Original article

Morphometric evaluation of human tendocalcaneus: a cadaveric study of south indian male population

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Summary

Introduction: **Tendocalcaneus or Achilles tendon is formed by the fusion of the tendons of gastrocnemius and soleus muscles. Normal morphometric measurements of tendo-calcaneus serves an important landmark in its anthropometric evaluation and biomechanical characteristics. Hence the objective of this study was to provide detailed morphometric profile of tendocalcaneus in south indian cadaveric male population.**
Materials and method: **A total of 64 dissected adult limbs was studied. Out of the 64 limbs: 37 belonged to right side while 27 were of the left side. These limbs were dissected to expose the extent of tendocalcaneus. Total length, proximal width and proximal circumference of the tendon, distal width and distal circumference of the tendon was measured. Results were tabulated and correlated using SPSS.**
Results: **Tendon length, width and circumference showed no statistically significant differences between the right and left side. However significant correlation was observed between proximal width and distal widths, proximal circumference and distal circumference, proximal width and proximal circumference and distal width and distal circumference of the tendon.**
Conclusion: **This cadaveric morphometric study of tendo-calcaneus would be very helpful to sports medicine physicians for diagnosis and treatment of tendo Achilles overuse injuries and tendinopathy.**
Level of evidence: IV.

KEY WORDS: tendocalcaneus, achilles tendon, morphometric, human cadaver, tendinopathy.

Introduction

Tendo-calcaneus (TC) or Achilles tendon is the strongest tendon of the human body and is principally responsible for the plantar flexion of the ankle. It is a conjoint tendon which is formed by the fusion of the tendons of gastrocnemius and soleus muscles. The normal length of the tendon is about 10-15 cm. TC is prone to rupture and would frequently undergo degeneration and inflammation[1]. TC is normally composed of type 1 collagen fibers[2]. However, following the injury, the resynthesized collagen would be of type III[3]. Age related changes in human Achilles tendon is reflected with the changes in its cellular and fibrous components. These changes are often manifested with flattening of the cells along with their decreased quantity[4]. Disorders of the tendon results in imbalance between mobility and stability. The morphological changes in the tendon size provides important health information of the tendon such as its undue thickening could be a precursor for tendon rupture[5, 6].
The morphological and morphometric variations of the TC are related to functional requirements. Therefore, normal morphometric measurements of TC serves as an important landmark in its anthropometric evaluation and biomechanical characteristics. Previous study on morphometric evaluation of the TC performed using ultrasound imaging in a normal population has reported that even though there is no strong correlation between TC measurements and anthropometric measures; the weight and body mass index had good correlation with tendon size[7].
There have been diverse opinion regarding morphometric changes of TC among various ethnicity and races. Some studies report that TC morphometry vary considerably in different ethnic groups while few studies mention that no such differences exist between various races.
Knowledge regarding the normal measurements of the TC is imperative before determining any pathological variations associated with the tendon. Most of the morphological studies are clinical studies using MRI and ul-

trasound but cadaveric studies are very few. Due to the limited data available in this regard, the morphometric study of TC was undertaken using adult human cadavers fixed in formalin solution. Cadaveric morphometry is simple, noninvasive, easy, no endangers of ionizing radiation as in MRI or no cost related issues as in ultrasound studies. Hence the objective of this study was to provide detailed morphometric profile of TC in south indian cadaveric male population.

Materials and method

This study was performed in accordance to the ethical and scientific standards discussed by Padulo et al.[8].
A total of 64 isolated adult limbs preserved in formalin solution was used in this study. These limbs belonged to male cadavers, whose age ranged between 60 to 75 yrs. Out of the 64 limbs; 37 belonged to right side while 27 were of the left side. These limbs were carefully dissected and cleaned to expose the tendocalcaneus. Deceased, fractured, limbs with cuts or scars and limbs belonging to female cadavers due to its adequate unavailability was excluded from the study. Following parameters were measured for each tendon using a scale: total length (from the musculotendinous junction of the soleus muscle till its attachment to the posterior part of calcaneus) (Fig. 1), proximal width and proximal circumference of the tendon (near its formation), distal width and distal circumference of the tendon (near its insertion) were measured and documented (Figs. 2-4). Because of the variability in the insertion of the tendocalcaneus at calcaneal tuberosity, the superior aspect of the calcaneal tuberosity was used as the reference point for measurement. A pin was placed at this anatomic landmark and this region was cleaned to expose the distal attachment. The distal width and distal circumference of the tendon was recorded at the closest point of insertion to the calcaneal tuberosity. These values were then tabulated using SPSS v 15.0 statistical package. Mann-Whitney U test was used for comparison of the parameters between two independent groups (right and left limb) to find whether there is statistically significant difference in the measurements between the two groups. Spearman's correlation analysis was done to determine the relationship between the measured parameters of the tendocalcaneus. P value less than 0.05 was considered as statistically significant.

Results

The mean values of various morphometric parameters of tendocalcaneus in right and left limbs are shown in Table I. TC length, width and circumference showed no statistically significant differences between the right and left side tendons (Graph I). The average length of the tendon was 7 cm which was most frequently observed (11%). Nevertheless, we observed a limb with longest tendon measuring 13.5 cm (Fig. 5) and a limb with shortest tendon measuring 3.4 cm. The mean length of the tendon on right side was 7.8 cm whereas on left side was 7.5 cm. The proximal circumference of the tendon varied from 2 to 4 cm, proximal width from 1 to 3.5 cm, distal width from 2.7 to 5.5 cm and distal circumference from 3 to 6 cm. No statistically significant difference was observed in these measurements between the right and left limbs. Furthermore, we could not relate the tendon measurements to BMI or foot and arch type because all the limbs studied by us were isolated limbs.
When we correlated the various parameters, slight correlation existed between the length of the tendon and its circumference (r=0.30 for proximal circumfer-

Figure 1. Dissection of the tendocalcaneus showing the measurement of the length (L) of the tendon.

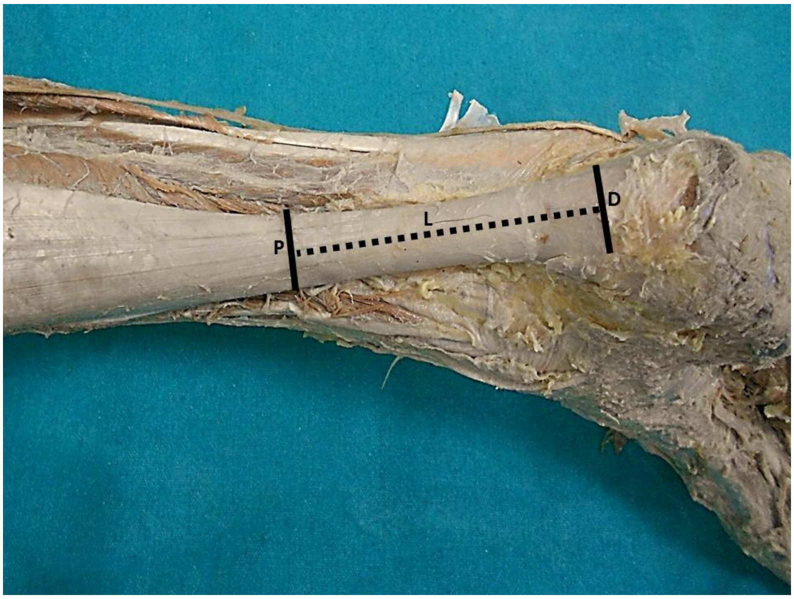


Figure 2. Tendocalcaneus morphometric view showing the measurement pattern. L: length of the tendon, P: proximal width, D: distal width. The proximal circumference was measured around the proximal width and distal circumference around the distal width.

Figure 3. Figure showing the measurement of the width of the tendon; A. Proximal width (PW); B. Distal width (DW).

Table I. Table showing the mean value and SD of the various measurements of tendocalcaneus.

	Length (cm)	Proximal width (cm)	Distal width (cm)	Proximal circumference (cm)	Distal circumference (cm)
Right limb (n= 37)	7.8 ± 1.9	2.2 ± 0.4	2.4 ± 0.3	4.0 ± 0.6	4.4 ± 0.6
Left limb (n=27)	7.5 ± 2.2	2.0 ± 0.4	2.5 ± 0.5	3.9 ± 0.7	4.3 ± 0.5

ence and r=0.09 for distal circumference) but it was not statistically significant. Weak correlation was observed between length of the tendon and other measurements. Significant correlation was observed between proximal width and distal widths (r=0.40, p=0.03), proximal circumference and distal circumference (r=0.42, p=0.01), proximal width and proximal circumference (r=0.65, p=0.001) and distal width and distal circumference (r=0.37, p=0.02) of the tendon.

Figure 4. Figure showing the measurement of the circumference of the tendon; A. Proximal circumference (PC); B. Distal circumference (DC).

Discussion

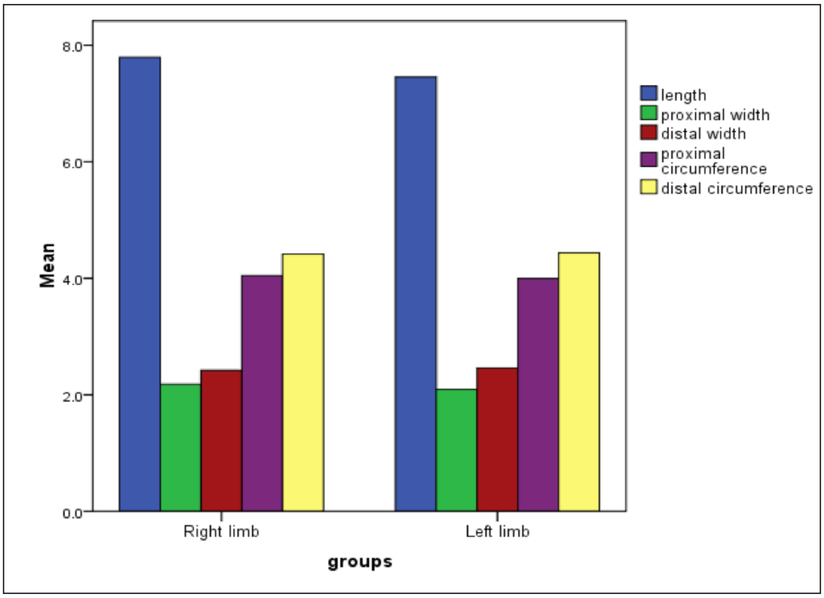
Tendocalcaneus or human Achilles tendon is the most easily accessible, superficial tendon of human body that transfers the force of muscles to the bones[9,10]. The normal thickness of the TC is considered to be 6 mm. The thickness of TC greatly varies based on anatomical and ethnic considerations[9]. During our literature review we came across many studies of morphometric evaluation of TC but studies on cadaveric TC is very less. A study done by Canbolat et al., has reported significant higher width, thickness, length and circumferential area of TC in male subjects when compared to female subjects[7]. Various studies have reported the thickness of TC in different parts of the world which has been summarized in Table II. From the available data, it is clear that not much differences in the thickness could be appreciated globally and hence we did not measure the thickness of the tendon.

Ricardo et al. restate that the TC measurements has no significant correlation with the age ranges or races. But width of the tendon would be higher in the overweight body mass index individuals as compared to normal individuals[16]. According to Canbolat et al., the width of the TC on the left side would be significantly smaller than right side in the age group of 18-29 years when compared to other age groups. The Authors also confirm that the length of the TC is smaller on both sides in this age group in comparison with the other age groups[7]. Differences in the cross sectional area of the TC has been reported to be larger in older age group[17].

Significant changes in the length and thickness of TC between dominant and non-dominant feet[18] as well as between right and left side[19] have been documented. Differences in the length of the tendon between dominant and non-dominant side was also confirmed in cadaveric study by Bailus et al.[20]. Studies which confirm the changes in various morphometric measurements among the individuals who are active in sports and sedentary life style have also been report-

Table II. Comparison of thickness pattern of the TC from various studies done across the world.

Study done by	Study population	Thickness of TC
Canbolat et al. [7]	Turkey	4 mm
Van Schie et al. [11]	Netherlands	6.8±1.2 mm
Fahlstrom and Alfredson [12]	Sweden	6±1 mm
Mabuchi et al. [13]	United States of America	6.03±0.2 mm
Pang and Yin [14]	Hong Kong	5.1±0.6 mm
Kallinen and Suomin [15]	Finland	5.7±1.4 mm
Ricardo et al. [16]	Brazil	5.5±0.6 mm



Graph I. Graph showing the mean value of tendocalcaneus morphometric measurements in right and left limbs.

Figure 5. Figure showing a very long Achilles tendon.

ed[7]. Morphometric study involving transverse and antero-posterior diameter of TC done using ultrasound technique in Brazilian population reported no significant differences between left and right side tendons. However, these parameters did show significant differences among the gender, with the higher mean values attributed to males[16].

Few studies done on the foot type and the TC morphometry opine that there exists an association between the two. Murley et al. have found a positive correlation of TC morphometry with foot type[21]. According to Koivunen-Niemela & Parkkola, the flat arched foot type is often associated with a thinner TC tendon[9]. This association could be because of low efficiency of flat arched feet to transfer force from the rear foot to forefoot during propulsion act of gait[22]. In the present cadaveric study we have not identified any statistically significant differences in length of TC between right and left side limbs of south indian population but the wide range of length as noted was varied from 7 to 13 cm.

Knobloch et al. found that the width of the tendon ranged from 2 to 6 cm. In our study we found that the width of the tendon ranged from 1 to 4 cm and its circumference ranged from 3 to 6 cm[23]. Koivunen and Parkkola believe that the variation in the shape of the tendon caused up to 25% variation in its width and that differences in population height could also be related to the tendon thickness[9]. Magnusson et al. found that the greater tendon size markedly lowers the stress on the tendon, which may reduce the risk of injury to the tendon[24].

In the present study we found significant correlation between proximal width and distal widths, proximal circumference and distal circumference, proximal width and proximal and distal width and distal circumference of the tendon which indicates that width, thickness and circumference of the tendon is interrelated and supports the above assumptions. Thinner tendons are vulnerable to the risk of tendinopathy and tendency of their rupture is also more when compared to thicker tendon[25]. Achilles tendinopathy is a common injury amongst athletes resulting from overuse of Achilles tendon. Its incidence is found to increase in recent years. Jhingan et al., in their study, demonstrated that thickness of tendocalcaneus is significantly related to Achilles tendinopathy and considers it as one of the risk factors[26]. If the tendon is under constant and excessive strain as a result of overuse and exposure to repetitive trauma, the microtears in the tendon increases and is vulnerable to hypertrophy[27]. Tendon hypertrophy could also occur in cases of regular exercise[28]. Running is also associated with physiologic hypertrophy of the tendocalcaneus and over-weight runners may precociously develop tendon abnormalities[29]. Body mass index plays an important role in the development of Achilles tendonitis as obesity is considered as an intrinsic risk factor for Achilles tendonitis[30].

Studies have shown that ultrasound image measurements of the tendocalcaneus had exact correlation with the measurements on cadavers indicating that morphometric evaluation of tendocalcaneus in cadavers is a valid and reliable tool which is considered as a gold standard for measurement[31]. Detailed morphometric evaluation and the analysis of correlation as done by gross examination of human cadavers in the present study gives an important information about the biomechanical characteristics of the tendon and its effect on the gait. This comprehensive study presenting normal values of TC would be very helpful to sports medicine physicians for diagnosis and treatment of Achilles tendon overuse injuries and explain the pathology associated with insertional tendinopathy.

Conflict of interest

The Author has no financial or personal relationships with other people or organizations that could inappropriately influence their work.

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