Journal of Anatomical Sciences

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J Anat Sci 10 (1)

Achilles tendon Thickness by High Resolution Ultrasonography in a Healthy Adult Population

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ABSTRACT
The objective of this study was to derive a population-specific normogram for Achilles tendon in Nigeria and to determine its variation with age, gender and body mass index (BMI). This was a prospective cross sectional study of 154 subjects in a health facility in Lagos, South West Nigeria. With each subject in the prone position each Achilles tendon was scanned in the longitudinal and transverse planes using a 5MHz linear transducer. The thickness and cross sectional area (CSA) of the tendon were measured at the level of the medial malleolus. Each individual's weight and height were measured and Body Mass Index calculated. Data were analysed using SPSS software version 20. The mean Achilles tendon antero-posterior diameter (AT-AP) for both legs is 11.76 ± 1.71 mm, mean width, 12.95 ± 1.67mm and mean cross sectional area (CSA) is 120.93 ± 31.18mm^2.The right Achilles tendon mean (AT-AP) diameter is11.95 ± 1.78 mm, width, 13.11 ± 1.77 mm and CSA is 124.61mm^2. For the left Achilles tendon the corresponding dimensions are11.57 ± 1.63 mm, 12.80 ± 1.56 mm and 117.25mm^2 ± 27.43 respectively. There is a significant difference in the tendon CSA between the right and left tendons ($p<0.05$).Female AT-AP diameter is thinner than male but their width and CSA are thicker than that of the male ($p < 0.05$).The mean Achilles tendon AT-AP diameter in our study differs significantly from those of the Caucasian population. The mean AT diameters very with age, gender and BMI. The mean values found in our study differ significantly from the majority of other studies on Caucasian populations with respect to Achilles tendon AP thickness and CSA.

Keywords: Achilles tendon; Normogram; Musculo-skeletal; ultrasonography.

INTRODUCTION
The Achilles tendon is the subject of investigation in sport injuries as it is one of the most common sites of injury[1,2] and the most injured tendon of athletes in the lower extremities, reputed for spontaneous rupture[1].According to studies, Achilles tendon is the largest and strongest tendon in the human body[1,2,3,4,5]. Human Achilles tendon is subjected to substantial force during human locomotion. So it is frequently associated with acute and overuse injuries related to habitual loading[6,7], including complete tendon ruptures[6,8].Ultrasound is used in Achilles tendon evaluation because ultrasonography is one of the best imaging modalities in musculoskeletal radiology as it is low in cost, has high spatial resolution, wide availability in hospitals, well-tolerated by patients and not biologically invasive[9].It does not use ionizing radiation unlike conventional radiography and computed tomography (CT)[10]. Hence ultrasonography has become the ideal modality for the diagnosis and follow-up of many musculoskeletal pathologies and rheumatic syndromes as well as evaluation of the effects of therapy[10].

Knowledge of normal sonographic size of Achilles tendon is essential in the clinical diagnosis and management of Achilles tendon pathologies. Studies have established that body weight, stature, ethnicity, habitual physical activity and some pathologies moderate tendon size in healthy as well as sick adults[11,12,13]. Unfortunately, there seems to be no established normogram for differentiating pathologic and none pathologic variations in tendon thickness in our locality. The aim of this study is to establish a normogram for Achilles tendon thickness in the normal adult population in Lagos Nigeria, and to compare its variation with respect to age, gender, height and BMI.

MATERIALS AND METHODS
A prospective cross-sectional design was adopted for this work and it involved the enlistment of 308 tendons from 154 normal asymptomatic subjects who met the inclusion criteria. This sample was selected out of the 10080 normal adult patients who underwent sonography examination at MRI Diagnostic Center during the study period, using multi-stage sampling technique. Pregnant women, subjects below the age of 18, as well as subjects with medical history of diabetes, inflammatory joint disease, and familial hypercholesterolemia, use of antibiotics or Achilles tendon pain or pathology were excluded. These exclusion criteria took into consideration the significant relationship between the concomitant occurrence of these conditions and an increase in the

number of Achilles tendon lesions and their effect on tendon morphometric values. Those below age 18were excluded because according to Nigerian constitution they cannot be classified as adults[14].

Ethical approval for this study was obtained from the management of Private Diagnostic Centers in Iba Lagos, and informed consent was secured in writing from each subject. Sonographic examinations were performed using a Sonoline 400 Ultrasound machine of Siemens Medical Systems, with 5MHz linear-array transducer. Each patient was made to lie prone on the ultrasound couch with the legs extended and placed in a neutral position, easily accessible. Coupling gel was applied and the thickness and width of each Achilles tendon was measured at the level of the medial malleolus for standardization of the measurements[2]. The thickness of the Achilles tendon was measured by the maximum antero-posterior diameter of the Achilles tendon in the longitudinal plane whereas the width of the tendon was measured in transverse plane. All scans and measurements were performed with the ankles in a relaxed, neutral position. The cross-sectional area (CSA) was calculated using the formula: CSA = π (thickness) x width/4[15].This is hinged on the fact that on a transverse scan, Achilles tendon appears as an elliptical structure[15]. The subjects' gender and age were recorded and their weight and height were measured using CURAmed Digital weighing scale and meter rule respectively. For each subject the BMI was calculated using their individual weight and height.

Classification of stature into tall, average and short stature in this work was based on the works of Goon et al.,[16] *Pedicelli et al.,*[17] and **Parmar**et al.,[18].Data were analysed using independent t-test, one-way analysis of variance, logistic regression and Chi-Square tests. SPSS software version 20 was used in computing the data. $P < 0.05$ was considered significant.

RESULTS

The distribution of Achilles tendon thickness with respect to patients' age, gender and side is shown in table I. The patients' age ranged from 18 to 66 years with a mean of 31.85 ± 8.43 years. There were 54 men and 100 women. The mean Achilles tendon thickness antero-posterior (ATT AP) diameter for both ankles was 11.76 ± 1.71 mm, the mean width was 12. 95 ± 1.67 mm and the mean CSA was 120.93 ±31.18 mm^2. The mean right ATT AP diameter was 11.95 ± 1.78 mm, the mean width was 13.11 ± 1.77 mm and the CSA was 124.61 mm^2 ± 25.14. For the left ankle the mean ATT AP diameter was 11.57 ± 1.63 mm with a width of 12.80 ± 1.56 mm and a CSA of 117.25 mm^2 ± 27.43. Table I further reveals that Achilles tendon thickness, width, and CSA tend to increase almost linearly with age. The female Achilles tendon AP thickness is thinner than the males; however their width and CSA are thicker than that of the males. However, there is no statistically significant difference in AP thickness, width and CSA between male and female ($p>0.05$). The right Achilles tendon is seen to be thicker than the left tendon both in AP, width and CSA dimensions. But while the difference in AP and width between the right and left tendons are not significant ($p > 0.05$), the difference in their CSA is statistically different ($p < 0.05$).

Table I: Age and gender and side distribution of Achilles tendon thickness of subjects.

Age (years)	Frequency	AP Thickness (mm)	Width (mm)	Cross sectional area (CSA) mm^2
18-23	12	11.27 ± 2.07	12.69 ± 1.84	114.58 ± 37.91
24-29	40	11.89 ± 1.68	13.13 ± 1.79	124.04 ± 32.67
30-35	45	11.63 ± 1.63	12.8 ± 1.93	118.3 ± 34.73
36-41	29	11.94 ± 1.52	12.89 ± 1.06	121.22 ± 20.10
42-47	12	12.07 ± 1.74	13.25 ± 1.19	126.19 ± 25.46
48-53	3	13 ± 1.67	13.5 ± 1.05	138.62 ± 26.71
54-59	2	11 ± 1.15	13.75 ± 0.96	119.38 ± 20.32
60-65	0	0 ± 0	0 ± 0	0 ± 0
66-71	1	13 ± 1.41	13.5 ± 0.71	137.44 ± 7.78
Male	54	11.81 ± 1.65	12.75 ± 1.08	119.24 ± 0
Female	100	11.73 ± 1.69	13.06 ± 0.86	121.87 ± 0
Right	154	11.95 ± 1.78	13.11 ± 1.77	126.61 ± 25.14
Left	154	11.57 ± 1.63	12.80 ± 1.56	117.25 ± 27.43

Table II: shows that Achilles tendon thickness, width, and CSA increase with subjects' height, although the trend appears non-linear. However there is no statistically significant difference in the variables across the various height groups ($p > 0.05$).

Table II: The distribution of Achilles tendon thickness with respect to subjects' height.

Class (cm)	Frequency	AP Thickness (mm)	Width (mm)	Cross sectional area (CSA) mm^2
138-145	1	9.7 ± 0	12.5 ± 0.71	95.23 ± 5.39
146-153	4	11.18 ± 1.8	13.33 ± 1.03	117.59 ± 24.38
154-161	43	11.5 ± 1.5	12.77 ± 1.32	116.4 ± 24.98
162-169	52	11.78 ± 1.53	13.02 ± 1.44	121.22 ± 26.31
170-177	40	11.93 ± 2.01	13.06 ± 2.21	124.38 ± 40.29
178-185	13	11.95 ± 1.39	12.65 ± 0.98	119.09 ± 19.14
186-193	1	17 ± 2.83	18.5 ± 0.71	247.79 ± 50.54

Table III below reveals that Achilles tendon thickness, width, and CSA increase with subjects' stature in both the male and female population. Statistically, there is no significant difference in AP thickness, width and CSA across the groups ($p > 0.05$).

Table III: Distribution of Achilles tendon thickness with respect to subjects' body stature.

Gender	Height (cm)	Class	Freq.	AP thickness (mm)	Width (mm)	CSA (mm^2)
Male	=154.2	Short	0	0 ± 0	0 ± 0	0 ± 0
	154.3-180.1	Average	46	11.62 ± 1.53	12.66±1.26	116.16 ± 21.53
	=180.2	Tall	9	12.78 ± 2.07	13.22 ± 2.13	135 ± 45.43
Female	=148.9	Short	1	9.7 ± 0	12.5 ± 0.71	95.23 ± 5.39
	150-171.6	Average	90	11.75 ± 1.75	13.06 ± 1.83	122.17 ± 34.47
	=171.7	Tall	8	11.78 ± 1.64	13.13 ± 1.31	121.85 ± 23.93

Classification of stature based on the works of Goon et al[16], Pedicelli et al[17] and Palmar et al[18].

Obese patients have thicker AP thickness, width and CSA compared to underweight, normal weight and overweight subjects, table IV. There is a uniform increase in AP thickness, width and CSA with respect to BMI. Statistically, there is significant difference in AP thickness, width and CSA across the various BMI groups, ($p<0.05$).

Table IV: Distribution of Achilles tendon thickness with respect to subjects' Body Mass Index (BMI).

Class	Frequency	AP Thickness (mm)	Width (mm)	Cross sectional area (CSA) mm^2
= 18.4	3	11.33 ± 1.21	11.83 ± 1.51	105.24 ± 20.47
18.5-24.9	85	11.48 ± 1.4	12.67 ± 1.14	115.07 ± 20.58
25-29.9	41	11.58 ± 2.2	12.88 ± 2.37	117.93 ± 47.25
= 30	25	13.05 ± 1.41	14.18 ± 0.89	147.67 ± 19.35

DISCUSSION

This study showed that there is no significant variation in the AP thickness and width of the Achilles tendons between the left and right ankles ($p > .05$), whereas the cross-sectional area of the right Achilles tendons is significantly larger than that of the left tendons ($p < .05$). This finding is in accordance with the studies done by Pang and Ying[2] except that in their study, the cross-sectional area of the left Achilles tendon was greater than the right. This discrepancy could be as a result of variation in the dominant and none dominant ankles in the study populations. In their study, Pang and Ying[2] defined the dominant (left) and none dominant (right) ankles which they did by the choice of leg a subject used to kick a ball, having been suggested that the ankle dominance affects tendon CSA. However, in this study, we did not take cognizance of that as our subjects are not athletes. Secondly, it has been reported that left Achilles tendons rupture more frequently than the right [4], probably because of the thinner CSA of left lower limb. Smaller tendon CSA may result in greater stress on the tendon[19].

Our study showed that although ATT, width and CSA tend to increase with age, there is no significant difference in the AP thickness, width and CSA of Achilles tendons between subjects of different age groups (p > .05). This corroborates the findings of other researchers[2,20,21] but is in contrast to the study done by Magnusson et al[22]which strongly suggest that age is accompanied by significant increase in human Achilles tendon CSA . It may be due to the fact that tendon hypertrophy causes enlargement of the whole tendon, and there is relatively only a small increase in the tendon thickness, width and CSA which may not be statistically significant. We therefore, in line with Ricardo et al[21], suggest that the use of appropriate values for each age range for evaluating adult patients is clinically unnecessary, except for pediatric and elderly patients who have not been included in this study. Studies carried out on children [13] and the elderly[22]suggest that tendon diameters and CSA increase with age.

We also note that, although female Achilles tendon AP thicknesses tend to be thinner than the males, while their width and CSA tend to be thicker than that of the males, the differences are not statistically significant, (p > 0.05). This is in line with the findings of Brittany[23]. Other researchers have noted significant gender based differences in the AP tendon thickness[13,20,21,24] and width[20]. Considering the small populations studied in these other researches, we would suggest a similar study be carried out on large population of subjects to remove error due to sample size. Besides, the discrepancy in findings could be as a result of variations in anthropometry between Caucasians and Africans.

This study shows that ATT, width, and CSA increase with subjects' height, although the trend appears non-linear, table II. However there is no statistically significant difference in these variables across the various height groups (p>0.05).This finding is in line with the findings of a previous study[2]with respect to AP thickness and CSA. Similarly we found no correlation between subjects' stature and ATT, width and CSA, table III. This finding was also corroborated by Pang and Ying[2]. This finding may not be unexpected since body stature is a function of height irrespective of classifications like "Tall, Average height and Short". *Goon et al, postulated that average male and female Nigerian heights are* 167.2 ± 6.5cm and 160.3 ± 5.7cm respectively[16] and *Pedicelliet al.*, defined short stature as an adult height that is more than two standard deviations below the mean for age and gender[17].Tall stature is defined as height beyond 97th percentile (that is over two standard deviations) of mean for age and sex[18].

From this study it can be inferred that body height and body stature are not pertinent factors in the variation of the size of Achilles tendons. On the contrary, some studies[13, 25]showed that ATT varied significantly with subject height. This could be as a result of small sample size employed in their studies compared to ours.

Obese patients, the study revealed, have thicker AP thickness, width and CSA compared to underweight, normal weight, and overweight subjects. And there is significant difference in AP thickness, width and CSA between various BMI groups (p<0.05). This finding is supported by a previous study[21] which noted that tendon width was significantly higher in the overweight group than in the normal BMI group and the overweight group presented significantly greater Achilles tendon width than the normal BMI group. On the contrary, Aydin et al noted a significant correlation between BMI and ATT[26]. Interestingly, the AP thickness of the Achilles tendon has been shown to be significantly greater in obese individuals, and this confirms observations made in animal models in which a greater content and cross-linking of tendon collagen was seen in obese rodents[11, 27]. Thus, Aydin et al suggests the need to include the data from BMI in comparative studies when defining normal values[26],since increase in BMI seems to bring about a corresponding increase in Achilles tendon morphometric parameters.

It is interesting to note that this is the first study to have found such high mean value for Achilles tendon AP diameters (11.76±1.71 mm) for normal asymptomatic adults. From available literature, the average normal values reported regarding Achilles tendon AP thickness/ diameter varies considerably in different studies[11,12,13,21,28]. Achilles tendon has been reported within the literature, with mean values ranging from as little as 3.3 mm to as much as 7.1 mm for healthy individuals[4,11,12,13,21,28]. And AP thickening of the tendon greater than 10 mm has been associated with pathological findings[29].Comparing average values found in our study with those in the literature, we observe that there is statistically significant difference in the antero-posterior diameter in relation to other studies (p < 0.05).

Regarding the Achilles tendon mean width, the mean value of 12.95 ± 1.67mm, derived in this study was not significantly different from those reported by other studies[20,21], using ultrasound and MRI[30].

The mean CSA reported in this study is 120.93 ± 31.18mm^2 which is different from the findings of other researchers. Pang and Ying[2] observed a mean CSA of 60.78 ±13.09 mm^2 while Magnusson et al[22]reported56.3 ± 3.0 mm^{2}for elderly women and 46.0 ± 1.9 mm^2 for young women. Similarly, Leung and Griffith[25] reported a mean value for CSA of 72 ± 0.15mm^2 at the calcaneal insertion. Maganaris and Paul[31]reported an average CSA of 90± 9 mm^2 while Brittany[23]reported a CSA of 85±29mm^2 and 82±26mm^2 for dominant and non-dominant legs respectively. These differences in the mean CSA of the Achilles tendon may equally be attributed to the variation in patient selection, the definition, sites and techniques of measurement. Most of the studies adopted tracing of the CSA, but this study calculated the CSA using the formula for elliptical structure hinged on the fact that on a transverse scan, Achilles tendon appears as an elliptical structure.

A previous study suggested that it was advantageous to have a thicker tendon, which would yield less strain energy, reduce the average stress (force/area) across the tendon and thereby provide a greater safety margin[32] since the smaller tendon CSA may result in greater stress on the tendon[19]. Furthermore, tendons with larger cross-sectional areas have more fibers to carry the loads while longer tendons must be stretched further before failure[23, 33]. Studies have revealed that the incidence of tendon ruptures in western countries far exceeds that in Africa[30,32]. So, it is possible that the relatively small cross-sectional area (CSA) identified in the studies carried out on Caucasians may explain the high incidence of tendon ruptures in western countries relative to Africa. So genetic factors might play a role as suggested by some researcher[11,30,32]. The Achilles tendon is covered along its entire length by a thin paratenon sheath which is composed of both visceral and parietal layers. And under the paratenon lies the epitenon, which is a loose connective tissue layer surrounding the Achilles tendon[13,34]. The limitation of this study may lie in the fact that the 5MHz linear probe used in our study might not perfectly differentiate the tendon from the paratenon, thereby including it in the measurements made. This might be responsible for the high mean values derived for Achilles tendon AP diameter in this study. Kharate and Chance-larsen[35] suggested that including epitenon and paratenon in Achilles tendon measurements, overestimates the tendon thickness by 10%.

Therefore, values reported by the greater number of authors studying populations different from ours were not confirmed in our African study, emphasizing even more the necessity to establish our own population standards and reinforcing our aversion to the application of Caucasian values in our daily clinical practice.

CONCLUSIONS

The mean values found in our study differ significantly from the majority of other studies in literature with respect to Achilles tendon AP thickness and CSA except tendon width. This underscores the importance of establishing our own normogram employing tables based on our population in daily clinical practice.

RECOMMENDATIONS

A comparative study on Achilles tendon morphometric values using MRI and Ultrasound in Nigeria. A morphemetric study of Achilles tendon in our locality using a higher frequency ultrasound probe of at least 7.5MHz probe is advised.

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