GHANA COLLEGE OF PHYSICIANS AND SURGEONS

FACULTY OF RADIOLOGY

Ultrasonographic Findings of the Achilles Tendon In Asymptomatic Volunteers at The Korle Bu Teaching Hospital, Accra.

A Dissertation

Submitted to the Faculty of Radiology, in partial fulfillment of the requirements for the conferment of a Fellow of the Ghana College of Physicians (FGCP)

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DECLARATION

I declare that this dissertation is my own work. It is being submitted to the Faculty of Radiology, Ghana College of Physicians, for consideration in partial fulfillment of the requirements for the award of Fellow of the Ghana College of Physicians (FGCP).

It has not been submitted before for award of any degree or examination to any other college.

Dr. Harold Ricketts Nixon

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To my family, for their love and support.

To my Head of Department, Dr (Mrs) Klenam Dzefi-Tettey for her guidance and mentorship.

LST OF ABBREVIATIONS

AT	-	Achilles Tendon
ANOVA	-	one-way Analysis of Variance
BMI	-	Body Mass Index
CT	-	Computed Tomography
DTI	-	Diffusion Tensor Imaging
DTFM	-	Deep transverse friction massage
ESWT	-	Extracorporeal shock wave therapy
GUESS	-	Glasgow ultrasound enthesitis scoring system
IVIM	-	Intravoxel incoherent motion MRI
KBTH	-	Korle Bu Teaching Hospital
MASEI	-	Madrid Sonographic enthesis index
MR	-	Magnetic Resonance
MRI	-	Magnetic Resonance imaging
NSAIDs	-	Non-steroidal anti-inflammatory drugs
IBM SPSS	-	International Business Machines Statistical package for social sciences
PASDAS	-	Psoriatic Arthritis Disease Activity Scoring
QUS	-	Quantitative ultrasound measurements
RI	-	Resistive Index
SEI	-	Sonographic enthesitis index
US	-	Ultrasound
USG	-	Ultrasonography
VISA-A	-	Victorian Institute of Sport Assessment-Achilles Questionnaire.

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ABSTRACT

Introduction:

The Achilles tendon (AT) is the thickest and strongest tendon in the human body. It is the conjoint tendon of the gastrocnemius and soleus muscles in the posterior compartment of the leg. It is one of the most commonly injured tendons and is frequently affected by a wide range of inflammatory and degenerative processes. However, AT pathology is often oligosymptomatic and under-evaluated; because symptoms and signs of tendon pathology are open to variable interpretation.

Traditional methods of investigating the AT have been magnetic resonance imaging (MRI) and computed tomography (CT) and most of the existing data was obtained from non-African individuals. Noting that genetic differences between the races can result in phenotypic variability, it is likely that the existing data does not fully represent the asymptomatic African AT.

Ultrasonography (USG) is a reliable, safe and inexpensive imaging modality for evaluating the AT. In our local setting; USG is the least expensive and most readily available of the available imaging modalities for evaluating the AT. However, there is no definitive work outlining the normal USG features of the AT in our region.

This knowledge gap in the USG imaging findings of the AT causes delays in the diagnosis and cost-efficient management of AT pathology. This study sought to determine the USG characteristics of the AT in the asymptomatic population of an African country; thence defining the 'normal' USG characteristics of the AT.

Objective: To determine the ultrasonographic imaging findings of the Achilles tendon in asymptomatic volunteers at the Korle Bu Teaching Hospital, Accra.

Materials and Methods: This was a hospital-based, cross-sectional study at the Radiology department of the Korle Bu Teaching Hospital. The participants (all asymptomatic volunteers above the age of 10 years) were selected with use of standardized questionnaires before inclusion into this study. USG examinations were carried out using a Toshiba Aplio 300 ultrasound machine (Toshiba medical systems corporation, Japan); equipped with a Linear Array 4.8-11 MHz transducer. In all patients, both ATs were scanned.

Analysis: Captured data was analyzed in Statistical Package for Social Science (SPSS Inc., Chicago, IL, USA) version 25.0. The main outcome parameters being the echogenicity and thickness of the AT. Ankle dominance and other variables such as age, sex, height and BMI were expressed as percentages and/or graphs.

Results: 342 subjects (including 162 males and 180 females) were recruited into the study and underwent bilateral ultrasound examination of their AT. 100% of the ATs reviewed were homogeneously hyperechoic - with mean thickness of 4.84 ± 0.92 mm. Males had thicker AT than females in all groups. 87.7% of dominant AT were thicker than non-dominant AT. Body height had a significant positive correlation with AT thickness.

Conclusions: The asymptomatic AT is homogeneously hyperechoic and has mean thickness of 4.84 ± 0.92 mm on USG examination. Departures from these measurements should alert a radiologist to possible pathology when scanning a patient. The results of this study differ from other studies done on non-African populations; suggesting the need for further study on our indigenous population.

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CHAPTER 1

1.1 INTRODUCTION

The Achilles tendon is approximately 15 centimeters in length[1] and is the strongest, largest, and thickest tendon in the human body[1]. It is also one of the most frequently injured tendons due to the high biomechanical loads placed upon it and its relatively poor vascularity.[1,2] Large tensile loads, which primarily occur during its elongation or contraction, render it susceptible to overuse injuries[1,2].

The Achilles tendon is the joint tendon of the gastrocnemius and soleus muscles[3]; it originates in the middle of the lower leg and is formed by the juncture of the two heads of the gastrocnemius and soleus muscles.[3]

The relative contribution of the two muscles to the tendon varies, but the gastrocnemius muscle forms the majority of the Achilles tendon.[2] The insertion of the Achilles tendon onto the calcaneus is an enthesis and is intimately related to the retrocalcaneal bursa[4], the only true anatomic bursa in the ankle.[4] The calcaneal insertion is designed to aid in the dissipation of tension from the tendon to the calcaneum.[1] The Achilles tendon is almost entirely enclosed by a paratenon[1,4]. The paratenon is similar to synovium in that it nourishes the tendon,[1] but because the axis of motion of the AT does not change, the lubrication function of synovium is unnecessary.[2,5]

The AT receives its blood supply from the musculotendinous junction, vessels in the surrounding connective tissue, and the osteotendinous junction[1]. The AT is innervated primarily by the sural nerve, with a smaller contribution from the tibial nerve.[1]

AT pathology:

The AT is commonly affected by a variety of pathologies, which can be broadly classified as inflammatory (including traumatic lesions) and degenerative.[2,5,6] Alternate classifications into "acute" and "chronic" processes; leave a subgroup of conditions that straddle the two categories as well as other conditions (such as enthesitis) that have both "acute" and "chronic" stages – with distinct imaging and clinical characteristics.

Not all conditions that cause pain, swelling, and other symptoms in the hindfoot and posterior ankle are directly associated with the AT. [1,2,6,7]

Figure 1 is provided to aid comprehension of the anatomy of the immediate surroundings of the AT.

Table 1. also shows some differential diagnoses for Achilles-related conditions.

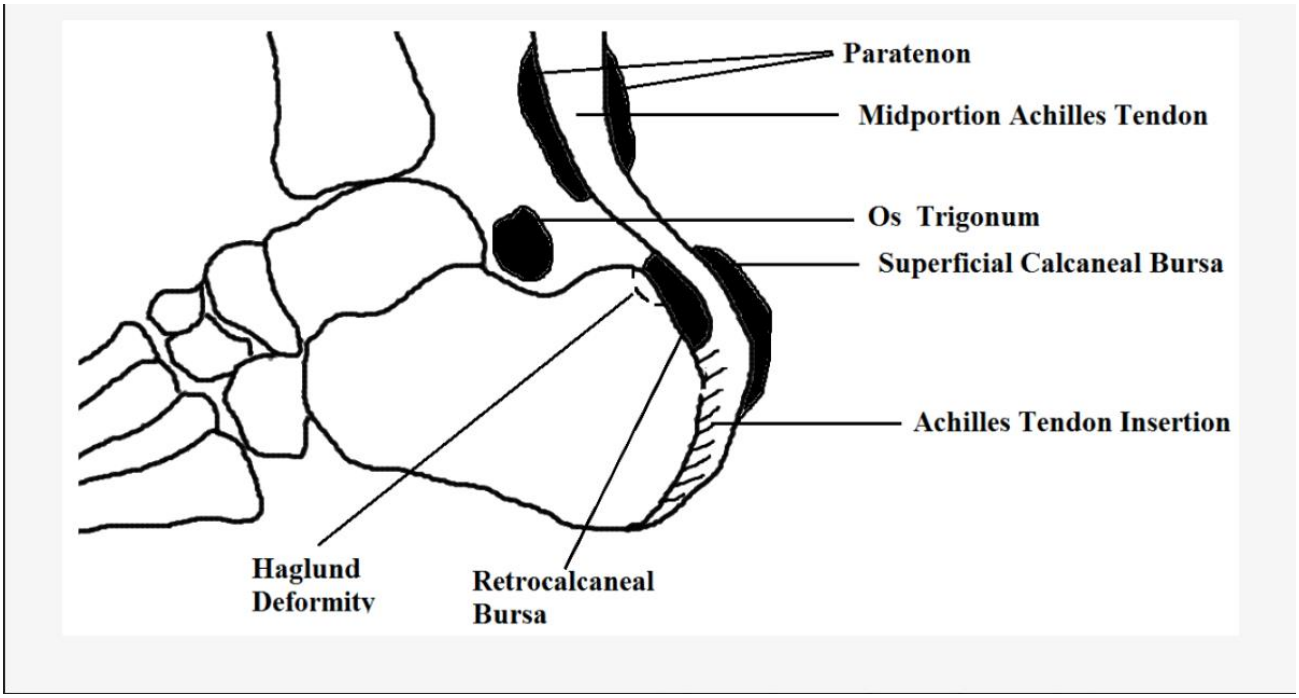


Figure 1: Hindfoot and posterior ankle anatomy

Table 1. Etiologies for hindfoot and posterior ankle pain and/or swelling.[9]

Differential Diagnoses for Conditions of the Achilles Region
Midportion Achilles tendinopathy
Insertional Achilles tendinopathy*
Achilles paratenonopathy
Midportion Achilles calcific tendonopathy
Insertional Achilles calcific tendinopathy*
Enthesopathy
Retrocalcaneal bursitis *,¶
Superficial calcaneal bursitis
Os trigonum syndrome
Tophaceous gout
Calcium pyrophosphate deposition disease
Achilles tendon xanthomata
Ruptured gastrocnemius
Ruptured plantaris
Ruptured popliteal cyst with extravasation down gastrocnemius
Calcaneal ossification (also known as Haglund deformity) ¶

Note: the above terms with the suffix -opathy include their respective -itis and -osis subclassifications.

* Features of enthesitis.

¶ Features of Haglund syndrome.

All these AT pathologies produce discernible alterations in the sonographic appearance of the AT,[6] that may be picked up on US examination.[8] Table 2 shows the ultrasound findings associated with some of the more common AT pathologies.

Table 2. Ultrasound findings for commonly encountered AT pathologies.[9]

Condition	Ultrasound Findings
Enthesopathy	• Decreased echogenicity of the enthesis • Increased dimensions of the enthesis • Structural lesions (such as enthesophytes) • Erosions • Increased vascularity seen on color power Doppler
Tendonopathy	• Echogenicity may be decreased • Tendon dimensions may be increased from secondary hypertrophy • Neovascularization seen on color power Doppler • Structural lesions (such as calcifications)
Bursitis	• Anechoic structure • Hyperechoic lining
Paratenonopathy	• Thickened paratenon • Neovascularization on color power Doppler • Increased echogenicity of pre-Achilles fat pad
Tendon tear	• Margined defect within the tendon itself • Fluid may be visualized separating the torn margins of the tendon fibers, which may exhibit edge artifact

Etiology and Pathophysiology of AT injury

Achilles tendon injuries can be acute or chronic.[10] In acute trauma, extrinsic factors predominate, whereas intrinsic and extrinsic factors interact in chronic disorders. [10–12] The most common AT injury is tearing or rupturing of the tendon. Other lesions such as peritendinitis and retrocalcaneal bursitis are less common.[7]

Changes in exercise routine/training pattern, poor training technique, previous injuries, inappropriate footwear, and training on hard, slippery, or sloping surfaces are extrinsic risk factors for acute AT injury.[7,13] Suboptimal tendon vascularity, gastrocnemius–soleus dysfunction, age, gender, body weight and height, pes cavus, and lateral ankle instability are important intrinsic factors in the development of chronic AT injuries.[10–12]

Excessive tendon loading is the primary cause of tendon injuries. [7] Tendons react to repetitive overload beyond their physiological threshold by inflammation of their sheath, degeneration of the tendon body or a combination of both. [14]

Different stresses may induce different responses, but fatigue damage must be actively repaired or tendons will eventually weaken and rupture.[15] Failure to adapt to repeated excessive loads causes the release of cytokines, which further modulate cell activity. [15] Since frequent microtrauma may not allow sufficient time for repair, even stresses within physiological limits may cause tendon damage.[7]

Microtrauma can also be caused by non-uniform stress within tendons,[15] which results in abnormal load concentrations and frictional forces between the fibrils, resulting in localized fiber damage. [15]

Achilles tendon tears

AT tears, ranging from microtears to full-thickness tears, are the most common ankle tendon injuries. [16,17] These injuries are reported most frequently in developed nations.[17] The incidence of Achilles tendon rupture in the general population is approximately 5 to 10 per 100,000, although it may be higher in certain regions and populations, and is on the rise overall.[17] Germany, Austria, Sweden, Denmark, and Switzerland exhibited the highest rates. The third world has lower prevalence rates. [18–20]

AT tears are frequently activity-related disorders,[17] with summer being the peak season for occurrence.[21] A significant correlation exists between recreational athletic activities and AT injuries.[22]

The middle third of the Achilles tendon is relatively hypovascular compared to the proximal and distal thirds.[1] It is in this region that most tears occur.[1,2]

Microtears, interstitial tears (parallel to the long axis of the Achilles), partial tears, and complete tears comprise the spectrum of Achilles tendon tears.[23]

Partial tears are characterized by focal defects within the tendon and/or AT tendon enlargement greater than 1cm in the anterior-posterior dimension and/or intrinsic tendon abnormalities.[24,25] However, isolated tendon enlargement does not equate to a tear.

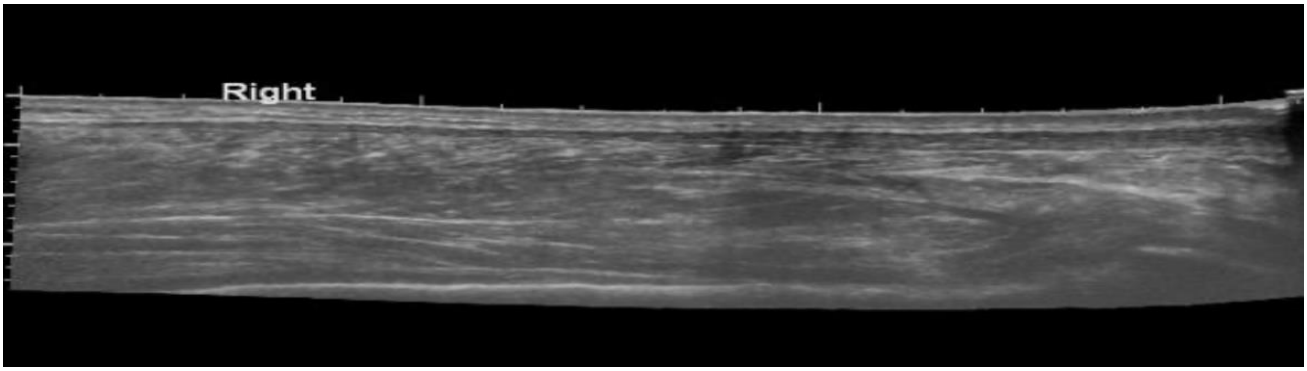
Full thickness tears (complete tears) are characterized by the complete disruption of tendon fibers and tendon retraction.[26] It is possible to see fluid separating the torn edges of the tendon fibers; these may exhibit edge artifact, also known as diffraction shadowing. [27,28]

Due to its more anterior insertion on the calcaneus, the plantaris muscle tendon is typically spared when present.[29] Figures 2B and 3 illustrate examples of full-thickness tears. Figures 4A and 4B illustrate a partial tear.

In the presence of a full-thickness AT tear, an intact plantaris tendon may be more apparent and mistaken for intact AT tendon fibers.[26] Herniation of Kager's fat into the tendon rupture site, as well as posterior acoustic shadowing from the torn tendon ends (refraction artifact) may also be seen.[26]

With hypoechoic edematous fat and fluid expanding craniocaudally, the US appearance of plantaris ruptures may resemble that of paratenonitis.[27] However, at the edges of the edema; the ruptured tendon ends are visible.[27]

2A



2B

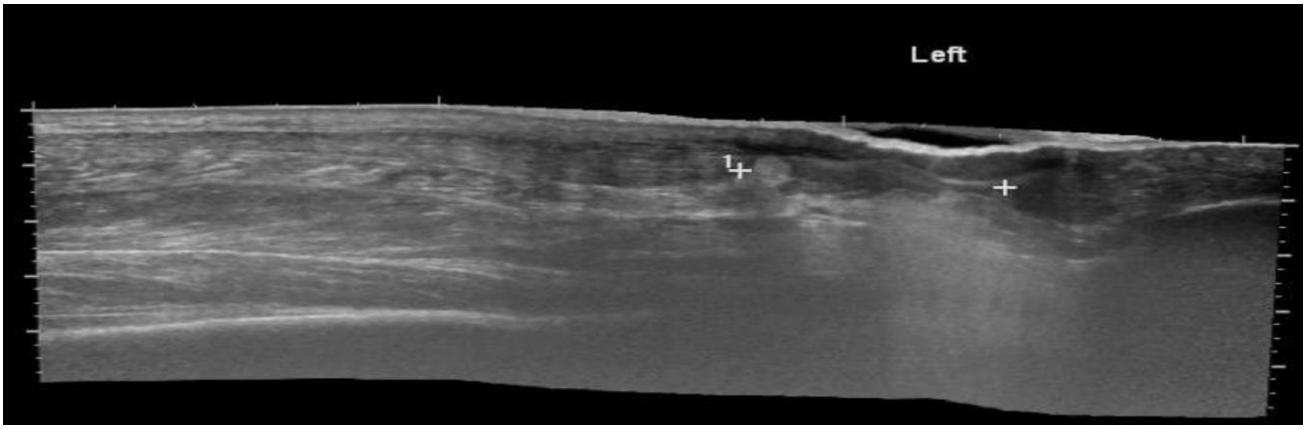


Figure 2: longitudinal grey scale ultrasound images of the Achilles tendon.[29]

2A: The 'normal' right Achilles tendon

2B: The symptomatic left Achilles tendon shows a complete tear with a gap between two edges. The distal tendon shows thickening and hypoechoic echopattern favoring tendinosis.

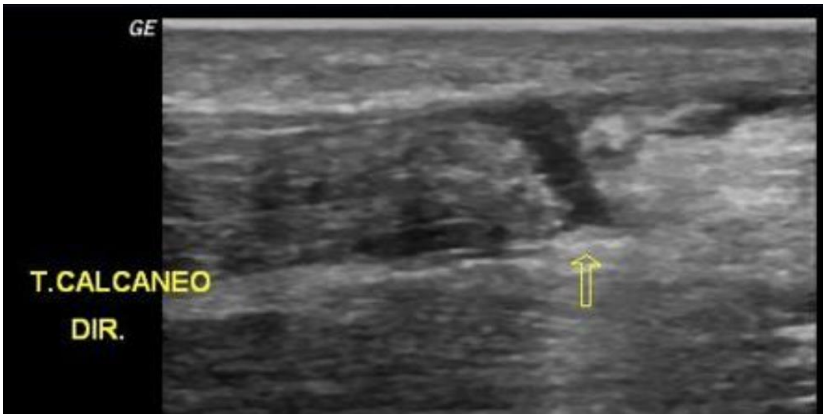
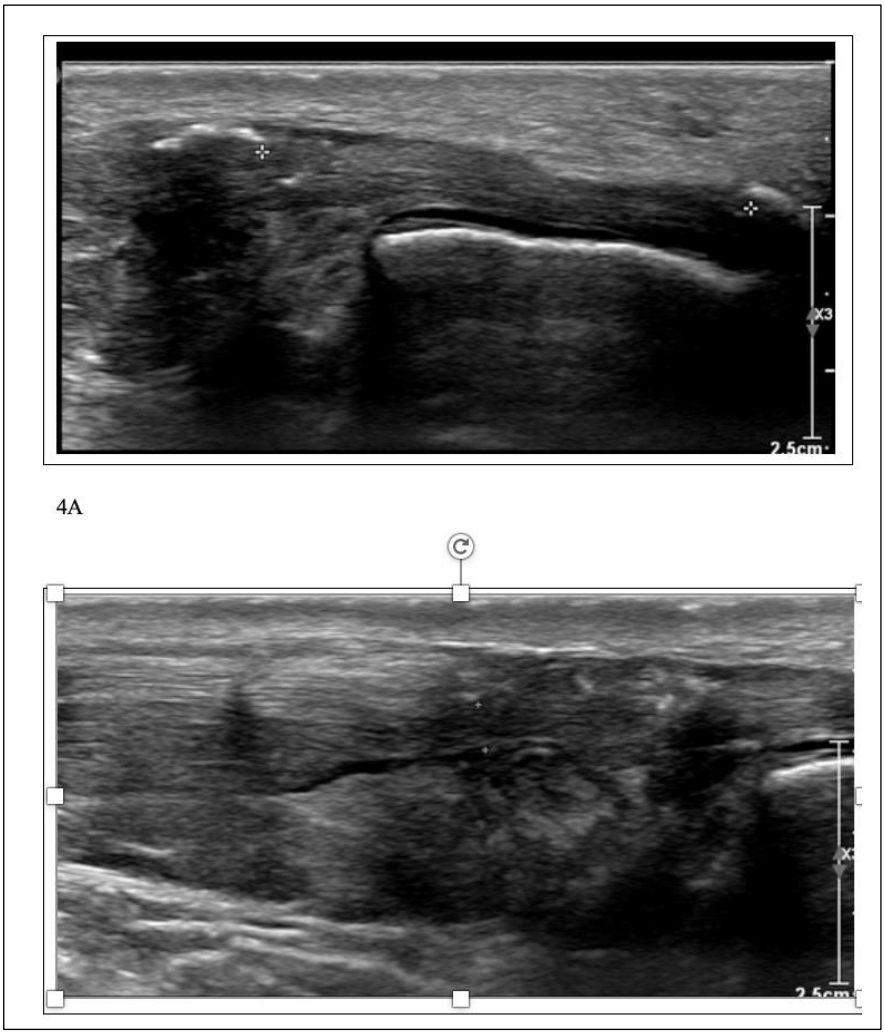


Figure 3: Full thickness tear of the Achilles tendon, with tendinous gap arrowed[29]



Figures 4A and 4B: grey scale ultrasound showing a partial tear of the Achilles tendon

There are fluid and debris within Kager's fat pad. The tendon is discontinuous, however a thin approximately 2.8 mm of the tendon appears intact at the level of the tear. Bone fragments are seen ~32 mm from the insertion of the tendon. Appearances are in keeping with a partial tendon tear.

Achilles tendon ruptures occur most frequently in younger people, with a mean age of 36.[24] However, AT rupture is extremely rare prior to the commencement of adolescence.[30,31] Given that Ghana has a young population,[30,31] it is necessary to document the normal appearance of the AT using a low-cost imaging modality that is easily accessible and reliable for optimal healthcare delivery.

Other inflammatory conditions

Bursitis

The Achilles tendon is shielded from primary inflammatory processes due to the absence of a true synovial sheath.[2,10] Due to the close relationship between the distal Achilles tendon and the retrocalcaneal bursa, however, the Achilles tendon is secondarily affected by inflammatory processes involving the retrocalcaneal bursa.[10]

Bursitis associated with the AT may affect the retrocalcaneal or superficial bursae – the two notable bursae of the hindfoot.[4] The retrocalcaneal bursa is located beneath the AT and adjacent to the calcaneus, whereas the superficial calcaneal bursa is located above the AT.[4,9] These structures are depicted in Figure 1.

Bursitis can be caused by infection, overuse, trauma, and inflammatory diseases [32].

The retrocalcaneal bursa is not routinely seen in ultrasound examination of normal healthy subjects. [33] Mahlfeld et al. found that it is the proliferation and exsudation of the bursa that make it detectable on US examination. Therefore, the evidence of bursitis is not the enlargement, but the fact that the bursa is demonstrable at all by ultrasonography.[33] However, because MRI is more sensitive to fluid; up to 15% of asymptomatic subjects have detectable retrocalcaneal bursae on routine MRI examination.[34]

Olivieri et al. [35] compared the relative sensitivity and specificity of US and MRI for identifying hindfoot bursitis - and found that US has 50% sensitivity and 100% specificity compared to MRI; which is the gold standard.[35]

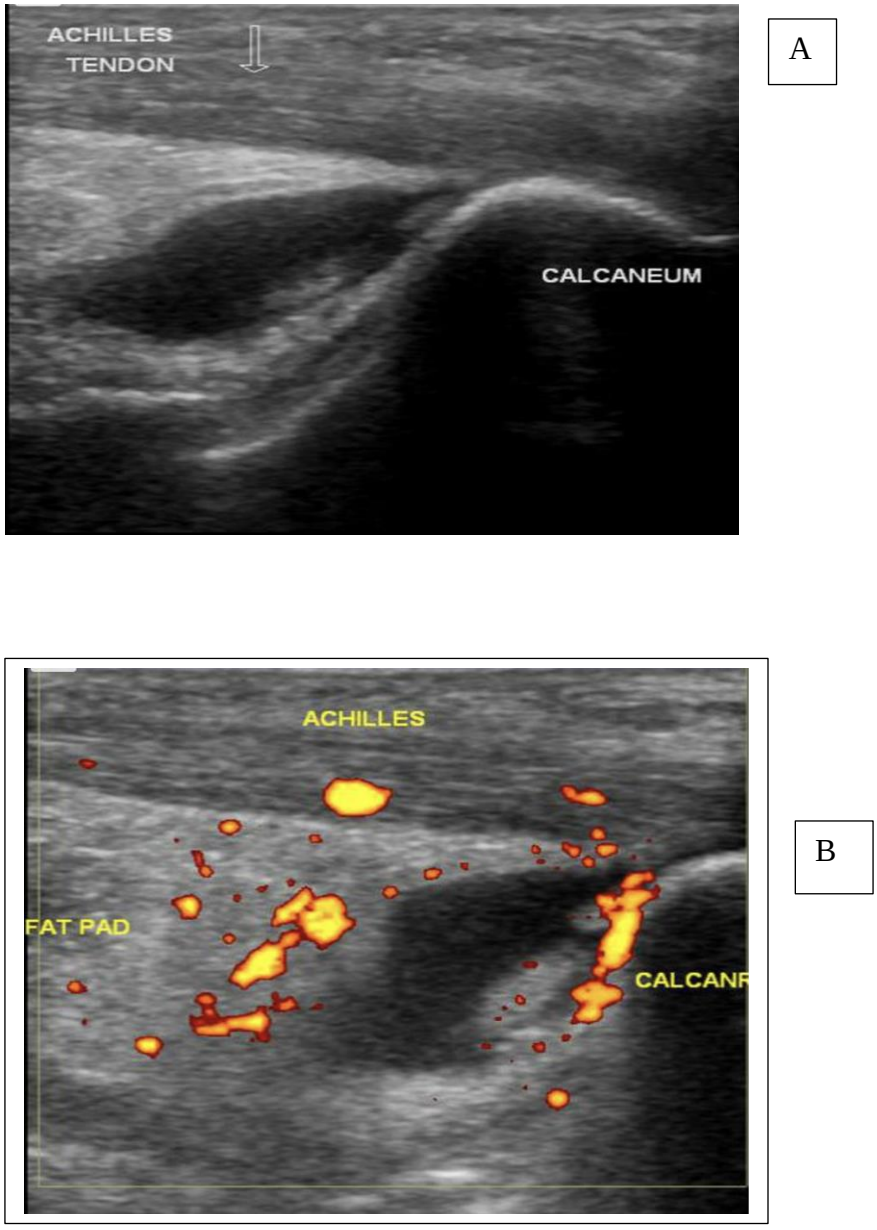


Figure 5. Retrocalcaneal Bursitis. [A] Ultrasound of the symptomatic side shows normal thickness and echopattern of the Achilles tendon. Fluid is noted deep to the tendon. [B] Hypervascularity is noted in the fat pad and also in the tendon.[122]

Paratenonopathy

The AT is not covered by a synovial sheath, unlike the majority of other human tendons.[1,2]

The paratenon is a loose, vascular, areolar, synovial-cell-lined connective tissue surrounding the tendon.[1,2,5] The paratenon is located around 5 cm proximal to the calcaneus, close to the AT.[1,2] It helps to provide blood to the AT.[2] Paratenon abnormalities are more commonly noted on the medial aspect of the Achilles tendon. [36].

Paratendinopathy may occur alone or in combination with degeneration of the tendon body.[37] Histologically, mucoid degeneration, fibrosis and vascular proliferation with a mild inflammatory infiltration have been documented.[38]

On US, the pathologic paratenon may appear as hypoechoic edematous fat and fluid extending several centimeters craniocaudally[9]

Degenerative AT conditions:

Tendonitis and tendinosis are the two most prevalent forms of Achilles tendonopathy.[1,2] Normal AT morphology on US is of parallel hyperechoic striations[10,39] Tendinopathy produces abnormalities in the morphology and echogenicity of the AT[1,10,39].

In tendonopathies, AT echogenicity is diminished due to intrasubstance parenchymal distortion and/or mucoid degeneration,[40] while tendon diameters may be increased due to secondary hypertrophy[40]. Color power Doppler examination may also detect signs of neovascularization.[27]

Degeneration of the AT is histologically a ‘tendinosis’ - as the process involves a disorganized healing response with intratendinous degeneration; without a significant inflammatory response.[6,37] Therefore, AT degeneration involves damage at the cellular level. [6,10,38,41,42]

The words 'tendinosis' and 'tendinopathy' are frequently used interchangeably in clinical practice; [38,41] with a substantial degree of overlap in their application. Historically, the word 'tendinitis' has been applied to chronic pain associated with a problematic tendon. This term is engrained in the scientific literature and falsely indicates that inflammation is important to the disease process.[6,10,37,38]

Therefore, it is suggested that 'tendinopathy' be used as a generic term to describe clinical disorders in and around tendons caused by overuse, with the terms tendinosis and tendinitis being applied only after histological analysis.[10,37]

Achilles tendinopathy can occur at the tendon insertion, in its midportion or proximally. [1,2] Due to its relatively poor blood supply in relation to the loads exerted upon it, tendinopathy of the middle third is twice as prevalent as at the other sites.[43,44]

Identifying the location of the tendinopathy has a direct impact on treatment options and prognosis,[43] with up to 80% of subjects with midportion tendinopathy responding to exercise-based management, whereas only up to 25% of those with insertional Achilles tendinopathy do so - with 47% eventually requiring surgery [45–48].

Pain is the primary sign of Achilles tendinopathy [42]. Typically, it occurs at the beginning and end of increased physical activity, with a period of reduced pain in between.[42]

As the degenerative process progresses, discomfort may develop during exercise, and in extreme cases, it may interfere with daily activities [42]. Many variables have been implicated in the pathophysiology of tendinopathy [24,25], including free radical damage on reperfusion following ischemia, hypoxia, heat, and defective tenocyte apoptosis [10,42].

In cases of Achilles tendinopathy, diagnostic imaging is frequently required to confirm clinical suspicion or to rule out other musculoskeletal disorders.[22,26]

Both diabetes and dyslipidemia are independent risk factors for the development of tendonopathies [49,50]. A high BMI and advancing age are related with an increased likelihood of developing insertional tendinopathy.[50] Additionally, elderly patients with a high BMI are more likely to develop intratendinous calcifications, bone deformities, and distal tendinosis [51,52]. Multiple genetic variations, including COL5A1, tenascin C, and matrix metalloproteinase 3 (MMP3) gene, have been proposed in relation to Achilles tendon injury [53–55].

Intratendinous calcifications can complicate tendinopathy, resulting in calcific tendinopathy.[56] At the Achilles insertion or more proximally in its midportion, calcification may occur.[56] Calcific insertional tendinopathy is characterized by ossification of the enthesial fibrocartilage and production of ossification or bone spurs at the tendon insertion.[56]

The therapy of calcific tendinopathy differs from the treatment of non-calcific tendonopathy. Tendon calcifications may react to extracorporeal shock wave therapy, prolotherapy, or surgery.[57–59]

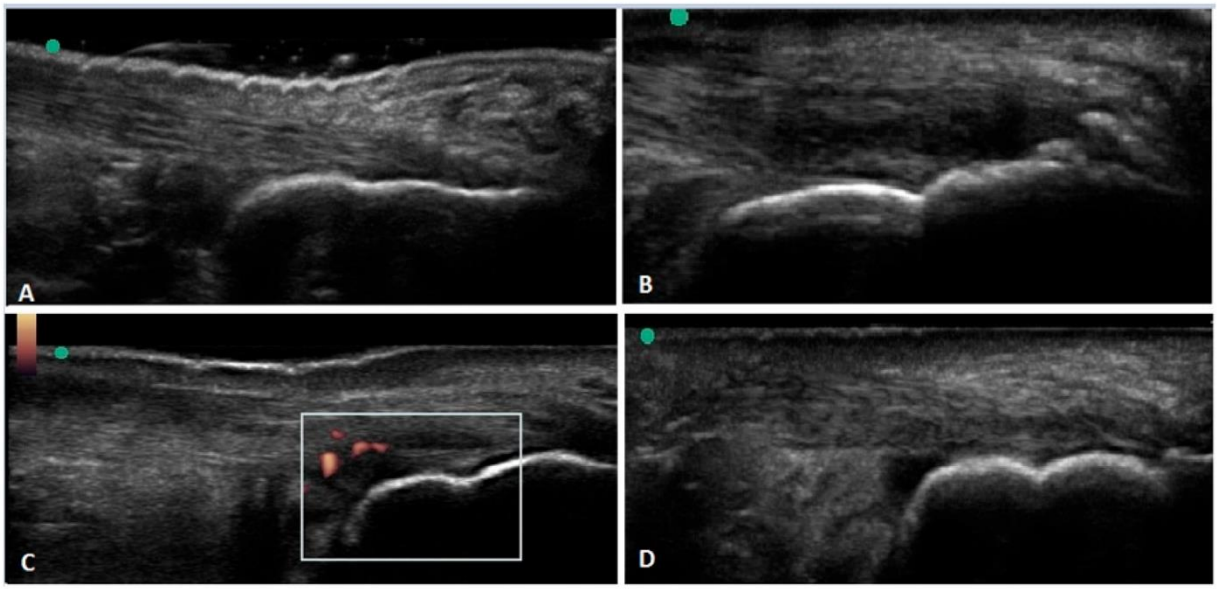


Figure 5. Ultrasound imaging of Achilles tendon. [56]

5A-D illustrate several examples of ultrasound findings in the posterior ankle and hindfoot.

(A) Normal imaging of hindfoot/posterior ankle.

(B) Insertional Achilles calcific tendonopathy.

(C) Intrasubstance Achilles tear with surrounding neovascularization.

(D) Retrocalcaneal bursitis. Note the green dot indicates probe orientation.

The box in C is the color box indicating the region of color Doppler assessment

Enthesopathy

Concerning enthesopathies, the initial phase of the disease is typically destructive and characterized by the predominance of microscopic inflammatory lesions.[1,2,44] Fibrous scarring and new bone formation eventually ensue. [1,2,44]

Decreased echogenicity and enlarged diameters of the enthesis, structural abnormalities (such as enthesophyte development), and increased vascularity on Doppler examination are associated US findings. [26,41,44,56] However, these lesions are not unique to inflammation and may be the result of other different forms of persistent injury and enthesis degeneration.[41,44] Therefore, when these defining characteristics are present and there is no apparent evidence of inflammation, the usage of 'enthesopathy' (as opposed to ‘enthesitis’) is recommended. [10,43,56,57]

The presence of blood vessels in the enthesis, which is particular to spondyloarthropathies, is essential for distinguishing inflammatory enthesitis from non-inflammatory enthesopathy using ultrasound.[6,9] D'Agostino et al.[58] studied the entheses of 164 individuals with spondyloarthropathy, 34 with mechanical back pain (MBP), and 30 with rheumatoid arthritis (RA), and discovered that 81% of the participants with spondyloarthropathy had vascularization at the entheses.[58] None of the MBP or RA patients exhibited signs of vascularization.[58] While this is not histological confirmation of inflammation, neovascularization in this region is the closest ultrasound correlation to tissue inflammation.[43,56]

Another relatively specific indicator for enthesitis (versus a non-inflammatory enthesopathy) is the observed increase in AT thickness in disease states.[1,2,6] There is a link between this discovery and clinical disease activity indexes.[6,60] In their study titled "ultrasonographic enthesopathy and disease activity in psoriatic arthritis" [60], Ahmed et al. matched 35 psoriatic patients with 30 healthy controls

and discovered that the thickness of the Achilles tendon in active psoriatic arthritis was highly correlated with the Psoriatic Arthritis Disease Activity Scoring [PASDAS]. ($r = 0.796$, $p < 0.001$) [60]

The Sonographic Enthesitis Index (SEI) was established to further differentiate between "acute" and "chronic" enthesopathy.[60] This index identifies tendon thickening, hypoechogenicity, peritendinous edema, and bursitis as more indicative of acute enthesopathies.[60] Chronic enthesopathies are associated with tendon tears, tendon atrophy, intratendinous calcifications, and bone erosions.[60] Bone erosions on the AT are more symptomatic of chronic enthesitis than chronic bursitis - which is more often seen in acute inflammation.[9]

Ultrasound is therefore a highly helpful diagnostic tool for enthesopathy,[60] as it can help to differentiate between degenerative and inflammatory lesions.[6,9,60] However, mechanical variables and/or obesity can complicate US evaluation [61,62]. Thus, currently deployed scoring systems (such as the Madrid sonographic Enthesis index (MASEI) and Glasgow Ultrasound Enthesitis Scoring System (GUESS) scoring systems) for enthesopathy are impacted by BMI, with scores increasing as BMI rises. [61,62]

The other causes of hindfoot and posterior ankle pain indicated in Table 1 should be investigated during the evaluation of a patient with a suspected case of enthesitis.

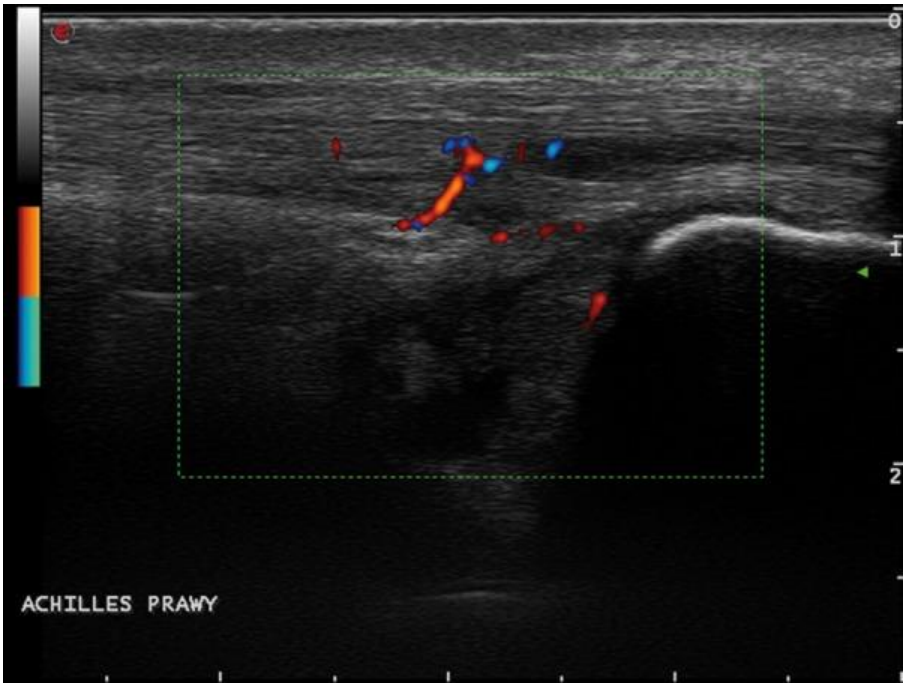


Figure 6A. Achilles enthesopathy. Exudate within the Achilles tendon bursa with thickening and vascularization of bursal synovium; delaminated tendon tears infiltrated by the vessels of the inflamed bursa.[63]

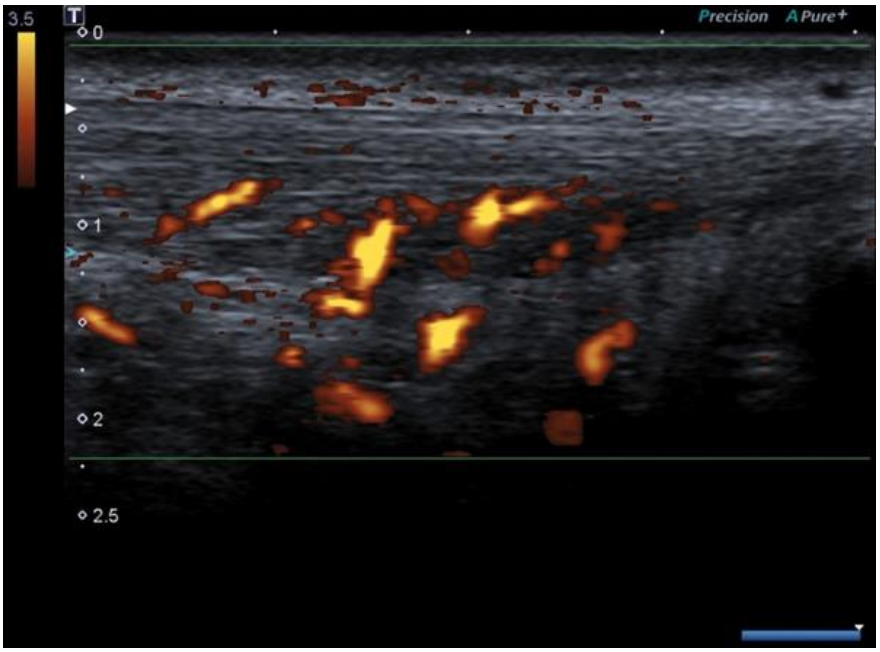


Figure 6B. Achilles enthesopathy. Edema and hypervascularization of Kager's fat pad; tendon infiltrated by the vessels of the inflamed adipose tissue.[63]

Role of US in AT imaging:

Tendons lend themselves well to ultrasonographic investigation.[1,2,10] They are easily distinguished from neighboring tissues due to their high collagen density.[1,2,26] In addition, they are superficial and can be visualized without difficulty using the most recent generation of high frequency transducers, which permit a spatial resolution of up to 0.2 mm.[26]

Ultrasonography is a widely accessible, reliable, noninvasive and cost-effective imaging tool for evaluating the AT. [26,64,65] It combines direct multiplanar tomographic evaluation of the AT with dynamic investigation of its mobility, thereby offering both anatomical and functional evaluation.[26] Ultrasound is generally inexpensive, space-efficient, patient-friendly, and transportable.[8,26,66] In addition, USG facilitates the safe and accurate placement of needles and medication injections for peri- and intra-lesional therapy.[6,64]

The normal AT is seen on longitudinal US scans as a relatively homogeneous hyperechoic structure – appearing as a tightly packed echoic structure with fine parallel internal linear echoes (fibrillar pattern) separated by fine anechoic lines. [26] The longitudinally oriented echoic lines correspond to large endotendineum septa.[65] The tendon contour being regular and sharply defined;[65] as shown in Figure 7A.

On transverse scans, the normal AT appears as an oval-to-round structure characterized by tightly packed echoic dots with a homogeneous distribution,[65] as shown in Figure 7B.

Echogenicity is the capability of a tissue to reflect or transmit sound waves [39]. On the display screen, hyperechoic structures look white, hypoechoic structures appear gray, and anechoic structures appear black. [39]

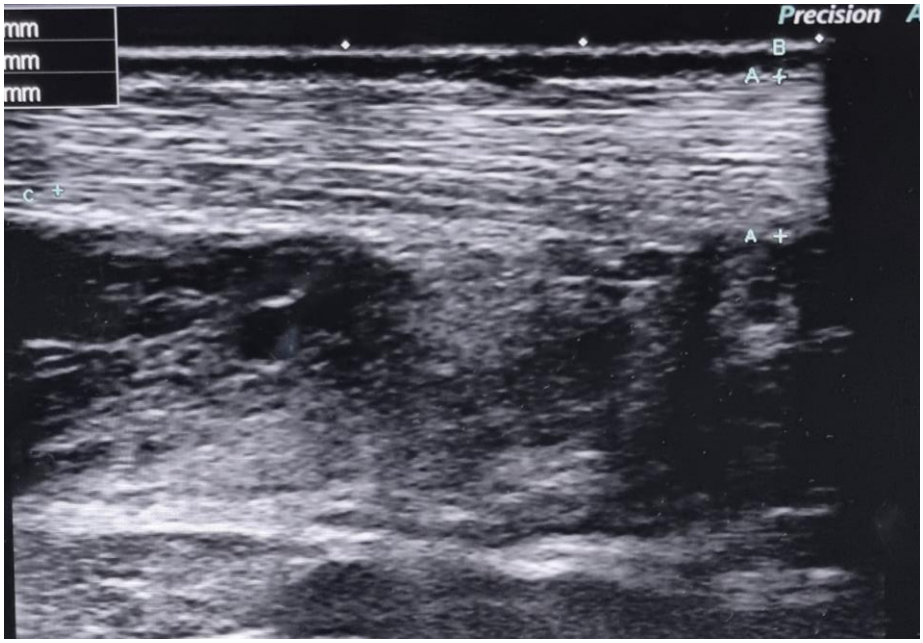


Figure 7A. Longitudinal grey scale USG image; showing an asymptomatic Achilles tendon.

Figure 7B. Transverse grey scale USG image; showing an asymptomatic Achilles tendon.

Despite the fact that MRI remains the gold standard,[1,2] musculoskeletal ultrasound is a very sensitive test for early identification of enthesitis that is significantly faster, cheaper, and more accessible than MRI.[6,10,26] Additionally, it is portable and can be performed at the bedside or in the consulting room.[67,68]

However, the greatest limitation of US imaging is that its sensitivity is operator-dependent.[1,26] The erroneous interpretation of artifacts, notably anisotropy and edge artifacts, is one of the key pitfalls associated with ultrasound imaging.[69–71]

Anisotropy arises when tissues exhibit aberrant echogenicity, most typically echogenicity loss, as a result of an oblique insonating angle [70,71]. Anisotropy may cause parts of tendons and ligaments to seem abnormally hypoechoic, which may be misconstrued as tendinosis and/or tearing. [70,71]

Edge artifacts are parallel hypoechoic lines that occur along the edges of a curved target after the target reflects US beams away from the transducer.[70–72] Sometimes, edge artifacts might obscure the AT margins, leading to a misperception of paratenon thickening. [71]

Comparing the sensitivity of ultrasound to clinical examination for the identification of AT tendonopathy, Khan et al.[73] found ultrasound to be 80 percent sensitive and 49 percent specific. The application of color Doppler or Power Doppler had no effect on the observed sensitivity. [73] Strong intraobserver and interobserver reliability for posterior ankle ultrasonography readings have been found by other studies.[74]

In spite of all the above, US has some limitations when diagnosing and assessing tendon morphology. As demonstrated in Table 3, the concept of what defines "normal" AT dimensions is uncertain, as different studies on diverse populations have shown varying values for the normal, healthy AT.

Table 3. Reported values of mean Achilles tendon thickness measured with US [89]

	AT thickness **Mean ± SD (range) mm**	**Population**	**US frequency**
Steinmetz et al	5.7 ± 0.7 (5-8)	German	5-7.5 MHz
Ebeling et al	4.9 ± 0.9 (4-7)	Finnish	7.5 MHz
Mathieson et al	6.2 (4-9)	North American	5 MHz
Holsbeeck et Introcaso	6.2 ±0.8 (sedentary) 5.7±0.8 (athletes)	Not Indicated	Not Indicated
Fornage	5.3 (4-6)	North American	5 MHz
Kallinen et Suominen	6.1 ± 0.9 (sedentary) 6.2 ± 0.9 (athletes)	Finnish	7.5 MHz
Yuzava et al	4.2 ± 0.5 (women) 4.7 ± 0.4 (men)	Japanese	7.5 MHz
Liem et al	6.2 ± 1.2	Dutch	Not Indicated

Previous Work on AT anatomy and imaging characteristics

Studies on the anatomy and imaging characteristics of the AT include work by Doral, et al. [1] Grassi, et al. [26] Grumbine et al.[3]. These outlined the gross anatomy of the AT and its functional relationships. Frey, et al in their work 'the retrocalcaneal bursa: anatomy and bursography' [4] described the retrocalcaneal bursae, their relationship to the AT, the technique of its opacification, and the application of this technique to the diagnosis and treatment of painful hindfoot syndromes. Schweitzer and Karasick in their work 'MR Imaging of Disorders of the Achilles Tendon'[2] extensively outlined various AT pathologies and their MRI correlates. P. Szaro, et al. also did similar work in 'MRI of the Achilles tendon — A comprehensive pictorial review. Part one'.[75]

Jozsa et al.[22] in their book 'Human tendon: Anatomy, physiology and pathology' also described the micro- and macro-anatomy of human tendons, their relevant anatomy and the myriad pathologic processes that affect them; and the pathophysiology of said pathologies.

In their paper titled "High-resolution MR imaging of the asymptomatic Achilles tendon: novel observations," Soila et al.[34] described the normal MRI characteristics of the asymptomatic Achilles tendon and peritendinous tissues in active asymptomatic volunteers. This study determined that the average anteroposterior diameter of the Achilles tendon (as evaluated by high-resolution MRI) to be 5.20 +/- 0.73 mm.[34] The anterior Achilles tendon margin was flat or concave in all cases, with the exception of ten tendons that displayed slight convexity.[34] In addition, the anterior margin of 56 tendons revealed a bulge that changed from lateral to medial in the craniocaudal direction, in a wavelike fashion.[34]

In 45 tendons, the signal intensity was heterogeneous.[34] Distal stripes or punctate foci were observed in these tendons. In four cases, a tiny (3 mm) intratendinous zone of intermediate intensity, presumed to reflect tendon degeneration, was identified.[34]

They found that the Achilles tendon and the vicinal peritendinous tissue are depicted in exquisite detail by high-resolution MR imaging,[34] and that the typical morphology of the asymptomatic Achilles tendon is variable.[34] The researchers then hypothesized that these normal anatomic variations could be a source of diagnostic misinterpretation.[34]

In their paper titled "High resolution ultrasound anatomy of normal Achilles tendon," Bertolotto et al.[76] evaluated the ultrasonographic appearance of normal Achilles tendons at various frequencies to develop anatomical correlations for ultrasonographic data.[76] After comparing in vitro sonograms and their matching anatomical parts side by side.[76] Two tendinous sections were identified based on the presence of an internal acoustic interface with distinct visual characteristics.[76]
This study concluded that:

- contrary to popular belief the normal AT is not a single uniform structure,[76]
- the use of high-resolution US permits the identification of the AT's constituent parts.[76]
- The identification of the various distinct components of the AT can prevent incorrect pathogenic diagnosis.[76]

Hattrup, et al, Maffulli et al, Raatikainen et al, Khan et al, and Jozsa et al. [23,24,77,78]reviewed the clinical and imaging findings in AT tears and ruptures in their respective works: 'A review of ruptures of the Achilles tendon', ‘Rupture of the Achilles tendon’, ‘Histopathology of common tendinopathies’ and 'Fine structural alterations of collagen fibers in degenerative tendinopathy'.

In their paper titled "Histopathology of common tendinopathies," Khan et al.[78] described the basic architecture of a healthy tendon, the underlying pathophysiologic mechanisms of tendon overuse diseases, and the majority of tendinopathies observed in clinical practice.[78] They also evaluated some

of the current treatments for tendinosis, including relative rest, strengthening, nonsteroidal anti-inflammatory drugs (NSAIDs), corticosteroids, other pharmacological agents, cryotherapy, braces and supports, and surgery.[78] Maffulli et al.[10] conducted comparable research in their article titled "Achilles tendinopathy: aetiology and therapy."

In their paper titled 'The correlations between dimensions of the normal tendon and tendinopathy altered Achilles tendon in routine magnetic resonance imaging,' Szaro et al.[79] investigated the correlation between tendinopathy-related lesions and alterations in Achilles tendon dimensions.[79] In a study of 81 individuals; it was found that the correlation between the thickness of the Achilles tendon and the thickness of the midportion was more significant in the tendinopathy cohort ($r = 0.49$ vs. $r = .01$, $p > .001$). [79] In abnormal tendons, there was a positive correlation between the width and length of the tendon insertion, whereas this correlation was negative in normal tendons.[79] In conclusion, they discovered that the dimensions of healthy and diseased/tendinopathic Achilles tendons differ significantly.[79]

The research of Grassi, et al. in 'sonographic imaging of tendons' [26] and Dong, et al. in 'Achilles tendon ultrasound technique' [64] served as some of the foundations for the development of AT ultrasonography.

Gibbon [80] explored the utility of ultrasonography in the diagnosis, treatment, and follow-up of musculoskeletal disorders, both as an adjuvant to clinical examination and as a "stand alone" modality, in his article titled "Musculoskeletal ultrasound." They concluded that musculoskeletal ultrasonography is likely to become an extension of the physical examination process, especially in the disciplines of rheumatology and sports medicine, as its usage in clinical settings becomes more prevalent in the future.[80] However, they emphasized the need for professional training of practitioners to avoid misdiagnosis.[26,76]

In 'A Narrative Review of the Classification and Use of Diagnostic Ultrasound for Conditions of the Achilles Tendon,'[9] Mascarenhas et al. reviewed the most common causes of hindfoot and posterior ankle symptoms, such as retrocalcaneal bursitis, insertional tendonopathy, midportion tendinopathy, paratenonopathy, superficial calcaneal bursitis, calcaneal ossification /Haglund deformity and calcific tendinopathy.

This narrative review described the many AT pathologies, the imaging modalities used for their diagnosis and treatment, and the benefits and drawbacks of these modalities.

In addition, they discovered that the current nomenclature contains numerous unclear and incorrectly applied phrases, which might lead to misclassification of hindfoot and/or posterior ankle symptoms. For example, recent investigations (using high frequency musculoskeletal ultrasonography, MRI, and CT scans) have demonstrated that the majority of cases of 'tendonitis' are actually degenerative lesions, with 'tendinosis' being a more appropriate name.

In addition, the vagueness and other issues associated with the usage of the 'umbrella' term 'enthesitis' and 'Haglund' terminology were examined. The primary source of confusion is because the majority of the diagnostic criteria for "enthesitis" are not specific for inflammation and frequently result from chronic degeneration and damage.[9] Thus, they proposed the term 'enthesosis,' which they believe is a more accurate description of enthesis degeneration.[9]

In addition, they stated that adoption of a uniform, consistent nomenclature is significant in terms of implications for the therapy of AT disease, as different pathologies respond differently to diverse degrees and/or types of medicine, exercise, and surgery.[9]

This study elaborated on the many AT diseases and their radiologic characteristics, as well as alternative causes of hindfoot and posterior ankle symptoms.

In their paper titled "Analysis of echotexture of tendons with US," Martinoli et al.[81] examined the echotexture of normal tendons at various frequencies and attempted to establish an anatomic link for fibrillar echoes. Normal calcaneal tendons from calves, lambs, and humans were investigated in vitro at 7.5, 10, 13, and 15 MHz. Several members of the human cohort had a confirmed diagnosis of Achilles tendon disease, including rupture.[81]

Normal tendons had a consistent network of fine parallel and fibrillar echoes at all frequencies, which grew more numerous and thinner as the probe frequency increased.[81] Variable deviations from these observations were observed in diseased tendons, including increased fibrillar thickness, interruption, fragmentation, and loss of echotexture.[81]

This study demonstrated the utility of musculoskeletal ultrasonography in detecting early and/or mild alterations in tendon structure

In their respective works, 'Human Achilles Tendon: Morphological and Morphometric Variations as a Function of Age' [82] and 'Ultrasonographic measurements of the Achilles tendon in elderly athletes and sedentary men,' [83] Strocchi et al. and Kallinen et al. examined the changes that occur in the Achilles tendon with advancing age. The researchers discovered that age-related morphometric changes include a decrease in the average maximum diameter and density of collagen fibrils, as well as an increase in fibril concentration.[82,83] It was believed that these modifications are strongly tied to functional requirements.[82,83]

Kallinen et al. discovered that the average width of the Achilles tendon in older athletes was substantially greater than in control subjects.[83] The thickness and cross-sectional area of the tendons did not differ substantially across the groups.[83] These numbers may indicate a tendency for athletes to have a bigger cross-sectional area, presumably as a result of tendon hypertrophy following extensive exercise.[83]

In their article titled "A therapy protocol for addressing Achilles tendinopathy: novel treatment options," Alfredson et al.[84] explored the pathophysiology of Achilles tendinopathy, including the numerous pain causes. They outlined an algorithm for the management of Achilles tendinopathy in which conservative treatment methods were pushed as the primary treatment option for tendinopathy and surgical surgery was only to be considered if conservative treatment failed.[84]

In their article titled "Achilles Tendon Rupture: Mechanisms of Injury, Principles of Rehabilitation, and Return to Play," Tarantino et al.[85] explored the seasonal fluctuations behind Achilles tendon injuries as well as the recovery principles for said injuries. This study illustrates the several ways in which musculoskeletal ultrasonography can aid in the diagnosis, treatment, and monitoring of Achilles tendon injury.[85]

Similar points of utility and/or intervention by musculoskeletal ultrasound are shown in the works ‘A Review of Ruptures of the Achilles Tendon’ by Hattrup et al.[24], Leppilahti et al.[17] in their work ‘Incidence of Achilles tendon rupture’ , Bennazzo et al.[14] in their work ‘An operative approach to Achilles tendinopathy’ , Kvist et al.[13] in their work ‘Achilles tendon injuries in athletes’, Jozsa et al.[86] in their work ‘The role of recreational sports activity in Achilles tendon rupture’ and Sandelin et al.[21] in their work ‘Outcome of sports injuries treated in a casualty department’.

All of these studies demonstrate that judicious and timely use of musculoskeletal ultrasound improves diagnostic accuracy, facilitates the treatment process (even facilitating 'real time' steroid injections and other interventions), and permits rigorous monitoring of patient rehabilitation and the healing process.

In their paper titled "Sonographic measurement of Achilles tendon thickness in seronegative spondyloarthropathies," Aydin et al.[87] examined the variations in Achilles tendon thickness caused by seronegative arthropathies.

To determine the optimal cut-off value for diagnosing Achilles tendon thickening in patients with spondyloarthropathies (SpA) relative to the established cut-off values in the literature, the Achilles tendon thickness of 101 subjects – 55 of whom had SpA and 46 of whom were age- and BMI-matched healthy controls – was measured (HC).[87]

Using ROC curve analysis, they identified the optimal cutoff value for diagnosing Achilles tendon thickening in both sexes.[87] The female values are 5.5 mm and the male values are 6.2 mm. Both of these figures differed from the value found in the scientific literature, which was 5.29 mm for both genders.[87] Also calculated were the number of measurements surpassing the cutoff values, as well as the sensitivity (SE), specificity (SP), positive (PPV) and negative (NPV) predictive values.[87]

They discovered a statistically significant difference in Achilles enthesis thickness between genders (mean SD: 4.60.7 mm in males vs. 4.00.8 mm in females, p0.00) and between spondyloarthritic patients (SpA) and healthy controls (HC) (mean SD: 4.40.8 mm in SpA patients vs. 4.00.8 mm in HC).[87] The examination of the ROC curve determined the optimal cutoff value to be 3.7 mm for females and 4.8 mm for males (SE: 43-70 percent , SP: 59-85 percent , PPV: 66-79 percent , NPV: 54-63 percent).[87] It was discovered that previously stated cutoff values have a high specificity (91-98%) but a very low sensitivity (2-11 percent).[87]

They determined that the thickness of the Achilles tendon changes across sexes; therefore, it is essential to refer to gender-specific normative values.[87]

The previously noted high cut-off values in the existing literature showed very low sensitivity in the current study;[87] and when Achilles enthesis thickening is used for screening enthesitis in spondylarthritis patients, a lower cut-off value has a higher sensitivity with slightly worse specificity, positive predictive values, and negative predictive values.[87]

Archambault et al. [88] posed the question, "Can ultrasound predict the outcome for patients with Achillodynia?" They examined the relationship between ultrasonography grading of Achilles tendon appearance and the patient's heel pain. They studied 33 patient – all with documented AT pain. After the sonographic examination; these tendons reviewed were organized according to a simple grading system as follows: grade 1, normal tendon; grade 2, enlarged tendon; and grade 3, tendon containing a hypoechoic area, regardless of size.[88]

The using survival analysis, the time required to recover from symptoms was compared between grades following a retrospective review of a case series of patients at a sports medicine clinic (including chart reviews, telephone follow-up interviews, and review of ultrasound images obtained during hospital visits).[88]

They discovered that achillodynia outcomes were favorably linked with ultrasonography pathology grading.[88] Specifically; patients with grade 1 tendons had a prompter resolution of symptoms than did patients with grade 2 or 3 tendons; and this difference was statistically significant ($p = 0.02$).

Thus, tendon sonography can be utilized as a complementary diagnostic method to physical examination.[88]

Koivunen-Nimela et al.[89] analyzed 267 normal controls of varied ages in their paper titled "Anatomy of the Achilles tendon (tendono calcaneus) with respect to tendon thickness measures." The Achilles tendons of these test subjects were measured using ultrasonography as a reference.[89] Then, 96 recruits

and 10 young women had additional MRI imaging of their Achilles tendons and calves for a more comprehensive evaluation of the parameters influencing Achilles tendon thickness.[89]
They discovered that the thickness of the Achilles tendon increases with age and that males have thicker Achilles tendons than women, but this difference between the sexes was only statistically significant in the oldest age group.[89]

A statistically significant association between tendon thickness and body height was also observed.[89] In addition, there was a variance of up to 25% in the measured thickness values (between the ultrasound and MRI readings for Achilles tendon thickness), which was attributed to the typical variation in tendon shape.[89] The researchers concluded that the disparities in population height could explain for the measured discrepancies in normal Achilles tendon thickness between Japanese and European and American subjects.[89]

In their paper titled "Sonographic measurement of Achilles tendons in asymptomatic subjects: variation with age, body height, and ankle dominance," Pang et al.[90] described the USG features of the AT in asymptomatic individuals.

In healthy individuals, they characterized ultrasonography Achilles tendon measurements (including thickness, width, cross-sectional area, and length) and identified significant correlating factors.[90] The obtained data comprised patient demographics, body type, and foot dominance information.[90]
Some of the conclusions reached by these researchers included: Sonography is an effective imaging method for evaluating Achilles tendons, and there is no significant difference between participants of different ages or dominant and nondominant ankles.[90] However, older individuals and those with dominant ankles have tendons with a higher cross-sectional area.[90] The correlational strength between AT measures and body height, weight, and BMI varied between investigations.[90]

In their paper titled "The Achilles Tendon in Healthy Subjects: Anthropometric and Ultrasound Mapping Study," Patel et al.[91] highlighted the advantages of ultrasonography as a cheap, rapid, and reliable imaging technology for evaluating the Achilles tendon. They also noted the lack of ultrasound data from healthy persons and attempted to further characterize the Achilles tendon measurements (including tendon width, thickness, cross-sectional area, and length) and identify significant associated factors in healthy individuals.[91] They gathered information regarding patient demographics, body type, activity level, foot dominance, and ankle angle at rest.[91]

Males showed considerably greater tendon length, width, thickness, and cross-sectional area than females.[91] When comparing right versus left leg dominance, no statistically significant differences in tendon parameters were found. Each tendon parameter (length, width, thickness, and cross-sectional area) correlated positively with subject height, weight, tibial length, and foot size when all participants were considered.[91]

Only the cross-sectional area of the Achilles correlated significantly with activity level.[91]
In conclusion, they discovered significant variations in the anatomy of the Achilles tendon in the healthy adult population and concluded that a greater understanding of the normal anatomy of the Achilles tendon and the characterization of its variations in the healthy population may permit improved pathologic diagnosis and surgical repair.[91]

1.2 PROBLEM STATEMENT:

The AT is susceptible to a variety of diseases that can be detected by clinical imaging. MRI has always been the imaging modality of choice. However, access to MR imaging is restricted and relatively expensive in our region. Consequently, while waiting for an MRI, the diagnosis and treatment of AT pathology are frequently significantly delayed. Therefore, it is prudent to invest in a less expensive and more readily accessible alternative to MRI.

Ultrasonography of the musculoskeletal system is an established, dependable, safe, affordable, and widely available technique for the diagnosis and treatment of AT disease. However, research data on the sonographic appearance of the AT in the asymptomatic African population are scarce. This is because the majority of ultrasound data comes from non-African populations.

1.3 RATIONALE FOR STUDY

This study seeks to determine the sonographic features of the AT in asymptomatic subjects. This information will increase the knowledge base on the sonographic characteristics of the AT in 'normal' African individuals and ultimately prove useful in the timely and cost-effective management of patients with AT pathology.

1.4 OBJECTIVES

AIM

To determine the ultrasonographic imaging findings of the Achilles tendon (AT) in asymptomatic volunteers at the Korle Bu Teaching Hospital, Accra.

SPECIFIC OBJECTIVES

The specific objectives of this study are:

1. **To evaluate the intrinsic echogenicity of the AT parenchyma –** whether:
   - **a.** 'normal' - homogeneously hyperechoic relative to the adjacent muscle
   - **b.** 'decreased' - hypoechoic; and whether this change is focal or diffuse.

2. **To determine the thickness of the AT (**the maximum anteroposterior diameter of the AT obtained via a transverse scan at the level of the medial malleolus).

3. **To assess the effects of Gender, ankle dominance, height, weight and BMI on AT thickness.**

CHAPTER 2

LITERATURE REVIEW

Gross Anatomy

The gastrocnemius, soleus, and plantaris muscles act to flex the foot. Walking, jumping, and running all engage the gastrocnemius muscle.[1,2] The Achilles tendon is the joint tendon of the gastrocnemius and soleus muscles. It begins in the middle of the lower leg and is created by the union of the two heads of the gastrocnemius and soleus muscles.[1,2] The origin of the gastrocnemius tendon is gradual, spanning around 3 to 4 cm. The Achilles tendon is not completely formed until the soleus muscle inserts onto the gastrocnemius tendon, approximately 3-4 cm distal to the gastrocnemius tendon origin. [2] The attachment of the Achilles tendon onto the calcaneus is an enthesis and is intimately tied to the retrocalcaneal bursa, the only real anatomic bursa in the ankle.[4]

The Achilles tendon is almost entirely surrounded by a paratenon.[1,2] The layers of this paratenon are visceral and parietal. [1,2] The paratenon is similar to synovium in that it nourishes the tendon, but because the AT does not shift its axis of motion, the lubricating function of synovium is unnecessary.[2]

Blood Supply:

AT receives its blood supply from the musculotendinous junction, vessels in the surrounding connective tissue, and the osteotendinous junction.[1,2] The vascular regions can be simply categorized into three segments, with the middle segment fed by the peroneal artery and the proximal and distal segments supplied by the posterior tibial artery.[1,2] This leaves a somewhat hypovascular region in the middle of the tendon, where the majority of issues arise.[1,2]

Innervation:

The AT is innervated primarily by the sural nerve and secondarily by the tibial nerve.[1,2,75] Tenocytes make type I collagen and constitute 90% of the typical tendon's cellular component.[1,2]

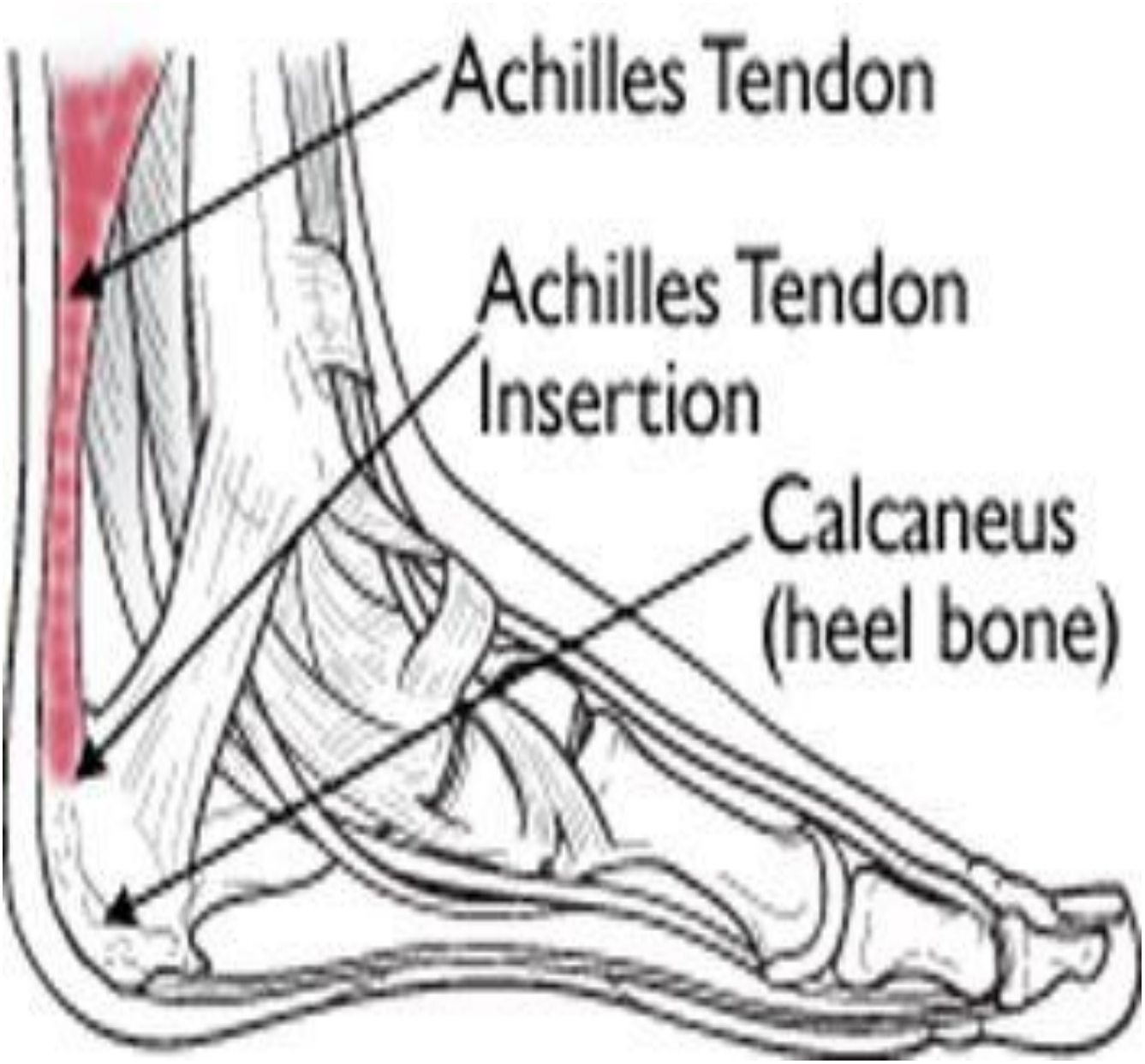


Figure 8A. Diagram showing sagittal view of the Achilles tendon [92]

Sonographic characteristics of the normal AT

High-quality, high-resolution sonographic equipment allow for a thorough evaluation of the AT.[26] Probes with a higher frequency improve the sensitivity of ultrasonographic tendon evaluation; and allow reliable observation of the AT, up to its distal insertion.[34,73]

On longitudinal scans, the AT of a healthy subject appears as a densely packed echoic structure with fine parallel internal linear echoes (fibrillar pattern) that are divided by fine anechoic lines.[8,26] Large endotendineum septa are shown by longitudinally directed echoic lines.[34,73] As illustrated in Figure 8, the tendon contour is regular and well-defined.

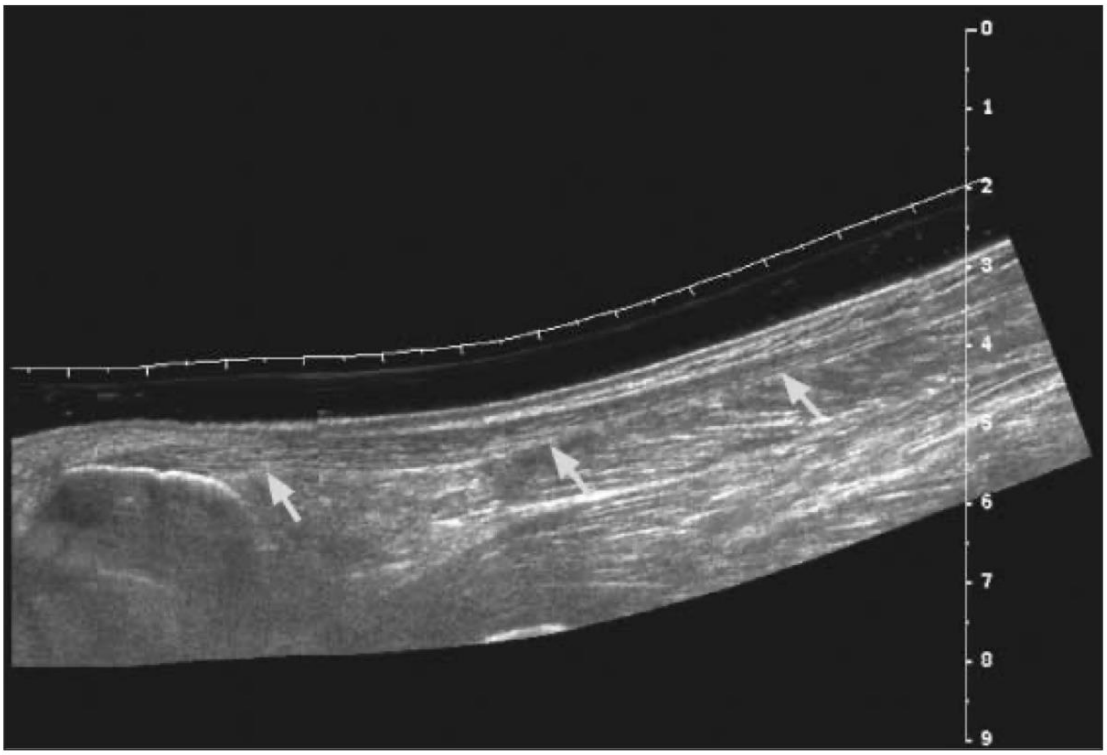


Figure 8B. Longitudinal extended field-of-view sonogram showing a normal Achilles tendon (arrowed) with the ankle in a relaxed, neutral position.[90]

On transverse scans, the normal AT appears as an oval-to-round structure characterized by tightly packed echoic dots with a homogeneous distribution,[34] as shown in Figure 9.

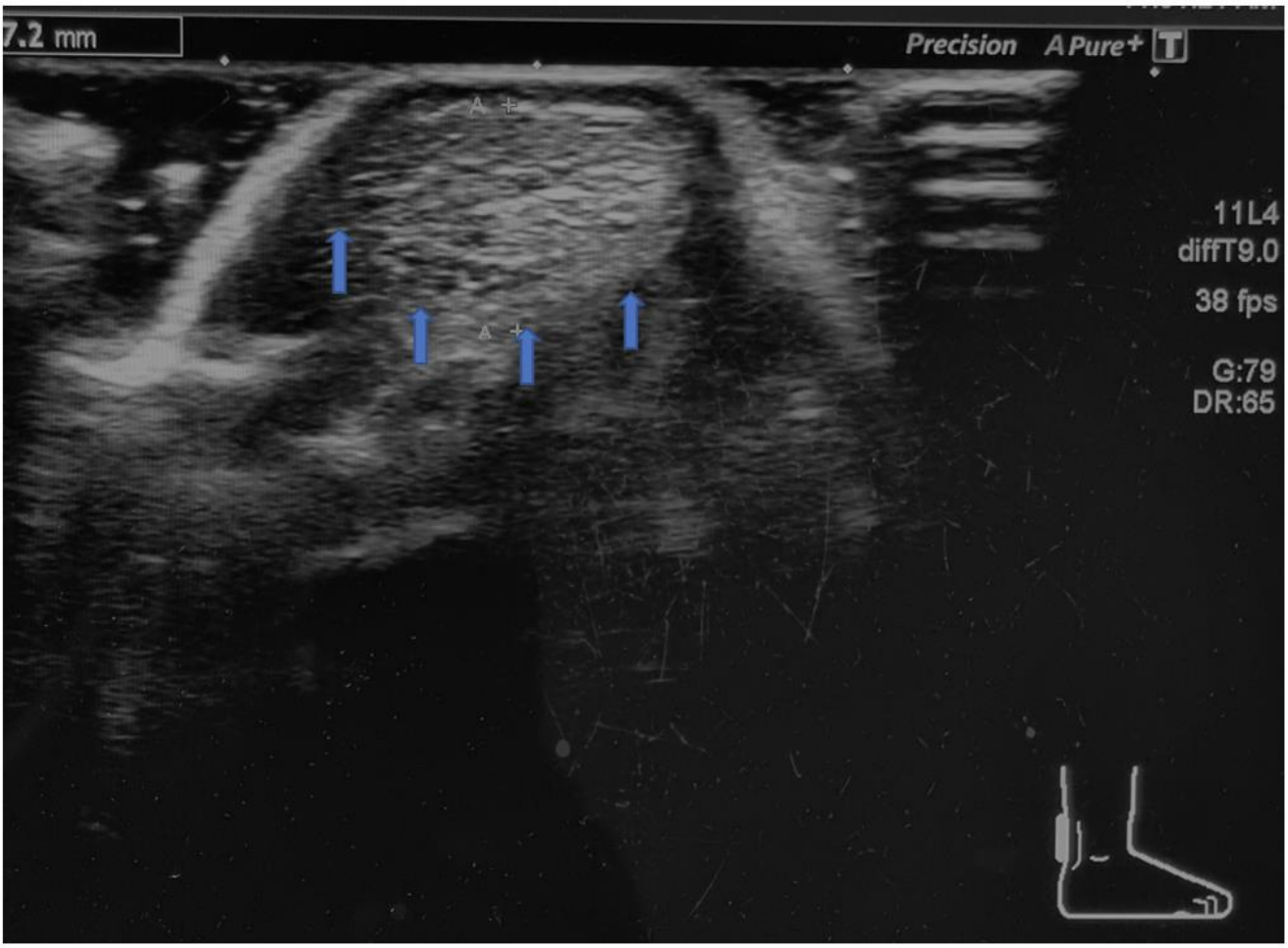


Figure 9. Transverse grey scale USG image; showing an asymptomatic Achilles tendon indicated by the blue arrows

The plantaris Muscle:

The plantaris is an accessory muscle, with 7-10% of the human population lacking it.[1,2,34] This tendon is one of the longest structures in the body.[2] The plantaris, in conjunction with the soleus and gastrocnemius, permits modest plantar flexion of the calf.[2]

In close contact with the lateral head of the gastrocnemius muscle, the plantaris muscle arises from the lateral meniscus and the lateral femoral epicondyle.[2]

The plantaris tendon extends medial to the Achilles tendon after crossing obliquely between the soleus and gastrocnemius muscles.[2] The majority of plantaris fibers insert on the medial aspect of the superior calcaneal tuberosity or 1 cm anterior and medial to the Achilles on the calcaneus, an insertion location unique from that of the Achilles.[2] The Achilles-plantaris complex is termed the 'triceps-surae complex' [2]

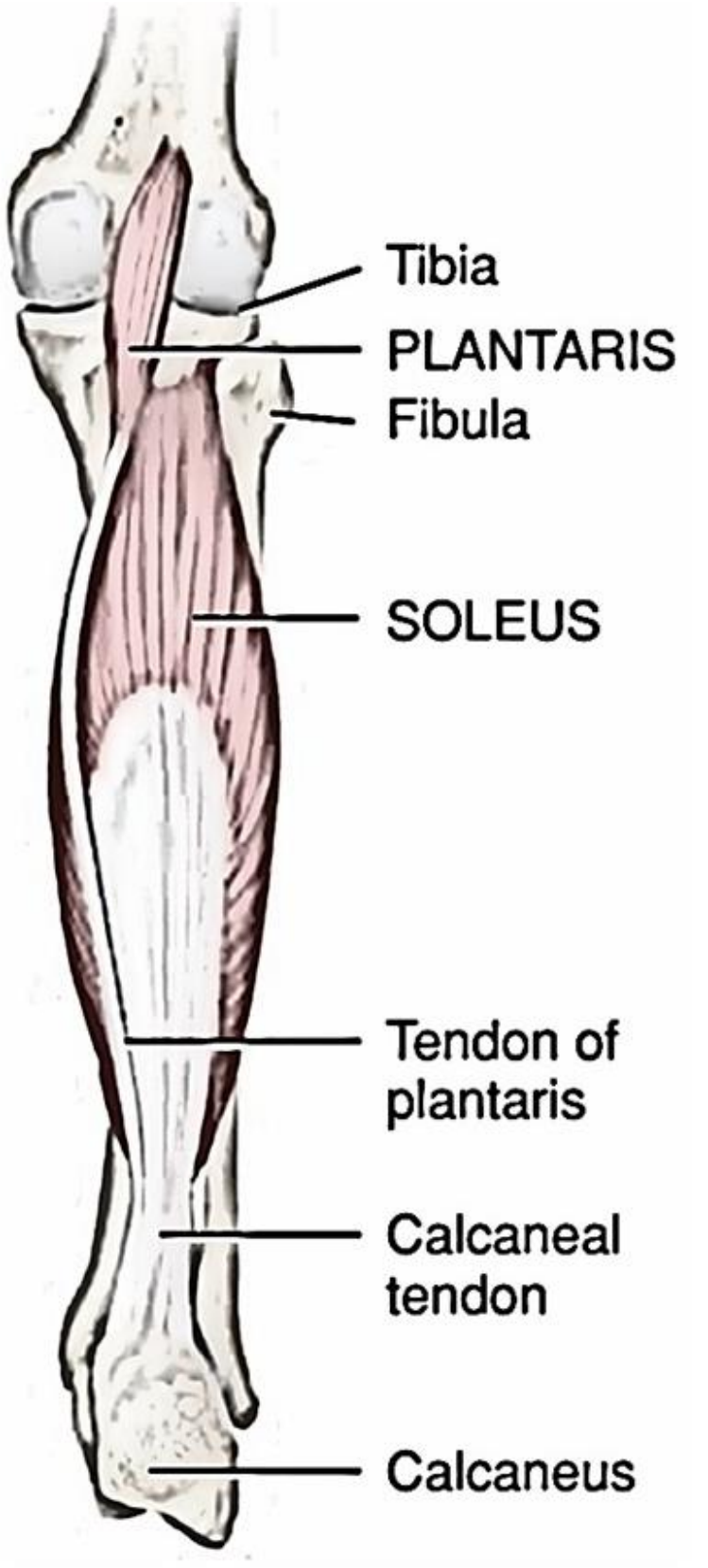


Figure `10. Diagram showing the plantaris muscle and its relations[93]

Previous Work on AT Anatomy, Function, Imaging and Pathology:

In their paper titled "Functional anatomy of the Achilles Tendon," Doral et al. detailed the general anatomy, macro- and micro-structure (including the spiralized fiber arrangement and implications for load distribution), blood and nerve supply, and insertion of the AT.[1] Despite being the strongest, biggest, and thickest tendon in the human body, the Achilles tendon is one of the most often injured tendons.[1,2,6] This is because a consequence of the high biomechanical loads placed on it versus its relatively insufficient vascularization.[1] During jogging, direct force measurements reveal that the AT is loaded up to 9 KN, or 12.5 times body weight.[84,94]

In their article titled "MR Imaging of Disorders of the Achilles Tendon," Schweitzer and Karasick [2] describe in detail the major AT pathologies and their MRI correlations. This seminal work elaborates on AT anatomy (including gross anatomy, tendon ultrastructure, and functional anatomy), MRI appearances of the normal AT, epidemiology of AT pathology, and MRI appearances of various AT pathologies (such as degeneration/tendinosis, paratendonitis, and insertional tendonitis).[2]
In addition, this paper discusses 'related osseous injuries and anomalies' such as enthesophyte production, calcaneal edema, microavulsions at the AT insertion, plantar muscle injury, and Haglund's disease.[2]
This study also examined the existing terminology for AT pathology and attempted to harmonize and/or define terms.[2] This seminal work was limited to MRI imaging and provided scant information on ultrasonographic correlations with MRI findings.[2]

In their paper titled "Achilles tendon: Functional anatomy and fresh developing models of imaging classification," Del Buono et al. [94] also reviewed the USG and MRI anatomy of the Achilles tendon (AT), imaging techniques for the AT, and the classification of AT pathologies. They also proposed a new classification based on the power Doppler features of the AT, which associated strongly with

clinical complaints and US gray-scale results.[94] Nonetheless, as the significance of neovascularization in the diagnosis and prognosis of AT illness is ambiguous, they urged for additional study to test the reliability and validity of their suggested classification system.[94]

In their paper titled "High resolution ultrasound anatomy of normal Achilles tendon," Bertolotto et al. [76] examined the varying ultrasound appearances of the normal Achilles tendon with increasing frequency and aimed to establish anatomical correlations for US findings.
They studied 30 normal tendons in vivo and three in vitro using mechanical sector probes of 10 MHz and 15 MHz. In vitro comparisons between sonograms and their corresponding anatomical regions were done. By identifying multiple internal acoustic interfaces in the Achilles tendon, the researchers discovered that high-resolution probes permit the identification of the Achilles tendon's constituent sections, which were previously assumed to be a single uniform structure.[76] By identifying the different components of the AT using high frequency ultrasonography, misdiagnoses of abnormal findings can be avoided.[76]

Sonographic imaging of tendons by Grassi et al. [26] details sonographic methodology, typical sonographic appearances, disease patterns (including tenosynovitis, tendinitis, tendinosis, and tendon tears/ruptures), imaging pitfalls, and advice for sonographic-guided therapy. They observed that even though ultrasonography is an imaging method of choice for identifying tendon pathology; sonographic images can be misleading and difficult to analyze.[26] Standardization of sonographic assessment is required to increase the efficacy of tendon sonography and decrease interobserver variability.[26]
In addition, they argued that ultrasonography should be regarded as a part of the clinical evaluation for patients with suspected tendon lesions, due to its potential to display several simple lesions.[26] Note that the emphasis of this study was not the AT, but rather a variety of tendons in the body and the utility of sonography for evaluating tendon involvement in rheumatic disorders.

In their paper titled "MRI of the Achilles Tendon: A Comprehensive Pictorial Review," P. Szaro et al. Part one of [75] reviewed the normal MRI anatomy of the AT, reviewed the strengths and weaknesses of ultrasonography versus MRI for the assessment of various AT pathologies, including paratendonitis, rupture, tendinopathy, post-operative changes, infection, tumors and tumor-like conditions, image guided treatment and dynamic assessment.

Some of the conclusions reached in this work included: ultrasound is as effective as MRI in detecting tendinopathy and full-thickness tears, but less sensitive than MRI for partial tears; the presence of normal septation between subtendons of the AT may mimic an intrasubstance tear; and Kager's fat pad is more involved in infection than postoperative changes.[75]

New MRI techniques (such as modified diffusion tensor imaging (DTI)) that are believed to detect tendinopathy-induced microstructural disarray in its earliest phases are discussed. Potential DTI uses in the imaging of regeneration, healing, remodeling, and treatment response progression are all discussed.[95] DTI may be used to evaluate the microarchitecture of the Achilles tendon following repair, with the possibility of fiber tracing.[95]

T2-mapping is also discussed as a viable tool for assessing tendon healing, due to the fact that the T2 value of a healthy tendon is shorter than that of an injured tendon.[75,96] T2-mapping can be used to quantify the healing process because the concentration of water is higher after trauma and subsequently declines with time.[96] It can be utilized therapeutically as a reliable indicator of tendon repair, making it easier to determine when to return to sport.[75,96]

Incoherent intravoxel motion MRI is also mentioned as a method for evaluating the microcirculation and microvasculature of the Achilles tendon.[75,97] This is vital for evaluating the formation of vascular networks, which are essential for AT repair following injury.[97]

Water in the Achilles tendon can be visualized quantitatively using MR spectroscopy.[97] Direct imaging of water within a tendon may be a useful diagnostic tool for assessment of tendon diseases.[97]

This study also examines sodium MRI as a method for indirect measurement of glycosaminoglycan concentration within the AT.[75] This is advantageous because diseased tendons contain a greater concentration of glycosaminoglycans, which attract sodium ions.
MR elastography is utilized to evaluate the mechanical properties of a muscle, specifically in neuromuscular diseases.[98] This study describes it as a promising approach with potential clinical uses for tendon disease.[75]

Grumbine et al.[3] in "The tendo Achillis in relation to rearfoot position. A new classification for evaluation of calcaneal stance position' [3] investigated the biomechanics of the foot during movement in relation to the Achilles tendon. They concluded after statistical analysis of 48 subjects (96 feet) that; as the foot moves from the neutral to the resting calcaneal stance position, the tendo Achillis alignment is displaced laterally to the center of gravity'. [3]This study shed more light on the force transmission and alignment of the hindfoot, the AT, and related tissues during locomotion.[3]

In their article titled "A Narrative Review of the Classification and Use of Diagnostic Ultrasound for Conditions of the Achilles Tendon," Mascarenhas et al. [9] examined the most common causes of hindfoot and posterior ankle symptoms, such as retrocalcaneal bursitis, insertional tendinopathy,

midportion tendinopathy, paratenonopathy, superficial calcaneal bursitis, calcaneal ossification, Haglund deformity and calcific tendinopathy.[9]

This narrative review described the many AT diseases, the imaging modalities used for their diagnosis and treatment, and the benefits and drawbacks of these modalities.[9]
In addition, they discovered that the current nomenclature comprises numerous unclear and incorrectly applied phrases, which might lead to misclassification of hindfoot and/or posterior ankle symptoms.[9]
Recent investigations (using high frequency musculoskeletal ultrasonography, MRI, and CT scans) have demonstrated that the majority of cases of 'tendonitis' are actually degenerative lesions, with 'tendinosis' being a more appropriate name.[9]

In addition, the vagueness and other issues associated with the usage of the 'umbrella' term 'enthesitis' and 'Haglund' terminology were examined.[9] The primary source of confusion is because the majority of the diagnostic criteria for "enthesitis" are not specific for inflammation and frequently result from chronic degeneration and damage.[9] Thus, they proposed the term 'enthesosis,' which they believe is a more accurate description of enthesis degeneration.[9]

In addition, they stated that adoption of a uniform, consistent nomenclature is significant in terms of implications for the therapy of AT disease, as different pathologies respond differently to diverse degrees and/or types of medicine, exercise, and surgery.[9]
This study elaborated on the many AT diseases and their radiologic characteristics, as well as alternative causes of hindfoot and posterior ankle symptoms.[9]

MRI is extraordinarily sensitive to structural abnormalities associated with AT diseases.[2] US reveals similar tendon anomalies in AT diseases as well, although with reduced sensitivity. The few

investigations that have evaluated both asymptomatic and symptomatic AT have revealed different degrees of overlap between US and MRI imaging findings.[9] On MRI, asymptomatic Achilles tendons frequently exhibit localized anomalies.[2,9] Therefore, it is probable that the structural abnormalities identified on US and/or MR imaging do not precisely correspond with the clinical picture.

The preceding caused Khan et al.[73] to compare the ultrasonic and magnetic resonance imaging findings with a clinical benchmark in the evaluation of chronic Achilles tendinopathy, and to determine whether ultrasound or MRI predicted the 12- and 24-month clinical outcome.
At the onset of the trial, each of the 45 participants underwent:
1. a clinical evaluation and bilateral US and MRI imaging,
2. A 12-month follow-up included a clinical evaluation and bilateral ultrasound, but no MRI and
3. A 24-month telephone follow-up clinical evaluation

They studied 45 consecutive patients (27 men, 18 women; mean age: 42 years, range: 20–66) with symptomatic Achilles tendinopathy (mean duration: 21 months, range: 0.5–120 months) who were referred to a secondary university sports medicine facility for treatment.

12 patients reported bilateral symptoms and 33 patients had unilateral symptoms at the beginning of the trial (baseline), for a total of 57 symptomatic tendons and 33 asymptomatic tendons.
28 of the asymptomatic tendons had never been symptomatic, whereas five had been painful in the past but not within the recent six months.

No patient presented with a history of systemic inflammatory diseases, such as rheumatoid arthritis, or hypercholesterolemia.

The referring clinician made the clinical diagnosis, which was then validated by a board-certified sports medicine physician. The most common complaints were activity-induced pain and morning stiffness.

A summary of their MR & US imaging findings is shown in the table below.

Table 4. Clinical, ultrasound (US) and magnetic resonance imaging (MRI) results in 50 tendons examined by both imaging modalities[73]

	Symptomatic	Asymptomatic
MRI positive	19	1
MRI negative	15	15
US positive	23	3
US negative	11	13

Only cases with MRI and US assessment in the same patient are included.

The clinical condition was evaluated at baseline, 12 months, and 24 months.

At baseline, symptoms of Achilles tendon pain were classified as present or absent, and when symptoms were present, their severity was rated using the Victorian Institute of Sport evaluation scale (VISA-A).[99] The scores can range from 0 to 100, where 100 represents no symptoms and perfect function. A difference of 25 points is clinically significant.[99]

At the 12-month clinical follow-up, a new clinical history and VISA assessment were conducted.

The 2-year follow-up was conducted through telephone.

This study employed "sporting success" and "symptomatic benefit" as outcome measures.

Symptomatic benefit refers to self-reported improvement relative to baseline.[73]

US detected aberrant morphology in 37 of 57 (65%) symptomatic tendons, while 19 of 28 (68%) asymptomatic tendons had normal morphology.[73] In identifying tendinopathy, US exhibited a sensitivity of 0.80 and a specificity of 0.49 compared to the clinical standard.[73]

Positive predictive value equaled 0.65, while negative predictive value equaled 0.68.

Color Doppler and Power Doppler test did not improve the accuracy of the US assessment.

MRI revealed aberrant morphology in 19 of the 34 symptomatic tendons (56 percent), while 15 of 16 asymptomatic tendons had normal morphology.[73]

In comparison to the clinical standard, MRI had a sensitivity of 0.95, a specificity of 0.50, a positive predictive value of 0.56, and a negative predictive value of 0.94 in identifying tendinopathy.[73]

36 of the 45 patients were available for follow-up at the 12-month mark.

There were 45 symptomatic tendons and 25 tendons without symptoms.

The link between imaging severity and clinical prognosis at 12 months is depicted in Table 5.

Correlation between MRI and Ultrasound Findings:

- Among the 34 symptomatic tendons, both US and MRI properly identified 18 tendons (53 percent) as positive and 10 tendons (29 percent) as negative (table 1).[73]
- Seven of eleven asymptomatic tendons were classified as normal by both MRI modalities.

Table 5. Relation between imaging severity and clinical outcome. Showing US at baseline and at 12 months clinical outcome as well as US at 12 month follow up and clinical status compared with baseline.

	Clinical follow up at 12 months			
	Improved	Same	Worse	Total
US appearance at baseline				
Normal	4	30	1	35
Thickened		3	0	3
Hypoechoic	10	23	0	33
Total	14	56	1	71
US appearance at follow up				
Normal	3	30	0	33
Thickened		7	1	8
Hypoechoic	10	17	0	27
Total	13	54	1	68

$\chi^2 = 16.8$; $p = 0.002$.

24 month follow up:

Two years after the initial measurement, 32 of the original 45 patients were available for follow-up, and all but two had returned to their previous level of athleticism. One of the two who had not returned to sport believed that she had improved tremendously. Thus, 94% of patients who were available for follow-up attained sporting success (as defined) and 97% experienced clinical improvement. At the two-year follow-up, the mean (95 percent confidence interval) VISA score was 91.8 (88.2 to 95.4).

Thus, it is observed that imaging anomalies of the Achilles tendon persist even in patients who have reached a full functional recovery.[73] Therefore, imaging appearance should not be used to determine whether or not a player with Achilles tendinopathy is fit to return to sport.[73]

In conclusion:

- Ultrasound and magnetic resonance imaging have only a moderate connection with the clinical evaluation of chronic Achilles tendinopathy.[73]
- MRI appearance grading was connected with clinical prognosis, whereas US was not.[73]

In the study titled "ultrasound identification of Achilles tendon disease in runners" [67], Maffulli et al. examined the Achilles tendon (AT) of 47 middle- and long-distance runners with various Achilles tendon pathologies. They conducted clinical evaluations of the AT, followed by ultrasound tests, not only to confirm the clinical diagnosis, but also to determine the kind of tendon modification, its anatomopathological stage, and to compare their findings to those of prior investigations.[67]

Before inclusion in the study, all participants were middle- or long-distance runners who had trained at least six days per week for at least one year. Since 2.5 +/- 6.3 months, they had all been diagnosed with Achilles tendon pathology. A board certified orthopedic surgeon made the diagnosis.[67]
Using a real-time ultrasound machine equipped with a linear 7 MHz probe and a sectorial 5 MHz probe, the radiologist evaluated the patients and completed the US examination. Two radiologists analyzed the images from the ultrasound scan. One of the radiologists was ‘blinded’ to the patient history and examination findings.

The following clinical classifications of Achilles tendon pathology were utilized in the study:

- Tenalgia: tendon discomfort with no signs of tendon change[67]
- The inflammatory processes of paratendonitis involves the highly vascularized peritendinous connective tissue[67]

- Tendonitis (pure or combined with paratendonitis): pathogenic involvement of the tendon as a whole or in a well-defined segment. These locations are rather weakly vascularized and may exhibit degenerative symptoms, leading to subcutaneous rupture if not detected.[13,81]
- enthesopathy: where the tendon is inserted into the bone, there are particular features due to the presence of a fibrocartilaginous transitional area with vessels coming from both bone and periosteum[60] and one or more bursae. These structures can be involved in inflammatory or degenerative processes.

The results of the examinations are shown below in Table 6.

Table 6. clinical and ultrasound diagnosis of alterations of the AT in 47 middle- and long-distance runners.[67]

Clinical and ultrasound diagnosis of alterations of the Achilles tendon in 47 middle and long distance runners.

	Clinical examination	Ultrasound scan
Tenalgia	12	8
Paratendonitis	18	5
Tendonitis	13	11
Tendonitis with paratendonitis	—	17
Enthesopathy	12	14
Total	55	55

Eight athletes were suffering from bilateral tendon pathology.

The following typical and abnormal characteristics were identified:

In 39 cases (84.0%), the normal tendon appeared as a ribbon-like, hypoechogenic structure demarcated by two thin and regular echogenic bands (as shown in Figure 7A. previously). It had a thickness of 5.1 +/- 0.4 mm on average.[67]

2. paratendonitis: in five cases (10.7%), a thickening of the tendon's anterior border and, in some cases, hyperechogenicity of Kager's triangle were observed. These findings were accompanied by an increase in the antero-posterior diameter of the tendon (from 50 to 100 percent compared to the normal contralateral diameter, with an average of 78 14 percent), but it was still possible to identify its normal waveform structure, which was lost in tendonitis cases.[67]

3. Tendinitis: 28 instances (59.6 percent) had ultrasonic tendonitis characteristics.[67]

Two distinct types of tendinitis were identified:

a. In seventeen cases (36.2 percent) of pure tendonitis, the tendon widened, either partially or along its whole length.[67]

b. In eleven cases (23.4%) with tendonitis associated with paratendonitis, there was hyperechogenicity of Kager's triangle and the anterior tendon border.[67]

4. In six cases (12.8 percent) with enthesopathy, the hypoechogenic region behind the tendon was enlarged. In an additional eight cases (17%), the distal tendon was expanded and its echogenicity was changed.[67]

They concluded that ultrasound provides a highly accurate depiction of both the peritendinous soft tissues and the tendon's internal anatomy.[67] It is feasible to develop anatomopathological diagnoses based on the US findings in conjunction with the clinical examination, resulting in more precise results.[67]

In their article titled "Current perspectives in the management of tendon problems," Rees et al.[6] examined the mechanical, vascular, and evolving neurological hypotheses that aim to explain the cause of degenerative tendinopathy.

In this article, the authors describe the epidemiology of tendon diseases in the general population and the pathophysiology of tendinopathy, demonstrating that it is mostly a degenerative process without a large inflammatory component.[6] This notion is confirmed by the fact that histological investigations of surgical specimens of chronic tendinopathy consistently reveal either no inflammation or moderate inflammation, with degenerative change being the major lesion.[6] The AT, rotator cuff, patella, and extensor carpi radialis brevis exhibit these alterations.[6]

Moreover, they highlight the crucial point that tendinopathy is not always symptomatic.[6] After weighing the strengths and weaknesses of the many classical theories of tendinopathy; they concluded that “in practice, the etiology of tendinopathy is likely to be the consequence of a combination of the mechanical, vascular, and neurological theories”.[6] This paper also considered the notion that tendinopathy is caused by a "failure of healing" and that for enthesis lesions, that "underuse" rather than "overuse" may be to blame.[6]

This work also examines the current treatments for the management of tendon disorders, such as nonsteroidal anti-inflammatory drugs (NSAIDs), corticosteroid injections, physical treatments (such as cryotherapy, therapeutic ultrasound, and low-intensity laser therapy), and Manual therapy techniques (such as Deep transverse friction massage (DTFM) and soft tissue mobilization).[6]

Biomechanical alterations (such as the use of heel pads for Achilles tendinopathy) and other novel treatments (such as Extracorporeal shock wave therapy (ESWT), heparin, dextrose, aprotinin, autologous red cell injection, sclerosant injections, topical glyceryl trinitrate, and Polysulphated glycosaminoglycans) are also discussed.[6]

They concluded that previous treatments for tendinopathy have incorrectly placed a strong emphasis on anti-inflammatory techniques.[6] Regarding new treatments, they write, "Unfortunately, few are supported by robust data." Specifically (with the exception of recent work on eccentric loading), physical therapy, strength deficits, lack of flexibility, and unsuitable equipment have not been evaluated under controlled and prospective conditions.[6]

In their paper titled "Sonographic measurement of Achilles tendon thickness in seronegative spondyloarthropathies," Aydin et al.[87] examined the variations in Achilles tendon thickness caused by seronegative arthropathies. They aimed to establish whether the literature-derived values for measuring Achilles tendon thickening in patients with spondyloarthropathies were specific and sensitive enough. To determine the optimal cut-off value for diagnosing Achilles tendon thickening in patients with spondyloarthropathies (relative to the established cut-off values in the literature), the Achilles tendon thickness of 101 subjects – 55 of whom had spondyloarthropathies and 46 of whom were age- and BMI-matched controls – was measured.[87]

Using ROC curve analysis, they identified the optimal cutoff value for diagnosing Achilles tendon thickening in both sexes. The female values are 5.5 mm and the male values are 6.2 mm.[87] Both of these figures differed from the value found in the scientific literature, which was 5.29 mm for both genders.[87] The number of measurements that exceeded the cutoff values, as well as the sensitivity, specificity, and positive and negative predictive values, were determined.

They discovered a statistically significant difference in Achilles enthesis thickness between genders (mean SD: 4.60.7 mm in males vs. 4.00.8 mm in females, p0.00) and between spondyloarthritic patients (SpA) and healthy controls (HC) (mean SD: 4.40.8 mm in SpA patients vs. 4.00.8 mm in HC).[87] The examination of the ROC curve determined the optimal cutoff value to be 3.7 mm for

females and 4.8 mm for males (SE: 43-70 percent , SP: 59-85 percent , PPV: 66-79 percent , NPV: 54-63 percent).[87] It was discovered that previously stated cutoff values have a high specificity (91-98%) but a very low sensitivity (2-11 percent).[87]

They determined that the thickness of the Achilles tendon changes across sexes; therefore, it is essential to refer to gender-specific normative values.[87]

As previously suggested in the literature, high cut-off values demonstrated very low sensitivity in the current study; and when Achilles enthesis thickening is used for screening enthesitis in spondylarthritis patients, a lower cut-off value has a higher sensitivity with slightly worse specificity, positive predictive values, and negative predictive values.[87]

Szaro et al. investigated how tendinopathy-related lesions alter correlations in the dimensions of the AT; in their work 'The correlations between dimensions of the normal tendon and tendinopathy altered Achilles tendon in routine magnetic resonance imaging,'[79] they determined how tendinopathy-related lesions alter these correlations.

The link between the thickness of the tendon and the width of the midportion was more significant in tendinopathy (r = 0.49 vs. r =.01, p .001), the researchers discovered.[79] Thus, proving that dimension correlations varied dramatically between normal Achilles tendon and tendinopathic tendon.[79]

In their study titled "Ultrasound Morphology of the Achilles in Asymptomatic Patients With and Without Diabetes,"[100] Abate et al. examined the prevalence of Achilles tendinopathy in 136 individuals with diabetes and 273 individuals without diabetes (for a total of 272 and 546 ATs, respectively). The purpose of this study was to evaluate the morphological parameters of the Achilles

tendon (AT) between patients with Diabetes Mellitus (DM) and controls without DM, and to determine whether DM increases the incidence of tendinopathy.[100]

Patients from the outpatient clinic were recruited. Patients having AT pain or a history of AT injury were excluded from the study. Diabetes was diagnosed based on the patient's medical history and current treatment. Demographic information (age and sex), anthropometric measurements (height, weight, and BMI), and duration of diabetes were recorded for all participants.[100]

US tests of their AT were done to document any degenerative characteristics (abnormal fibrillar pattern, hypo-hyperechoic regions), indications of enthesopathy (bone erosion, enthesophytes, and bursitis), and intratendinous neovessel formation.[100]

They found:

- Asymptomatic sonographic abnormalities (ASA) were substantially elevated in diabetic participants (35/136 [25.7 percent] versus 32/273 [11.7 percent], P =.0003).[100]
- In the DM group, ASA were typically identified at the enthesis (32/60 [53.3%] vs 9/45 [20%], P =.0005). However, ASA were more prevalent in the middle region of the AT in the non-DM group (38/45 [84.4%] vs 36/60 [60%], P <.006).[100]
- As anticipated, the DM group had a higher BMI and prevalence of cardiovascular, renal, vascular, and neurologic disorders.[100]
- The research also demonstrated that the pathogenetic role of diabetes was independent of obesity. Indeed, a greater prevalence of ASA was found in people with higher BMI (both patients and controls).[100]
- No statistically significant variations in age or Male : Female ratio were detected.[100]

They concluded that DM predisposes to AT tendinopathy; which is often at the enthesis - as opposed to midportion disease in the general population.[100]

There is a need for longitudinal investigations to determine if US anomalies in the AT of diabetics progress to clinical enthesopathy or calcaneal spur development.[100]

Achilles tendinopathy is frequent in athletes [12,69,81] due to the stress exerted by recurrent stresses on the tendon - with consequent tissue microinjuries, degeneration and efforts at repair.[11,15] The incidence of Achilles tendinopathy in asymptomatic runners is not known. [67,101]

Because asymptomatic tendinopathy is more likely to develop in aberrant tendons, recognizing asymptomatic athletes with pathologic tendons will help prevent future injury. [101]

In their study titled "Using Ultrasound Measurement of the Achilles Tendon in Asymptomatic Runners to Assist in Predicting Tendinopathy," Kudron et al. sought to determine the US measures of the AT in asymptomatic runners and to see if these findings were beneficial in predicting tendinopathy.[101]

They analyzed the relationships between dominant and nondominant side tendon size (cross-sectional area [CSA] and thickness) and athlete attributes among 27 asymptomatic National Collegiate Athletic Association Division I cross-country athletes. Additionally, tendon anomalies suggestive of Achilles tendinopathy were evaluated.[101]

Eleven percent of asymptomatic athletes were found to have tendon anomalies.[101]

There was no statistically significant difference ($P>0.05$) between the thickness or CSA of the dominant and non-dominant tendons.[101] CSA was found to connect positively with height, weight, BMI, weekly kilometers run, and gender, with men having a greater CSA. ($p<0.05$) [101]

The strongest correlation was between AT thickness and weekly mileage ($p<0.05$). [101]

They concluded that tendinopathy can be diagnosed by changes in tendon size and related anomalies via US assessment of the AT tendon size; however, more normative data should be collected.[101]

There are indications that the plantaris muscle may have a significant role in the development of Achilles tendinopathy in the midportion.[10,14,43] Using Ultrasound tissue characterization (UTC) and VISA clinical outcome score; Masci et al. [102] investigated the effect of surgical plantaris tendon excision and operational scraping in patients with midportion Achilles tendinopathy with probable plantaris involvement.

UTC is a novel imaging technique used to assess Achilles tendon structure and measure tendon matrix integrity.[102] UTC objectively quantifies grey-scale tendon matrix changes into four distinct echotypes related to tendon integrity, unlike 2D US and color Doppler (CD).[102]
All pre- and post-operative examinations were conducted at the Pure Sports Medicine Clinic in London, United Kingdom, between August 2013 and August 2014. The patients included were referred by UK general practitioners, physiotherapists, and sports medicine physicians.

The study comprised patients with midportion Achilles tendinopathy with medial tendon discomfort (history), medial tendon soreness (palpation), and localized medial tendon abnormalities (US and UTC).[102]

Included were nine Achilles tendons from eight individuals (seven males and one women) with a mean age of 39 (range: 26–56) years. The duration of symptoms varied between 6 and 48 months.
All patients complained of activity-related medial tendon pain and had Achilles tendon medial side tenderness. Each individual had failed a tendon loading program (eccentric training).

All patients were physically active, with six runners (two at the highest level), one cricketer, and one footballer among them. Patients having a history of Achilles tendon surgery were excluded.

The participants then received a clinical evaluation, an ultrasound and color Doppler examination, the UTC, and the operation. The surgical treatment comprised of plantaris tendon release and excision distal to the calcaneal insertion and proximal to the distal medial soleus muscle insertion.[102]

The structure of the tendon was evaluated using UTC and a VISA-A score was obtained.
Self-reporting was used to measure patient satisfaction with the operation's outcome (satisfied or not satisfied). When patients were satisfied with the treatment and returned to full Achilles tendon loading, the outcome was deemed positive.[102]

Six months after surgical therapy, a check-in was conducted.

- UTC exhibited a statistically significant ($t = 5.40$, $p<0.001$) rise in the mean organized matrix (echo-type I+II) and a decrease in the mean disorderly matrix (echo-type III+IV) at this time.[102]
- The VISAA score increased considerably ($p<0.001$) from 56.8 (range 34–73) preoperatively to 93.3 (range 87–100) postoperatively, resulting in the satisfaction of seven out of eight patients.[102]

Thus; they concluded that in chronic midportion tendinopathy, excision of the plantaris tendon and scraping of the ventromedial Achilles tendon appear to have the ability to improve tendon structure and decrease tendon pain.[102] However, investigations with a bigger patient population and a longer follow-up time are required.

The prevalence and incidence of midsubstance Achilles tendinopathy (i.e., in the middle third of the tendon) are high in athletes, cases are also frequently reported in sedentary individuals.[11,83] The aetiology and pathogenesis of AT tendinopathy have been the subject of much research, but with inconsistent findings [2,6]. Hence, treating people suffering from this pathology remains challenging for rehabilitation professionals and the success rate of conservative treatments is variable.

This prompted Nadeau et al. [103] to investigate:
[1] if quantitative ultrasound measures (QUS measurements) of the AT could estimate AT integrity
[2] To try to find the optimal methodology for QUS measurement collection in clinical practice.

23 ATs with documented Achilles tendinopathy and 63 asymptomatic ATs were evaluated.
At each visit, four researchers performed ultrasound examinations on each AT and captured two images each, for a total of eight photographs per AT.[103]

Multiple sets of QUS measurements were acquired: geometry (thickness, width, and area), first-order statistics (computed from a grayscale histogram distribution: echogenicity, variance, skewness, kurtosis, and entropy), and texture features (computed from co-occurrence matrices: contrast, energy, homogeneity).[103] A generalizability study measured the dependability and standard error of measurement (accuracy) of each QUS measurement, while a decision study determined the optimal protocols for conducting measurements.[103]

They discovered that geometric QUS measurements exhibited exceptional precision and dependability.[103] The precision and dependability of QUS measurements derived from the grayscale histogram distribution were deficient.[103] The accuracy and reliability of QUS measurements derived from co-occurrence matrices varied from mediocre to outstanding.[103]

They concluded that the application of geometric QUS measurements permits the quantification of AT integrity in clinical practice and research environments.[103] More research is required on QUS measurements derived from co-occurrence matrices.[103]
In clinical practice, they suggested that averaging the results of three images acquired by a single assessor during a single visit is acceptable.[103]

Tendinopathy and enhanced vascularization in Achilles tendons have a clear association, however the details of this relationship remain debatable.[60–62] This association was investigated by Genovese et al. in their paper titled "Analysis of Achilles Tendon Vascularity with Second-Generation Contrast-Enhanced Ultrasound."[104] They compared the morphological, power Doppler, and contrast-enhanced ultrasonography (CEUS) characteristics of the Achilles tendon comparing asymptomatic athletes and athletes who had undergone surgical repair of a previous rupture. They concluded that:

- in athletes with an Achilles tendon injury, CEUS discovered tiny vessels that power Doppler ultrasound did not identify in the uninjured contralateral Achilles tendon.[104]
- CEUS is excellent for assessing vascularity undetected by other imaging methods.[104]
- The vascularity of the undamaged tendon appears to be greater in patients with a history of rupture.[104]

Richards et al. [105] aimed to determine if the AT anomalies shown on spectral US and MRI are related to the development of aberrant flow patterns on Power Doppler US. In their study titled "Achilles Tendon (TA) Size and Power Doppler Ultrasound (PD) Changes Compared to MRI: A Preliminary Observational Study," they analyzed six patients with Achilles tendon (AT) symptoms and five patients with other ankle problems.

Then, two radiologists measured the mean maximal anteroposterior diameter on MRI and traditional US (classified as normal at 56 mm, mild at 6.110 mm, moderate at 1.11.5 cm, and substantially enlarged at 41.6 cm), appraised morphology, and examined the vasculature with power Doppler.
In total, 21 AT from 6 women and 5 men (aged 45-77 years) were investigated (mean 57.6 years),
The radiologists reached an agreement regarding disparities.
As a control, sonography of the contralateral side was done within 24 hours.

They discovered twelve tendons with normal morphology and size (<6mm). Power Doppler examination of these tendons did not reveal flow (interobserver agreement K40.74).[105]
Of the 12 tendons studied by MRI:

- five were normal,
- seven tendons were enlarged, five of which had a proportionate increase in PD flow at the margin on the deep surface and four also had vessels in the center of the tendon.
- All 5 of these tendons (with increased PD flow) also had high signal on T2-weighting (T2W).
- Of the two mildly enlarged tendons of intermediate signal on T1 and T2W, one showed PD flow and the other did not.

Even in the absence of tears, they determined that Power Doppler reveals an aberrant proliferation of arteries in larger pathologic AT tendons.[105]

AT of the midportion is a frequent disorder of the hindfoot. [10,11,43,44] MRI and conventional US are frequently used to evaluate the anatomy and size of the Achilles tendon in this condition and to differentiate it from insertional AT disease.[43,45]
Power Doppler (PD) ultrasound permits calculations of blood flow in Achilles tendinopathy, even when the arteries are too tiny to be seen using spectral ultrasound or MRI.[106,107]

Normal tendons do not demonstrate power Doppler flow on MRI and spectral ultrasonography, however morphologically aberrant and larger Achilles with tendinopathy do.[108] Thus, Richards et al. [108] opted to undertake a longitudinal prospective pilot study to compare the natural history of Achilles tendon microvascularization to symptoms using a disease-specific validated questionnaire.

9 patients, 5 men and 4 women [mean age 47 (range 30–62) years] with midportion Achilles tendinopathy receiving conservative treatment (eccentric exercise) were evaluated over the course of 1 year using:

a. post-contrast magnetic resonance imaging (MRI), time–intensity curve (TIC) enhancement,
b. ultrasound (US), and
c. power Doppler (PD) evaluation of tendinopathy.
d. To assess symptoms, a validated disease-specific questionnaire [the (VISA-A)] was utilized.

They found:

- Six asymptomatic tendons with normal US and MRI appearance; that demonstrated less enhancement than the tibial metaphysis and a flat, consistent, but extremely low rate of enhancement in the bone and Achilles tendon (9–73 TIC units). Imaging revealed that the size of these typical Achilles tendons remained unchanged throughout the year (mean 4.9 mm)[108]

- At baseline, the TIC augmentation of tendons with tendinopathy was greater than that of tendons without tendinopathy, ranging from 90 to 509 TIC units.[108]

- 11 aberrant ATs whose symptoms subsided were related with a reduction in MRI enhancement, a reduction in the number of vessels on power Doppler (8.0 to 2.7), an improvement in tendon morphology, and a reduction in tendon size (mean 15–10.7 mm) over time.[108]

The above findings caused them to conclude that:

- MRI enhancement and Power Doppler vascularity are reduced in patients with conservatively managed midportion AT tendinopathy.[108] These modifications were followed by morphological enhancements and a reduction in the size of the AT.[108]
- Power Doppler visualization of vessels refers to aberrant tendon morphology and size rather than symptom intensity.[108]
- The symptoms improve before the Achilles size decreases and imaging returns to normal over time.[108]

Doppler ultrasound is now so advanced that it can identify perfusion/vascularity in typical resting musculoskeletal tissue.[105] The resistive index (RI) produced by spectral Doppler is useful for discriminating between normal and pathological tissue blood flow.[105] It has been assumed that in tissues with no observable flow, RI can be defined as 1.00.[61,62] While inflammatory tissues typically have low RI values.

Koenig et al. in their work 'Ultrasound Doppler of the Achilles Tendon before and after Injection of an Ultrasound Contrast Agent – Findings in Asymptomatic Subjects'[68] set out find if normal tendinous vessels could be visualized with a contrast agent, and if such vessels had normal RI.
Using a 14 MHz linear transducer, they performed ultrasound examinations on 22 asymptomatic Achilles tendons from 12 patients. However, just five of these asymptomatic tendons were sonographically normal. Note that 18 of these 'asymptomatic' tendons were classified as normal by the physician, a board-certified orthopedic surgeon.

Table 7. Demographics of the participants divided according to US findings[68]

	normal tendons on US	abnormal tendons on US
number of tendons	5	17
male/female	5/0	13/4
age, mean (range)	41 years (27 – 50)	38 years (27 – 59)
BMI, mean (range)	24.3 (22.5 – 26.5)	26 (22.2 – 35.7)
activity hours/week Median (range)	3 – 6 hours ([0 – 1h] to [6 – 10h])	3 – 6 hours ([0 – 1h] to [6 – 10h])
smoker/non-smoker	2/3	3/14
clinically normal/ abnormal	3/2	15/2

SonoVue® (an American contrast agent) was then utilized to visualize the blood vessels within these tendons. SonoVue® (Bracco, Milan, Italy) is a microbubble suspension of stabilized Sulphur hexafluoride in 0.9% saline. US contrast chemicals such as SonoVue® enable the detection of vessels as tiny as 40 microns in diameter utilizing sophisticated Doppler equipment.[68]

A bolus of 2.4 milliliters. SonoVue® was manually injected through a forearm vein, then a 20 ml saline bolus injection was administered. Immediately after seeing a significant rise in blooming artifact in the peritendinous tissue, measurements commenced. As intratendinous Doppler signals faded, the examination was concluded. Figure 11 illustrates an example of U.S. findings.

They found:

- Arteries could be seen in all (one hundred percent) of the "sonographically normal" tendons.
- 100 percent of these vessels were situated in the Achilles tendon's middle part.

- With a RI of 1.00, the flow profile of these arteries was normal.

They concluded that:

a. caution should be used when diagnosing Achilles tendinopathy with grayscale US. Even though all of the individuals were asymptomatic, the majority of tendons (17 out of 22) revealed some anomalies on US.[68]
b. Similar caution should be maintained while utilizing Doppler US for the diagnosis of Achilles tendinopathy, as administration of an ultrasound contrast agent reveals that all Achilles tendons have arteries in their middle thirds. Thus, the criteria for classifying tendons as normal cannot be based solely on the presence or lack of vascularity on Doppler US.[68]
c. Normal is intratendinous flow observed solely after injection of a contrast agent. This is due to the fact that all sonographically normal tendons that demonstrated blood flow after contrast medium administration were clearly 'normal' on clinical exam and non-contrast US exam - devoid of anatomical lesions or spontaneous Doppler activity.[68]
d. Only five of the twenty-two asymptomatic tendons were sonographically normal. Doppler examination revealed that the majority of tendons in the sample exhibited anomalies. They hypothesized that these aberrations might reflect age-related degenerative alterations, and age stratification had to be taken into account when defining normality.[68]
e. Lastly, there was a substantial disparity between 'sonographic normalcy' and clinical diagnosis.[68]

This study's findings are useful for the follow-up of patients with tendinopathy, because when the color Doppler activity within the tendon disappears during treatment, it is reasonable to assume that the tendon is returning to normal, and when such vessels are investigated with a contrast agent, we now know the normal patterns of vascularity.[68]

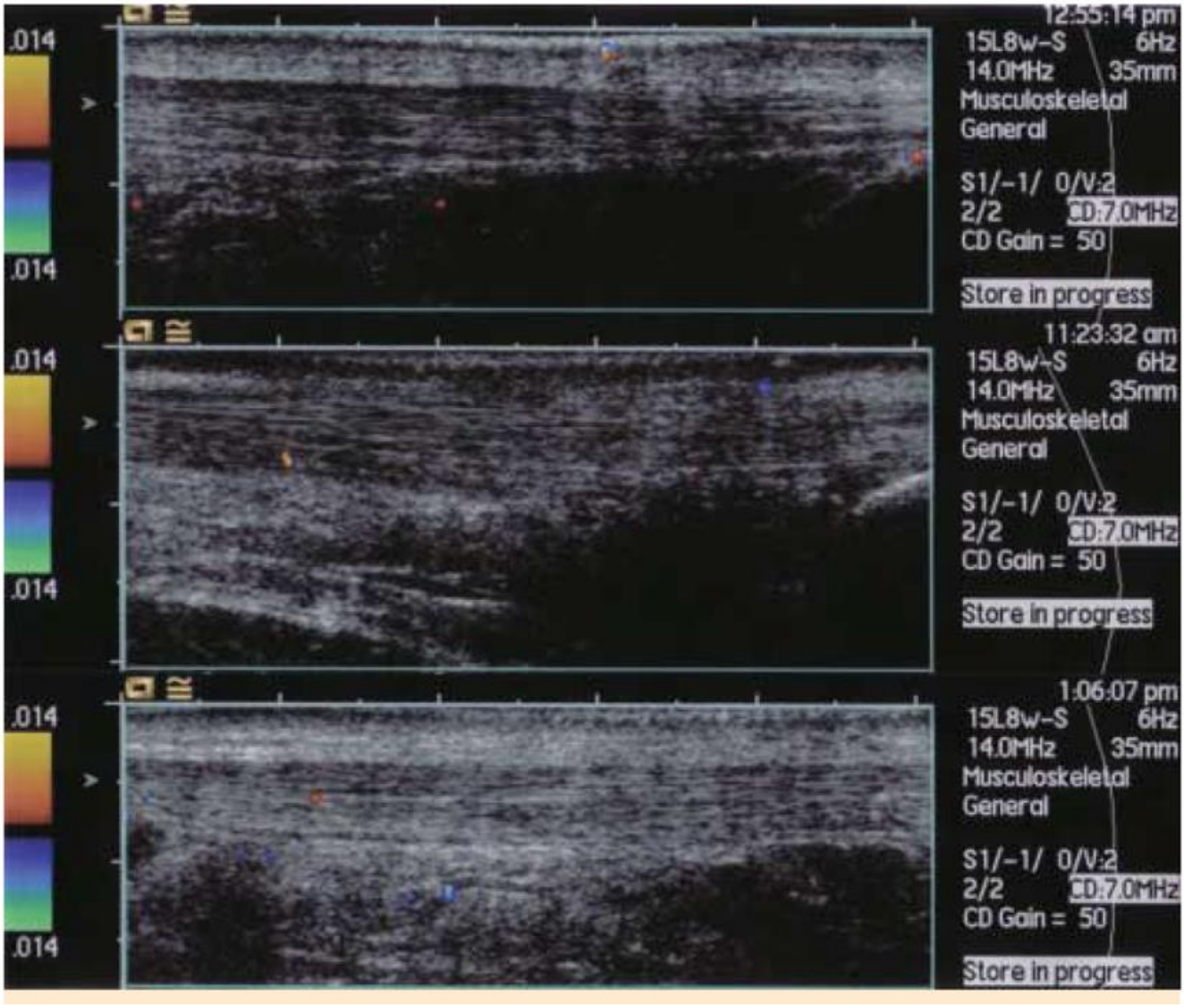


Figure 11. Longitudinal color Doppler images of normal and abnormal Achilles tendons. Cranial is oriented left and posterior is oriented above. In all images, the color Doppler box fills the image from side to side. Inside the box, the signals are analyzed for motion, which is equal to flow when the subject and examiner are immobile. Upward movement in the image is given red and orange hues – downward movement blue and green hues.

In the top image, a normal Achilles tendon is seen with a homogenous internal architecture, continuous fiber structure, sharp demarcation towards the surrounding tissues, and absence of intratendinous Doppler activity.

In the middle image, an Achilles tendon is seen with spindle-shape, heterogeneous architecture, discontinuity in fiber structure, indistinct anterior demarcation of the tendon just proximal to the calcaneus (on the far right of the image), and with presence of intratendinous Doppler activity (three spots).

In the bottom image, the same Achilles tendon as in the top image is seen after injection of contrast agent. A single Doppler focus is seen within the tendon.[68]

Nicol et al. [69] aimed to detect cases of degenerative alterations in the Achilles tendons of asymptomatic people and establish a connection between these cases and their activity levels.

In their study titled "Use of ultrasonography to diagnose chronic Achilles tendinosis in an active asymptomatic population,"[69] 146 healthy adults (mean age 33,1; range 20–50; 78 males and 48 females) were analyzed. Using a questionnaire and Allied Dunbar Fitness Survey criteria, activity levels were evaluated and rated.

All 252 Achilles tendons underwent US examinations by a single investigator, whose scanning approach was evaluated for reliability by comparison with an experienced musculoskeletal radiologist. This individual was blind to the subjects' activity levels. Each tendon was inspected for hypoechoic areas and localized fusiform thickening, and its cross-sectional diameter was assessed.

They found:

a. Overall, 59 percent (149) of tendons revealed ultrasonography evidence of hypoechoic areas, according to their findings.[69]
b. There was a history of Achilles pain in 50 tendons (in 31 patients), and 84% of these tendons had hypoechoic areas.[69]
c. 33% of patients in the least active quartile exhibited hypoechoic areas, compared to 72.6% of subjects in the most active quartile (p 0.01).[69]

d. Only 5.6% of Achilles tendons had ultrasound evidence of localized fusiform thickening, with none in the inactive group and 6.4% in the extremely active group (Pearson Chi2 p =0.03).[69]

These findings are detailed in Table 8A. and 8B below.

Table 8A. Descriptive statistics and prevalence of ultrasound findings consistent with chronic Achilles tendinosis in subjects with differing activity levels[69]

	Activity level (modified Allied Dunbar Units)				
	Low	Mild	Moderate	Very active	Total
n (tendons)	72	52	66	62	252
Mean age (range)	37.1 (28-49)	34.5 (20-50)	31.7 (21-46)	32.3 (21-50)	33.1 (20-50)
Mean BMI (range)	24.9 (19.1-37.8)	24.9 (21.1-29.7)	24.8 (19.0-33.4)	24.3 (18.0-30.9)	24.6 (18.0-37.8)
Total No. of tendons with hypoechoic region (% within that group)	24 (33.3%)	35 (67.3%)	44 (66.7%)	45 (72.6%)	148 (58.7%)
No. of tendons with thickened regions (% within that group)	0	3	(5.8%)	7	(10.6%)
Years in sport (mean)	3.8	14.7	17.8	17.8	14.2
No. with a previous Achilles injury	8	11	16	15	50

Table 8B. Achilles diameter in subjects of differing activity levels

Activity group	Tendons (n)	Mean (mm)	Range (mm)	SD
Low	72	4.6	3.6 – 5.9	0.63
Mild	52	4.9	3.1 – 6.0	0.63
Moderate	66	4.9	3.5 – 6.4	0.95
Very active	62	5.0	3.8 – 8.7	0.72
Total	252	4.8	3.1 – 8.7	0.76

They concluded that ultrasound frequently detects hypoechoic lesions and other degenerative alterations in asymptomatic Achilles tendons.[69] There is a direct correlation between these alterations with current and lifetime activity levels.[69] It is uncertain how asymptomatic chronic Achilles tendinosis develops and how it relates to future pain or tendon damage.[69]

In their study titled "Symptomatic Achilles Tendons are Thicker than Asymptomatic Tendons on Ultrasound Examination in Middle-Aged Recreational Long-Distance Runners," Tillander et al. [109] aimed to determine whether tendon thickness and morphological changes in the Achilles tendon detected in ultrasound examinations are associated with local symptoms in middle-aged recreational long-distance runners.

Bearing mind that a systematic evaluation conducted by Lopes et al. [110] revealed a significant incidence (9–11%) and prevalence (6–10%) of Achilles tendinopathy (pain and dysfunction) in runners. In September 2017, 21 middle-aged (35–60 years) recreational runners from the *Lidingoloppet 30k cross-country race (Stockholm, Sweden)* were recruited for the study.

Before the ultrasound examination, the participants completed a written consent form and answered the eight validated questions for Achilles tendon problems, using the VISA-A-S[104].

All surveys were completed just before to the ultrasound examination. The respondent indicated whether he or she was experiencing symptoms and which side(s) were impacted. A VISA score of less than 90 was considered symptomatic. According to earlier reports, a score of 90 indicates complete recovery from Achilles tendinopathy. [99]

The individuals next underwent bilateral US examinations of their AT, during which their AT morphology was statistically and qualitatively assessed. In several models of factors related with reporting a symptomatic tendon, the Generalized Estimating Equations approach was utilized.

They discovered 11 symptomatic Achilles tendons and 31 asymptomatic Achilles tendons.[109]
Using several models that utilized tendon thickness assessed 30 mm proximal to the distal insertion, there was a connection between AT thickness and reporting a symptomatic tendon ($p<0.001$; OR 12.9; 95% CI 3.1 to 53.2). A qualitative morphological score was not significantly linked with symptomatic tendon reporting ($p = 0.10$).[109]

They concluded that symptomatic Achilles tendons were thicker than asymptomatic tendons in recreational long-distance runners who underwent ultrasound evaluation, and that the significance of similar morphological findings should be examined further in prospective investigations.[109]

In their study titled 'Thicker Achilles tendons are a risk factor for developing Achilles tendinopathy in elite professional soccer players,'[111] Jhingan et al. sought to determine if the prevalence of Achilles

tendinopathy symptoms was related to the presence of baseline abnormalities in Achilles tendon structure as measured by ultrasound.

This prospective cohort study examined the prevalence of Achilles tendinopathy symptoms among professional soccer players with and without ultrasonography abnormalities at baseline.[111] They also evaluated the connection between tendon thickness at baseline and symptom development.[111]

In 2009, 18 athletes were assessed with ultrasonography for hypoechoicity, paratenon blurring, localized thickening, and/or neovascularization, and anteroposterior tendon thickness was determined.
One year later, symptom development throughout the follow-up period was evaluated through an interview.

They discovered that baseline mid-tendon thickness was larger (p=0.041) in tendons that developed symptoms the following year [median (IQR): 0.53 (0.51–0.55) cm] than in tendons that remained asymptomatic [0.48 (0.45–0.55) cm].[111]

There was no correlation between the presence of ultrasonography abnormalities at baseline and the development of symptoms in the subsequent year (Chi-Square: 1.180, p=0.277).[111]
A thicker baseline mid-tendon thickness was discovered as a risk predictor for the development of Achilles tendinopathy in professional soccer players.

Koivunen-Niemela and Parkkola in their work ‘Anatomy of the Achilles tendon with respect to tendon thickness measurements’[89] made AT thickness measurements of 267 normal controls of different ages by USG for reference. They found that mean AT thickness increases with age and that women had

slightly thinner tendons than men, but that this difference was statistically significant only in the oldest age group. A significant correlation was found between the AT thickness and body height. [89]

In their study titled "Sonographic evaluation of the size of Achilles tendon: the effect of exercise and ankle dominance," [74]Ying et al. compared the thickness and cross-sectional area of the Achilles tendon in an asymptomatic Chinese population with frequent- and infrequent-exercise subjects, and in dominant versus non-dominant ankles. Additionally, they tried to evaluate interobserver variability in the ultrasound measurements of the size of the Achilles tendon.[74]

Achilles tendon ultrasounds were performed bilaterally on 40 volunteers (20 who exercised regularly (at least 3 days per week and at least 2 hours per session) and another 20 who exercised infrequently (at least 1 day per week and less than 2 hours per session).

Using a transverse scan at the level of the medial malleolus, the Achilles thickness and cross-sectional area were acquired. Five operators measured the Achilles tendons of each individual to determine the interobserver variation in measurements.

In a healthy Chinese population, the mean thickness and cross-sectional area of the Achilles tendon are 5.23 mm and 56.91 mm2 respectively.[74] The mean thickness of the Achilles tendon was considerably larger in frequent exercisers (dominant ankle 5.43 mm, nondominant ankle 5.38 mm) than in infrequent exercisers (dominant ankle 5.08 mm, nondominant ankle 5.04 mm) (p 0.05).[74]

The cross-sectional area of the tendons was likewise greater in frequent-exercise individuals, but only in dominant ankles (frequent-exercise subjects 60.46 mm2, infrequent-exercise subjects 54.71 mm2; p 0.05).[74] This was not the case for the nondominant ankles (regular exercisers had 57.09 mm2 against 55.4 mm2 for infrequent exercisers; $p > 0.05$).[74]

There was no statistically significant difference in the mean thickness and cross-sectional area of the Achilles tendon between dominant and nondominant ankles in persons who exercised frequently or infrequently ($p > 0.05$).[74] Sonographic measurements of the thickness (68%) and cross-sectional area (81%) of Achilles tendons showed remarkable repeatability.[74]

They concluded that:

- frequent exercise would increase the Achilles tendon's thickness and cross-sectional area.[74]
- Sonographic measurements of Achilles tendons demonstrate no substantial interobserver variability.[74]

In their paper titled "The Achilles Tendon in Healthy Subjects: Anthropometric and Ultrasound Mapping Study,"[91] Patel et al. highlighted the advantages of ultrasonography as a cheap, rapid, and reliable imaging technology for evaluating the Achilles tendon. They also noted the lack of ultrasound data from healthy persons and attempted to further characterize the Achilles tendon measurements (including tendon width, thickness, cross-sectional area, and length) and identify significant associated factors in healthy individuals.[91]

They gathered information regarding patient demographics, body type, activity level, foot dominance, and ankle angle at rest. Males showed considerably greater tendon length, width, thickness, and cross-sectional area than females.[91] When comparing right versus left leg dominance, no statistically significant differences in tendon parameters were found.[91]

Each tendon parameter (length, width, thickness, and cross-sectional area) correlated positively with subject height, weight, tibial length, and foot size when all participants were considered.[91]

Only the cross-sectional area of the Achilles linked substantially with exercise level.[91]

In conclusion, they discovered significant variations in the anatomy of the Achilles tendon in the healthy adult population and concluded that a greater understanding of the normal anatomy of the Achilles tendon and the characterization of its variations in the healthy population may permit improved pathologic diagnosis and surgical repair.[91]

In their paper titled "Sonographic measurement of Achilles tendons in asymptomatic subjects: variation with age, body height, and ankle dominance," [90]Pang et al. described the USG features of the AT in asymptomatic individuals.

In healthy individuals, they characterized ultrasonography Achilles tendon measurements (including thickness, width, cross-sectional area, and length) and identified significant correlating factors. The obtained data comprised patient demographics, body type, and foot dominance information.

Sonography is an effective imaging method for evaluating Achilles tendons, and there is no significant difference between participants of different ages or dominant and nondominant ankles.[90] However, older individuals and those with dominant ankles have tendons with a higher cross-sectional area.[90]
The correlational strength between AT measures and body height, weight, and BMI varied between investigations.[90] This study demonstrated that the typical variation of tendon morphologic properties should be taken into account during clinical diagnosis.[90]

Thus, most of the existing literature describes the AT in terms of its gross anatomy and/or its MRI features and/or alterations in same following disease. Those studies that examine the ultrasound characteristics of the normal asymptomatic AT are limited by small sample size (N=40 for Pang et al and N=50 for Patel et al respectively) and were conducted South east Asia and North America respectively.

Significant genetic and phenotypic differences exist between South East Asians, North Americans and West Africans [112–115] - with mean North American population height and weight being higher than that for South East Asians and West Africans. These phenotypic differences between the races produce observable differences in the sonographic characteristics of the Achilles Tendon as shown in Table 3.

Table 3. Reported values of mean Achilles tendon thickness measured with US[89]

	AT thickness Mean ± SD (range) mm	**Population**	**US frequency**
Steinmetz et al	5.7 ± 0.7 (5-8)	German	5-7.5 MHz
Ebeling et al	4.9 ± 0.9 (4-7)	Finnish	7.5 MHz
Mathieson et al	6.2 (4-9)	North American	5 MHz
Holsbeeck et Introcaso	6.2 ±0.8 (sedentary)	Not Indicated	Not Indicated
	5.7±0.8 (athletes)		
Fornage	5.3 (4-6)	North American	5 MHz
Kallinen et Suominen	6.1 ± 0.9 (sedentary)	Finnish	7.5 MHz
	6.2 ± 0.9 (athletes)		
Yuzava et al	4.2 ± 0.5 (women)	Japanese	7.5 MHz
	4.7 ± 0.4 (men)		
Liem et al	6.2 ± 1.2	Dutch	Not Indicated

CHAPTER 3

3.1 MATERIALS AND METHODS

Study design

This was a hospital-based, cross-sectional study at the Radiology department of the Korle Bu Teaching Hospital. This study was carried out over a 3-month period; spanning October – December, 2022. The individuals to be included in this study were interviewed with use of a standardized questionnaire before inclusion into the study.

Study site

The study was undertaken at the radiology department of the Korle Bu Teaching Hospital (KBTH). KBTH is the premier teaching hospital in Ghana and the third biggest referral center in Africa; with 2,000 beds, 21 clinical and diagnostic departments and three Centers of Excellence.[116] It also has an average outpatient attendance of 1,500 with about 250 inpatient admissions. It is a major referral center for the whole of Ghana and the West African sub-region. [116]

The Radiology department is one of the flagship units of the hospital with the capacity for radiodiagnosis and interventions in a wide range of pathologies. The ultrasound unit (of the radiology department) performed more than 11,000 ultrasound scans in 2020 – these including abdominal, pelvic, obstetric, vascular and musculoskeletal scans (2020 Annual performance Review Report). The department is manned by prominent Fellows of the Faculties of radiology of the West African College of Surgeons and the Ghana College of Physicians.

Subjects

A. Inclusion Criteria

1. Individuals aged 10 years or older.
2. Subject must be ‘asymptomatic’.

An ‘asymptomatic’ individual is defined for the purposes of this study; as one who has not reported heel or foot pain during walking, standing, or any activity over the past 2 years. This is because most AT pathology presents with pain and/or swelling in the region of the ankle, heel or foot. [6,10,45,84] This provision therefore sought to ensure that patients with occult AT pathology were not inadvertently included in the study.

Asymptomatic individuals above the age of 10 years who satisfied the inclusion criteria were selected for this study. This is because; most AT pathology (including tendinopathy and tears/ruptures) is uncommon below the age of 10 years. This assertion supported by Hattrup et al. in their work ‘A review of rupture of the Achilles tendon’[24]; who found that AT rupture almost never occurs in patients before the onset of adolescence. In addition; AT tendinopathy is a chronic process and is uncommon in prepubescent individuals. [34,94]

B. Exclusion Criteria

1. Individuals who had previously undergone foot surgery
2. Those who had previously gone to a doctor because of foot complaints.
3. Individuals with a history of ankle/heel/foot trauma in the past 2 years
4. Individuals with systemic metabolic and/or inflammatory disease (e.g., ankylosing spondylitis, rheumatoid arthritis, psoriasis, gout) which may affect the size of the AT. [2,75]
5. Individuals who had engaged in strenuous physical activity within the past 72 hours.

Sampling Technique

Convenience sampling was employed – with participants being selected based on availability and willingness to participate in the study. Specifically; all patients who reported to the ultrasound unit (of the Radiology Department) were approached by the researcher and/or research assistant and those who were willing to participate in this study and satisfied the inclusion criteria were recruited.

Study Instruments

1. Study questionnaires (i.e., Appendices 1,3 and 4) – which were structured questionnaires that determined subject suitability for enrolment into this study.
2. The consent form (Appendix 2) was then completed; after explaining the study to the subject.
3. The ultrasound examination was then performed; and the data obtained captured on the Data Capture sheet (Appendix 5)

List of Equipment

1. Toshiba Aplio 300 ultrasound machine (Toshiba medical systems corporation, Japan); equipped with a Linear Array 4.8-11 MHz transducer.
2. Transducer gel
3. Examination couch
4. Disposable gloves, disposable wipes and face masks (for the patient and researcher – in keeping with COVID-19 protocols)
5. Weighing scale and a stadiometer for weight and height measurements respectively.
6. Soft ball – to aid in determination of the dominant ankle.

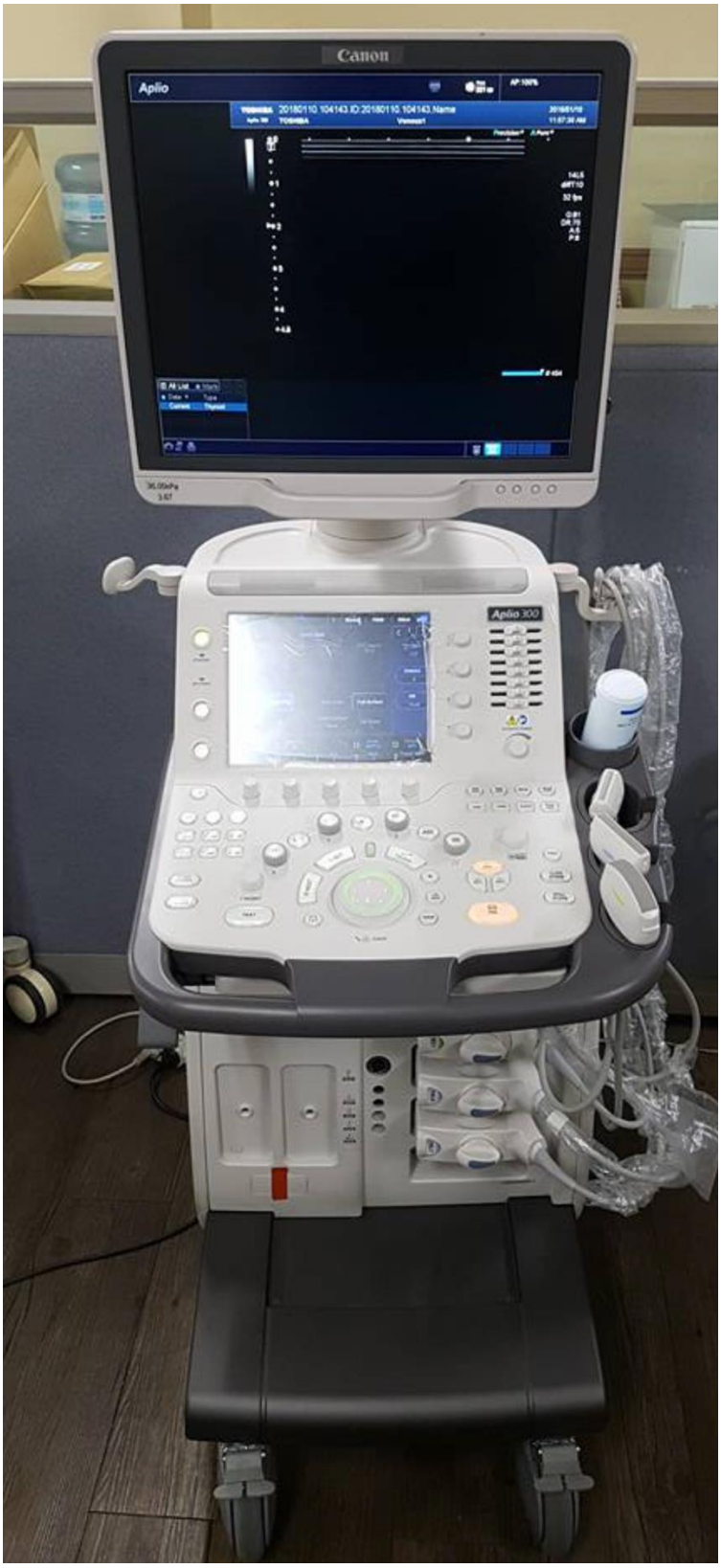


Figure 12: Photographs of the Toshiba Aplio 300 ultrasound machine used for the study

Figure 13: A close up photograph of a linear array probe.

Figure 14. Photograph showing the technique of transverse ultrasonography of the left AT of an asymptomatic volunteer

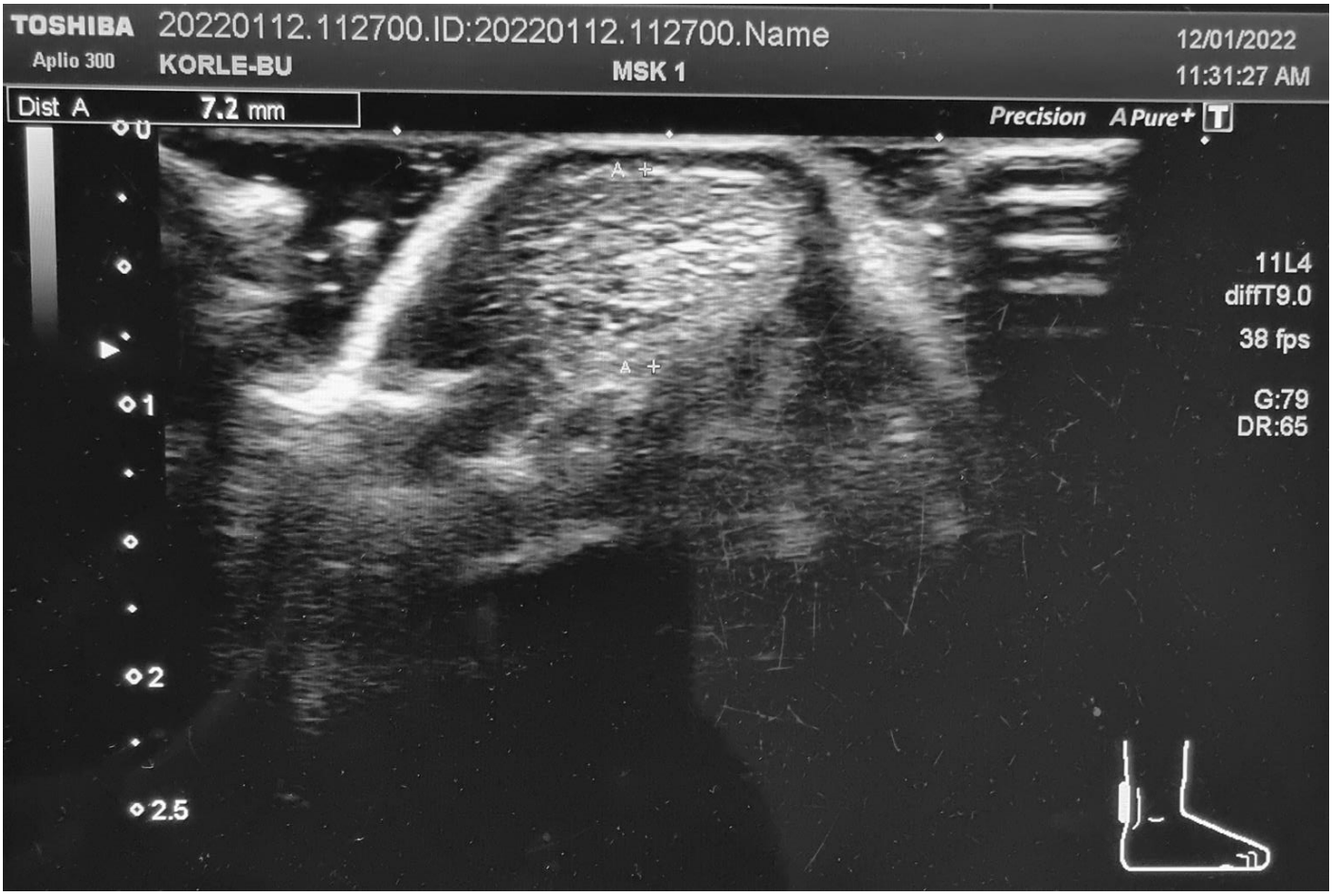


Figure 15.Transverse sonogram of an Achilles tendon. Calipers (A-A) indicate measurement of tendon thickness

Sample size determination

The sample size for this study was calculated using the formula from Charan and Biswas[117] below:

$$\text{Sample size} = \frac{Z_{1-\alpha/2}{}^2 SD^2}{d^2}$$

Where $Z_{1-\alpha/2}$ = the standard normal variate [at 5% type 1 error ($P < 0.05$)] and is 1.96

SD = the standard deviation of the variable. In this case, AT thickness taken from a previous study by Pang et al.[90] which was 0.63mm.

d = absolute error or precision. Set at 0.07mm for this study.

Thus:

$$\text{Sample size} = \frac{1.96^2 \times (0.63\text{mm})^2}{(0.07\text{mm})^2} = 311.17.$$

Adding a 10% buffer of 31; gives at total of 342.

Thus, 342 volunteers were recruited for this study. These volunteers were stratified into 6 age-defined groupings as follows:

(1) 10 to 19 years

(2) 20 to 29 years,

(3) 30 to 39 years,

(4) 40 to 49 years

(5) 50 to 59 years

and (6) 60 years and over.

Ultrasound Technique & data collection procedure

USG examinations were carried out with subjects in the prone position with their feet hanging off the examination table in a neutral position (90 degrees of flexion) using a Toshiba Aplio 300 ultrasound machine (Toshiba medical systems corporation, Japan); equipped with a Linear Array 4.8-11 MHz transducer. In all patients, both Achilles tendons were scanned.

In recognition of the fact that tendon echogenicity decreases artificially if the angle between tendon and ultrasound beam is higher or lower than 90°, both on longitudinal and on transverse scans. [26,84,118] The AT was initially scanned transversely with the transducer perpendicular to the AT long axis. The transducer was then angled cranially and caudally until the scan plane showed the AT with maximum echogenicity; which was then noted. Thus; assessment of AT echogenicity was carried out over its entire length.

The thickness of the AT was measured at the level of the medial malleolus as shown in figure 15. The medial malleolus being an obvious external landmark; and chosen as the level of measurement in this study to allow for standardization of the scanning method.

Other findings pertaining to the AT, including

- tears,
- degeneration,
- ossification,
- enthesopathy,
- peritendinitis,
- soft tissue edema were documented; if present.

Anthropometric Measurements

The body heights and weights of volunteers were measured and thence the BMI obtained.

BMI being the weight in kilograms divided by the square of the height in meters.

Dominance of ankles was assessed by a direct question in the questionnaire (Appendix 5).

The answer is confirmed by asking the subject to electively kick a soft ball using either the right or left foot. The elected foot used for ball kicking was deemed the 'non-dominant' side; and the contralateral AT 'dominant'. On account of usage of the contralateral limb to 'push off' [74].

3.2 DATA MANAGEMENT AND ANALYSIS

Data validity & reliability

To ensure that the accuracy, validity and reliability of the data obtained; the results of the first 20 scans were verified by a Consultant Radiologist with more than 15 years' experience in medical ultrasound imaging. In addition; to minimize intraobserver error during assessment of AT thickness, 3 separate measurements were taken at the same point and then averaged.

A pilot study of 20 subjects was undertaken (under the guidance of the Consultant radiologist) to ensure that accurate measurements were taken.

Data handling

All patients recruited in this study were identified by their hospital identification number. Their demographic and clinical data as well as the results of their USG scans were coded using Microsoft Excel for Mac 2018.

All data obtained for the purpose of this study was stored in a protected file and locked in a cabinet. Only the investigator and the supervisor had access to this data. Data cleaning was done to ensure accuracy and the data was then exported to IBM® Statistical Package for Social Sciences, version 25 (SPSS) for analysis.

Statistical analysis

Data collected was first entered in Microsoft excel and exported to Statistical Package for Social Science (SPSS Inc., Chicago, IL, USA) version 25.0 for the analyses. For all statistical analyses done to explore

differences, preliminary analysis was done to check for possible violations of any of the assumptions of the test statistic, particularly for normality and homogeneity of variance.

A test for normality on the thickness of the Achilles Tendon was done using the Kolmogorov-Smirnov test whereas Levene's test for equality of variance was used to check for homoscedasticity.

Categorical variables were expressed as counts and percentages whilst continuous variables were expressed as mean ± standard deviation.

An independent sample t-test was used to compare the statistical differences in the thickness of the Achilles Tendon in the dominant and non-dominant ankle between males and females and a Mann-Whitney U test was used where appropriate, depending on the pattern of distribution.
The differences in the thickness among the age groups was done using one-way Analysis of Variance (ANOVA).

A Pearson correlation analysis was performed to examine the relationship between the tendon thickness and subject-specific parameters (i.e., age, body height, weight, BMI and ankle dominance). Interpretation of the correlation coefficients followed those by Mukaka[119].

Multiple regression analysis was done to explore the contribution of each independent variable to AT thickness. Prior to that; we checked for any violation of assumptions including: multicollinearity, normality, nature of dependent variable (must be continuous) and ordered pairs within the data set. The variance inflation factor (VIF) and the tolerance level (TL) were used to check for multicollinearity – the rule of thumb being that a VIF <10 and a minimum TL of 10; indicate no multicollinearity.

Statistical significance was defined at the 5% ($p \leq .05$) level, except for Pearson correlation analysis where P-values <0.01 were considered statistically significant.

Dissemination of results

The results of this study will be disseminated to the following:

1. The Faculty of Radiology, Ghana College of Physicians.
2. The Department of Radiology, Korle Bu Teaching Hospital
3. A relevant scientific journal for publishing.

3.3 ETHICAL CONSIDERATIONS

Ethical approval was sought from the Korle Bu Teaching Hospital Ethical Review Committee.

Written consent was obtained from all volunteers recruited for this study.

The volunteers had a right to refuse participation in this study. Refusal to participate in this study did not affect how the individual was treated.

All data collected in the course of this study was kept confidential. Participants were anonymized and were only identified via participant and hospital identification numbers.

No third parties had access to the raw data obtained from this study.

There are no conflicts of interest to declare.

CHAPTER 4

RESULTS

A total of 342 asymptomatic subjects, including 162 males (47.4%) and 180 females (52.6%) were recruited into the study and underwent bilateral ultrasound examination of their AT.

All the subjects (N=342) were black people.

The mean age of the subjects was 42.11 ± 18.51 years – the youngest subject being 12 years old; whilst the oldest was 91 years old. The study population had mean height of 166.39 ± 9.222 cm, mean weight of 71.30 ± 10.361 kg and mean BMI of 25.91 ± 4.395 kg/m^2.

314 (91.8%) of the subjects were right-footed and 28 (8.2%) were left-footed. However, 320 (93.6%) were right-handed and 22 (6.4%) were left-handed. This data is presented in further detail in Tables 9 and 10 below.

Table 9. Age distribution, hand & foot dominance of sample population (N = 342 participants [47.4% male, 52.6% female])

Characteristic	Count	Percentage
Age Group (years)		
10 – 19	35	10.2
20 – 29	70	20.5
30 – 39	70	20.5
40 – 49	57	16.7
50 – 59	41	12.0
60 and above	69	20.2
Dominant hand		
Left	22	6.4
Right	320	93.6
Dominant foot		
Left	28	8.2
Right	314	91.8

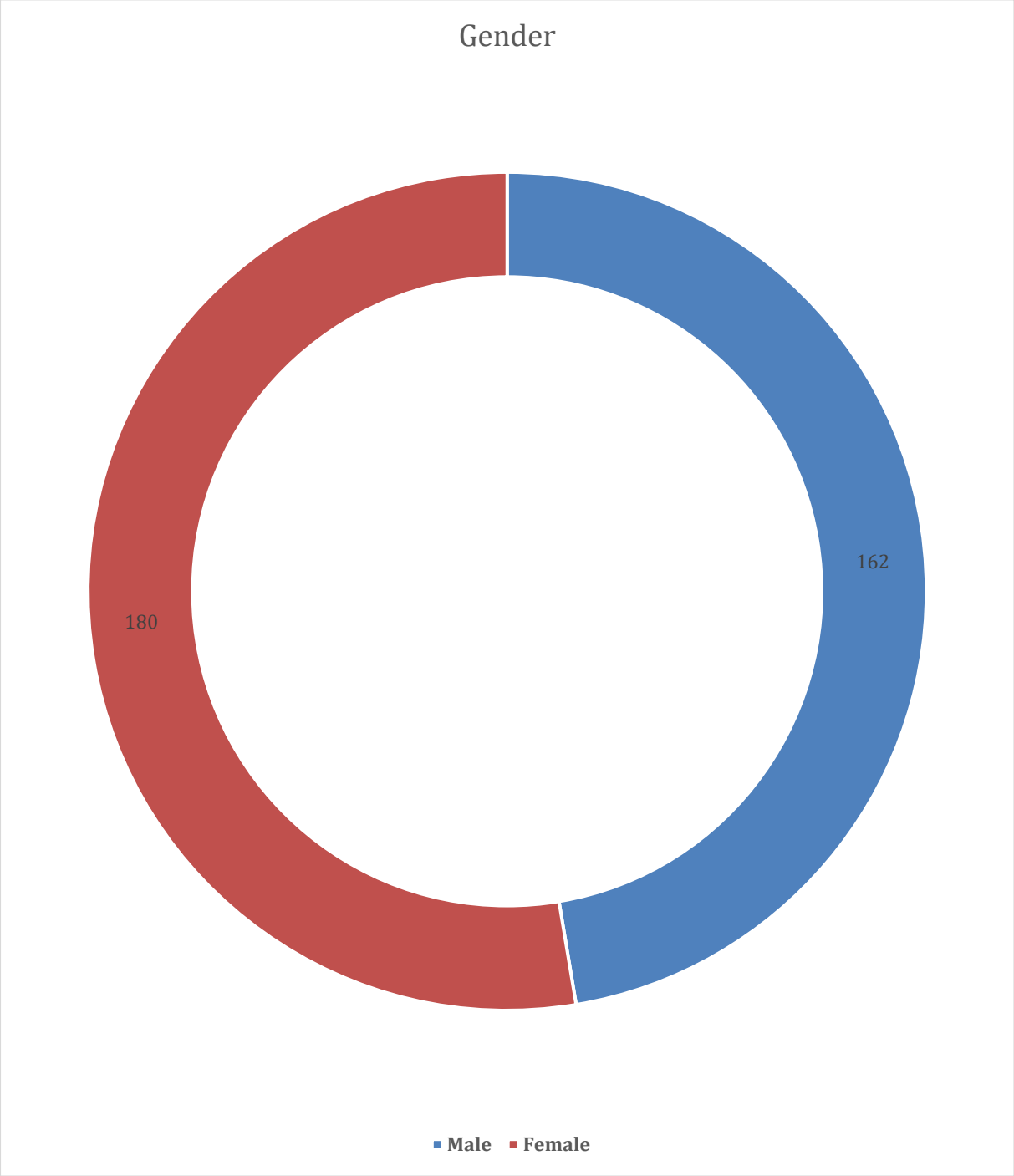


Figure 16. Pie chart showing distribution of subjects by sex

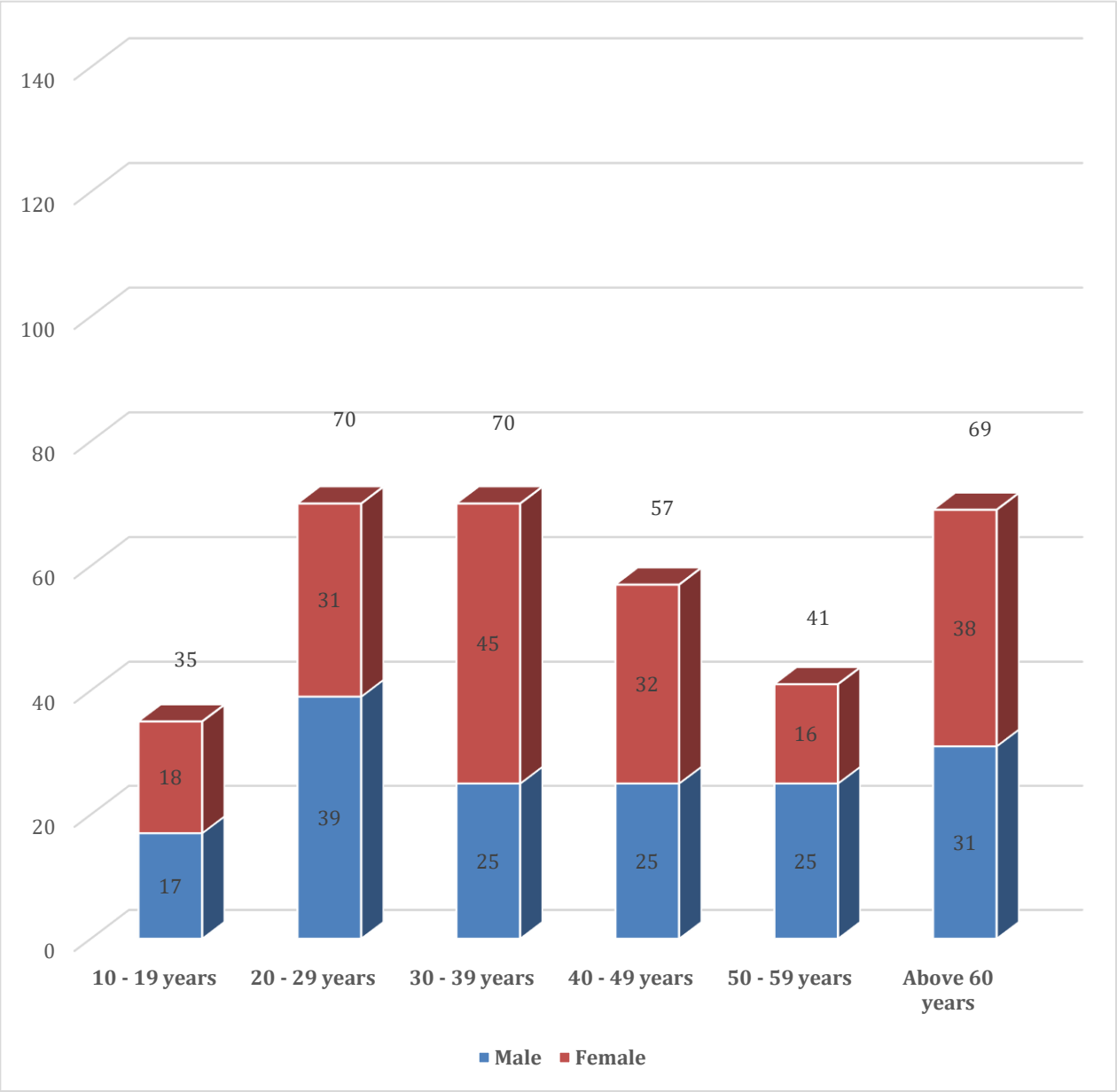


Figure 17. Stacked bar chart showing the proportion of males and females in each age grouping.

The mean height of the study population was 166.39 ± 9.222 cm; the shortest subject being 118 cm tall whilst the tallest subject was 190 cm tall.

The mean weight of the study population was 71.30 ± 10.361 kg ; the lightest subject weighing 45 kg whilst the heaviest subject weighed 110 kg.

The BMI ranged between a high of 54.6 kg/m^2 to a low of 15.8 kg/m^2; the mean BMI being 25.91 ± 4.40 kg/m^2. This information is detailed in Table 10 below.

Table 10. Sample population characteristics (N = 342 participants [47.4% male, 52.6% female])

Characteristic	**Min**	**Max**	**Mean ± Standard Deviation**
Age (years)	12	91	42.11 ± 18.509
Height (cm)	118	190	166.39 ± 9.222
Weight (kg)	45	110	71.30 ± 10.361
Body Mass Index (kg/m^2)	15.8	54.6	25.91 ± 4.40

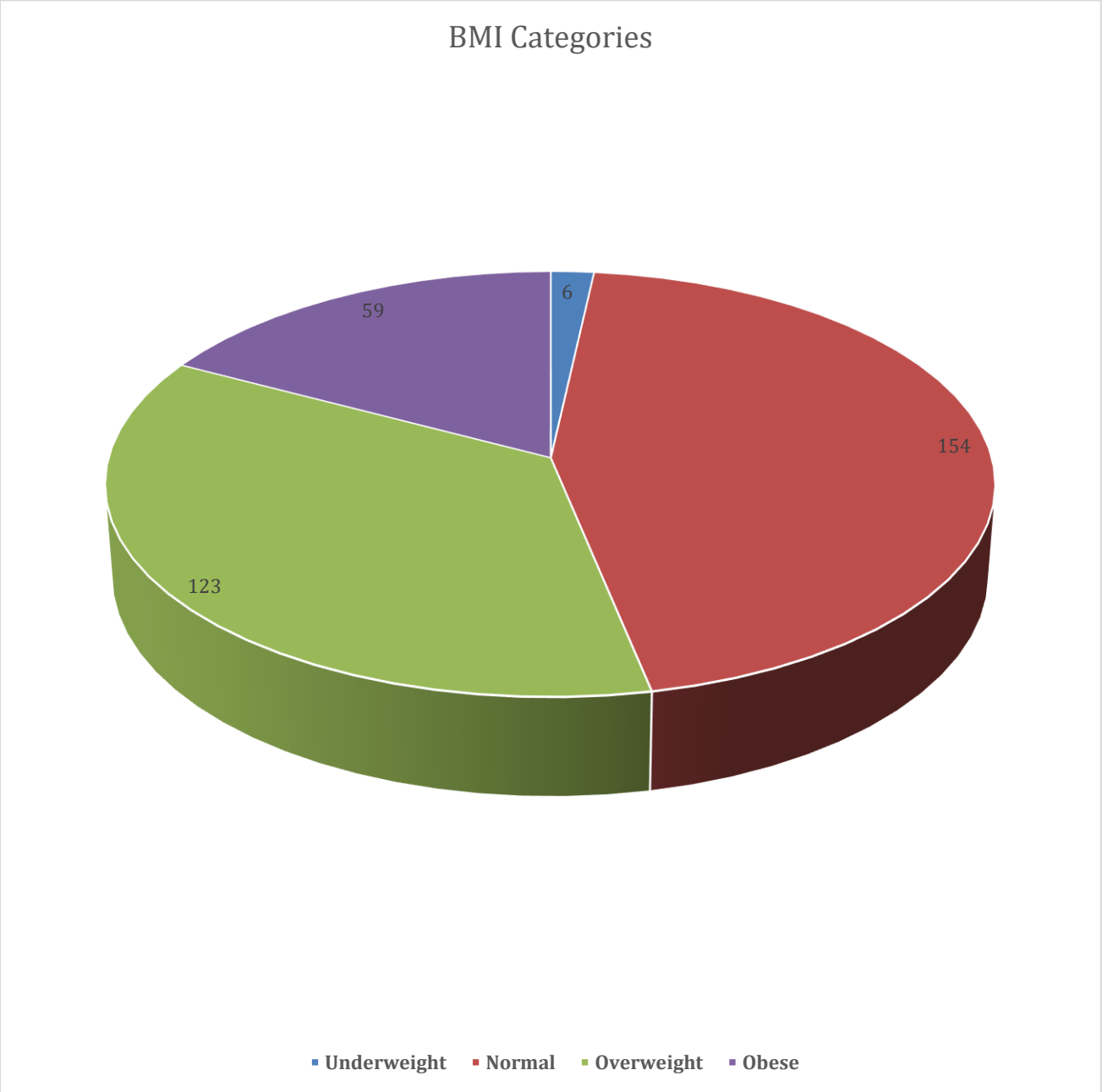


Figure 18: Pie Chart showing distribution of BMI among the study population

Ultrasound examination revealed all the subjects to have normal echogenicity (i.e., homogeneously hyperechoic) of the AT in both ankles. An example of these findings (observed in participant number 113, a 27-year-old male) is shown in Figures 19a and 19b below.

However, 1 patient (a 57-year-old female) was found to have a distended retrocalcaneal bursa; even so both her right and left AT showed normal echogenicity. There were no suggestions of inflammation of the paratenon or other related hindfoot structures.

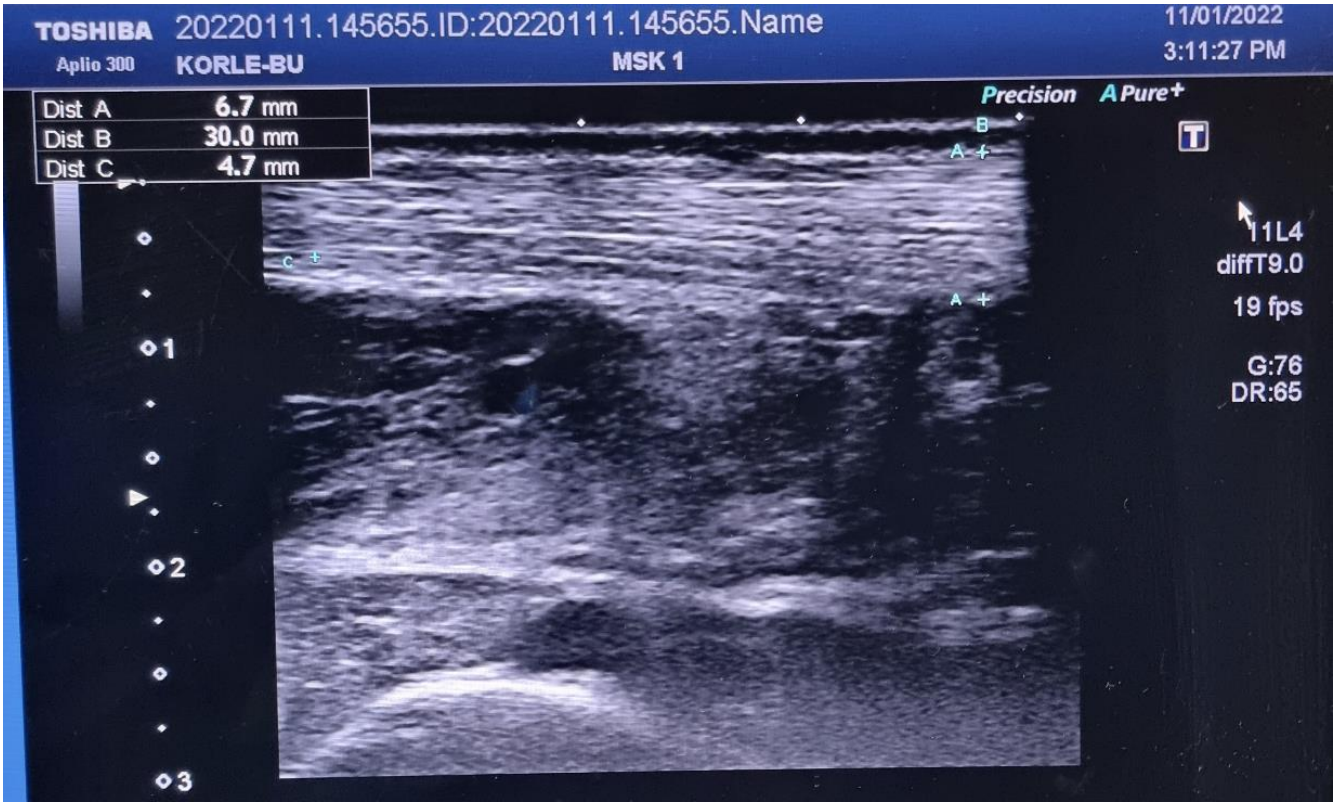


Figure 19a: grey scale longitudinal ultrasound image of the right AT of participant number 113. The AT shows a normal uniformly hyperechoic, fine fibrillar pattern.

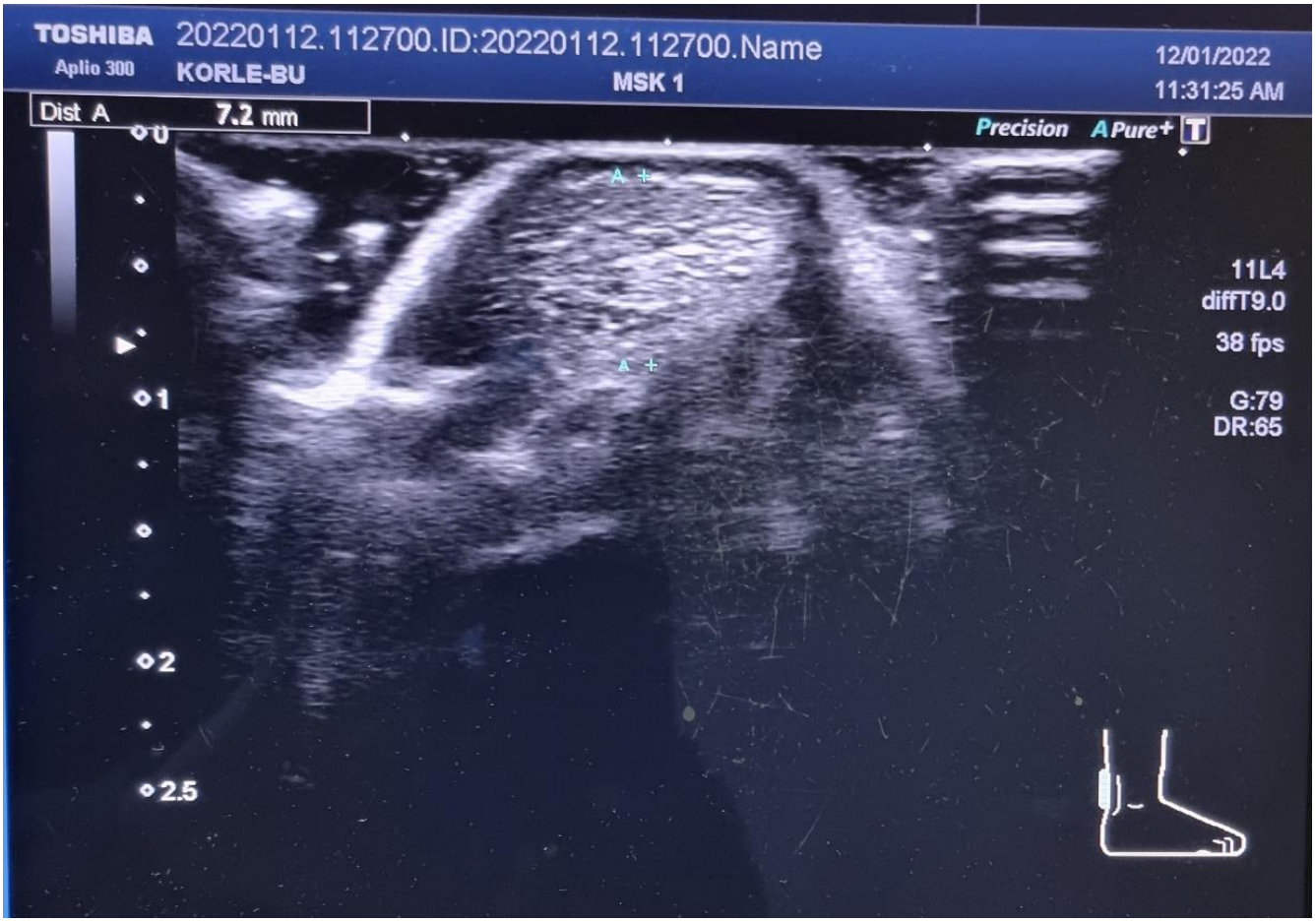


Figure 19b: grey scale transverse ultrasound image of the right AT of participant number 113. The AT appears as an ovoid aggregate of tightly packed echoic dots with a homogeneous distribution.

The overall mean AT thickness was 4.84 ± 0.917 mm. Males had significantly thicker Achilles tendons (mean AT thickness of 5.29 ± 0.919 mm) compared to females (mean thickness of 4.573 ± 0.868 mm) – with a P-value of < 0.001.

For both right-footed males and females, the thickness recorded for the dominant Achilles (i.e., the left AT) was significantly thicker than what was found in the non-dominant Achilles (P < 0.001). The mean thickness for the dominant Achilles tendon in right-footed males being 5.409 ± 0.917 mm and that in right-footed females being 4.623 ± 0.910 mm.

Similarly, in left-footed individuals; the dominant AT (i.e., the right) was thicker than the non-dominant AT; and this difference was statistically significant ($P < 0.001$). This information is described in greater detail in Table 11 below.

Table 11. AT thickness stratified by gender and foot dominance

	Dominant right foot				
	Male	**Female**	**P-value$^{\mu}$**	**Totals for both sexes**	**P-value$^{\beta}$**
Left(Dominant) Achilles					< 0.001
Min	3.15	2.84	< 0.001	2.96	
Max	7.28	6.88		7.17	
Mean ± SD	5.409 ± 0.917	4.623 ± 0.910		4.915 ± 0.978	
Right(Non-dominant) Achilles					
Min	3.11	2.94	< 0.001	2.94	
Max	7.07	7.12		7.12	
Mean ± SD	5.240 ± 0.931	4.467 ± 0.885		4.834 ± 0.985	
	Dominant left foot				
Right(Dominant) Achilles					< 0.001
Min	3.78	3.99	0.708	3.78	
Max	6.27	6.31		6.31	
Mean ± SD	4.900 ± 0.941	5.017 ± 0.696		4.962 ± 0.805	
Left(Non-dominant) Achilles					
Min	3.65	4.01	0.864	3.65	
Max	6.17	5.60		6.17	
Mean ± SD	4.783 ± 0.852	4.738 ± 0.541		4.759 ± 0.689	

μ - Compare difference between male and female
β – Compare difference between dominant and non-dominant Achilles
SD – Standard Deviation
All thicknesses measured in mm.

Males in the 50 – 59-year-old group (representing 12.0% of sample population) had the highest mean Achilles tendon thickness of 5.669 ± 0.705 mm, whilst females in the 40 – 49-year-old group had the lowest mean AT thickness of 4.520 ± 0.879 mm.

In all age groups, males had a thicker Achilles tendon compared to females; and these differences were statistically significant. However, taking overall means (i.e., disregarding gender) there was no significant difference in the thickness of Achilles tendon between the different age groupings (P = 0.103). Table 12 has a more detailed description of these findings.

Table 12: Comparison of AT thickness stratified by age groupings

	Thickness of Achilles Tendon (mm)				
Age group	**Male**	**Female**	**P-value$^{\mu}$**	**Total**	**P-value$^{\beta}$**
10 – 19	5.517 ± 1.141	4.621 ± 0.930	0.015	5.0561 ± 1.119	
20 – 29	5.201 ± 1.059	4.626 ± 0.825	0.013	4.948 ± 0.999	
30 – 39	5.214 ± 0.701	4.549 ± 0.879	0.001	4.786 ± 0.827	0.103
40 – 49	5.140 ± 0.789	4.520 ± 0.879	0.008	4.791 ± 0.889	
50 – 59	5.669 ± 0.705	4.623 ± 0.626	< 0.001	5.261 ± 0.844	
Above 60	5.128 ± 0.955	4.559 ± 1.058	0.023	4.815 ± 1.045	

μ - Compare mean thickness between males and females within the age groups

β – Compare mean thickness among the age groups

88.5% of the right-footed study subjects had their dominant (i.e., left AT) being thicker than the non-dominant AT – this difference ranging from 0.1mm to 1.75mm. Similar findings were noted in left-footed subjects; where the dominant AT (i.e., the right AT) was thicker than the non-dominant AT in 78.6% - the difference ranging from 0.01 mm to 0.99 mm.

Overall, mean thickness of the dominant AT was 4.992 ± 0.978 mm, whilst that for non-dominant AT Achilles was 4.828 ± 0.963 mm. Thus; dominant AT were 0.164 mm thicker than non-dominant AT; and this difference was statistically significant (P <0.001). This information is shown in Figures 20a and 20b below.

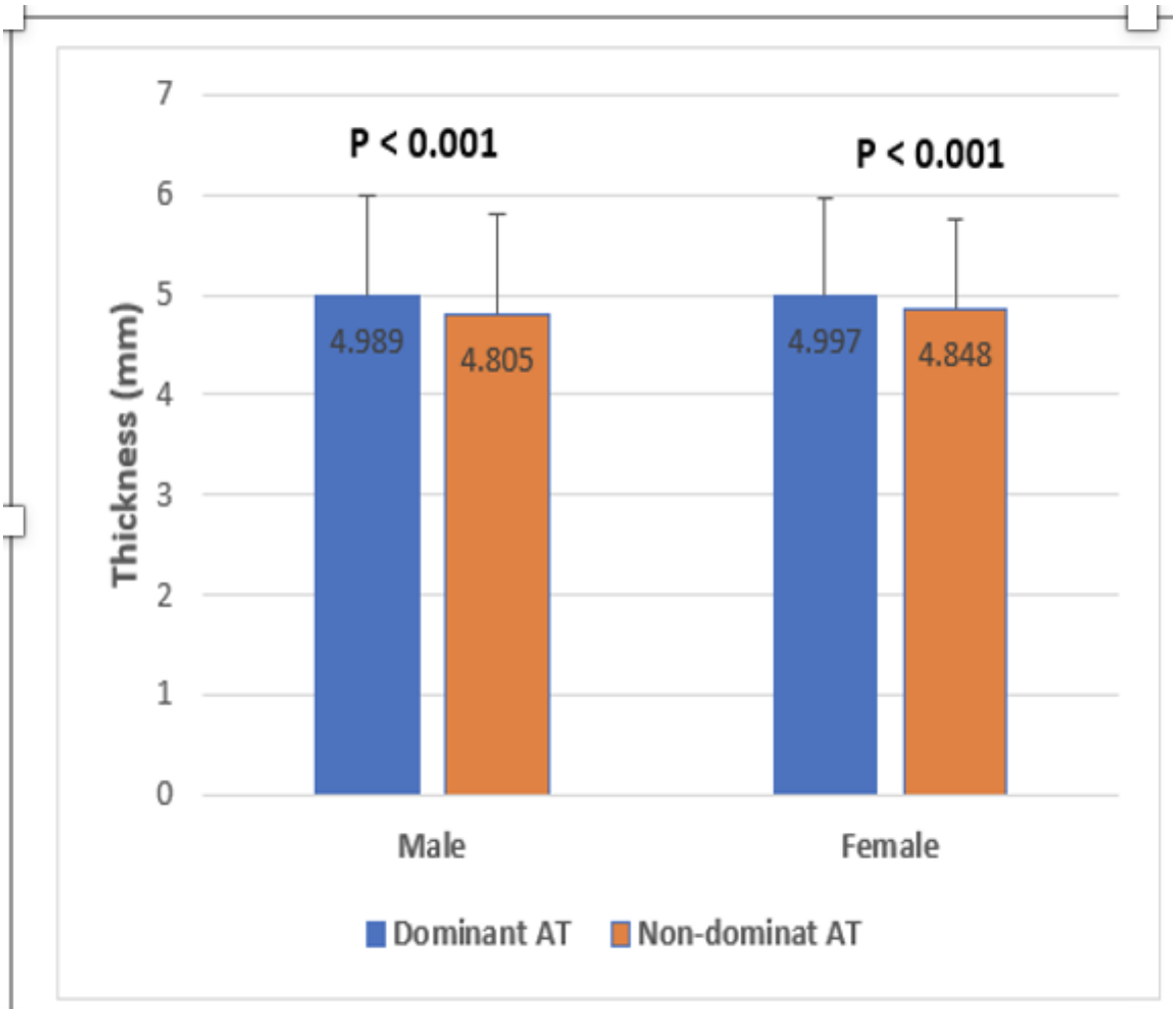


Figure 20a: Comparison of AT thickness between dominant AT and non-dominant AT; between the sexes

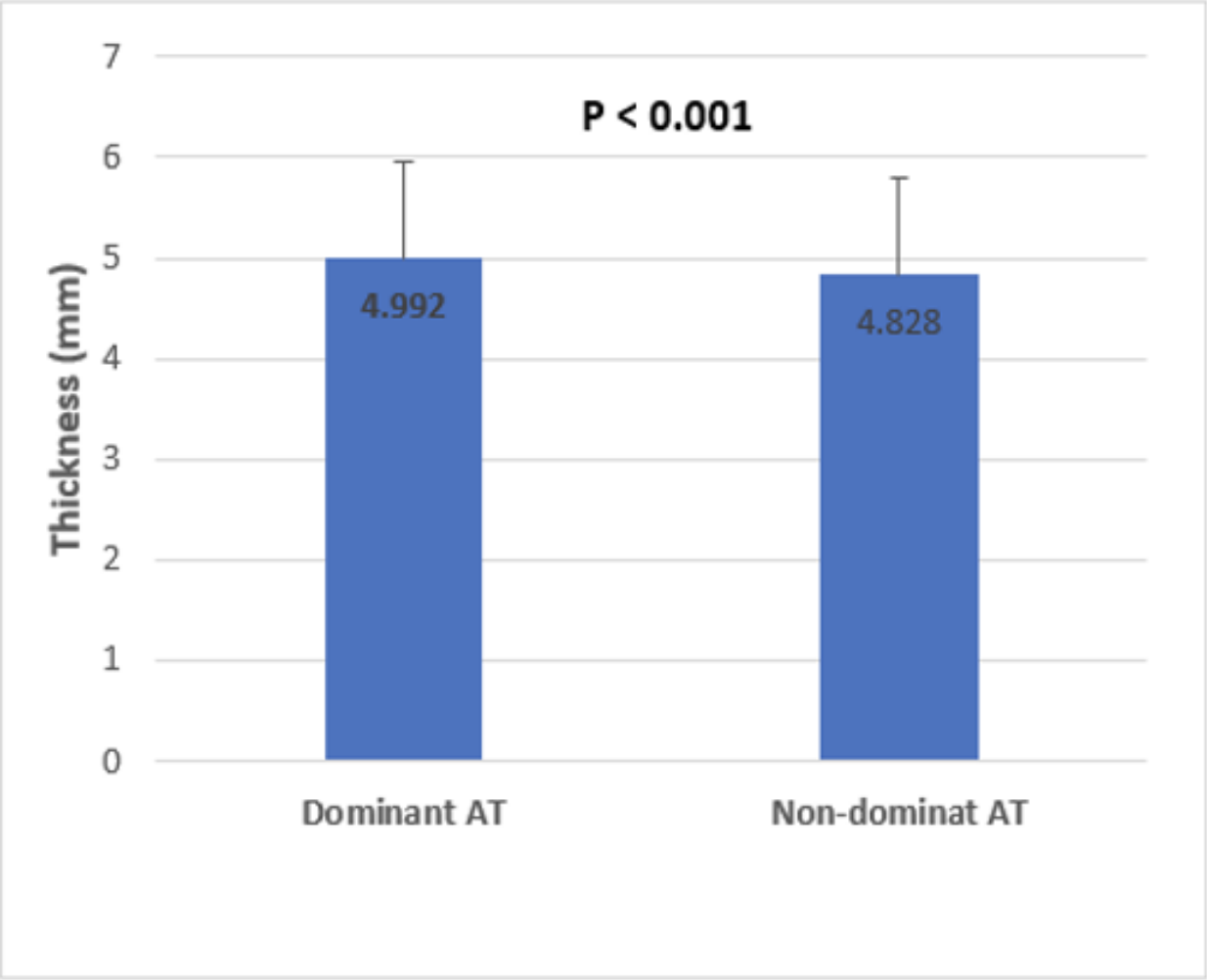


Figure 20b: Comparison of overall AT thickness between the dominant AT and non-dominant AT

Note that 9.6% of right-footed subjects and 14.3% of left-footed subjects had their non-dominant AT being thicker than their dominant AT.

8 subjects (5 males and 3 females) had equally thick AT in both ankles. Each age group had at least one individual with equal AT thickness in both ankles, except for the 10 – 19-year age group.

The correlation analysis revealed AT thickness to:

- have a low positive correlation (r = 0.146) with body weight, which is statistically significant (P = 0.007).
- have a moderately positive correlation (r = 0.509) with body height; which is statistically significant (p < 0.001).
- have a moderate negative correlation of AT thickness with age (r = -0.390) which is not statistically significant (p = 0.472). have a low negative correlation (r = -0.200) with BMI, which is also statistically significant (P <0.001).
- This information is detailed in Table 13 and the scatter plots in Figure 21a-d.

Table 13: Relationship between AT thickness and various subject-specific parameters

	Thickness of AT	
	Correlation coefficient (r)	**P-value**
Body height	0.509	< 0.001
Body weight	0.146	0.007
BMI	-0.200	< 0.001
Age	-0.390	0.472

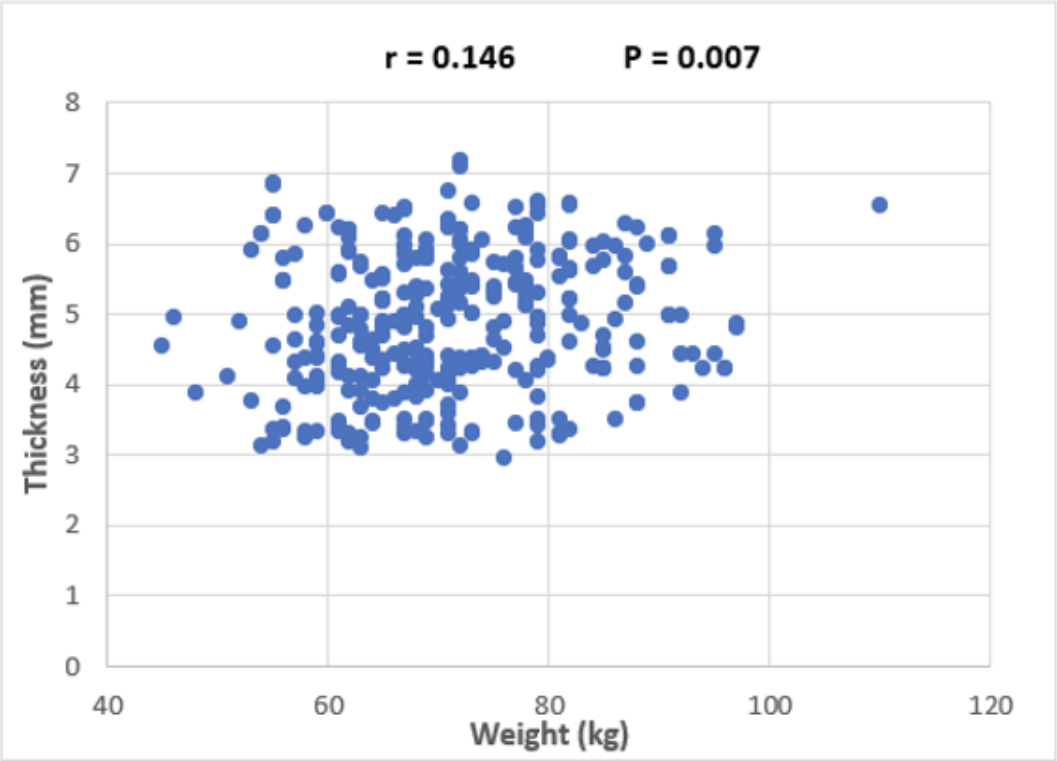


Figure 21a. scatter plot showing the relationship of weight with AT thickness

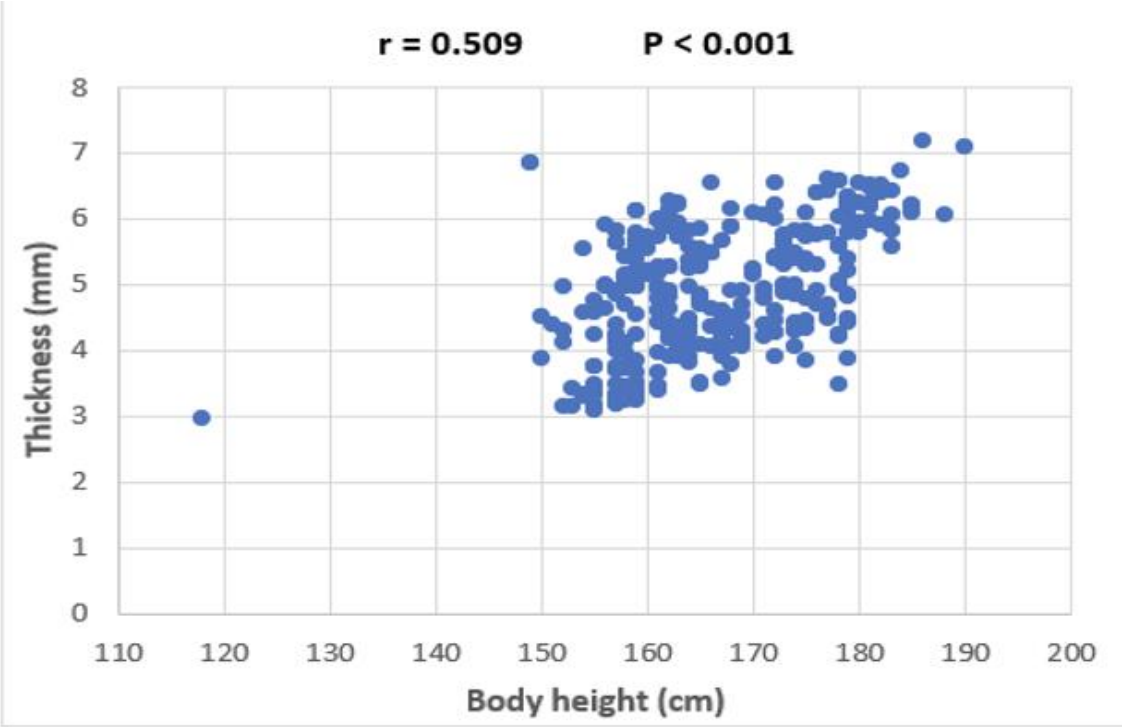


Figure 21b. Scatter plot showing the relationship between body height and AT thickness

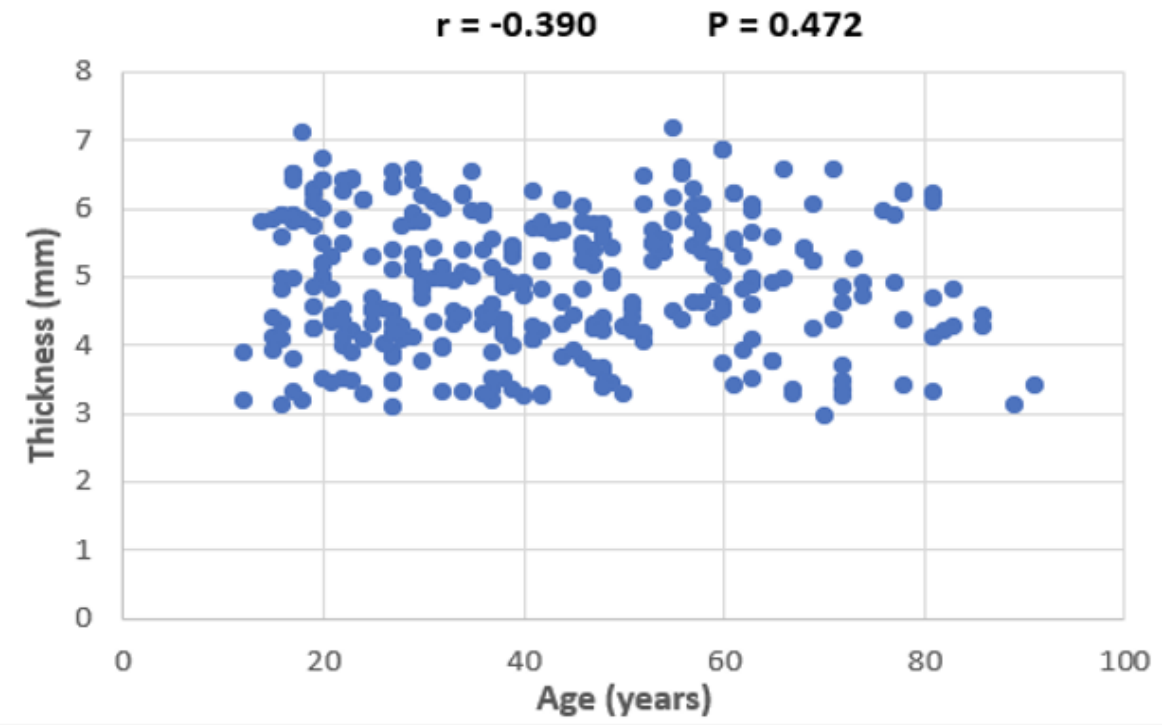


Figure 21c. Scatter plot showing relationship between subject age and AT thickness

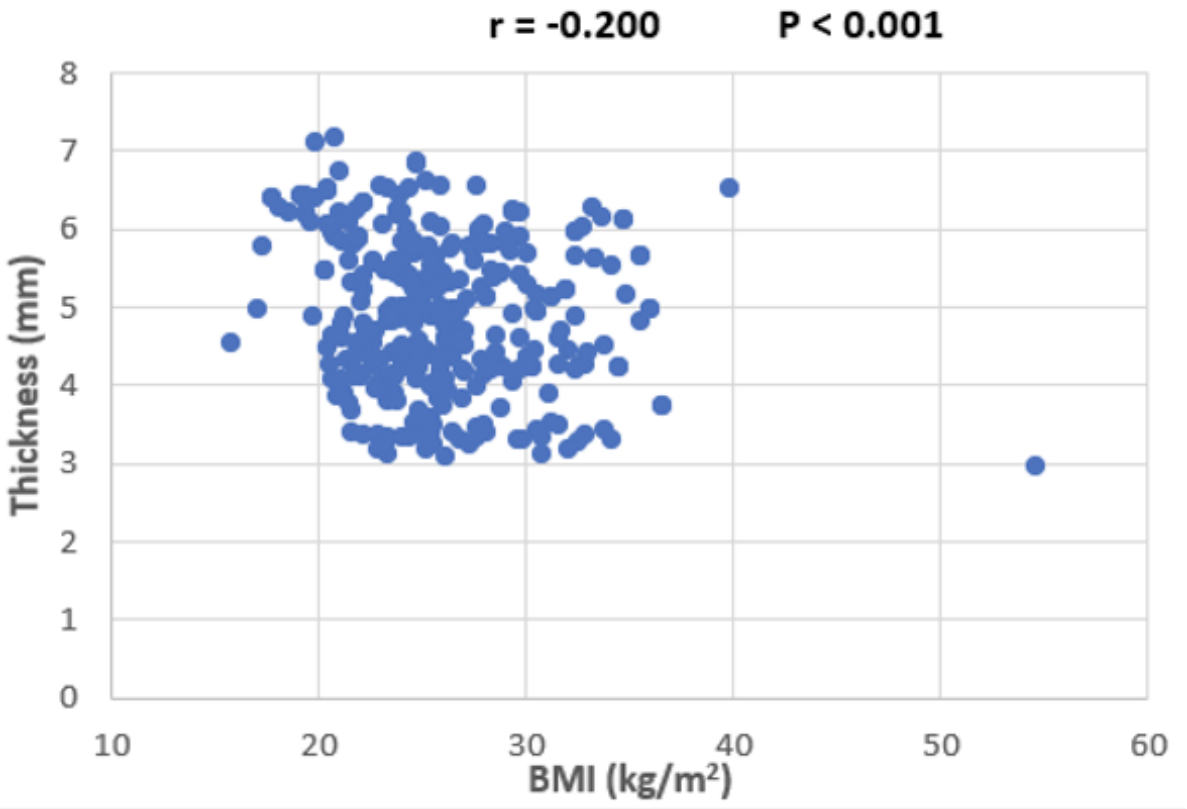


Figure 21d. Scatter plot showing relationship between BMI and AT thickness

Strong positive correlations were noted between AT thickness and ankle dominance, specifically:

- A strong positive correlation exists between AT thickness and ankle dominance in right-footed individuals. This is seen in both dominant and non-dominant ankles ($r = 0.989$, $P < 0.001$).

- A similar, but less strong positive correlation is seen in left-footed individuals – where ($r = 0.983$, $P < 0.001$) and ($r = 0.976$, $P < 0.001$) for the dominant (i.e., Left) AT and non-dominant (i.e., Right) AT respectively. This information is described further in Table 14.

Table 14. Relationship between AT thickness and ankle dominance

Ankle dominance	**Correlation Coefficient (r)**	**P-value**
Right footed		
Dominant AT (Left)	0.989	< 0.001
Non-dominant AT (right)	0.989	< 0.001
Left Footed		
Dominant AT (Right)	0.983	< 0.001
Non-dominant AT (left)	0.976	< 0.001

A multiple regression analysis was done to explore the contribution of age, body height, weight and BMI in determining the outcome of the thickness of the Achilles tendon. The regression model was statistically significant with the inclusion of the independent variables ($P < 0.001$).

The predictors (body height, body weight, and BMI) explain 27.0% of the variation of the dependent variable (thickness of the Achilles tendon) and 26.1% when adjusted for the effects of confounding factors (Table 15).

Table 15: Multiple regression analysis

Model	**R**	**R^2**	**Adjusted R^2**	**Std. Error**
	0.520[a]	0.270	0.261	0.8245
	ANOVA			
	Sum of squares	**df**	**F**	**P-value**
Regression	84.776	4	31.165	< 0.001[b]
Residual	229.182	337		

a Dependent variable
b Predictors

The contribution of each independent variable was checked to determine its significance to the model. It was noted that body height and BMI significantly contributed to the outcome of the thickness of the Achilles tendon ($P < 0.001$ and $P = 0.035$ respectively) as shown in Table 16.

Table 16: Contribution of each independent variable in the model

Predictor	Coefficient	P-value
Age	0.001	0.975
Body height	0.891	< 0.001
Weight	0.464	0.057
BMI	0.578	0.035
Constant	3.274	0.001

CHAPTER 5

5.1 DISCUSSION

Ultrasonography is a safe, reliable and inexpensive imaging modality for assessing the AT [64,76,78]. This study was predicated on the assumption that reviewing the USG data of a statistically significant sample of asymptomatic subjects should reveal the 'normal' USG characteristics of the AT.

Knowing the 'normal' ultrasonographic characteristics of the AT is an invaluable tool in the diagnosis and management of the various pathologies that afflict the AT. This knowledge should also show the extent of normal anatomic variations within the asymptomatic population; and allow us to make some predictions on some subject-specific differences.

I found that 100% of all subjects had normal AT echogenicity [i.e., homogeneously hyperechoic relative to the adjacent muscle]. This finding is in keeping with data from Grassi et al. and Gibbon et al. [8,26,80]. No other findings (including enthesopathy, ossification, peritendinitis, soft tissue masses) were found; with the exception of a single 57-year-old female who was found to have a distended retrocalcaneal bursa. This finding is similar to that from Soila et al. who found 15 out of 100 asymptomatic volunteers to have distended retrocalcaneal bursae.[34,101] However, Mathieson et al.[118] could only image the superficial tendo Achilles bursa (via sonography) when it was inflamed.

The finding of 100% normal AT morphology and other US characteristics in this study is different from data from other studies [101,109] – where variable numbers of asymptomatic individuals were found to have abnormalities within their AT. This difference is explained by the use of the prescreening techniques outlined in Appendix 3. This ensured that any individual recruited into the study was truly healthy.

In particular; the 2-year stipulation [of being heel and/or foot pain free, no foot or heel surgeries, no doctor visits for foot complaints, absence of ankle/heel/foot trauma, absence of medical history of diabetes, psoriasis, gout and other inflammatory disorders known to affect the AT] proved to be highly effective.

For example, this study screened out an individual who had had a partial AT tear 18 months previously; but was now fully recovered and showing no symptoms.
Some of the other studies[101,109] would have included such an individual into their test groups - which probably explains why those other studies had some AT lesions in asymptomatic individuals.

This study found the mean thickness of the AT in asymptomatic subjects at the Korle Bu teaching Hospital, Accra to be 4.844 ± 0.917 mm. This finding is different from data from previous studies in other populations. Specifically; Mathieson et al. [118] and Schweitzer et al.[2] who investigated Caucasians where the mean AT thickness was 6.0 to 6.2mm.

Also, in South East Asian populations; Pang et al.[90] and Ying et al.[74] found the mean AT thickness to be 5.1 ± 0.63 mm (range 3.8–6.9 mm) and 5.23 mm respectively. These differences between my study subjects (at the Korle Bu teaching Hospital, Accra who were 100% West African) and the Caucasian subjects may be explained by differences in body height[76,82]. Caucasians are generally taller than West Africans and thus their mean AT thickness is expected to be higher [2,76]. In addition; the South East Asian studies were carried out on small sample sizes (N=40), which may have produced non-representative data.

The difference in AT thickness between South East Asians and West Africans is smaller than the difference between either of these two populations and Caucasians; and may also be attributed to the fact

that Caucasians are on average taller and heavier than both Africans and South East Asians.[113,114,120,121] Table 3 shows various reported AT thickness values by other researchers studying different populations.

Table 3. Reported values of mean Achilles tendon thickness measured by US[89]

	AT thickness Mean ± SD (range) mm	**Population**	**US frequency**
Steinmetz et al	5.7 ± 0.7 (5-8)	German	5-7.5 MHz
Ebeling et al	4.9 ± 0.9 (4-7)	Finnish	7.5 MHz
Mathieson et al	6.2 (4-9)	North American	5 MHz
Holsbeeck et Introcaso	6.2 ±0.8 (sedentary)	Not Indicated	Not Indicated
	5.7±0.8 (athletes)		
Fornage	5.3 (4-6)	North American	5 MHz
Kallinen et Suominen	6.1 ± 0.9 (sedentary)	Finnish	7.5 MHz
	6.2 ± 0.9 (athletes)		
Yuzava et al	4.2 ± 0.5 (women)	Japanese	7.5 MHz
	4.7 ± 0.4 (men)		
Liem et al	6.2 ± 1.2	Dutch	Not Indicated

Overall, males were found to have significantly thicker Achilles tendons (mean AT thickness of 5.29 ± 0.92 mm) compared to females (mean thickness of 4.573 ± 0.868 mm) – with a P-value of < 0.001. This sexual dimorphism persists across all age groupings; and this difference is statistically significant (see Table 12).

These findings are in agreement with data from Patel et al.[91] who found all AT parameters (including thickness, length and cross-sectional area) to be higher in males. This difference in AT size between the sexes is due to the fact that on average; males are heavier and taller than age-matched females - and body height is known to positively correlate with AT size. [2,76]

In this study; strong positive correlations were noted between AT thickness and ankle dominance. Specifically; irrespective of footedness; the dominant AT was thicker than the non-dominant AT as shown in Table 7. This finding was noted in 87.7% of the study population, the mean difference between dominant and non-dominant AT being 0.164 mm – with this difference being statistically significant ($P < 0.001$).

This difference can be explained by higher stresses and loads on the dominant AT when the subject attempts to push off[74]. This results in more frequent microtrauma to the dominant AT; with constant remodeling, attempts at healing and resulting AT hypertrophy [81,89,94].

The abovementioned difference disagrees with data from Pang et al.[90] and Ying et al.[74] who did not find any significant variation in the thickness of the Achilles tendons between dominant and nondominant ankles. A possible reason for this difference might be the relatively smaller sample sizes of those studies (i.e., 40 subjects in each case)

The data shows a moderate positive correlation between body height and AT thickness ($r = 0.509$) which is statistically significant (P-value of < 0.001. see Table 6). This finding is in agreement with data from Koivunen-Nimela et al. [89] – who found the Achilles tendon to be thicker in tall patients, in men and in the elderly. Schweitzer et al. [2] and Patel et al. [91] also had similar findings.

Direct conclusions may be drawn from this moderate statistical association. For example; the tallest subject (a right-footed 18-year-old, with height of 190 cm) had a tendon thickness of 7.10 mm; which was the second highest AT thickness recorded in the study. He was only surpassed by his father (a right footed 55-year-old male, with height 186 cm) with AT thickness of 7.17 mm. At the lower end; the shortest subject (a right-footed 60-year-old female, with height 118 cm) also had the thinnest AT measuring 2.96 mm.

The above is in contradistinction to other studies [89] where even though there was a stronger correlation between body height and AT thickness (r = 0.52, versus r of 0.509 in this study) their tallest subjects did not have the thickest AT. A search of the literature did not offer a direct explanation for why taller individuals tend to have thicker AT; and further study in this direction is recommended.

AT thickness was found to have a low positive correlation with body weight, with this relationship being statistically significant (P = 0.007). Patel et al and Koivunen-Nimela et al [89,91] both found similar, but stronger correlations with r = 0.25 and r = 0.587 respectively. Both studies found AT thickness to increase as measures of body stature (including BMI, tibial length and foot size) increased.

BMI was found to have a low negative correlation with AT thickness, which is also statistically significant. This finding is different from other studies [89,91]; where BMI was found to be positively correlated with AT thickness. A possible explanation for this finding is that a majority of the taller study subjects (i.e., height > 177cm, N = 62 subjects) who tend to have thicker AT had relatively low BMI – with a mean BMI of 22.78 kg/m2 versus a mean BMI of 25.91 kg/m2 for the entire study population. Alternatively, other factors like tibial length (and thence AT length) may be involved in this finding and further work in the future may reveal the required answers.

In this study; AT thickness had a moderate negative correlation with age (r = -0.390) which is not statistically significant (p = 0.472). This finding is in agreement with data from Pang et al[53] but not the study data from Koivunen-Nimela et al. [89]

This may be due to the fact tendon hypertrophy causes an increase in the size of the whole AT; with only a small, statistically insignificant increase in thickness [90]. This led Pang et al.[90] and Patel et al.[91] to suggest that AT cross-sectional area may be a more representative parameter for assessing AT size than thickness.

From the multiple regression analysis; it is observed that body height significantly contributes to the thickness of the Achilles tendon. This means that a tall individual is likely to have a thicker AT than a shorter subject. A similar effect is observed with BMI; but to a lesser extent.

With respect to BMI; it is projected that an obese individual (with high BMI) is more likely to have a thicker AT than an underweight individual. This is agreement with data from Abate et al.[100] who also found increasing AT abnormalities in subjects with high BMI. They also noted that the Achilles tendon abnormalities in non-Diabetics tended to be in the midportion of the AT *whereas* diabetics tended to have enthesial lesions.

However, from the model no statistical projections regarding AT thickness can be made based on the subject age and/or weight.

5.2 LIMITATIONS

1. Usage of a non-probability sampling method (i.e., convenience sampling). This limited the study population to 'asymptomatic' subjects who happened to be in the ultrasound unit for some reason. The effect of this 'volunteer bias' was ameliorated by the prescreening techniques; which ensured that subjects were indeed 'asymptomatic' before inclusion into the study. Ideally a probability sampling method (e.g., Simple random or Systematic sampling) would have produced a more representative study population.

2. Inability to incorporate AT length as an investigative parameter. This is due to the researcher's inability to access an ultrasound machine with panoramic/extended-field-of-view capability. Some previous studies have shown some correlation between AT length and body height, whilst others have not. It would have been useful to investigate the relationship between the two variables; if any.

3. A simple ultrasound technique was used. More advanced techniques such as sonoelastography could have provided more information regarding tendon structure and composition.

4. The usage of higher frequency US transducers increases the resolution of imaging; and thence the sensitivity of US for detecting abnormalities within the AT. The linear probe used in this study had a maximum frequency of 11 MHz. Newer probes have much higher frequencies and have detected some focal lesions in other studies of asymptomatic Achilles tendons.

5.3 CONCLUSION

The AT of an asymptomatic volunteer was found to be homogeneously hyperechoic – without focal or diffuse alterations in echogenicity, with mean thickness of 4.84 ± 0.92 mm.

In all age groups; males have thicker AT than their age-matched female counterparts.

Dominant AT (i.e., the tendon in the non-dominant foot) are often thicker than the non-dominant AT (87.7% of the time; in this study). The mean difference between the thickness of the dominant and non-dominant AT being 0.164 mm.

There is a moderate, statistically significant correlation between body height and AT thickness – with taller subjects having thicker AT.

However, the relationships between age, body weight, BMI and AT thickness are less defined.

5.4 RECOMMENDATIONS

This study has found the normal asymptomatic AT to be homogeneously hyperechoic, with mean thickness 4.84 ± 0.92 mm. In addition; the mean difference in thickness between the dominant and non-dominant AT in an individual is averagely 0.164 mm.

Since there is high interobserver reliability (when a standardized scanning technique is used) in assessing the thickness of the AT, radiologists should be alerted to possibility of AT pathology when there are significant departures from these measurements.

REFERENCES

1. Doral MN, Alam M, Bozkurt M, Turhan E, Atay OA, Dönmez G, et al. Functional anatomy of the Achilles tendon. Knee Surgery, Sports Traumatology, Arthroscopy 2010;18(5):638–43.
2. Schweitzer ME, Karasick D. MR Imaging of Disorders of the Achilles Tendon. American Journal of Roentgenology 2000;175(3):613–25.
3. Grumbine NA, Santoro JP. The tendo Achillis as it relates to rearfoot position. A new classification for evaluation of calcaneal stance position. Clin Podiatr Med Surg 1990;7(2):203–16.
4. Frey C, Rosenberg Z, Shereff MJ, Kim H. The Retrocalcaneal Bursa: Anatomy and Bursography. Foot Ankle 1992;13(4):203–7.
5. Mercer NP, Gianakos AL, Kaplan DJ, Dankert JF, Kanakamedala A, Chen JS, et al. Achilles Paratenon Needle Tendoscopy in the Office Setting. Arthrosc Tech 2022;11(3):e315–20.
6. Rees JD, Wilson AM, Wolman RL. Current concepts in the management of tendon disorders. Rheumatology 2006;45(5):508–21.
7. Selvanetti A, Cipolla M, Puddu G. Overuse tendon injuries: Basic science and classification. Oper Tech Sports Med 1997;5(3):110–7.
8. Grassi W, Cervini C. Ultrasonography in rheumatology: an evolving technique. Ann Rheum Dis 1998;57(5):268–71.
9. Mascarenhas S. A Narrative Review of the Classification and Use of Diagnostic Ultrasound for Conditions of the Achilles Tendon. Diagnostics 2020;10(11):944.
10. Maffulli N, Sharma P, Luscombe KL. Achilles tendinopathy: aetiology and management. J R Soc Med 2004;97(10):472–6.
11. Khan KM, Maffulli N. Tendinopathy: an Achilles' heel for athletes and clinicians. Clin J Sport Med 1998;8(3):151–4.
12. Williams JGP. Achilles Tendon Lesions in Sport. Sports Medicine 1986;3(2):114–35.

13. Kvist M. Achilles tendon injuries in athletes. Ann Chir Gynaecol 1991;80(2):188–201.
14. Benazzo F, Zanon G, Maffulli N. An Operative Approach to Achilles Tendinopathy. Sports Med Arthrosc Rev 2000;8(1):96–101.
15. Leadbetter WB. Cell-matrix response in tendon injury. Clin Sports Med 1992;11(3):533–78.
16. Kleinman M, Gross AE. Achilles tendon rupture following steroid injection. Report of three cases. J Bone Joint Surg Am 1983;65(9):1345–7.
17. Leppilahti J, Puranen J, Orava S. Incidence of Achilles tendon rupture. Acta Orthop Scand 1996;67(3):277–9.
18. Suchak AA, Bostick G, Reid D, Blitz S, Jomha N. The Incidence of Achilles Tendon Ruptures in Edmonton, Canada. Foot Ankle Int 2005;26(11):932–6.
19. Huttunen TT, Kannus P, Rolf C, Felländer-Tsai L, Mattila VM. Acute Achilles Tendon Ruptures. Am J Sports Med 2014;42(10):2419–23.
20. Sheth U, Wasserstein D, Jenkinson R, Moineddin R, Kreder H, Jaglal SB. The epidemiology and trends in management of acute Achilles tendon ruptures in Ontario, Canada: a population-based study of 27 607 patients. Bone Joint J 2017;99-B(1):78–86.
21. Sandelin J, Kiviluoto O, Santavirta S, Honkanen R. Outcome of sports injuries treated in a casualty department. Br J Sports Med 1985;19(2):103–6.
22. Jozsa, Laszlo G, Kannus, Pekka. Human Tendon: Anatomy, Physiology and Pathology. Champaign. 1997.
23. Józsa L, Bálint BJ, Réffy A, Demel Z. Fine structural alterations of collagen fibers in degenerative tendinopathy. Arch Orthop Trauma Surg 1984;103(1):47–51.
24. Hattrup SJ, Johnson KA. A Review of Ruptures of the Achilles Tendon. Foot Ankle 1985;6(1):34–8.
25. Aström M, Rausing A. Chronic Achilles tendinopathy. A survey of surgical and histopathologic findings. Clin Orthop Relat Res 1995;(316):151–64.

26. Grassi W, Filippucci E, Farina A, Cervini C. Sonographic imaging of tendons. Arthritis Rheum 2000;43(5):969–76.

27. Robinson P. Sonography of common tendon injuries. AJR Am J Roentgenol 2009;193(3):607–18.

28. Berg K, Peck J, Boulger C, Bahner DP. Patellar tendon rupture: an ultrasound case report. BMJ Case Rep 2013;2013.

29. https://radiopaedia.org/articles/achilles-tendon-tear?lang=us. Accessed 28.12.2022. Achilles tendon tear .

30. Ghana statistical Service. Press Release on Provisional Results. 2021 Population and Housing Census. . 2021.

31. Ghana statistical Service. 2010 Population and Housing Census. Summary report of Final Results. 2012.

32. Schmidt WA, Schmidt H, Schicke B, Gromnica-Ihle E. Standard reference values for musculoskeletal ultrasonography. Ann Rheum Dis 2004;63(8):988–94.

33. Mahlfeld K, Kayser R, Mahlfeld A, Grasshoff H, Franke J. [Value of ultrasound in diagnosis of bursopathies in the area of the Achilles tendon]. Ultraschall Med 2001;22(2):87–90.

34. Soila K, Karjalainen PT, Aronen HJ, Pihlajamäki HK, Tirman PJ. High-resolution MR imaging of the asymptomatic Achilles tendon: new observations. AJR Am J Roentgenol 1999;173(2):323–8.

35. Olivieri I, Barozzi L, Padula A, de Matteis M, Pierro A, Cantini F, et al. Retrocalcaneal bursitis in spondyloarthropathy: assessment by ultrasonography and magnetic resonance imaging. J Rheumatol 1998;25(7):1352–7.

36. Stecco A, Busoni F, Stecco C, Mattioli-Belmonte M, Soldani P, Condino S, et al. Comparative ultrasonographic evaluation of the Achilles paratenon in symptomatic and asymptomatic subjects: an imaging study. Surg Radiol Anat 2015;37(3):281–5.

37. Fredberg U. Letters to the Editor-in-Chief. Scand J Med Sci Sports 2004;14(4):270–2.

38. Maffulli N. Overuse tendon conditions: Time to change a confusing terminology. Arthroscopy: The Journal of Arthroscopic & Related Surgery 1998;14(8):840–3.

39. Kainberger FM, Engel A, Barton P, Huebsch P, Neuhold A, Salomonowitz E. Injury of the Achilles tendon: diagnosis with sonography. AJR Am J Roentgenol 1990;155(5):1031–6.

40. El-Khalek AMA, Borga M, El-Essawya. Role of ultrasonography in the evaluation of Achilles tendon disorders. . Benha Med J 2016;33(54).

41. Federer AE, Steele JR, Dekker TJ, Liles JL, Adams SB. Tendonitis and Tendinopathy. Foot Ankle Clin 2017;22(4):665–76.

42. Bestwick C, Maffulli N. Reactive oxygen species and tendon problems: Review and hypothesis. Sports Med Arthrosc Rev 2000;8(1):616–616.

43. Paavola M, Kannus P, Järvinen TAH, Khan K, Józsa L, Järvinen M. Achilles tendinopathy. J Bone Joint Surg Am 2002;84(11):2062–76.

44. Li HY, Hua YH. Achilles Tendinopathy: Current Concepts about the Basic Science and Clinical Treatments. Biomed Res Int 2016;2016:6492597.

45. Wiegerinck, G M Kerkhoffs, M N van Sterkenburg. Treatment for insertional Achilles tendinopathy: a systematic review. Knee Surgery, Sports Traumatology, Arthroscopy 2013;arthroscopy(june).

46. Fahlström M, Jonsson P, Lorentzon R, Alfredson H. Chronic Achilles tendon pain treated with eccentric calf-muscle training. Knee Surg Sports Traumatol Arthrosc 2003;11(5):327–33.

47. Mafi N, Lorentzon R, Alfredson H. Superior short-term results with eccentric calf muscle training compared to concentric training in a randomized prospective multicenter study on patients with chronic Achilles tendinosis. Knee Surg Sports Traumatol Arthrosc 2001;9(1):42–7.

48. Nicholson CW, Berlet GC, Lee TH. Prediction of the success of nonoperative treatment of insertional Achilles tendinosis based on MRI. Foot Ankle Int 2007;28(4):472–7.

49. Gaida JE, Alfredson L, Kiss ZS, Wilson AM, Alfredson H, Cook JL. Dyslipidemia in Achilles tendinopathy is characteristic of insulin resistance. Med Sci Sports Exerc 2009;41(6):1194–7.

50. Franceschi F, Papalia R, Paciotti M, Franceschetti E, di Martino A, Maffulli N, et al. Obesity as a risk factor for tendinopathy: a systematic review. Int J Endocrinol 2014;2014:670262.

51. Scott RT, Hyer CF, Granata A. The correlation of Achilles tendinopathy and body mass index. Foot Ankle Spec 2013;6(4):283–5.

52. Mokone GG, Schwellnus MP, Noakes TD, Collins M. The COL5A1 gene and Achilles tendon pathology. Scand J Med Sci Sports 2006;16(1):19–26.

53. Mokone GG, Gajjar M, September A v, Schwellnus MP, Greenberg J, Noakes TD, et al. The guanine-thymine dinucleotide repeat polymorphism within the tenascin-C gene is associated with achilles tendon injuries. Am J Sports Med 2005;33(7):1016–21.

54. Raleigh SM, van der Merwe L, Ribbans WJ, Smith RKW, Schwellnus MP, Collins M. Variants within the MMP3 gene are associated with Achilles tendinopathy: possible interaction with the COL5A1 gene. Br J Sports Med 2009;43(7):514–20.

55. Cheng Y, Zhang J, Cai Y. Utility of Ultrasonography in Assessing the Effectiveness of Extracorporeal Shock Wave Therapy in Insertional Achilles Tendinopathy. Biomed Res Int 2016;2016:2580969.

56. Vaishya R, Agarwal AK, Azizi AT, Vijay V. Haglund's Syndrome: A Commonly Seen Mysterious Condition. Cureus 2016;8(10):e820.

57. Johansson KJJ, Sarimo JJ, Lempainen LL, Laitala-Leinonen T, Orava SY. Calcific spurs at the insertion of the Achilles tendon: a clinical and histological study. Muscles Ligaments Tendons J 2012;2(4):273–7.

58. D'Agostino MA, Said-Nahal R, Hacquard-Bouder C, Brasseur JL, Dougados M, Breban M. Assessment of peripheral enthesitis in the spondylarthropathies by ultrasonography combined with power Doppler: A cross-sectional study. Arthritis Rheum 2003;48(2):523–33.

59. Buchanan BK, DeLuca JP, Lammlein KP. Technical Innovation Case Report: Ultrasound-Guided Prolotherapy Injection for Insertional Achilles Calcific Tendinosis. Case Rep Orthop 2016;2016:1560161.

60. Ahmed MM, Elolemy GG, Alfeeli AK, Baqer AB, Gad AM. Ultrasonographic Enthesopathy and Disease Activity in Psoriatic Arthritis. Open Access Maced J Med Sci 2017;5(5):651–6.

61. Kaeley GS. Enthesitis in psoriatic arthritis (Part 2): imaging. Rheumatology (Oxford) 2020;59(Suppl 1):i15–20.

62. Gisondi P, Tinazzi I, El-Dalati G, Gallo M, Biasi D, Barbara LM, et al. Lower limb enthesopathy in patients with psoriasis without clinical signs of arthropathy: a hospital-based case-control study. Ann Rheum Dis 2008;67(1):26–30.

63. Sudoł-Szopińska I, Zaniewicz-Kaniewska K, Kwiatkowska B. Spectrum of ultrasound pathologies of achilles tendon, plantar aponeurosis and flexor digiti brevis tendon heel entheses in patients with clinically suspected enthesitis. Pol J Radiol 2014;79:402–8.

64. Dong Q, Fessell DP. Achilles Tendon Ultrasound Technique. American Journal of Roentgenology 2009;193(3):W173–W173.

65. Nichols CE. Patella tendon injuries. . Clinical Sports Medicine 1992;11:807–13.

66. Maffulli N, Waterston SW, Squair J, Reaper J, Douglas AS. Changing incidence of Achilles tendon rupture in Scotland: a 15-year study. Clin J Sport Med 1999;9(3):157–60.

67. Maffulli N, Regine R, Angelillo M, Capasso G, Filice S. Ultrasound diagnosis of Achilles tendon pathology in runners. Br J Sports Med 1987;21(4):158–62.

68. Koenig M, Torp-Pedersen S, Holmich P, Terslev L, Nielsen M, Boesen M, et al. Ultrasound Doppler of the Achilles Tendon before and after Injection of an Ultrasound Contrast Agent - Findings in Asymptomatic Subjects. Ultraschall in der Medizin - European Journal of Ultrasound 2006;28(01):52–6.

69. Nicol AM, McCurdie I, Etherington J. Use of ultrasound to identify chronic Achilles tendinosis in an active asymptomatic population. J R Army Med Corps 2006;152(4):212–6.

70. Baad M, Lu ZF, Reiser I, Paushter D. Clinical Significance of US Artifacts. RadioGraphics 2017;37(5):1408–23.

71. Wu WT, Chang KV, Hsu YC, Hsu PC, Ricci V, Özçakar L. Artifacts in Musculoskeletal Ultrasonography: From Physics to Clinics. Diagnostics (Basel) 2020;10(9).

72. Ricci V, Soylu AR, Özçakar L. Artifacts and Artistic Facts: A Visual Simulation for Ultrasound Training. Am J Phys Med Rehabil 2019;98(6):521–5.

73. Khan KM, Forster BB, Robinson J, Cheong Y, Louis L, Maclean L, et al. Are ultrasound and magnetic resonance imaging of value in assessment of Achilles tendon disorders? A two year prospective study. Br J Sports Med 2003;37(2):149–53.

74. Ying M, Yeung E, Li B, Li W, Lui M, Tsoi CW. Sonographic evaluation of the size of Achilles tendon: the effect of exercise and dominance of the ankle. Ultrasound Med Biol 2003;29(5):637–42.

75. Szaro P, Nilsson-Helander K, Carmont M. MRI of the Achilles tendon-A comprehensive pictorial review. Part one. Eur J Radiol Open 2021;8:100342.

76. Bertolotto M, Perrone R, Martinoli C, Rollandi GA, Patetta R, Derchi LE. High resolution ultrasound anatomy of normal Achilles tendon. Br J Radiol 1995;68(813):986–91.

77. Maffulli N. Rupture of the Achilles tendon. J Bone Joint Surg Am 1999;81(7):1019–36.

78. Khan KM, Cook JL, Bonar F, Harcourt P, Astrom M. Histopathology of common tendinopathies. Update and implications for clinical management. Sports Med 1999;27(6):393–408.

79. Szaro P, Ghali Gataa K. The correlations between dimensions of the normal tendon and tendinopathy changed Achilles tendon in routine magnetic resonance imaging. Sci Rep 2021;11(1).

80. Gibbon WW. Musculoskeletal ultrasound. Baillieres Clin Rheumatol 1996;10(4):561–88.

81. Martinoli C, Derchi LE, Pastorino C, Bertolotto M, Silvestri E. Analysis of echotexture of tendons with US. Radiology 1993;186(3):839–43.

82. Strocchi R, de Pasquale V, Guizzardi S, Govoni P, Facchini A, Raspanti M, et al. Human Achilles tendon: morphological and morphometric variations as a function of age. Foot Ankle 1991;12(2):100–4.

83. Kallinen M, Suominen H. Ultrasonographic measurements of the Achilles tendon in elderly athletes and sedentary men. Acta Radiol 1994;35(6):560–3.

84. Alfredson H, Cook J. A treatment algorithm for managing Achilles tendinopathy: new treatment options. Br J Sports Med 2007;41(4):211–6.

85. Tarantino D, Palermi S, Sirico F, Corrado B. Achilles Tendon Rupture: Mechanisms of Injury, Principles of Rehabilitation and Return to Play. J Funct Morphol Kinesiol 2020;5(4).

86. Józsa L, Kvist M, Bálint BJ, Reffy A, Järvinen M, Lehto M, et al. The role of recreational sport activity in Achilles tendon rupture. A clinical, pathoanatomical, and sociological study of 292 cases. Am J Sports Med 1989;17(3):338–43.

87. Aydın SZ, Filippucci E, Atagündüz P, Yavuz Ş, Grassi W, Direskeneli H. Sonographic measurement of Achilles tendon thickness in seronegative spondyloarthropathies. Eur J Rheumatol 2014;1(1):7–10.

88. Archambault JM, Wiley JP, Bray RC, Verhoef M, Wiseman DA, Elliott PD. Can sonography predict the outcome in patients with achillodynia? J Clin Ultrasound 1998;26(7):335–9.

89. Koivunen-Niemelä T, Parkkola K. Anatomy of the Achilles tendon (tendo calcaneus) with respect to tendon thickness measurements. Surg Radiol Anat 1995;17(3):263–8.

90. Pang BSF, Ying M. Sonographic measurement of achilles tendons in asymptomatic subjects: variation with age, body height, and dominance of ankle. J Ultrasound Med 2006;25(10):1291–6.

91. Patel NN, Labib SA. The Achilles Tendon in Healthy Subjects: An Anthropometric and Ultrasound Mapping Study. J Foot Ankle Surg 2018;57(2):285–8.

92. Orthoinfo.aaos.org. https://orthoinfo.aaos.org/en/diseases--conditions/achilles-tendinitis/ Accessed 28.12.2022. The Achilles tendon.

93. Earthslab website (2021) plantaris muscle. Available at https://www.earthslab.com/anatomy/plantaris-muscle/. Accessed on 05.10.21. plantaris muscle. Earthslab website (2021) plantaris muscle. .

94. del Buono A, Chan O, Maffulli N. Achilles tendon: functional anatomy and novel emerging models of imaging classification. Int Orthop 2013;37(4):715–21.

95. Wengler K, Tank D, Fukuda T, Paci JM, Huang M, Schweitzer ME, et al. Diffusion tensor imaging of human Achilles tendon by stimulated echo readout-segmented EPI (ste-RS-EPI). Magn Reson Med 2018;80(6):2464–74.

96. Fukawa T, Yamaguchi S, Watanabe A, Sasho T, Akagi R, Muramatsu Y, et al. Quantitative Assessment of Tendon Healing by Using MR T2 Mapping in a Rabbit Achilles Tendon Transection Model Treated with Platelet-rich Plasma. Radiology 2015;276(3):748–55.

97. Wengler K, Fukuda T, Tank D, Huang M, Gould ES, Schweitzer ME, et al. Intravoxel incoherent motion (IVIM) imaging in human achilles tendon. J Magn Reson Imaging 2018;48(6):1690–9.

98. Bensamoun SF, Ringleb SI, Littrell L, Chen Q, Brennan M, Ehman RL, et al. Determination of thigh muscle stiffness using magnetic resonance elastography. J Magn Reson Imaging 2006;23(2):242–7.

99. Robinson JM, Cook JL, Purdam C, Visentini PJ, Ross J, Maffulli N, et al. The VISA-A questionnaire: A valid and reliable index of the clinical severity of Achilles tendinopathy. Br J Sports Med 2001;35(5).

100. Abate M, Salini V, Antinolfi P, Schiavone C. Ultrasound Morphology of the Achilles in Asymptomatic Patients With and Without Diabetes. Foot Ankle Int 2014;35(1):44–9.

101. Kudron C, Carlson MJ, Meron A, Sridhar B, Brakke Holman R. Using Ultrasound Measurement of the Achilles Tendon in Asymptomatic Runners to Assist in Predicting Tendinopathy. Journal of Ultrasound in Medicine 2020;39(3):491–6.

102. Masci L, Spang C, van Schie HTM, Alfredson H. Achilles tendinopathy—do plantaris tendon removal and Achilles tendon scraping improve tendon structure? A prospective study using ultrasound tissue characterisation. BMJ Open Sport Exerc Med 2015;1(1):e000005.

103. Nadeau MJ, Desrochers A, Lamontagne M, Larivière C, Gagnon DH. Quantitative ultrasound imaging of Achilles tendon integrity in symptomatic and asymptomatic individuals: reliability and minimal detectable change. J Foot Ankle Res 2016;9:30.

104. Genovese E, Ronga M, Recaldini C, Fontana F, Callegari L, Maffulli N, et al. Analysis of achilles tendon vascularity with second-generation contrast-enhanced ultrasound. Journal of Clinical Ultrasound 2011;39(3):141–5.

105. Richards PJ, Dheer AK, McCall IM. Achilles Tendon (TA) Size and Power Doppler Ultrasound (PD) Changes Compared to MRI: A Preliminary Observational Study. Clin Radiol 2001;56(10):843–50.

106. D'Agostino MA, Aegerter P, Bechara K, Salliot C, Judet O, Chimenti MS, et al. How to diagnose spondyloarthritis early? Accuracy of peripheral enthesitis detection by power Doppler ultrasonography. Ann Rheum Dis 2011;70(8):1433–40.

107. Rubin JM, Bude RO, Carson PL, Bree RL, Adler RS. Power Doppler US: a potentially useful alternative to mean frequency-based color Doppler US. Radiology 1994;190(3):853–6.

108. Richards PJ, McCall IW, Day C, Belcher J, Maffulli N. Longitudinal microvascularity in Achilles tendinopathy (power Doppler ultrasound, magnetic resonance imaging time–intensity curves and the Victorian Institute of Sport Assessment–Achilles questionnaire): a pilot study. Skeletal Radiol 2010;39(6):509–21.

109. Tillander B, Gauffin H, Lyth J, Knutsson A, Timpka T. Symptomatic Achilles Tendons are Thicker than Asymptomatic Tendons on Ultrasound Examination in Recreational Long-Distance Runners. Sports 2019;7(12):245.

110. Lopes AD, Hespanhol LC, Yeung SS, Costa LOP. What are the main running-related musculoskeletal injuries? A systematic review. Sports Medicine2012;42(10).

111. Jhingan S, Perry M, O'Driscoll G, Lewin C, Teatino R, Malliaras P, et al. Thicker Achilles tendons are a risk factor to develop Achilles tendinopathy in elite professional soccer players. Muscles Ligaments Tendons J 2011;1(2):51–6.

112. Peter BM, Petkova D, Novembre J. Genetic Landscapes Reveal How Human Genetic Diversity Aligns with Geography. Mol Biol Evol 2020;37(4):943–51.

113. Lettre G. Recent progress in the study of the genetics of height. Hum Genet 2011;129(5):465–72.

114. Serre D, Pääbo S. Evidence for gradients of human genetic diversity within and among continents. Genome Res 2004;14(9):1679–85.

115. Brakohiapa EKK, Botwe BO, Sarkodie BD, Ofori EK, Coleman J. Radiographic determination of cardiomegaly using cardiothoracic ratio and transverse cardiac diameter: Can one size fit all? Part one. Pan African Medical Journal 2017;27.

116. Korle Bu Teaching Hospital website (2020) A brief history. Available at :https://kbth.gov.gh/brief-history/. Accessed on: 05.10.21. Korle Bu Teaching Hospital. A brief history. .

117. Charan J, Biswas T. How to calculate sample size for different study designs in medical research? Indian J Psychol Med 2013;35(2):121–6.

118. Mathieson JR, Connell DG, Cooperberg PL, Lloyd-Smith DR. Sonography of the Achilles tendon and adjacent bursae. AJR Am J Roentgenol 1988;151(1):127–31.

119. Mukaka MM. Statistics corner: A guide to appropriate use of correlation coefficient in medical research. Malawi Med J 2012;24(3):69–71.

120. Mittal M, Gupta P, Kalra S, Bantwal G, Garg MK. Short Stature: Understanding the Stature of Ethnicity in Height Determination. Indian J Endocrinol Metab 2021;25(5):381–8.

121. Hur YM, Kaprio J, Iacono WG, Boomsma DI, McGue M, Silventoinen K, et al. Genetic influences on the difference in variability of height, weight and body mass index between Caucasian and East Asian adolescent twins. Int J Obes (Lond) 2008;32(10):1455–67.

122. Radiopaedia.com. https://radiopaedia.org/cases/retrocalcaneal-bursitis.Accessed 28.12.2022. Retrocalcaneal Bursitis.

APPENDICES

Appendix 1: PARTICIPANT INFORMATION SHEET

DATE: 1st February, 2022

PARTICIPANT ID:

HOSPITAL ID:

STUDY TITLE: ULTRASONOGRAPHIC FINDINGS OF THE ACHILLES TENDON IN ASYMPTOMATIC VOLUNTEERS AT THE KORLE BU TEACHING HOSPITAL, ACCRA.

NAME OF INVESTIGATOR: Dr. Harold Ricketts Nixon

I am conducting this study as part of the requirements for the award of Fellow of the Faculty of Radiology, Ghana College of Physicians. I am supported by Dr. Dzefi-Tettey, Dr. Brakohiapa and Dr. Sarkodie; who are all consultant radiologists at the Department of Radiology, Korle Bu Teaching Hospital [KBTH].

Purpose of study:

The purpose of this study is to determine the ultrasound appearance characteristics of the Achilles tendons (AT) in 'asymptomatic' individuals.

Funding:

This research is wholly funded by the researcher.

Procedures:

If you consent to participate in this study; the demographic information in your clinical folder will be captured by the investigator, your height and weight will be measured and an additional ultrasound

examination of your ankles will be done at the end of your regular scheduled scan (e.g. breast scan). This will involve you lying face-down on the examination couch and exposing your ankles.

Benefits:

There may not be a direct benefit to you. However, this study will help us refine our methods for the management of patients with suspected Achilles tendon disease. Thence, optimizing patient care and reducing wastage of time and resources.

Cost:

There will be no additional cost to you; aside from the additional 5-10mins that you will spend doing the Achilles scan at the end of your regular scheduled ultrasound scan.

Payment:

There will be no payment for participation in this study.

Risk:

Participation in this study does not pose any additional risk to you.

Confidentiality:

All the data obtained during the course of this study will be kept confidential. You will be assigned a code by means of which your data will be anonymized. Thus; there will be no personal identifiers attached to the data you provide. Apart from the research team and the Ghana College, no other parties shall have access to the raw data you provide.

Additional Information:

If you do not wish to take part in this study, it will not interfere with your treatment. You may withdraw from this study at any point (even after your ultrasound scan has been performed) for any or no reason. The research team will be happy to review this document and answer any questions you may have.

Who to contact:

This study has been reviewed and approved by the Institutional Review Board of KBTH, which is a committee whose task it is to make sure that research participants are protected from harm. If you wish to find out more about the ethics review committee, please contact the Research Office via email rdo@kbth.gov.gh or Telephone 0302739510 ext. Research Office/Medical Directorate. The researcher may also be reached at the Department of Radiology, Korle Bu Teaching Hospital or on Tel. 0573102942 or at haroldnixon@yahoo.com.

Appendix 2: CONSENT FORM

Study Title: ULTRASONOGRAPHIC FINDINGS OF THE ACHILLES TENDON IN ASYMPTOMATIC VOLUNTEERS AT THE KORLE BU TEACHING HOSPITAL, ACCRA.

Date:

Participant identification number:

Name of Researcher: Dr. Harold Ricketts Nixon

- I can confirm that I have read and understood the information sheet dated 01/02/2022 for the above study.
- I have had the opportunity to consider the information, asked questions and had these answered satisfactorily.
- I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical rights being affected.
- I agree to take part in the above research study.

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Signature/Thumbprint of Participant	**Researcher's Signature**	**Signature/Thumbprint of Witness**

Appendix 3: PRESCREENING QUESTIONNAIRE

STUDY TITLE: ULTRASONOGRAPHIC FINDINGS OF THE ACHILLES TENDON IN ASYMPTOMATIC VOLUNTEERS AT THE KORLE BU TEACHING HOSPITAL, ACCRA.

A. DEMOGRAPHIC AND CLINICAL INFORMATION

1. Date……
2. Participant ID……
3. Age at last birthday…….
4. Gender…….

B. EXCLUSION CRITERIA

Over the past 2 years, have you:

a. Had heel or foot pain during walking, standing, or any activity? [Y] [N]
b. Undergone foot surgery? [Y] [N]
c. Gone to a doctor because of foot complaints? [Y] [N]
d. Had ankle/heel/foot trauma? [Y] [N]
e. Have you been diagnosed with a systemic metabolic and/or inflammatory disease (e.g., ankylosing spondylitis, rheumatoid arthritis, gout)? [Y] [N]
f. Have you engaged in strenuous physical activity (like running, cycling) over the past 72 hours? [Y] [N]

Appendix 4: QUESTIONNAIRE

STUDY TITLE: ULTRASONOGRAPHIC FINDINGS OF THE ACHILLES TENDON IN ASYMPTOMATIC VOLUNTEERS AT THE KORLE BU TEACHING HOSPITAL, ACCRA.

DEMOGRAPHIC INFORMATION

a. Date…….
b. Participant ID……..
c. Hospital identification number……
d. Age at last birthday…….
e. Gender…….
f. Race/Ethnicity…….
g. Occupation…….
h. Which is your dominant hand [R] [L] [NOT SURE]
i. Which is your dominant foot [R] [L] [NOT SURE]

CLINICAL INFORMATION

Date of first presentation…….

Principal complaints at first presentation……

……..

……..

Comorbidities/preexisting conditions....……

Appendix 5: DATA CAPTURE SHEET

STUDY TITLE: ULTRASONOGRAPHIC FINDINGS OF THE ACHILLES TENDON IN ASYMPTOMATIC VOLUNTEERS AT THE KORLE BU TEACHING HOSPITAL, ACCRA.

DEMOGRAPHIC AND CLINICAL INFORMATION

a. Date……
b. Participant ID…….
c. Hospital identification number……
d. Age at last birthday…….
e. Gender…….
f. Race/Ethnicity…….
g. Height (in m) …… weight (in kg) …….
h. BMI……
i. Which is your dominant foot? [R] [L]
j. If answer in 'i' equivocal. Foot used to electively kick the soft ball. [R] [L]

	RT ANKLE				**LT ANKLE**			
AT ECHOGENICITY	NORMAL		DECREASED		NORMAL		DECREASED	
			FOCAL	DIFFUSE			FOCAL	DIFFUSE
AT THICKNESS AT MEDIAL MALLEOLUS	**MEASUREMENTS**							
	1^{ST}	2^{ND}	3^{RD}	**MEAN**	1^{ST}	2^{ND}	3^{RD}	**MEAN**
OTHER FINDINGS Including tears, degeneration, enthesopathy, edema								

Appendix 6: ETHICAL CLEARANCE

In case of reply the number
And the date of this
Letter should be quoted
My Ref. No. KBTH/MD/GS/22
Your Ref. No.....

KORLE BU TEACHING HOS
P. O. BOX KB 77,
KORLE BU, ACCRA.

Tel: +233 302 667759/673034-
Fax: +233 302 667759
Email: Info@kbth.gov.gh
pr@kbth.gov.gh
Website: www.kbth.gov.gh

28th September, 2022

DR HAROLD RICKETTS NIXON
GHANA COLLEGE OF PHYSICIANS AND SURGEONS
FACULTY OF RADIOLOGY
KORLE BU

SCIENTIFIC AND TECHNICAL COMMITTEE APPROVAL
PROTOCOL IDENTIFICATION NUMBER: KBTH-STC 000138/2022

The Korle Bu Teaching Hospital Scientific and Technical Committee (KBTH-STC), on 28th September, 2022, approved your submitted study protocol.

TITLE OF PROTOCOL: "Ultrasonographic Findings of The Achilles Tendon in Asymptomatic Volunteers at The Korle Bu Teaching Hospital, Accra."

This approval requires that you **forward your approved document to Korle Bu Teaching Hospital –Institutional Review Board (KBTH-IRB) for the ethical aspect of the proposal to be assessed before the project can be initiated.**

PRINCIPAL INVESTIGATOR: **Harold Ricketts Nixon**

This STC approval is valid till 30th March, 2023

You may, however, request extension of the approval period, or renewal as the case may be, should the study extend beyond the stated period.

Upon completion, you are required to submit a final report on the study to the STC. This is to enable the STC ensure among others that, the project has been implemented as per the approved protocol. You are also required to inform the KBTH-STC and Research Directorate of any publications that may emanate from the research findings.

Kindly note that, should the need arise, the KBTH-STC or IRB may institute appropriate measures to satisfy itself that study is being conducted according to the highest scientific and ethical standards.

Please note that any modification to the study protocol without Scientific Technical Committee (STC) approval renders this approval invalid.

Prof. G. Obeng Adjei
Chairman, KBTH-STC

Cc: The Chairman, KBTH-IRB

In case of reply the number
And the date of this
Letter should be quoted

My Ref. No. KBTH/MA/03122

Your Ref. No......

KORLE BU TEACHING HOSPITAL
P. O. BOX KB 77,
KORLE BU, ACCRA.

Tel: +233 302 667759/673034-6
Fax: +233 302 667759
Email: Info@kbth.gov.gh
pr@kbth.gov.gh
Website: www.kbth.gov.gh

7th October, 2022

DR HAROLD RICKETTS NIXON
DEPARTMENT OF RADIOLOGY
KORLE BU TEACHING HOSPITAL
KORLE BU

INSTITUTIONAL APPROVAL: KORLE BU TEACHING HOSPITAL-SCIENTIFIC AND TECHNICAL COMMITTEE/INSTITUTIONAL REVIEW BOARD (KBTH-STC/IRB/000138/2022

Following approval of your study entitled "Ultrasonographic Findings of the Achilles Tendon in Symptomatic Volunteers at the Korle Bu Teaching Hospital, Accra" by the Korle Bu Teaching Hospital-Scientific and Technical Committee/Institutional Review Board.

I am pleased to inform you that institutional approval has been granted for the conduct of your study in Korle Bu Teaching Hospital.

Please contact the Head of Department to discuss the commencement date of the study.

Please note that, this institutional approval is rendered invalid if the terms of the Institutional Reviewed Board/Scientific and Technical Committee approval are violated.

Sincere regards,

Dr. Ali Samba
Director of Medical Affairs
For: Chief Executive

In case of reply the number
And the date of this
Letter should be quoted

My Ref. No. KBTH/IRB/138/22

Your Ref. No.....

KORLE BU TEACHING HOSPITAL
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Tel: +233 302 667759/673834-6
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4th October, 2022

DR HAROLD RICKETTS NIXON
DEPARTMENT OF RADIOLOGY
KORLE BU TEACHING HOSPITAL
KORLE BU

ULTRA SONOGRAPHIC FINDINGS OF THE ACHILLES TENDON IN SYMPTOMATIC VOLUNTEERS AT THE KORLE BU TEACHING HOSPITAL, ACCRA

KBTH-IRB 000138/2022

Investigator: **DR HAROLD RICKETTS NIXON**

The Korle Bu Teaching Hospital Institutional Review Board (KBTH IRB) reviewed and granted approval to the study entitled: "Ultra Sonographic Findings of the Achilles Tendon in Symptomatic Volunteers at the Korle Bu Teaching Hospital, Accra"

Please note that the Board requires you to submit a final review report on completion of this study to the KBTH-IRB.

Kindly, note that, any modification/amendment to the approved study protocol without approval from KBTH-IRB renders this certificate invalid.

Please report all serious adverse events related to this study to KBTH-IRB within seven days verbally and fourteen days in writing.

This IRB approval is valid till 30th September, 2023. You are to submit annual report for continuing review.

Sincere regards,

DR. DANIEL ANKRAH
VICE CHAIR (KBTH-IRB)
FOR: CHAIR (KBTH-IRB)

Cc: The Chief Executive Officer, KBTH
The Director of Medical Affairs, KBTH