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ORIGINAL ARTICLE

The Immediate Effect of Cumulative Transverse Strain via Exercise on the Achilles Tendon in Individuals with and Without Flat Feet

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Background: Flat feet change lower extremity alignment, and it may change the load distribution on Achilles tendon during exercise. The purpose of the present study was to investigate the immediate effect of cumulative transverse strain via resistive ankle plantarflexion exercise on the Achilles tendon in individuals with flat feet.

Methods: Fourteen individuals with flat feet and 14 age-matched individuals with normal foot posture were enrolled in the present study. Achilles tendon thickness was measured by an ultrasonography device with a linear probe at 3 points: 1 cm (AT-1), 2 cm (AT-2), and 3 cm (AT-3) proximal to the superior aspect of the calcaneus. Ultrasonography measurements were performed before and after participants completed 90 repetitions of double-leg calf raise exercises which included moving the foot from full ankle dorsiflexion to full ankle plantarflexion.

Results: Achilles tendon thickness at all points measured was thinner in the flat feet group at both pre- and post-exercise conditions compared with that of the control group ($p<0.05$). Achilles tendon thickness at AT-1, AT-2, and AT-3 decreased after the exercise in both groups ($p<0.001$). The differences in Achilles tendon thickness at all points measured between pre- and post-exercise conditions were lower in individuals with flat feet than those of the control group ($p<0.05$).

Conclusion: There was a significant decrease in Achilles tendon thickness after exercise in both groups; however, the tendon thickness markedly diminished in individuals with normal foot posture. The results are thought to result from changes in tendon structure and in load distribution on the Achilles tendon.

Flat feet (FF), also known as pes planus, are one of the most prevalent foot abnormality in adults, characterized by decreased medial longitudinal arch height and the dorsiflexed and abducted forefoot[1]. FF are caused by a wide variety of factors including body composition[2], foot intrinsic and extrinsic muscle weakness[3], foot and ankle injuries[4], hereditary features[5], iatrogenic variables[6], pregnancy[7], and neurological problems[8]. On the other hand, FF could lead to insufficient foot function such as failure in body weight support or alteration in force distribution[9], and it is associated with foot pathological conditions such as metatarsalgia[10] or plantar fasciitis[11] as well as Achilles tendinopathy[12]. There are some biomechanical approaches to explain the relationship between FF and Achilles tendon (AT) pathologies. Excessive foot pronation related to FF creates a torsional or whipping action on the AT as foot rotates quickly from a supinated position at heel strike to an excessive pronated position in mid-stance[13]. This recurrent whipping phenomenon could cause microtears in the tendon, and it could trigger an inflammatory process in AT[14,15]. In addition, this whipping phenomenon is thought to result in vascular blanching of the midportion of the AT, and it results in vascular damage and degenerative processes in the AT[15]. Furthermore, FF cause an increase in hindfoot valgus because of reduced medial longitudinal height, and they change the load distribution on the AT

[16,17]. It is widely believed that tendinopathies are overuse injuries caused by the inability of the tendon to adapt to loading conditions[18]. Theoretically, above-mentioned changes in the tendon have the potential to alter the AT structure and/or morphology over time. There are very limited studies investigating the changes in AT morphology in individuals with FF. These studies reported that adults[19] and children[20] with FF had lower AT thickness compared to control group. The decrease in AT thickness is thought to result from decreased load on the AT [19,20]. However, to our knowledge, there is no study which investigated the immediate response of the AT to cumulative transverse strain via exercise in individuals with FF. Changes in tendon thickness due to loading via exercise provide important information about changes in tendon structure such as deficiency in tendon extracellular matrix or collagen fibril disorganization [21-24]. In theory, tendon structure changes impair the fluid movement with the application of tensile load, and fluid movement impairment is manifested by less reduction in tendon thickness against loads via cumulative transverse strain[21,25-27]. The immediate response of the AT that occur in the tendon against loads via cumulative transverse strain can provide important information about the abnormal loads in AT and/or change in the tendon structure in individuals with FF. Therefore, the aim of the present study was to investigate the immediate effect of cumulative transverse strain via resistive ankle plantarflexion exercise on the AT, and to compare the results with individuals with normal foot posture. Another aim of the study was to expose the effects of FF in morphological features of the AT. We hypothesized that (1) AT

thickness will be lower in individuals with FF, and (2) the amount of decrease in AT thickness will be less after cumulative transverse strain via exercise in participants with FF compared to the control group.

Materials and Methods

Participants

A total of 28 individuals (6 males and 22 females) between ages of 20 and 38 years (23.5±5.1 years) were included in this study. The Navicular Drop Test (NDT) and the Foot Posture Index (FPI) were used to decide whether individuals had FF. The NDT and the FPI were reported as reliable and valid in identifying FF in adults[28-30]. Participants with an FPI score between 0 and 5 were considered to have normal foot posture, while an FPI score of 6 or higher were considered to indicate that the individual has FF[28,29]. The NDT was performed to measure the difference in distance between the navicular tuberosity and the floor during sitting (both feet flat on the ground with hips and knees flexed at 90°) and standing (placing equal amounts of body weight on each leg) positions. Individuals with NDT≥1 cm was considered to have FF[31]. Based on the NDT and FPI, 14 individuals (11 females and 3 males) were determined as having a normal foot posture, and 14 individuals (11 females and 3 males) as having FF. Individuals were excluded from the study if they met any of the following non-inclusion criteria: (1) having a systemic or neurological disease; (2) having a lower extremities orthopedic disorder such as Achilles tendinitis, ligament injuries, or meniscopathy; (3) having a history of lower extremity surgery or major trauma; or (4) having a marked postural deformities in lower extremities such as genu valgum, genu recurvatum or coxa vara; (5) performing any strenuous exercises within 24 h prior to measurements; or, (6) having a body mass index more than 30. This study was performed in line with the principles of the Declaration of Helsinki. Ethical approval was obtained from Toros University Ethics Committee (Protocol Number: 2021-05-62). An informed consent form was signed by each participant.

Ultrasonographic measurements

The measurements of AT thickness were performed using an ultrasonography device with a linear probe (5-12 MHz) (MicrUs Scanner, Telemed, Lithuania). The measurements were performed by an operator with 6 years of experience about musculoskeletal ultrasonography. The operator was blinded to group allocations. Measurements were performed only on the dominant extremity. The dominant leg of the participants was determined by questioning the leg that they used to kick the ball[32]. All measurements were carried out between 9 a.m. to 11 a.m. In accordance with previous studies[23,33], ultrasonographic assessments were performed while the participants were in a prone position with their feet hanging over the end of the examination table. Prior to the ultrasonographic measurements, the individuals were allowed to have 10 min rest in this position. Ultrasonographic measurements were made parallel to the longitudinal axis of the AT. The ultrasound probe was placed on the skin with a light pressure to avoid any deformation in the tendon thickness. Ultrasonic images recorded the tendon that included the superior aspect of the calcaneus and the distal AT. The images were analyzed by a software package (RadiAnt DICOM Viewer, Medixant, Poznan - Poland). The analyses were performed by a researcher who was blinded to group allocations. In accordance with previous studies[23,33-35], the AT thickness was measured using ultrasonic images recorded at 3 different points, 1 cm (AT-1), 2 cm (AT-2), and 3 cm (AT-3) proximal to the superior aspect of the calcaneus (Figure 1).

Exercise protocol

After ultrasonographic measurements, the participants completed the exercise protocol. Similar to previous studies [22,23,33], the exercise protocol consisted of 90 repetitions of double-leg calf raise exercises, which included moving the foot from full ankle dorsiflexion to full ankle plantarflexion at a rate of ~1 Hz. It was reported that the exercise causes a resistance of between 100% and 150% of body weight on the AT, which is similar to the tensile loads exerted by AT during gait[22,23,33]. The ultrasonographic measurements were repeated immediately after the exercise protocol.

Statistical analyses

A statistical software package was used to perform statistical analyses (SPSS for Windows version 22, IBM Corporation, Armonk, NY, USA). To decide whether the assessed parameters were normally distributed, analytical (Shapiro–Wilk's test or Kolmogorov–Smirnov) and visual methods (probability plots and histograms) were used. Demographic data and the assessed parameters are presented using mean and standard deviation. The Independent Student's t-test was used to compare the assessed parameters between FF and control groups. The Paired Student's t-Test was used when comparing pre- and post-exercise AT thickness. Any P value less than 0.05 was considered statistically significant.

Results

Both groups were similar in age ($p=0.537$), height ($p=0.679$), body mass ($p=0.752$), and body mass index ($p=0.943$) (Table 1). The AT thickness at the points of AT-1, AT-2, and AT-3 were significantly lower at both pre- and post-exercise conditions in individuals with FF compared to the control group ($p<0.05$). Thickness at AT-1, AT-2, and AT-3 decreased after exercise in both groups ($p<0.001$). The differences in thickness at AT-1, AT-2, and AT-3 between pre- and post-exercise were higher in controls compared to individuals with FF ($p<0.05$) (Table 2).

Discussion

One of the aims of this study was to investigate the effect of foot posture on AT morphology. We hypothesized that AT thickness in individuals with FF will be lower compared with individuals with normal foot posture. In consistent with the hypothesis, it was found that individuals with FF had a thinner AT compared to those with normal foot posture. There are a few studies investigating the effect of foot posture on AT morphology. Similar to our findings, Murley et al[19] found that AT thickness was lower in adults with FF compared to adults with normal foot posture. Furthermore, Gonul et al[20] indicated a decrease in AT thickness in children with FF. The reduction in AT thickness is thought to result from decreased load on the AT during gait[19,20]. There are some potential reasons caused a decrease in load on the AT. It was reported that FF increased the valgus hindfoot moment arm, and caused a reduction in the moment arm of the AT as well as in the load on the AT at standing[16,17]. Moreover, increased hindfoot valgus causes insufficient foot rigidity during locomotion and propulsion[36]. Insufficient foot rigidity causes an impairment or inefficiency in load transfer from the hindfoot to the forefoot during the propulsion phase of gait[19,36], and it decreases the lever arm of the AT as well as the load on the AT[19]. The mechanical loading is very important to ensure tendon hemostasis. The decreased mechanical loading could cause a decrease in new extracellular matrix formation and collagen fiber synthesis, and it could cause a decrease in tendon thickness overtime[37-39]. On the other hand, a decrease in AT thickness may cause an increase in predisposition to AT pathologies such as tendinopathy or rupture. It was suggested that tendon ruptures more easily in a thinner tendon because of the increased stress concentration compared to the thicker tendon[40,41].

To our knowledge, this is the first study investigating the immediate effect of resistance exercise on the AT in individuals with FF. The findings of the present study demonstrated that AT thickness significantly decreased following double-leg calf raise exercises in both individuals with and without FF. There are several studies that have reported the immediate effects of intense or prolonged ankle exercises on AT thickness in healthy or asymptomatic individuals. Similar to the present results, these studies have reported a 15%-20% reduction in AT after intense or prolonged ankle exercises in healthy individuals[21-23,33]. The decrease in AT thickness is thought to result from the movement of fluid out of the tendon due to loading and tension of the tendon following the exercises[22,23,33]. On the other hand, it was hypothesized that the response of AT will be different against cumulative transverse strain via exercise in individuals with and without FF. In line with our hypothesis, it was found that the amount of decrease in AT thickness after double-leg calf raise exercises in individuals with FF (approx. 11 % reduction) was less than that of the control group (approx. 15 % reduction). There may be some reasons for the difference in the exercise response of the tendon between groups. The AT may be exposed to less load during exercises in individuals with FF because of the above-mentioned changes such as the decrease in the moment arm of the AT, and it might cause less movement of fluid out of the tendon because fluid movement usually occurs with tendon loading[25-27]. Less fluid out of the tendon will cause less reduction in tendon thickness in individuals with FF. Moreover, less fluid movement may be related to changes in collagen structure due to changes in the load of the AT in individuals with FF. Previous studies have hypothesized that changes in collagen structure such as collagen fibril disorganization or thinning reduce the interfibrillar space, and it could cause a decrease in intratendinous fluid mobility and /or movement of fluid out of the tendon when the tendon is under tension or load[21,24,25]. On the other hand, the intratendinous fluid mobility is considered to play an important role for tendon homeostasis[42], and a reduction in the intratendinous fluid mobility may cause an impairment in nutritional pathways in tendon[43]. Speculatively, reduced intratendinous fluid mobility may cause an increase in predisposition to AT pathology observed in individuals with FF.

The present study has a few limitations. First, AT thickness measurements were only conducted in the longitudinal plane. The use of horizontal plane for cross-sectional area measurements would provide more information about the effect of FF on AT. Second, the present study included only young and asymptomatic individuals. The effect of resistive ankle plantarflexion exercises may be different in middle aged and/or older adult because age can cause changes in AT structure[44,45]. Third, ultrasonographic measurement was performed only before and after eccentric ankle exercises. In future studies, additional measurements may be performed at some intervals following eccentric exercises to investigate time-dependent changes. Finally, in the current investigation, changes in the morphological features of the AT in individuals with FF were compared to those of healthy people. Further research is needed to increase clarification of morphological changes in AT thickness in patients with varying levels of FF severity, which may have more practical significance for FF management.

Conclusion

It was found that individuals with FF had a thinner AT compared to individuals with normal foot posture. In addition, there was a significant decrease in AT thickness after exercise in both groups; however, the reduction of AT thickness was lower in individuals with FF than in the control group (approx. 15% reduction for controls and approx. 11% reduction for the FF group). The result is thought to result from structural changes in the AT and/or decreased load on the AT that might cause a decrease in interstitial fluid movement during loading on the tendon. These changes may be related to the higher prevalence of AT pathologies in individuals with FF. The therapeutic approaches such as orthoses and exercises, which maintain normal medial arch height, may help prevent structural changes in the tendon or AT pathologies in individuals with FF.

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Conflict of Interest: None reported.

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Table 1. The mean (standard deviation) values of demographic data of individuals with flat foot and controls.

Parameters	Flat feet (n=14)	Control (n=14)	*p value*
Age (years)	22. 9 (3.9)	24.1 (6.2)	0.537
Height (m)	1.69 (0.1)	1.71 (0.1)	0.679
Mass (kg)	61.2 (14.6)	63.2 (17.4)	0.752
Body mass index (kg/m^2)	21.2 (3.0)	21.3 (3.0)	0.943
Foot Posture Index (score)	7.5 (1.3)	2.4 (1.7)	**<0.001***
Navicular drop (cm)	1.3 (0.2)	0.5 (0.2)	**<0.001***
Sex			
Male, n (%)	3 (23.4 %)	3 (23.4 %)	
Female, n (%)	11 (76.6 %)	11 (76.6 %)	
Dominant limb			
Right, n (%)	14 (100 %)	13 (93 %)	
Left. n (%)	0 (0 %)	1 (7 %)	

* p<0.05, Student’s t-test.

Table 2. The mean (standard deviation) values of pre and post exercise conditions in individuals with and without flat foot.

Parameters	Flat feet (n=14)	Control (n=14)	*p value*
AT-1			
Pre-exercise (mm)	3.6 (0.5)	4.3 (0.6)	**0.001***
Post-exercise (mm)	3.3 (0.4)	3.7 (0.5)	**0.007***
Difference (mm)	0.3 (0.2)	0.6 (0.3)	**0.009***
Difference (%)	9.1 (3.4)	13.4 (6.0)	**0.028***
AT-2			
Pre-exercise (mm)	3.7 (0.5)	4.5 (0.6)	**0.001***
Post-exercise (mm)	3.3 (0.4)	3.7 (0.5)	**0.041***
Difference (mm)	0.4 (0.2)	0.8 (0.3)	**0.001***
Difference (%)	11.1 (4.6)	17.5 (5.9)	**0.003***
AT-3			
Pre-exercise (mm)	3.9 (0.4)	4.6 (0.5)	**0.003***
Post-exercise (mm)	3.5 (0.4)	3.8 (0.5)	0.061
Difference (mm)	0.5 (0.2)	0.7 (0.3)	**0.010***
Difference (%)	11.3 (5.1)	15.8 (5.9)	**0.038***

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* $p<0.05$, Student's t-test. AT-1, Achilles tendon thickness at 1-cm proximal to the superior aspect of the calcaneus; AT-2, Achilles tendon thickness at 2-cm proximal to the superior aspect of the calcaneus; AT-3, Achilles tendon thickness at 3-cm proximal to the superior aspect of the calcaneus.

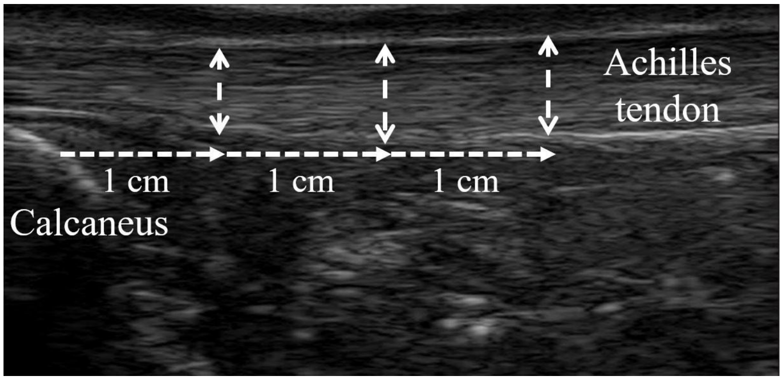

Figure 1. Measurements of Achilles tendon thickness at 1 cm, 2 cm and 3 cm proximal to the superior aspect of the calcaneus.