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Short communication

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Received: 14 Aug 2023 - **Accepted:** 19 Dec 2023 - **Published:** 14 Feb 2024

Keywords: Achilles tendon, Achilles tendinopathy, morphology, morphometry, calcaneus bone

Cite this article: Emmanuel Peter et al. Morphometric evaluation of human Achilles tendon: a cadaveric study of Malawian adult male population. PAMJ Clinical Medicine. 2024;14(20). 10.11604/pamj-cm.2024.14.20.41445

Available online at: https://www.clinical-medicine.panafrican-med-journal.com//content/article/14/20/full

Morphometric evaluation of human Achilles tendon: a cadaveric study of Malawian adult male population

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PAMJ Clinical Medicine

Abstract

The anatomy of the Achilles tendon and its relationship to the posterior compartment of the leg dimensions are critical in managing Achilles tendinopathy. Individuals show considerable differences in the dimensions of the Achilles tendon across populations. This study aimed to determine the morphology and morphometric dimensions of the Achilles tendon in adult male Malawian cadavers and to suggest clinical implications associated with Achilles tendinopathy. Male adult Achilles tendon specimens (n=14) obtained from the dissection laboratory at Kamuzu University of Health Sciences were dissected to assess the tendon length, proximal width, middle width, distal width, proximal circumference, middle circumference, distal circumference, proximal thickness, middle thickness, distal thickness, and gastrocnemius bulkiness using a standard Vernier caliper. The study found that the mean Achilles tendon length was 4.06 cm. The tendon length, width, circumference, and thickness showed no statistically significant difference between the right and left lower limbs; however, there was a positive correlation between gastrocnemius bulkiness and Achilles tendon proximal thickness. The current study has described the morphology and morphometry of the Achilles tendon concerning the risk of Achilles tendinopathy. Our sample population generally showed smaller Achilles tendon dimensions than other populations. This should be considered during the management of Achilles tendinopathy and preoperative planning of surgical operations of the posterior compartment of the leg.

Introduction

The Achilles tendon (AT) is a conjoined tendon of the soleus and gastrocnemius muscles contained in the posterior compartment of the leg [1]. The tendon originates from the musculotendinous junction of the soleus and gastrocnemius muscles and is inserted on the posterior medial aspect of the calcaneus bone [2,3]. Soleus and gastrocnemius muscles form a three-headed triceps surae whose primary function is to provide plantarflexion of the ankle joint [3]. Collectively, the triceps surae provide up to 93% of the total plantarflexion force which the Achilles tendon transfers to the calcaneus bone [4,5]. In essence, the Achilles tendon plays a key role in functional activities such as walking and running [6-8]. Because of its limited blood supply and the immense amount of stress pressing on it, the Achilles tendon's nature and function expose it to a variety of pathologies [7,9] including tendon ruptures and tendinopathies [7]. Achilles tendinopathy usually causes collagen degradation, collagen separation, and tendon cell matrix disorganization [10-12]. Changes in the transfer of forces may occur as a result of the loss of collagen continuity that connects the fibers, resulting in a weakened tendon. The thickness of the Achilles tendon changes as a result of natural degeneration, such as wear and tear in tendinosis. All these alterations may have an impact on the Achilles tendon morphology, biomechanics, and morphometric values, mostly seen in Achilles tendinopathy [13].

Achilles tendinopathy is widely considered one of the most prevalent musculoskeletal disorders globally. However, previous authors have also demonstrated that the prevalence of Achilles tendinopathy may differ significantly depending on the geographical setting. Findings of previous studies from the United Kingdom [8,14], Nigeria [15], the United States of America [16], and Italy [17] suggested a considerable difference in the prevalence of Achilles tendinopathy. The patient's history, tendon palpation [10], and musculoskeletal diagnostic tests [9] are often preferred when diagnosing a patient presenting with Achilles tendinopathy. However, ultrasound imaging is regarded as a valuable tool for enhancing diagnostic accuracy [11,18,19]. Ultrasonographic findings, such as changes in tendon echogenicity, evidence of neovascularization, and a notable increase in tendon morphometry are consistent with Achilles tendinopathy [19-21]. The metric values of the tendon under ultrasound examination are frequently compared to the unaffected limb or to previously established reference values to determine whether a tendon is showing any significant morphometric alterations [19-21]. Previous authors have reported that the measures of the Achilles tendon in different populations vary [14-17]. However, there is a paucity of information regarding the metric values of the Achilles tendon in the Malawian population. The current reference standards for the ultrasonographic diagnosis of Achilles tendinopathy in Malawi are based on research done in other populations. This presents considerable challenges. Thus, the current study aimed to provide a morphometric description of the Achilles tendon in a Malawian setting. Physiotherapists, sports medicine physicians, podiatrists, anatomists, radiologists, and orthopedic surgeons may find the findings of this study useful, particularly in the management of Achilles tendon disorders.

Methods

Study design: a cross-sectional study was conducted to determine the morphometric dimensions of the Achilles tendon in adult male Malawian cadavers and to suggest clinical implications associated with Achilles tendinopathy.

Study setting, population, and size: the current study was conducted on the Achilles tendon of adult male Malawian cadaveric specimens, obtained from the Anatomy Division dissection laboratory at Kamuzu University of Health Sciences, School of Life Sciences and Allied Health Professions, Blantyre, Malawi. The study period was one year from June 2020 to July 2021. A total of 28 paired lower limbs were available to the researchers during the data collection period, 13 of the lower limbs were too dry and one presented with a fractured tibia, as a result, they were excluded from the study. Data were collected from the 14 paired lower limbs (7 left and 7 right) that met the inclusion criteria. Due to a shortage of female cadaveric specimens in the Anatomy Division at Kamuzu University of Health Sciences, limbs from a female population were excluded from this study. Limbs having ruptured Achilles tendons, or a fractured tibia were eliminated because the metric values obtained from these would not accurately reflect non-pathological AT values.

Variables: the following variables were collected in this study: 1) AT tendon length, 2) AT proximal width, 3) AT middle width, 4) AT distal width, 5) AT proximal circumference, 6) AT middle circumference, 7) AT distal circumference, 8) AT proximal thickness, 9) AT middle thickness, 10) AT distal thickness, and 11) the gastrocnemius bulkiness. We considered possible confounders in our analysis.

Data collection: Grant's dissector, 16th edition, served as a guide for the dissection procedure that was used [22]. All lower limbs of the sampled cadaveric specimens were dissected and cleaned to reveal the Achilles tendon [22]. The fascia for the Achilles tendon was removed, and the tendon was cleansed [22,23]. Following that, measurements were taken. Three landmarks were identified: the midpoint of the tendon, the posterior-superior surface of the calcaneal tuberosity (distal landmark), and the musculotendinous junction of the soleus muscle (proximal landmark). The AT length and width were all measured using a standard analog stainless steel vernier caliper (measuring range; 0 - 150 mm x 0.02 mm, manufactured by Aexit, USA). The length of the tendon was measured from the musculotendinous junction of the soleus muscle to the posterior-superior aspect of the calcaneal tuberosity (Figure 1A). The width of the tendon was measured at three points: 0.5 cm from the musculotendinous junction of the soleus muscle, the mid-point of the AT length, and the posterior-superior surface of the calcaneal tuberosity (Figure 1B). The thickness of the AT was also measured using a vernier caliper at the proximal, mid-point, and distal landmarks

(Figure 1C). However, the circumference of the proximal, mid-point, and distal landmarks were all measured using a thread. The thread was then stretched across a ruler to determine the collect value as shown in Figure 2A and B respectively. The bulkiness (circumference) of the gastrocnemius muscle was measured at the muscle belly using a tape measure as shown in Figure 2C. All metric measurements were independently performed by two investigators, and the information was only recorded on the data collecting sheet once the investigators had reached an agreement on the precise value for a given tendon.

Data management and analysis: Microsoft Excel 2019 was used to manage data acquired. The IBM Statistical Package for Social Science software (SPSS version 28.0.0.0) was used for data analysis. Tables containing descriptive data, such as ranges, means, and standard deviations, were created to describe the data. A p-value of less than 5% was considered statistically significant. Measurements of the right and left AT were compared for statistically significant differences, using a paired student T-test. One-way ANOVA was used to compare independent measurements taken at the three landmarks (proximal, mid-point, and distal) to assess for statistically significant differences. The Pearson correlation test was used to evaluate the relationship between gastrocnemius bulkiness and tendon thickness. The results of this study were then compared to those from related studies carried out in other populations to account for geographic differences.

Ethical consideration: the current study was conducted following the World Medical Association Declaration of Helsinki and the Malawian Government's Anatomy Act No. 14 of 1990 (updated 2016). The study was approved by the Kamuzu University of Health Sciences Research Ethics Committee (Formerly the University of Malawi´s College of Medicine Research and Ethics Committee) with a clearance number U.2/21/3254.

Results

This study examined 14 cadaveric lower limbs with exposed Achilles tendons. The average morphometric values of the Achilles tendon for both the right and left legs are presented in Table 1 and Table 2. All measurements did not show a statistically significant difference between the right and left sides (T-test, $p > 0.05$). In addition, the width, circumference, and thickness measurements of the Achilles tendons on both sides did not exhibit significant side differences at three landmarks (ANOVA, $p > 0.05$). A statistically significant positive linear correlation was observed between the bulkiness (circumference) of the gastrocnemius muscle and the proximal thickness of the Achilles tendon ($p = 0.037$, $r = +0.59$). However, the correlation between the gastrocnemius bulkiness and the AT thickness at the mid-point and distal landmarks was not statistically significant ($p > 0.05$).

Discussion

The current study explored the morphometric dimensions (length, width, thickness, and circumference) of the Achilles tendon in adult male Malawian cadavers. The mean length of the AT was 4.06 ± 0.99 cm, but the average length was 7 cm in a study conducted by Kumar *et al.* (2017) in India [1], and 7.15 ± 2.37 cm in another study conducted by Singhal *et al.* (2019) in India [7]. Furthermore, according to a study conducted by Apaydin *et al.* (2009) in Italy, the average length was 15 cm, ranging from 11 cm to 23 cm [12]. The closeness in results by Kumar *et al.* (2017) and Singhal *et al.* (2019) could be due to the shared racial group. On the other hand, disparities in the results of this study and Apaydin *et al.* (2009) compared to those of India could be due to racial and geographical differences. Additionally, our sample size was different from the sample size of other studies. We used a sample size of 14 whereas Singhal *et al.* (2019) and Kumar *et al.* (2017) conducted cadaveric studies with 108 and 64 specimens, respectively [1,7].

According to studies conducted by Kumar *et al.* (2017) and Singhal *et al.* (2019) in India, there were no statistically significant differences in the AT length of the left and right sides, which is similar to studies conducted by Apaydin *et al.* (2009) in Italy and Canbolat *et al.*(2015) in Turkey [1,7,11,12]. This is in line with the findings of the current study, which demonstrated no significant difference between the left and right sides (p = 0.47). On the other hand, Balius *et al.* (2016) cadaveric investigation discovered that there is a variation in length between the dominant and non-dominant sides [9]. Since the specimen's limb dominance history was unclear, the current cadaveric investigation did not examine length in connection to leg dominance. These findings may suggest that clinicians should continue to compare the affected and non-affected sides, but clinical reasoning may be required because there may be discrepancies in AT length to leg dominance.

There is an extensive report on the thickness of the AT in various populations [1,11,12]. Despite disparities in race and geographic regions, the studies demonstrated no significant differences in thickness [1,12]. In our study, the average thickness of AT (7.9 mm) is generally higher compared to other studies done in Turkey, Finland, and the Netherlands [1,12], which showed tendon thickness ranging from 4 - 6.8 mm. This may mean that the Malawian population has a higher AT thickness, or these results may be due to a limited sample size. Factors such as race, physical fitness, and environment may have contributed to the elevated mean thickness values. Malawians generally engage in physical activities such as walking considerable distances, according to a study by Chisati *et al.* (2015) [24]. The current study demonstrated no significant difference in AT thickness between the left and right sides, which is similar to Canbolat *et al.* (2015) study in Turkey; however, Egwu *et al.* (2014) study in Nigeria reported a substantial variation in thickness between the left and right sides [11,25]. The variations could be explained by differences in sample size and data collection methods. These differences in AT thickness findings may necessitate further research to make a definitive determination on the feasibility of comparing the affected side to the non-affected side as a reference point.

The width of the AT in this study was found to be similar to the studies done by Singhal *et al.* (2019) and Apaydin *et al.* (2009) [7,12]. The proximal (origin) width was large; the middle width was small, and the insertion width was large (distal). Our findings were also similar to this morphology of the tendon´s width. In the present study, the average width at the origin was 1.73 ± 0.29 cm; the middle was 1.51 ± 0.35 cm, and the insertion was 1.99 ± 0.32 cm. Singhal *et al.* (2019) found the average width in men at proximal to be 1.23 ± 0.33 cm, at middle 1.25 ± 0.45 cm, and distal to be 2.13 ± 0.63 cm [7]. The average male width was 15.38 mm, according to Canbolat *et al.* (2015) [11]. We discovered that the average circumference of the AT is 4.03 ± 0.45 cm at the proximal, 3.86 ± 0.52 cm at the middle, and 4.95 ± 0.54 cm at the distal, which appears similar to the width morphology where the circumference is greater at the origin, decreases at the middle and increases at the insertion in the current study. The morphological configuration of the AT suggests that anatomists, surgeons, or clinicians should expect the AT´s size to be greater at the origin, decrease at the middle, and increase at the insertion. The relationship between gastrocnemius bulkiness and the AT thickness was also investigated in this study. The results revealed a statistically significant positive correlation between the gastrocnemius bulkiness and proximal thickness (r = +0.59, p = 0.027), but no link between gastrocnemius bulkiness and middle or distal thickness. This outcome could clinically propose that training the gastrocnemius muscle could affect the origin of the AT. Unfortunately, we were unable to locate a study that looked into the relationship between gastrocnemius bulkiness and AT thickness. Therefore, the present study suggests for further study on the relationship between gastrocnemius bulkiness and AT thickness.

Achilles tendinopathy is less likely to occur if the tendon is thicker [1]. This is supported by the assertion made by Kumar *et al.* (2017) that thinner tendons are more susceptible to tendinopathy as a result of persistent mechanical strain [1]. Athletes who participate in activities such as marathons, netball, and football are at a higher risk of Achilles tendinopathy [11]. A majority of previous studies on the Achilles tendon used ultrasonography, which is the current gold standard for diagnosing Achilles tendinopathy. A few cadaveric investigations generally have been explored. Kumar *et al.* (2017) and Singhal *et al.* (2019) found an identical connection between ultrasound and cadaveric morphometric measurements of the AT [1,7], suggesting the interpretation that cadaveric morphometric evaluation of the AT is a viable and trustworthy approach that may be used as a gold standard. Therefore, getting data from the local context regarding the AT morphometric evaluation is critical. The present study managed to determine the basic morphometric values of the Achilles tendon in Malawian adult males. These values may be useful to physiotherapists, sports medicine doctors, podiatrists, anatomists, radiologists, and orthopedic surgeons in the diagnosis, management, and evaluation of Achilles tendon overuse, injuries, and tendinopathy, among other conditions. Furthermore, the study's findings may serve as a baseline for future research.

Strengths and limitations of the study: this study was well-designed, with all investigators working together to reduce personal data-gathering errors. Furthermore, the data was rigorously analyzed by utilizing up-to-date and dependable software and statistical methods. To conclude, the findings were thoroughly discussed concerning the findings of previous investigations. This study was able to explore the AT´s metric values despite encountering limitations such as small sample size; and lack of literature about the analyzed cadaveric specimen's lifestyle, including physical activities, and the findings may not be generalized due to the absence of female population specimens.

Conclusion

This study has determined the basic morphometric values of the Achilles tendon for the human adult male population of Malawian origin. The average dimensions of the AT of the human adult male Malawians are generally smaller compared to other populations. The width, circumference, and thickness show similar morphometric behavior from the origin, middle to insertion; the gastrocnemius bulkiness seems to only affect the tendon at the origin. These values will help practitioners (physiotherapists, sports medicine physicians, podiatrists, anatomists, radiologists, and orthopedic surgeons) in the diagnosis and evaluation of Achilles tendon overuse injuries and tendinopathy amongst other pathologies. The study's findings also serve as baseline measure values for future research.

What is known about this topic

- *The anatomy of the Achilles tendon and its relationship to the posterior compartment of the leg dimensions are critical in the management of Achilles tendinopathy;*
- *Individuals show considerable differences in the dimensions of the Achilles tendon across populations;*
- *The thickness of the Achilles tendon changes as a result of natural degeneration, such as wear and tear, and these alterations have an impact on the Achilles tendon morphology, biomechanics, and morphometric values mostly seen in Achilles tendinopathy.*

What this study adds

- *Our sample population generally shows smaller Achilles tendon dimensions than other populations;*
- *The relationship between gastrocnemius bulkiness (circumference) and proximal Achilles tendon thickness was found to be statistically significant (p = 0.037) with a positive correlation of 0.59;*

- *The Achilles tendon length, width, circumference, and thickness showed no statistically significant difference between the right and left lower limbs.*

Competing interests

The authors declare no competing interests.

Authors' contributions

Anthony Mwakikunga, Gbenga Anthony Adefolaju, and Thom Kaledzera conceived the study. Emmanuel Peter, Hilda Jere, Charles Chiopsa, Patricia Chipinga, and Anthony Mwakikunga collected data and reviewed samples. Emmanuel Peter, Hilda Jere, Charles Chiopsa, Patricia Chipinga, Thom Kaledzera, Gbenga Anthony Adefolaju, Brian Matundu, Juziel Manda, and Anthony Mwakikunga, supervised data quality and participated in the analysis and definition of intellectual content. Anthony Mwakikunga, Thom Kaledzera, and Juziel Manda jointly supervised the study. All authors prepared and reviewed the manuscript. Emmanuel Peter, Juziel Manda, Gbenga Anthony Adefolaju, Brian Matundu, and Anthony Mwakikunga finalized the manuscript. All authors have read and agreed to the final manuscript.

Acknowledgments

The authors thank the African Center of Excellence in Public Health and Herbal Medicine (ACEPHEM), for providing a workshop through which this paper's manuscript was first developed; Mr. Bruno Ndoma and Mr. Charles Nyasa at the Kamuzu University of Health Sciences for providing technical support in the Anatomy dissection laboratory during data collection, and Mr. Alinune Musopole, the statistician for his technical support during data analysis.

Tables and figures

Table 1: a summary of descriptive analyses of the Achilles tendon length, proximal width, middle width, distal width, proximal circumference, middle circumference, distal circumference, proximal thickness, middle thickness and distal thickness

Table 2: comparison of means of the Achilles tendon length, width, circumference, and thickness between the right lower limbs (RLL) and left lower limbs (LLL)

Figure 1: morphometric measurements of the Achilles tendon to assess: (A) length; (B) width; (C) thickness

Figure 2: photographs showing how the metric measures were taken: (A) and (B) showing Achilles tendon circumference and (C) showing gastrocnemius bulkiness

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Table 1: a summary of descriptive analyses of the Achilles tendon length, proximal width, middle width, distal width, proximal circumference, middle circumference, distal circumference, proximal thickness, middle thickness and distal thickness

Variable	**Parameters in centimeters (cm)**									
	Length (L)	Proximal width (PW)	Middle width (MW)	Distal width (DW)	Proximal circumference (PC)	Middle circumference (MC)	Distal circumference (DC)	Proximal thickness (PT)	Middle thickness (MT)	Distal thickness (DT)
Range	2.5 - 5.6	1.0 - 2.1	0.9 - 2.0	1.4 - 2.5	3.4 - 4.6	3.2 - 4.7	4.2 - 5.8	0.5 - 1.0	0.4 - 1.1	0.6 - 1.10
Mean and Std. Deviation	4.06 ± 0.99	1.73 ± 0.29	1.51 ± 0.35	1.99 ± 0.32	4.03 ± 0.45	3.86 ± 0.52	4.95 ± 0.54	0.79 ± 0.15	0.71 ± 0.17	0.84 ± 0.12

Table 2: comparison of means of the Achilles tendon length, width, circumference, and thickness between the right lower limbs (RLL) and left lower limbs (LLL)

	Length (cm)	Width of Achilles Tendon in (cm)			The circumference of Achilles tendon (cm)			The Thickness of Achilles Tendon (cm)		
		Proximal	Middle	Distal	Proximal	Middle	Distal	Proximal	Middle	Distal
RLL	3.86 ± 1.05	1.76 ± 0.20	1.56 ± 0.37	2.00 ± 0.28	4.01 ± 0.49	3.89 ± 0.58	5.00 ± 0.54	0.80 ± 0.18	0.73 ± 0.22	0.86 ± 0.17
LLL	4.26 ± 0.96	1.70 ± 0.38	1.46 ± 0.34	1.99 ± 0.38	4.04 ± 0.49	3.83 ± 0.51	4.90 ± 0.57	0.77 ± 0.13	0.69 ± 0.12	0.81 ± 0.69
P-value	0.47	0.73	0.61	0.94	0.91	0.85	0.74	0.74	0.66	0.47
Remark	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

n = 14; S= Significant difference; NS= No significant difference

Figure 2: photographs showing how the metric measures were taken: (A) and (B) showing Achilles tendon circumference and (C) showing gastrocnemius bulkiness

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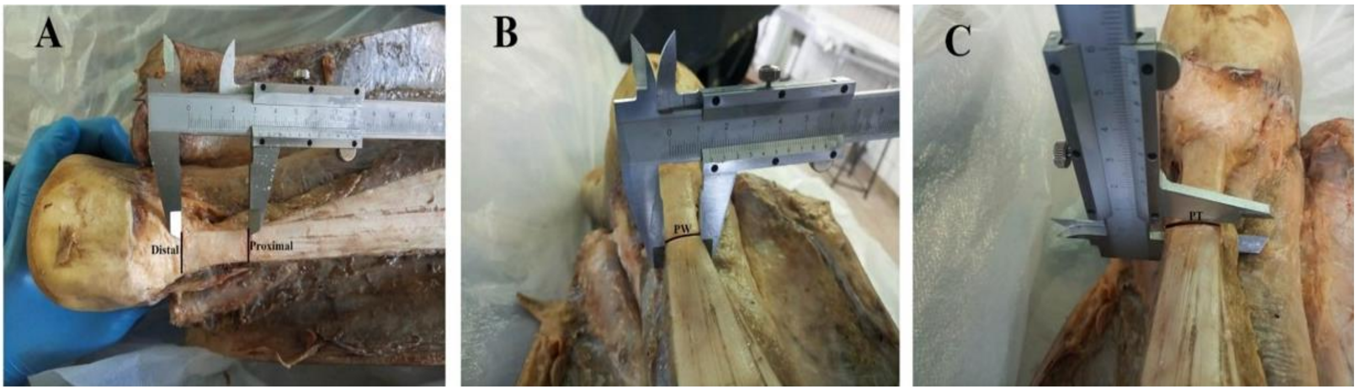

Figure 1: morphometric measurements of the Achilles tendon to assess: (A) length; (B) width; (C) thickness