cross-sectional scan (Fig. A). Measurements of the tendon thickness, width, and cross-sectional area were taken at the level of the tip of the medial malleolus to ensure standardization. Tendon thickness was measured at the maximum anteroposterior diameter and the tendon width at the maximum mediolateral diameter on the cross-sectional image at the level of the medial malleolus. The cross-sectional area was quantified using the continuous trace method to outline the tendon border, with subsequent area calculation using the ultrasound machine. Extended field-of-view (EFOV) ultrasonography was used longitudinally on the posterior leg to measure the tendon length (Fig. B). In the present study, the Achilles tendon length was specifically quantified as the distance from the musculotendinous junction to the tendon insertion on the calcaneus. The same operator performed the ultrasound analysis on all subjects to maintain uniformity.

Statistical Analysis

One-way analysis of variance and Student's *t* test were used to compare the mean values of the data. In particular, these were used to compare the mean tendon length, width, thickness, and cross-sectional area in each of the following categorical breakdowns: gender, race, and foot dominance. The relationship between 2 continuous variables was evaluated using the Pearson correlation test. Specifically, it was used to determine the correlation between the tendon parameters and the patient-specific factors. Statistical significance was defined at the 5% ($p \le .05$) level.

Results

A total of 50 subjects, including 29 (58%) females and 21 (42%) males, were enrolled in the present investigation and underwent bilateral Achilles tendon ultrasound examination. The enrolled participants had a mean age of 34.1 years, mean height of 169.1 cm, mean weight of 76.1 kg, and mean BMI of 26.6 kg/m^2. More comprehensive descriptive data of the study sample are listed in Table 1.

Ultrasound examination revealed a mean Achilles tendon length of 9.35 cm, mean width of 1.39 cm, mean thickness of 0.42 cm, and mean tendon cross-sectional area of 0.51 cm^2 (Table 2). When comparing genders, males had a statistically significant greater tendon length (10.77 versus 8.75 cm), tendon width (1.52 versus 1.34 cm),