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OBESITY-INDUCED CHANGES IN TENDON MORPHOLOGY: A COMPARATIVE ULTRASOUND STUDY OF PATELLAR AND ACHILLES TENDONS

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Abstract

Tendons' health is strongly linked to obesity where it leads to alterations such as tendon hypertrophy and decreased flexibility. The patellar and Achilles tendons are two of the prominent structures in the lower limb which are under a lot of stress as far as mechanical and metabolic demand is concerned in the obese population. The present study is designed to measure and contrast the Achilles and Patellar tendon thickness in targeted individuals Obese and Non-Obese subjects and to examine the correlations between BMI and tendon thickness. It also aimed at identifying gender specific variations in the tendon morphology. In this cross-sectional study, the subjects were 218 in total, of which 109 were non-obese with BMI of 18.5 to 24.9 kg/m2 and 109 were obese with BMI≥30kg/m2. Tendon thickness was measured by ultrasonography at specific points of the tendon. The statistical analysis consisted of t-test to compare the tendon thickness and correlation to examine the association between BMI and tendon cross sectional area. Results: It was revealed that the patellar and Achilles tendon thickness was higher in obese subjects when compared with the non-obese subjects ($p < 0.001$). Only moderate positive correlations were observed between BMI and tendon thickness for both tendons ($r=0.59$, $p<0,001$). Also, the gender specific analysis showed that the tendons were thicker in males and this could be explained by hormonal and mechanical factors. These findings indicate that obesity leads to significant structural changes in tendons which is a consequence of mechanical factors as well as systemic inflammation. These findings highlight the need to incorporate ultrasonography as part of the clinical assessment for obese patients specially to identify tendon pathology at the earliest possible time.

Keywords: *Achilles tendon, Obesity-related tendon changes, Obesity, Patellar tendon, Tendon thickness, Ultrasonographic assessment of tendons*

INTRODUCTION

The patellar tendon is a very essential portion of the knee joint. It is the connective point that joins the patella (kneecap) with the tibial tuberosity (1). Because of its responsibility to transmit load through movement it is subjected to considerable mechanical stress and trauma (2). People doing high impact sport activities usually get injured to the patellar tendon. Populations at higher risk include females, obese individuals, and those with muscle weakness (3). These factors lead to anatomical and biomechanical changes in the tendon leading to structural changes that increases injury risk (4).

The Achilles tendon, or calcaneal tendon, is the strongest and longest tendon of the human body (5). It connects gastrocnemius soleus and plantaris muscles to calcaneum aiding in foot plantar flexion and knee flexion. This unique spiral orientation of the fibers of the tendon makes the tendon better able to transmit force efficiently (6). The crescent shaped insertion into the calcaneus dissipated mechanical stress at the tendon bone interface lowering the risk of injury. But the tendon is prone to damage because of certain anatomical features (7). For example, the mid portion of the tendon is hypo vascular in that it receives relatively little (if any) blood perfusion from the peroneal artery, as shown in Figure 1. Its characteristic predisposition to degeneration and rupture is aggravated in the middle aged (8). The proximal and distal regions are better vascularized than the turricula, with blood supplied by the posterior tibial artery and to the musculotendinous junctions (9).

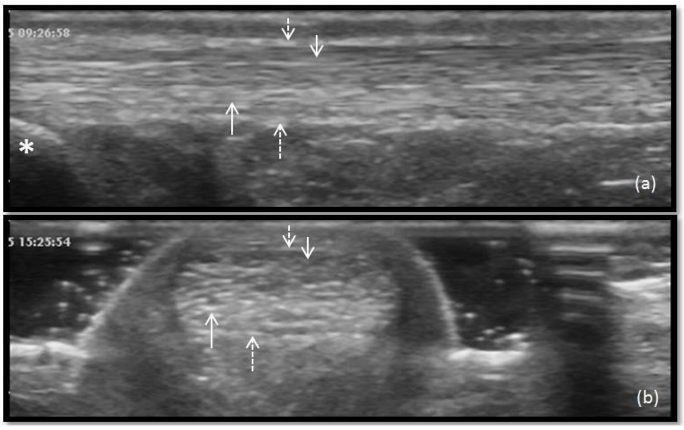

Fig. 1. (a) Normal tendons (b) Inflamed tendons

Gender based differences in fat distribution that predispose into Achilles tendon pathology have been observed in research. Greater fat (central) accumulation among male and greater distribution (peripherally) among women is associated with asymptomatic tendon changes. This observation is consistent with a role for systemic inflammation or dyslipidemia in tendon degeneration (10). Two primary mechanisms are: during movement, this excessive stress on tendons results in micro damage and structural changes because of increased body weight and proinflammatory mediators, or adipokines, are secreted adipose tissues which further exacerbate tendon degeneration. Chronic inflammation in tendinopathy is a condition called 'adiposopathy' or 'sick fat syndrome' (11).

The World Health Organization (WHO) provides distinct BMI classifications for general and Asian populations, highlighting the role of regional and genetic differences in obesity-related health risks as seen in Table I.

Table I. BMI classification

BMI classification (General)	WHO classification (Asian)
Ideal (18.5-24.9 kg/m^2)	Ideal (18.5-23 kg/m^2)
Underweight (<18.5 kg/m^2)	Underweight (<18.5 kg/m^2)
Obese (≥30kg/m^2)	Obese (≥27kg/m^2)
Overweight (25.0-29.90 kg/m^2)	Overweight (23-27.5 kg.m^2)

These classifications aid the delineation of populations at specific risk for obesity related tendon conditions (12). US have become a first line modality for evaluating tendon pathology, with the ability to provide real time dynamic imaging of the musculoskeletal structures. US in evaluation of patellar tendinopathy reveals hallmark changes: tendon thickening, disruption of the normal fibrillar pattern, hypoechoic regions representing degeneration (13). The appearance of neovascularization in and around the tendon supportive of increased vascular activity can be detected by Doppler imaging (14). Compared to magnetic resonance imaging (MRI), ultrasound offers several practical benefits: affordability and portability, dynamic visualization of structures allows assessment of tendon movement and subluxation, and patient friendliness option as it does not involve ionizing radiation (15).

While all these have advantages, ultrasound is limited by high operator dependency that can therefore affect diagnostic accuracy. One limitation we attempt to overcome with this limitation is the need for comprehensive training and standardized protocols (16). Evaluation of tendons is complicated by artefacts such as anisotropy and refraction. Ultrasound beam anisotropy arises when the ultrasound beam intersects with the tendon at a non-perpendicular angle and the tendon appears hypoechoic and mimics pathology. The misinterpretation of any signal depends critically on proper beam orientation. Just like, refraction artefacts may produce false shadow effects, and hence the importance of good scanning techniques (17). The tendinopathies are multifactorial disorders occurring in mechanics, inflammation, and degenerative processes. When combined with mechanical overload, excess weight heightens tendon damage in obesity, due to systemic inflammation. Exercise is important for tendon repair, but it's important not to overdo it and with excessive high intensity activity, that can actually worsen the condition. Management effective requires management of both the mechanical and metabolic risk factors (18). MRI is still the gold standard in tendon assessment, however ultrasound is becoming increasingly popular due to the practicality factor. Nevertheless, operator dependency and variability in diagnostic accuracy restricts its usage.

This study aims to review the interobserver variability of ultrasound and MRI in tendinopathy assessment. It will provide standard protocols of ultrasound imaging and it will find out necessities of training systems to make it consistent and reliable. The research aims to close the gaps mentioned above by establishing ultrasound as the principal diagnostic tool for tendinopathies, and facilitating saving in healthcare costs and improving patient outcomes. To use ultrasonography to assess and compare the thickness of the Achilles and patellar tendons in obese and non-obese people.

METHODOLOGY

STUDY DESIGN, STUDY SETTINGS AND SAMPLE COLLECTION

This study used cross-sectional comparative design to compare and evaluate the thickness of obese and non-obese, individuals with the use of sonography regarding patellar and Achilles tendons. This approach allowed for differentiation between these two groups based on BMI category regarding their tendon thickness. Measurements of tendon were the primary diagnostic modality used during ultrasound imaging. The research was done in Al-Aziz Surgical Hospital, Chakwal, Pakistan. This imaging facility has the most up-to-date imaging technology available including state of the art ultrasound systems capable of high-resolution musculoskeletal evaluation. All of the ultrasound procedures and data collection was done in the hospital's radiology department. The study lasted nine months, from December 2023 to August 2024. We recruited patients by taking approval, collected data and imaged patients.

Sample Size

The sample size was determined using the formula:

$$n = \frac{\left(Z_1 - \frac{\alpha}{2} + Z\beta\right)^2}{d^2} \cdot \sigma^2$$

Where:

$Z\alpha/2$: Z-value corresponding to a 95% confidence interval.

$Z\beta$: Z-value for study power of eighty percent.

d: Effect size.

σ: Standard deviation for width of tendon derived from previous studies.

The method of opportunistic sampling was used to enlist participants. This approach eased the availability of volunteers who visited the hospital and provided efficient data within the assigned period of time. Samples were selected based on following inclusion and exclusion criteria. The inclusion criteria contain; adults both genders (18-64years), participants (obese) with BMI > 30 kg/m2 and non-obese with BMI between 18.5 and 24.9 kg/m2, and individuals with consent. Participants with history of tendon injuries, surgeries or rupture which involves the patellar or Achilles tendon, patients with inflammatory or degenerative joint disorders, individuals without consent and pregnant women were excluded from the study.

EQUIPMENT AND DATA COLLECTION

The primary imaging device was Zureo 100 mega transducer with primary ultrasound system. This system facilitated high-resolution imaging for detailed assessment of the patellar and Achilles tendons. Participants were positioned in such a way that their knees were partially flexed in order to take optimized image. The patellar tendon was measured in the longitudinal section at two specific sites by using a high-frequency transducer. This ensured the minimal compression of the tendon during examination: 1 cm distal to the patellar bone-tendon junction and 1 cm proximal to the tibial bone-tendon junction. The Achilles tendon was assessed with the participant lying prone on an examination table, with feet hanging off the edge to allow slight ankle dorsiflexion. Ample transmission gel was applied to enhance imaging quality. Thickness measurements were taken longitudinally at two locations: At the insertion point of the tendon on the calcaneus bone and 3 cm proximal to 1st measurement.

Both longitudinal and transverse plane imaging was utilized to examine tendon uniformity, echogenicity, and morphology. Special attention was given to identifying abnormalities in tendon appearance. SPSS version 23 software was used for the analyzation of measurements of ultrasound. Mean and standard deviation was calculated along with other statistics for width of tendon. T-tests were used for independent samples to compare width of tendon among obese and normal individuals. P-values smaller than 0.05 were taken as significance in statistical analysis.

MATERIALS

Data, including clinical history and sonographic measurements, were systematically recorded and analyzed for intergroup comparisons. This study included 218 participants in total, equally divided into two groups: BMIs of ≥ 30 kg/m2 in 109 obese individuals and BMIs of 18.5–24.9 kg/m2 in 109 nonobese individuals. Age of the patients ranged from 18 to 64 years with mean age 43.1 ± 12.4 years. Gender-wise no significant variations was seen as p-value < 0.001 in Table II.

Table II. Clinical characteristics of obese and Non-obese participants

Characteristic	Obese (n = 109)	Normal (n = 109)	P-Value
Age (in years)	44.0 ± 12.9	42.2 ± 11.8	0.623
Gender (males and females)	55 males 54 females	54 males 55 females	0.798
BMI in kg/m²	32.1 ± 3.5	22.2 ± 1.8	< 0.001

Ultrasound imaging was used to measure the width of both of the tendons in obese and normal groups. The results showed that obese group had thicker tendons for both anatomical locations. In the given Table III, the results for patellar tendon thickness measurements are defined. At 1 cm away from the patella, obese candidates had thicker tendons (6.4 ± 0.7 mm) than non-obese candidates (5.0 ± 0.6 mm, p < 0.001). Similarly, at 1 cm closer to the tibia, thickness of tendons in the obese group was noted to be thicker 6.2 ± 0.6 mm, whereas it was only 4.8 ± 0.5 mm in the non-obese group while the p-value for both was <0.001.

Table III. Patellar tendon width measurements

Measurement Point	Obese (Mean ± SD)	Normal (Mean ± SD)	P-Value
1 cm away from patella	6.4 ± 0.7 mm	5.0 ± 0.6 mm	< 0.001
1 cm closer to the tibia	6.2 ± 0.6 mm	4.8 ± 0.5 mm	< 0.001

In the given Table IV the results for Achilles tendon thickness measurements are defined. Measurements at the heel attachment indicated that the tendons in obese individuals were thicker (7.0 ± 0.5 mm) than their nonobese counterparts (5.7 ± 0.4 mm, p < 0.001). The obese group tendons were significantly greater at 6.9 ± 0.6 mm at 3 cm proximal to the myotendinous junction compared to the measurement of the non-obese group at 5.5 ± 0.5 mm. The p-value for both was <0.001.

Table IV. Achilles tendon width measurements

Point of Measurement	Obese patients (Mean ± SD)	Non-obese patients (Mean ± SD)	P-Value
At heel attachment	7.0 ± 0.5 mm	5.7 ± 0.4 mm	< 0.001
3 cm proximal to 1st measurement	6.9 ± 0.6 mm	5.5 ± 0.5 mm	< 0.001

Measurements of width in the tendons (Patellar and Achilles) were found to be significantly different between the obese and non-obese groups by performing independent t tests (p < 0.001 for all comparisons). Additionally, BMI and tendon thickness were found to be moderately positively correlated (r = 0.59, p < 0.001). This indicates that tendon thickness increases as BMI increases in both the regions. In Fig.2, the graph shows the measurement of thickness of Achilles and patellar in both obese and non-obese patients.

In short, these results define that thickness of tendons is notably higher in obese patients than in normal patients. Hence obesity is directly related with thickness of tendons. These results also suggest that ultrasonography is an effective imaging modality for detecting these alterations. The gender-specific variations showed that males tend to have thicker tendons than females.

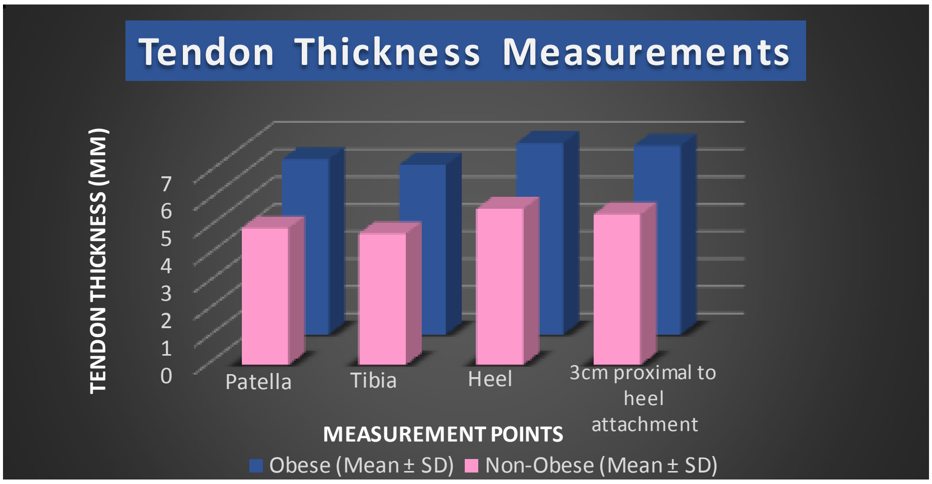

Fig. 2. Tendon thickness measurement graph

DISCUSSION

In this present study it was found that obesity do have a relationship with greater tendon thickness for both the patellar and Achilles tendons supporting the fact that an increased BMI causes significant change in tendons. The results identified elevated tendons of the obese subjects as compared to the non-obese controls time and again, with variations being highly significant at all the measures. These results suggest that not only obesogenic mechanical loading but also metabolic factors can cause structural alterations in tendons and provide important pathological information on tendons under obesity. The patellar and Achilles tendons are the essential link with load-bearing characteristics and are dependent on forces during activity (19). Since the latter structure carries the increased mechanical load resulting from excess weight of the body, in obese individuals, it produces hypertrophic changes. It is a form of adaptative mechanism used to ensure the structural experiences higher stress (20). Thus, long-lasting contact with mechanical load may provoke adaptive changes that are pathologically expressed in microtrauma, decreased elasticity, and tendinopathy. These findings support the original proposition that tendon hypertrophy in obesity is adaptive but potentially pathogenic when protective responses are overcome. These metabolic changes can add to mechanics stress in obesity for changed tendons (21). A condition of chronic low-grade inflammation is due to increased concentration of pro inflammatory cytokines. The findings of the present study add to the existing evidence that metabolic changes ensuing obesity cause aberrant tendon structure and biomechanics (22).

Males were also found to have thicker tendons than females in this study based on all the BMI groups (23). To a certain extent, these results support other works estimating that tendon changes are gender-specific because of hormonal effects, muscle, and Calvin's physiological and athletic activities (24). Males may have higher tendon collagen synthesis and hypertrophy through testosterone and females may have changes in tendon structure through estrogen increased collagen turnover and increased elasticity (25). Knowledge of these differences is crucial in differentiating and examining effective approaches to tendons in each sex and subsequent design of appropriate gender-oriented treatment approaches (26). The conclusions obtained in the present study are in accordance with the previous data on repeatedly revealed connection between obesity and thickened tendons. Similar hypertrophic changes at the tibial insertion site were observed by one study among the obese subjects who also showed signs of hypertrophy of the patellar tendon due to mechanical overload and systemic inflammatory processes. This study builds upon those observations by adding the Achilles tendon to the analysis, thus giving a more comprehensive view of the biomechanical and metabolic load factors on several weight-bearing tendons in obesity (27). Additional support for the study results can be derived from one study that noted that large clients have thicker tendons, less echogenicity and structural failures. These changes were associated with perturbed collagen structure, common for obesity-induced metabolic abnormalities (28). Likewise, a study highlighted that tendon pathologies in obese patients are likely to be up to six times more susceptible to develop because the obese apply more mechanical stress on tendons as well as disturb the homeostatic balance in the tendon (29). These studies support the current study by emphasizing mechanical and metabolic influence in tendon morphology.

On the same note, this affirms the need to consider both biomechanical a metabolic factor in the assessment of tendon status. Gender differences reported in the current study are well in agreement with other studies. Research has shown some differences about tendon structure with sex, due to hormonal and biomechanical factors and the amount of loading disparity between men and women as cited in two studies (30,31). The greater tendon thickness seen in males in the current study could be attributed to the testosterone anabolic effect that enhances collagen deposition and the greater muscle pull to tendon forces in view of increased muscle mass (32). Concerning the nature of estrogen interaction with collagen synthesis and turnover and with tendon elasticity and viscoelasticity, it is possible to explain the relatively higher tendon diameter in male animals and the thinner tendons in female animals (33). Although, mechanical loading is proposed by several studies, including the present one, a research described that, compared to peripheral fat deposition in females, central fat distribution, typical for males, is linked to greater tendon pathology. This more complex understanding of fat location and metabolic effects also strengthens the case for gender-targeted strategies concerning tendon (34). Infact, one study observed smaller ACLs in diabetic obese patients than in the control group. This difference could be explained by differences in approaches used, sample size used in the studies and imaging methods used among others. Employing MRI, a study stopped short of comprehensively evaluating fiber architecture, whereas the present study employed ultrasonography to visualize tendon morphology with a higher spatial resolution (35).

Further, the study extends the literature of osteoarthritis diagnosis using ultrasonography as a dependable technique. An earlier study defined the time-honored benefits of ultrasonography over MRI for tendon studies, especially in looking at super-facial structures like the patellar and Achilles tendons (36). These results provide the ultrasonography evidence to validate its feasibility in clinical application, reaffirm its position as the preliminary imaging tool for tendon assessment especially in resource limited regions (37). Mechanical as well as metabolic factors have been focused in this study which is in synergy with the incumbent literature in recognizing obesity-induced tendon modification to be poly factorial. In one study, authors wrote the opinion that systematically activated inflammation in conjunction with biomechanically changed loading and decreased collagen synthesis represents a combined tendon load that results in tendon structure and function degradation (38). As an extension of previous literature, this study not only demonstrates the multifactorial influences in patellar tendon and Achilles tendon, but also includes both of them in the analysis. This study confirms the practical applicability of using ultrasonography as an imaging technique for evaluating tendons. Hence, due to its noninvasive and inexpensive, ultrasonography can be adopted for regular check up on high risk groups which include the obese (39). Another advantage is its capacity to promptly assess changes in tendon thickness, which may be useful in preventing further evolution to the stage of a symptomatic tendinopathy. Weight loss and management of obese through strict diet and exercise remain strategic options in the conquering of tendon stress. Research also indicates that low number fat loss may decrease tendon loading, stabilize or enhance collagen synthesis and turn over, and contrast irritation which is favorable for the functioning of tendons (40). There is also evidence that planned rehabilitation strategies involving tendon-friendly activities, including swimming, cycling or aquatic exercises, may enhance tendon loading tolerance without producing further mechanical irritation. Odd targeted exercises stand out as beneficial for increasing tendon mass and compliance, thus becoming an important part of the primary and secondary prevention and treatment programs (41).

However, the study does not offer the evidence to prove causality between BMI and tendon thickness. Successfully translating these findings into interventions to improve tendon health and function, requires long-term, repeated measures studies to evaluate the dynamics of these changes and their modifiers. The experiment carried out in the current study did not investigate the functional consequences of these structural alterations in tendons, including the stiffness, elasticity, or biomechanical properties. Thus, realized via the non-probability convenience sampling, the research risks only limited generalization of the results to the population. More studies must be carried out to understand tendons' hypertrophy process in obesity, especially with reference to inflammation, collagen synthesis, and degradation, and extracellular matrix. Future observational studies comparing the effects of weight loss, exercise and various pharmacological treatments on tendon health are likely to form the basis for developing future prevention and treatment strategies.

CONCLUSION

The study was based upon how obesity causes effect on patellar and Achilles tendon thickness by employing ultrasonography. As for the two melanoma genes, the results showed that obesity affects the morphological characteristics of tendons, with significantly increased tendons thickness among obese people compared with non-obese individuals. Characteristics of obesity itself and concomitant metabolic disturbances as well as mechanical overload of organs were also found to play a role in these changes. The findings of this study showed that ultrasonography is a suitable noninvasive technique to evaluate tendon morphology and identify initial structural modifications. It also extended gender differences to the results of the tendon's thickness; males had a significantly higher tendon thickness than females, which means that gender should be considered in clinical evaluations and interventions. In all, this work emphasizes obesity as a reversible risk factor in musculoskeletal well-being and offers a window into the nature of tendons biomechanical and metabolic loading.

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