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Evaluation of the morphometric features of Achilles tendon with tendinopathy: an MRI study

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Abstract

Objectives: The Achilles tendon, the biggest tendon in the body, transmits the mechanical force received from the body to the ankle through the calcaneus. The aim of this study was to evaluate the effects of morphometric characteristics of the soleus and gastrocnemius muscles that make up the Achilles tendon on tendinopathy by MRI.

Methods: Foot magnetic resonance images of 128 patients (121 males and 107 females) were retrospectively analyzed. The cases were divided into two groups, the tendinopathy group and the control group. The length and the thickness of the Achilles tendon and the distance of the maximum thickness from the calcaneal insertion were measured in both groups and evaluated for differences between the groups and between genders.

Results: In the comparison between genders, the thickness of the Achilles tendon and the distance of the maximum thickness to the calcaneal insertion were higher in males than in females. The length and the thickness of the Achilles tendon was significantly increased in the tendinopathy group compared to the control group.

Conclusion: In this study, we investigated the relationship between Achilles tendinopathy and the morphometric properties of the muscles forming the Achilles tendon. The results of our study showed that Achilles tendon length and tendon thickness increased in patients with tendinopathy compared to the control group.

Keywords: Achilles tendon; gastrocnemius; soleus; tendinopathy

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Introduction

The Achilles tendon is the common tendon of the triceps surae formed by the two heads of the gastrocnemius and soleus and is the largest tendon in the body.[1,2] The name Achilles tendon was first mentioned in Verheyen's book "Corporis Humani Anatomiae" written in 1693.[3]

The Achilles tendon is very important in ankle motion because it transmits mechanical force from the triceps surae to the calcaneus.[4] The posterior part of the tendon is formed by the medial layer of the triceps surae. The anterior part of the tendon is formed by the lateral layer of the gastrocnemius. The middle and medial parts are formed by the soleus.[1,2] The vascularization in the middle part of the tendon is weaker. The nutrition of this segment is more variable compared to other segments. This is thought to affect the progression of tendinopathy.[5]

Tendinopathy is a multipathological condition characterized by tendon dysfunction, pain and decreased exercise capacity.[6] The human body contains hundreds of muscles and tendons. However, tendinopathy most commonly affects the shoulders, elbows, hips, knees and ankles.[7] Foot and ankle pathologies, including the Achilles tendon, are common in the elderly and athletes.[8] Furthermore, recent studies have revealed that Achilles tendinopathy is becoming more common in amateur and professional athletes. Consequently, identification and elucidation of risk factors for tendinopathy is of critical importance. Determination of the anatomy of the Achilles tendon and variations in tendon anatomy will help research in this area.[9]

With the advancement of magnetic resonance imaging (MRI) studies, new information about the anatomy of the Achilles tendon and surrounding soft tissues has been obtained. The presence of morphologic and signal changes in the tendon has increased the accuracy of tendinopathy diagnosis.[10,11] Furthermore, understanding the anatomy and variations of the Achilles tendon and surrounding soft tissues improves surgical techniques and reduces the risk of iatrogenic injury.[12] The aim of this study was to demonstrate the morphologic features and anatomic variations of the gastrocnemius and soleus tendons and the relationship between these variations and tendinopathy using magnetic resonance imaging.

Materials and Methods

The study was conducted retrospectively at Erzincan Binali Yıldırım University Faculty of Medicine Mengücek Gazi Training and Research Hospital between January 1, 2020 and January 1, 2022. Exclusion criteria included Achilles tendon rupture, any disease that disrupts the anatomy and physiology of the musculoskeletal system (malignancy, soft tissue infections), history of ankle surgery, calcaneal fracture, and inability to obtain appropriate images due to diffuse motion. Patients who did not meet the exclusion criteria in contrast-enhanced and non-contrast-enhanced ankle MRI examinations performed for any reason and who had good anatomic and pathophysiologic image quality related to the musculoskeletal system were included in our study.

The ankle was imaged on a 1.5T 32-channel MRI machine (Siemens magnetoma aera, Erlangen, Germany) using 18-channel coils. Images from the PACS (Picture Archiving Communication System) archive were analyzed using the Siemens Somatom Sensation-Syngo.via software program (Siemens Healthineers, Erlangen, Germany) and evaluated by a radiologist with 6 years of musculoskeletal experience.

All patients in the study underwent T1-weighted sequences in the coronal and sagittal planes, T2-weighted sequences in the axial and sagittal planes, and PD-weighted fat-suppressed sequences in the axial and coronal planes. The most commonly used protocol is PD-weighted TSE (turbo spin echo) TE (echo time) 21 ms, TR (repetition time) 2400 ms. T2-weighted (TSE) TE 56 ms, TR 3920 ms. T1-weighted: TE 10 ms, TR 797 ms. Voxel 0.8×0.8×3.5 mm, slice thickness 4 mm, FOV (Field of view) 200 mm. The diagnosis of Achilles tendinopathy was based on the presence of high signal on T2-weighted and proton density-weighted fat-suppressed axial and sagittal images, tendon thickness exceeding 6 mm on axial images, and convex anterior edge of the tendon.[13]

The most distal part of the soleus fibers was determined on axial images and the length between this point and the most proximal-superior point where the Achilles tendon attaches to the calcaneus on sagittal images was calculated as the free Achilles tendon length (SPM) (**Figure 1**). Similarly, the distance between most distal part the soleus fibers which was determined on axial images, and the most distal point where the Achilles tendon attaches to the calcaneus was measured on sagittal images and recorded as the total Achilles tendon length (SDM) (**Figure 2**).

In the axial section, the thickest part of the free portion of the Achilles tendon in the anteroposterior plane was measured. Sagittal sections were also used to confirm this (APM) (**Figure 3**). The distance from the point where the tendon reached maximum thickness to the proximal insertion of the Achilles tendon into the calcaneus was measured (MKPM) (**Figure 3**). Then, the ratio of maximum tendon thickness to proximal calcaneal insertion (MKPM/SPM) was calculated and recorded.

SPSS version 21 (Social Sciences Software for Windows, IBM Inc., Chicago, IL, USA) was used for statistical analysis. The Kolmogorov-Smirnov test was used to assess the conformity of the variables to normal distribution. The t-test was used to examine differences in the mean values of the measurements between groups, genders and sides, as well as independent values. Pearson correlation was used to investigate the relationship between length and age. Statistical significance was defined as a p value less than 0.05.

Results

Our study included 121 male patients aged 18–71 years with a mean age of 42.1±15.1 years and 107 female patients aged 18–70 years with a mean age of 41.3±13.2 years. A total of 228 ankle MRI examinations, including 114 right ankle and 114 left ankle, were performed in our study (**Table 1**). In addition, 27 patients were excluded due to exclusion criteria. The study group consisted of 2 groups. Group 1 included 114 MRIs with clinically suspected tendinopathy and confirmed tendinopathy diagnosis by MRI. Group 2 was the control group and included 114 MRI studies performed for pathologies other than pathologies related to the Achilles tendon. Group 1 consisted of 50 women and 64 men with a mean age of 49.8±9.8 (30–70) years and included MRI sections of 56 right and 58 left ankles. Group 2 consisted of 57 female and 59 male patients with a mean age of 33.6±12.2 (18–71) years and included MRI sections of 58 right and

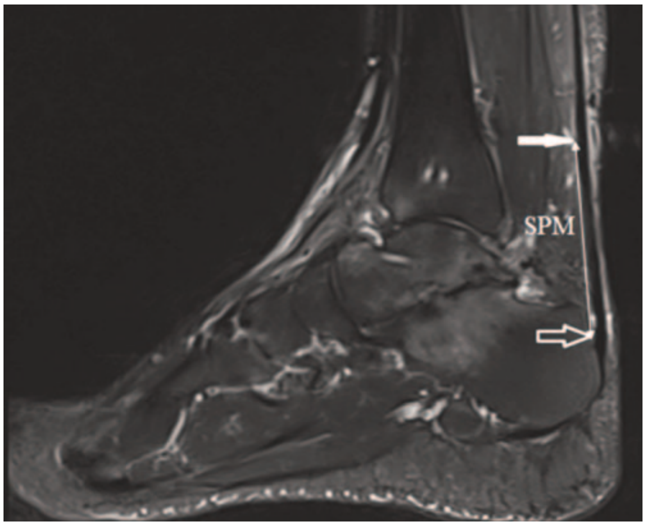

Figure 1. T2 fat-suppressed sequence showing the Achilles tendon. The most distal part of the soleus (**white paint filled arrow**) and the most proximal anterior calcaneal insertion of the Achilles tendon (**hollow white arrow**). The distance between the two arrows is defined as the SPM distance (free tendon length).

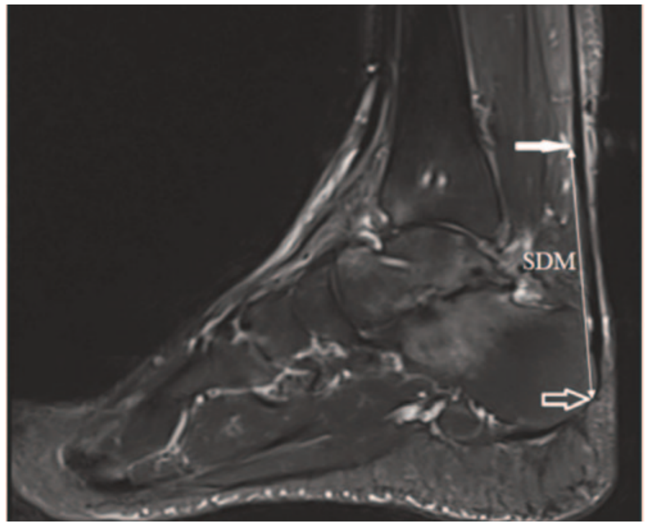

Figure 2. T2 fat-suppressed sequence showing the Achilles tendon. The most distal part of the soleus (**white paint filled arrow**) and the most distal calcaneal insertion of the Achilles tendon (**hollow white arrow**). The distance between the two arrows is defined as the SDM distance (total tendon length).

56 left ankles (**Table 1**). None of the patients included in the study were athletes. Gender and side comparison of patients with tendinopathy are shown in **Tables 1** and **2**.

The free Achilles tendon length between the most distal part of the soleus fibers and the proximal calcaneal insertion of the Achilles tendon, called the SPM distance, was

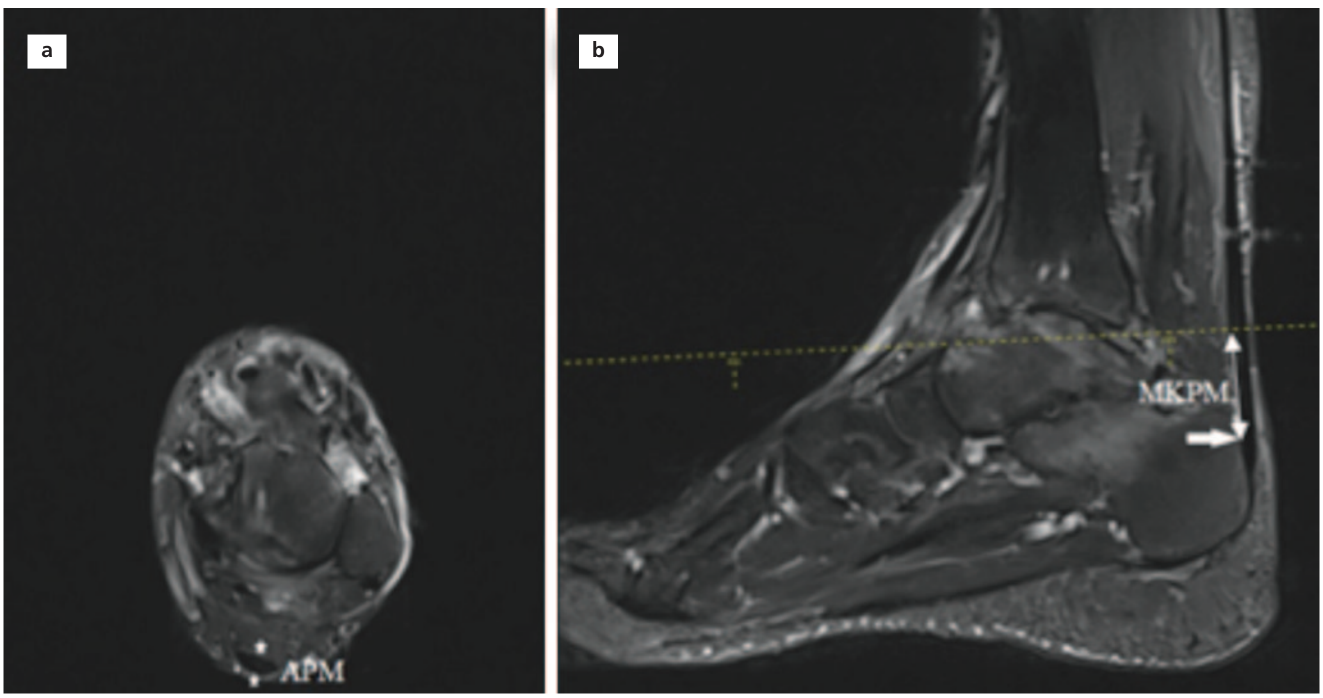

Figure 3. Axial (**a**) and sagittal (**b**) sections of the Achilles tendon in T2 fat-suppressed sequence. The thickest part of the Achilles tendon in the axial sections (**the distance between the two white stars**) was determined, and the anteroposterior thickness of the tendon at this level was defined as the APM distance. In addition, this level was determined in sagittal sections (**dashed yellow line**), and the distance from the point determined in sagittal sections to the calcaneus antero-proximal insertion of the Achilles tendon (**white paint filled arrow**) was defined as the MKPM distance.

Table 1
Demographic characteristics of the Group 1 (tendinopathy group) and Group 2 (control group).

	Age (years) Mean±SD (range)	Gender (female/male)	Side (right/left)
Total	41.7±14.2 (18-71)	107/121	114/114
Group 1	49.8±9.8 (30-70)	50/64	56/58
Group 2	33.6±12.2 (18-71)	57/59	58/56

SD: standard deviation.

53.9±16.7 (range: 25.9–103) mm. The total Achilles tendon length between the most distal part of the soleus fibers and the distal calcaneal insertion of the Achilles tendon, referred to as the SDM distance, was 78.2±18.2 (range: 45.1–125.8) mm. The thickest part of the free Achilles tendon in the anteroposterior plane, called the APM distance, was 9.69±3.1 (range: 4.8–19.9) mm. The distance from the point where the Achilles tendon reached maximum thickness to the proximal insertion of the calcaneus, called the MKPM distance, was measured as 23.8±3.39 (range: 15.1–299) mm. The ratio of the distance from the maximum tendon thickness to the proximal calcaneal insertion, called MKPM/SPM, was 44.2± 15.45% (range: 15.5–98.2 mm) (**Table 2**). There was no statistically significant difference between the measurements made in terms of gender and direction in the group with tendinopathy (p>0.05).

In the control group, SPM was 38.1±12.8 (range: 7.2–68.6) mm, SDM was 59.5±12.4 (range: 26–91.1) mm, APM was 4.8±0.5 (range: 3.6–5.7) mm, and MKPM was 18.5±4 (range: 3.9–22.6) mm. The MKPM/SPM ratio was calculated as 48.5±17.2% (range 21.2–94.3) (**Table 3**).

The results of the comparison between the control group and patients with tendinopathy according to gender and side are given in **Tables 2** and **Table 3**. In both patients with tendinopathy and the control group, there

Table 2
Gender and side comparison of the measured distances (mean±standard deviation) of the patients with tendinopathy (Group 1).

	Side			Gender		
Distances	Right (mm)	Left (mm)	p-value	Male (mm)	Female (mm)	p-value
SPM	55.1±16.4	52.8±17	>0.05	54.1±16.4	53.7±17.1	>0.05
SDM	80.6±16.5	76±19.9	>0.05	82.1±17.5	82.2±19.1	>0.05
APM	9.9±2.8	9.5±3.4	>0.05	10.8±2.9	10.5±2.8	>0.05
MKPM	24.8±3.6	23±3.2	>0.05	22.8±3.8	24.2±3.2	>0.05
MKPM/SPM (percent)	45.0±15.1	43.5±15.8	>0.05	42.1±16	45.0±14.7	>0.05

Table 3
Gender and side comparison of the measured distances (mean±standard deviation) of the control group (Group 2).

	Side			Gender		
Distances	Right (mm)	Left (mm)	p-value	Male (mm)	Female (mm)	p-value
SPM	36.5±11.9	39.9±13.8	>0.05	39.6±11.6	35.3±13.6	>0.05
SDM	58.2±12.1	60.9±12.9	>0.05	62.8±12.9	54±11.6	>0.05
APM	4.8±0.5	4.8±0.6	>0.05	4.9±0.5	4.5±0.5	0.002
MKPM	18.1±4.1	19±3.9	>0.05	18.9±3.6	17.5±4.2	0.005
MKPM/SPM (percent)	49.5±19.3	47.6±15.2	>0.05	47.7±17.7	49.5±16.2	>0.05

was no statistically significant difference in the measurements between the right and left ankles. In the control group, APM and MKPM distances were statistically significantly greater in males than females (**Table 3**). There were no other differences in the measurements between the two genders.

Table 4 shows the comparison of the mean values of measurements in the control and tendinopathy groups. The SPM distance (mean free length of the Achilles tendon) was 53.9 mm in patients with tendinopathy and 38.1 mm in the control group and was significantly higher in the tendinopathy group (p=0.002). SDM distance (mean total length of the Achilles tendon) was 78.2 mm in patients with tendinopathy and 59.5 mm in the control group and was significantly higher in the tendinopathy group (p=0.001). APM (maximum thickness of the tendon) was 9.6 mm in the tendinopathy group and 4.8 mm in the control group and was significantly greater in the tendinopathy group (p=0.001). The distance between the level of maximum thickness of the tendon and the proximal calcaneal insertion was 23.8 mm in the tendinopathy group and 18.5 mm in the control group, and this value was significantly greater in the tendinopathy group (p=0.001). The MKPM/SPM ratio, which expresses the relative distance of the maximum thickness area to the proximal calcaneal insertion, was 44.2% in patients with tendinopathy and 48.5% in the control group (p=0.001).

Discussion

The Achilles tendon, which is composed of fibers from the gastrocnemius and soleus muscles, is the thickest of the tendons in the body.[2] The Achilles tendon is one of the most common sites of tendinopathy and Achilles tendon injury is a condition characterized by decreased function, tendon pain and decreased exercise.[6,7,13] Achilles tendinopathy causes thickening of the tendon, roughening of its surface and a brownish color. Histopathologic examination of patients with tendinopathy may show macrophages, neutrophils and other immune cells. There are no visible inflammatory cells. Consequently, the term tendinitis would be inappropriate when discussing tendinopathy.[14]

When we look at the different types of Achilles tendon degeneration in the literature, four different types of degeneration stand out. These four types are hypoxic degenerative tendinopathy, mucoid degeneration, tendolipomatosis and calcified tendinopathy. Kannus and Jozsa[15] discovered that patients with hypoxic degenerative tendinopathy and mucoid degeneration were more prone to spontaneous rupture. When the patients were analyzed, it was found that these pathologic conditions were seen together rather than separately.[15,16]

The natural history of Achilles tendinopathy is unknown and there is little clear information about its clinical course. While the disease may be self-limiting in many individuals, treatment options include physical therapy and surgery. The data obtained from the literature for the comparative evaluation of conservative and surgical methods in Achilles tendinopathy seems to be insufficient for the time being. Numerous guidelines on Achilles tendinopathy have been published. However, none of these guidelines, which often reflect expert opinion, have been rigorously tested for efficacy.[17,18]

Achilles tendinopathy has recently become more common in athletes. The anatomy and anatomical variations of the Achilles tendon will help research on this subject. In this study, morphometric differences in measurements of the Achilles tendon were compared in patients with tendinopathy and in the control group. In our study, when the length of the free Achilles tendon was compared between patients with tendinopathy and the control group, it was observed that the length of the Achilles tendon was significantly increased in patients with tendinopathy compared to the control group. This may mean that as the length of the Achilles tendon increases, its stability decreases. Similar to our study, Drakonaki et al.[10] found that Achilles tendon length (59.7 mm) was significantly higher in patients with tendinopathy compared to the control group (38.5). Weber et al.[19] measured Achilles tendons in pathologic and control groups and found 83.2 mm

Table 4
Comparison of the measurements of the group with tendinopathy (Group 1) and the control group (Group 2).

	SPM (mm)	SDM (mm)	APM (mm)	MKPM (mm)	MKPM/SPM (percent)
Group 1	53.9±16.7 (25.9–103)	78.2±18.2 (45.1–125.8)	9.69±3.1 (4.8–19.9)	23.8±3.39 (15.1-29.9)	46.6±15.45 (15.1–29.9)
Group 2	38.1±12.8 (7.2–68.6)	59.5±12.4 (26–91.1)	4.8±0.5 (3.6–5.7)	18.5±4 (3.9–22.6)	52.5±17.2 (21.2–94.3)
p-value	0.002	0.001	0.001	0.001	0.001

in the pathologic group and 45.9 mm in the control group. When compared with the control group, it can be said that it increased significantly in the pathologic group. Soila et al.[20] measured the length of tendons with changes in morphologic properties due to any pathology and found the tendon length to be 52 mm in pathologic tendons, similar to our study. In our study, unlike Weber et al.,[19] the distance between the distal soleus fibers and the proximal insertion of the calcaneus was measured while calculating the tendon length, and the difference was thought to be due to the difference in the measurement method.

The free Achilles tendon is the part of the tendon that is not covered with muscle and is covered with Kager fat. According to research, the free portion of the Achilles tendon is more sensitive to mechanical changes caused by the tendon and is more exposed to stresses and mechanical effects during exercise than the muscularized tendon portion.[21] During exercise, the free portion of the Achilles tendon is subjected to 2–3 times more strain than the gastrocnemius tendon.[22] According to these studies, the free portion of the Achilles tendon is more sensitive to acute changes in mechanical behavior in response to exercise. Stresses experienced during exercise are more important in determining the long-term adaptation of the tendon.[23] Szaro et al.[1] discovered that Achilles tendon injury is related to the muscle from which the damaged tendon fibers originate. Since tendinopathy is most common in the middle of the Achilles tendon, it is possible that it originates from the soleus muscle rather than the gastrocnemius muscle. The level of tendinous attachment of the muscle may also have an effect on tendinopathy as a result of the influence of the musculus soleus. Kager's fat is thought to play a role in the development of tendinopathy because it envelops the free portion of the Achilles tendon and has a springing effect on the tendon.[24]

According to the results of our study, the maximum thickness of the free portion of the Achilles tendon was 3.6 to 5.7 mm and was statistically significantly thicker in men in gender comparison. Achilles tendon thickness was similar between the same sexes. In studies on Achilles tendon thickness in the literature, Soila et al.[20] found Achilles tendon thickness to be 5.2 mm and Drakonaki et al.[10] found Achilles tendon thickness as 5.2 mm and 4.8 mm, which is similar to our study. It should also be kept in mind that the thickness of the Achilles tendon may increase physiologically. Rosager et al.[25] found that Achilles tendon thickness increased four times in athletes compared to the general population. The fact that there were no athletes in both groups in our study is important in terms of not affecting tendon thicknesses. Astrom et al.[26] reported that in some individuals the distal gastrocnemius and soleus muscles may appear thickened on axial MR images, but this should not be confused with focal thickening. On imaging, a false anterior thickening may be seen if the course of the tendon is not parallel to the sagittal planes.[20] In our study, the mean Achilles tendon thickness in the tendinopathy group ranged from 4.8 to 19.9 mm and was significantly greater than in the control group. Similar to our study, Haims et al.[16] found that tendon thickness increased in conditions that cause tendon degeneration such as tendinopathy. Nuri et al.[27] compared tendons with tendinopathy to contralateral tendons in their study and found that tendon thickness increased significantly on the tendinopathy side. Similar to our study, Drakonaki et al.[10] revealed increased tendon thickness in all subgroups of patients with tendinopathy. Volume loss in tendinopathic tendons during exercise may be due to fluid movement into the peritendinous space or a decrease in tendon blood volume due to tendinopathy and associated contraction of the tendon.[28]

In our study, MKPM/SPM ratio was used to calculate the ratio of tendon maximum thickness to proximal calcaneal insertion. The MKPM/SPM ratio was 44.2% in the tendinopathy group and 48.5% in the control group. The fact that this ratio was lower in the tendinopathy group suggests that the part of the tendon affected and thickened by tendinopathy is more distal to the tendon. Although the number of studies on this subject is limited, Drakonaki et al.[10] found that this rate was lower in patients with tendinopathy, which is consistent with our findings. The confirmation of these findings in our study increases the reliability of the results and is important in terms of its contribution to the literature. However, when compared to our study, Drakonaki et al.[10] revealed that the proportional data for the Achilles tendon were lower compared to the control and tendinopathy groups. This may be due to individual differences between the patients included in the study.

Our study has some limitations. The first limitation of our study is that it was retrospective. In addition to this, the number of patients in our study is relatively small. Detailed anamnesis and laboratory values of the patients were not available. Therefore, conditions that increase tendon thickness such as hyperlipidemia could not be determined. Since only one person performed the measurements at a time, inter- and intra-observer consistency data are not available. Height and BMI values of the patients were not recorded, so these values could not be included. If similar studies are performed in larger patient populations in the future, the reliability of our results will be confirmed.

Conclusion

Achilles tendinopathy is a multipathological clinical syndrome characterized by pain, swelling and decreased performance. Our findings show that patients with Achilles tendinopathy have various anatomical and physiopathologic abnormalities. Our study showed that SPM, SDM, APM and MKPM distances were significantly higher in the tendinopathy group. Although the number of patients in our study was higher than in the literature, what is known about Achilles tendinopathy is limited and further research is needed.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Author Contributions

TK: conceptualization, data acquisition, data analysis or interpretation, drafting the manuscript, approval of the final version of the manuscript; DCS and MK: drafting the manuscript, critical revision of the manuscript, approval of the final version of the manuscript; SA and MS: conceptualization, critical revision of the manuscript, approval of the final version of the manuscript.

Ethics Approval

This study involving human participants complies with the ethical standards of the institutional and national research committee and the 1964 Declaration of Helsinki and subsequent amendments or comparable ethical standards. This study was approved by Ethics Committee of Erzincan Binali Yıldırım University Clinical Research Ethics Committee (protocol E-21142744-804.99-150727.).

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