ORIGINAL ARTICLE

Sonoelastographic Assessment of the Gender-related Changes of Achilles the Tendon

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ABSTRACT

Objective: *To assess the gender-related differences in the elasticity and thickness of the Achilles tendon among healthy young participants.*
Methods: *A total of 48 volunteers, who were healthy adults between the ages of 20 and 25 years, were included in this study. The metabolic equivalent (MET) scores, tendon thickness and shear wave velocities (SWVs) were compared between the males and females.*
Results: *The median age of the males was 24 years and that of the females was 23 years. The mean body mass index (BMI) score was 22.22 ± 1.92 kg/m^2 among the males and 21.84 ± 2.29 kg/m^2 among the females. The median MET score of both the males and the females was 4. The median SWV was found to be 4.76 m/s in the males and 4.77 m/s in the females. There was no statistically significant difference in age, BMI, MET scores and SWV values between the males and the females (*$p = 0.349$*,* $p = 0.537$*,* $p = 0.923$ *and* $p = 0.578$*, respectively). The mean thickness of the Achilles tendon was found to be statistically significantly higher in the males than in the females (4.47 ± 0.41 mm and 4.03 ± 0.44 mm, respectively) (*$p = 0.001$*).*
Conclusion: *The effect of gender on the Achilles tendon's elastic property is not a significant covariate in the young, healthy sample. Muscle strength may play a more important role in the Achilles tendon's injury rather than in tendon's elasticity.*

Keywords: Achilles elastography, gender

INTRODUCTION

The Achilles tendon is the thickest and most robust tendon in the body. Additionally, the Achilles tendon is also the tendon that ruptures most commonly. During a run, nearly 12.5 times of the bodyweight is loaded on the Achilles tendon, which explains the high rate of injury to the tendon (1, 2). Tendon injury may be linked to many factors, but frequently occurs due to excessive load on the tendon during activities. Both external (training and equipment) and internal (anatomical conditions or systemic diseases) conditions affecting the Achilles tendon had been described (3, 4).

One of the anatomical conditions is tendon elasticity. The elasticity of the Achilles tendon determines its elastic strain energy storage and release (5). As a result of this mechanism, the economy and performance of motion are ensured (5, 6). Previous studies showed that tendon elasticity decreased with age (7, 8). A decrease in tendon elasticity is related to increased tendon injury (6, 9). Additionally, it is known that tendon injury is higher in males than that in females (6, 10). It is also not clear whether tendon damage in males is due to the differences in muscle strength or tendon elasticity.

Currently, tendon elasticity can be measured ultrasonographically with different methods like 'real-time elastography and shear wave elastography'. Shear wave is a new elastography technique that does not require manual compression reducing the dependence on the user and allowing quantitative evaluation. There are a number of studies which had shown that mechanical properties and metabolism in tendon are different in men and women. In these human studies, variable methods such as the tendon biopsy investigation and ultrasonography (US) were used (6, 10–12). To the best of our

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knowledge, there are only two studies on elastography comparing the Achilles tendon's elasticity based on gender in adults with a wide age range (8, 13).

In our study to examine the effect of gender differences on Achilles tendon's elasticity, Achilles tendon was evaluated sonoelastographically in healthy individuals from 20 to 25 years of age with similar levels of physical activity.

MATERIALS AND METHODS

Setting and study sample

This observational study was conducted at the ultrasonography unit, which had been in service for 23 years, and serves approximately 25 000 patients annually, at the department of radiology at a university hospital in Turkey. The study was approved by our institution's human research ethics committee. Informed consent was obtained from all the participants. The minimum required sample size was 42 (21 males, 21 females) for Student's *t* test and Mann–Whitney *U* test, with a 0.05 of α error, a 0.80 of power ($1-\beta$ error), and a 0.80 of effect size. The volunteers were recruited from the medical students as healthy adults between the ages of 20 and 25 years. Their levels of physical activities were calculated with metabolic equivalent (MET) scores according to the American College of Sports Medicine guidelines (14). Individuals with chronic disease, trauma, previous orthopaedic surgery, history of peripheral artery disease, body mass index (BMI) outside of the normal limits (lower than 18.5 kg/m^2, greater than 24.9 kg/m^2) and MET scores > 6 and < 3 were excluded from this study. A total of 48 volunteers (24 males, 24 females) were included in this study (Fig. 1).

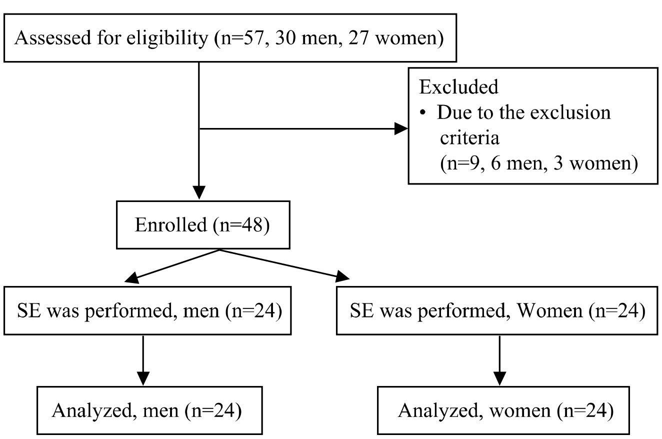

Figure 1: Flow diagram of the study.

Ultrasound technique

All the volunteers were subjected to the US examination involving the use of a Siemens Acuson S3000 ultrasound system equipped with the virtual touch tissue imaging quantification (VTIQ) software (Siemens Medical Solutions, Mountain View, CA, USA). The examinations were done in a relaxed position on the right Achilles tendon while the volunteer was lying prone with his/her feet hanging freely down the side of the table (Fig. 2). A 9 MHz transducer was equipped for B-mode ultrasound and elastography examinations. The probe was moved gently with no downward pressure and was held perpendicular to the tendon while performing the examination to avoid anisotropy. The Achilles tendons were divided into three parts during the examination: proximal third (musculotendinous junction), the middle third (2–6 cm above the insertion) and the distal third (15). The middle third of the Achilles tendon, which is a more hypo-vascular part of the tendon, was used for the measurements (16, 17). To standardize the shear wave velocities (SWVs) measurements, the sites that were approximately 4 cm above the insertion on the calcaneus were selected as the regions of interest (ROI) (Fig. 3).

Figure 2: B-mode imaging of the right Achilles tendon in a state of relaxation in a healthy 24-year-old man.

The anteroposterior dimension of the tendon in the B-mode, was measured as the tendon's thickness. The size of the VTIQ measuring box was adjusted to include the tendon and the surrounding tissue. The size of ROI was 1.5 × 1.5 mm^2 which is specified by the manufacturer. For each tendon, six ROIs were identified, and the mean SWVs of the ROIs were taken. The B-mode estimations included the tendon's thickness, homogeneity and structural abnormalities. The size of the VTIQ measuring box and the location of the ROIs were adjusted by the consensus of two radiologists who had more than 5 year experience.

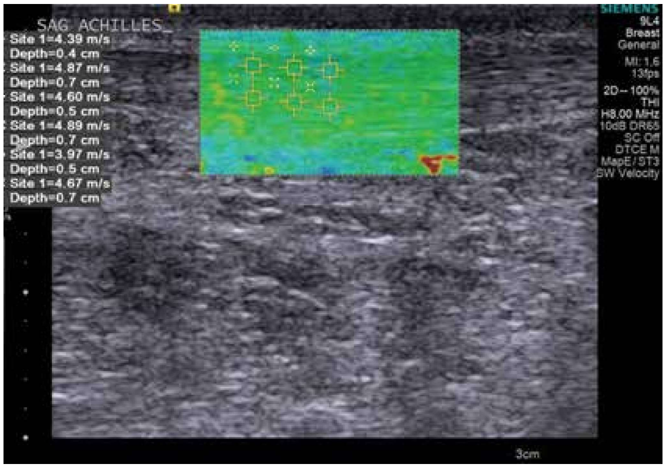

Figure 3: The shear wave velocities measurement of the right Achilles tendon in a state of relaxation with virtual touch tissue imaging quantification.

Statistical analyses

The G*Power 3 (Erdfelder, Faul, and Buchner, 1996) was used for determining the sample size (18). For the statistical analyses, the SPSS for Windows version 19 software package (SPSS Inc., Chicago, IL, USA) was used. The descriptive statistics of the continuous variables were given as the means and standard deviations, or as the median and the interquartile range (IQR). The Shapiro–Wilk test was used to test the normality of the data. The student's *t*-test was used for two group comparisons of the normally distributed variables, and Mann–Whitney *U* test was used for the non-normal distributed variables.

RESULTS

The baseline characteristics and the B-mode findings of the volunteers are presented in Table. The median age of the males was 24 years (IQR: 27.75–23.00) and that of the females was 23 years (IQR: 24.75–22.25). The mean BMI score was 22.22 ± 1.92 kg/m^2 among the males and 21.84 ± 2.29 kg/m^2 among the females. The MET score of the males was 4.00 (IQR: 5.00–3.25) and that of the females was also 4.00 (IQR: 5.00–3.25). There was no statistically significant difference in the age, BMI and MET scores between the males and the females (p = 0.349, p = 0.537 and p = 0.923, respectively) (Table).

On the B-mode examination, the mean thickness of the Achilles tendon was found to be statistically significantly higher in the males than that in the females (4.47 ± 0.41 mm and 4.03 ± 0.44 mm, respectively) (p = 0.001). The median of the SWVs was 4.76 m/s (IQR: 5.61–4.47) in the males and 4.77 m/s (IQR: 5.26–4.41) in the females. The SWVs scores were statistically similar between the males and the females (p = 0.578) (Table).

Table: Baseline characteristics and the B-mode findings of the participants

	Male (n = 24)	Female (n = 24)	*p*
Age (years), median (IQR)	24.00 (27.75–23.00)	23.00 (24.75–22.25)	0.349*
BMI (kg/m^2), mean ± sd	22.22 ± 1.92	21.84 ± 2.29	0.537**
MET score, median (IQR)	4.00 (5.00–3.25)	4.00 (5.00–3.25)	0.923*
Tendon thickness (mm), mean ± sd	4.47 ± 0.41	4.03 ± 0.44	0.001**
SWVs (m/s), median (IQR)	4.76 (5.61–4.47)	4.77 (5.26–4.41)	0.578*

*Mann–Whitney *U* test was used for comparison; **Student's *t*-test was used for comparison.
BMI = body mass index; MET = metabolic equivalents; IQR = interquartile range; sd = standard deviation; SWVs = shear wave velocities.

DISCUSSION

Epidemiologic studies showed that men had a higher risk than women of getting lower limb tendon's pathologies and Achilles tendon's rupture (19, 20). Both the differences in muscle strength and sex hormone effects on the tendon's elasticity were shown to be the reason for the gender differences in Achilles tendon's pathology (6, 10, 21–24).

It is known that by the alteration of gene expression, sex hormone has effects on the soft tissues (25, 26). Some studies had identified oestrogen receptors in the tibial and flexor digitorum longus tendons (25). On the other hand, sex hormone receptor expression has not been directly studied in Achilles tendons and the effect of sex hormones on the Achilles tendon is still controversial. Wojtys *et al* showed that during the ovulatory phase when the oestrogen levels are most elevated, the incidence of anterior collateral ligament rupture increased and also further they added that using oral contraceptives decreased the injury incidence peak observed during the ovulatory phase (27, 28). Additionally, another study by Lee *et al* revealed evidence that oestrogen reduced fibroblast synthesis (29). This may indirectly reduce collagen density in the tissue and resistance to tissue injury. Despite the fact that tendons differ from ligaments in terminology, both of them have a similar hierarchical structure and mechanical function. However, Burgess *et al* reported that there was no difference in the mechanical properties of medial gastrocnemius and the patellar tendon with acute fluctuations in either the progesterone or the oestrogen (30, 31). Likewise, Bryant *et al* showed that acute fluctuations in plasma oestrogen during the menstrual period did not change the Achilles tendon's strain management (32).

In our study, our results showed that with homogeneous age distribution and physical activities, the Achilles tendon elasticity of the young volunteers did not vary linked to their gender. This showed that the sex hormones' effect on the Achilles tendons elastic property was not a significant covariate in the young healthy sample. The effect of external and internal risk factors on muscle strength might play a more important role in the tendon's elasticity and biomechanics rather than hormonal effects. Further work to resolve tendon's injury risk factors may provide better insight into why these injuries occur less frequently in women.

Similar to our results, Muraoka *et al* found that there was no gender-related difference in the mechanical properties of the Achilles tendon (6). They indicated that the difference in the Achilles tendon's mechanical properties between men and women was correlated to the difference in their muscle strength and not to their gender. Morrison *et al* compared 10 male and 10 female cyclists who had overlapping ranges for mass and height, and they reported that their Achilles tendon's stiffness varied with their muscle strength and not their gender (24).

In a recent study, which primarily investigated the age-related alterations in the Achilles tendon using sonoelastography, with a study group consisting of both women and men, it was found that there was a significant positive correlation between their age and Achilles tendon's thickness (7). However, the authors did not evaluate the association between gender and tendon's thickness. Ruan *et al* used the virtual tissue quantification (VTQ) sonoelastography technique to evaluate the gender- and age-related changes in the Achilles tendon (8). They reported that, there were significant differences between the different age groups, but there were no significant differences between the men and the women in any age group. VTQ provides a single-point SWV measurement, whereas VTIQ displays a colour-coded two-dimensional SWV map, allowing the measurement of SWV in multiple locations. VTQ is used with 5×5 mm^2 ROI so that neighbouring soft tissue enters the measurement field of the evaluated tendon. The entry into the measurement field of the surrounding soft tissue causes serious variation in the mean velocity values linked to the tendon's thickness.

With the VTIQ method, a 1.5×1.5 mm^2 ROI is used, so optimal measurements can be made within the area of interest of the user. In a more recent study by Fu *et al* with 326 healthy volunteers older than 18 years of age, the Achilles tendon's thickness was found to be positively correlated with age in the men and women, and it was larger in the men than in the women in all the age groups (13). The authors also reported that, the SWV of the tendon in the sagittal section decreased slightly with age, but there were no significant differences between the men and the women in any group.

Kubo *et al* studied the viscoelastic properties of the tendon of the medial gastrocnemius muscle among men and women, and they found that the maximum strain was significantly greater and the stiffness and Young's modulus were significantly lower in the women than in the men (10). They concluded that there were gender differences in the viscoelastic properties of tendon structures, which might explain the performance differences between males and females. In a recent mice study, while the Achilles tendons were found 6% larger in the male than in the female mice, and the cell density of the female mice was 19% greater than that of the males, tendons had very similar mechanical properties and biochemical composition in the males and the females, with small increases in some extracellular matrix proteins and proteoglycans evident in the female tendons (33).

This study has many limitations. It was a single-centred, prospective analysis with a relatively small sample. This might affect the external validity of the results. Instead of laboratory tests, oral interview was used to rule out concomitant diseases and metabolic disorders of the volunteers. This method produced a limited source of information in terms of the diseases in which people had not yet been diagnosed or known. All elastography techniques, including VTIQ, are US-based techniques; hence, they have all the limitations of the ultrasonography such as operator dependence. To avoid operator dependence, two radiologists, who were highly experienced in the field of musculoskeletal imaging, performed the sonoelastography. Also, the ultrasonographers were blinded to each other's results. To assess the interobserver agreement, 20 randomly selected volunteers were re-examined, and it was found to be excellent with a K index of 0.90.

CONCLUSION

The effect of gender differences on the Achilles tendon's elastic property was not a significant covariate in this study's young, healthy sample. Muscle strength might play a more important role in Achilles tendon's injury rather than in tendon's elasticity. To investigate the gender effect on Achilles tendon's stiffness by VTIQ, further studies with larger sample sizes are needed.

AUTHORS' NOTE

EC conceived the manuscript, oversaw the data collection, conducted the data analyses, wrote the manuscript and approved the final version. IIO participated in the study design, data analyses and interpretations, critically revised the manuscript and approved the final version. The authors declare that they have no conflicts of interest.

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