Spor Hekimliği Dergisi, 58(1):8-14; 2023
Turkish Journal of Sports Medicine
Turk J Sports Med. DOI: 10.47447/tjsm.0701

Research Article / Araştırma Makalesi

The association between ankle mobility and Achilles tendon, plantar fascia, iliotibial band stiffness and elasticity in athletes

Sporcularda ayak bileği mobilitesi ile Aşil tendonu, plantar fasya, iliotibial bant sertliği ve elastikiyeti arasındaki ilişki

Serkan Usgu[1], Seda Biçici Uluşahin[2], Tuğba Gönen[1]

[1] *Department of Physiotherapy and Rehabilitation, Hasan Kalyoncu University, Gaziantep, Turkiye*

[2] *Department of Physiotherapy and Rehabilitation, University of Health Sciences, Ankara, Turkiye*

ABSTRACT

Objectives: The ankle range of motion in the kinetic chain is very important. The joint mobility can affect soft tissue mechanical features and alter athletic performance. This study aimed to determine whether there was a relationship between the stiffness and elasticity of iliotibial band (ITB), Achilles tendon (AT), plantar fascia (PF), and ankle mobility in athletes.

Materials and Methods: Thirty professional athletes (n=10, basketball, n=10, volleyball, n=10, running) participated in this study. ITB-AT-PF- mechanical properties (stiffness and elasticity) were measured bilaterally with a Myoton-Pro. Ankle mobility was measured with an inclinometer during knee to wall lunge test.

Results: Ankle mobility was not correlated with the mechanical properties (p>0.05). AT-stiffness had weak negative correlation with AT-elasticity (r=-0.46), ITB-stiffness had moderate negative correlation with ITB elasticity and weak positive correlation with AT-stiffness on the nondominant side (r=-0.65,0.44). AT-elasticity had moderate and weak negative correlations between AT and PF-stiffness, respectively (r=-0.63,-0.41), ITB-stiffness had weak negative correlation with ITB-elasticity on the dominant side (r=-0.36). Dominant side AT and nondominant side ITB-elasticity of runners and nondominant and dominant side ITB-stiffness of basketball players were significantly higher (p<0.05).

Conclusion: There was no significant relationship between ankle mobility and mechanical properties of the ITB-AT-PF. These findings may be useful in planning rehabilitation or conditioning programs in terms of injury prevention.

Keywords: *Stiffness, elasticity, ankle mobility, relation, athletes*

ÖZ

Amaç: Kinetik zincirde ayak bileği hareket açıklığı çok önemlidir. Eklem hareketliliği yumuşak doku mekanik özelliklerini etkileyebilir ve atletik performansı değiştirebilir. Bu çalışma, sporcularda ayak bileği mobilitesinin iliotibial bant (ITB), Aşil tendonu (AT), plantar fasya (PF) sertlik ve elastikiyeti ile ilişkisini belirlemek amacıyla yapıldı.

Gereç ve Yöntemler: Çalışmaya 30 profesyonel sporcu (n=10 basketbolcu, n=10 voleybolcu, n=10 koşucu) katıldı. ITB, AT ve PF mekanik özellikleri (sertlik ve elastikiyet) Myoton-Pro cihazı ile bilateral ölçüldü. Ayak bileği mobilitesi inklinometre ile diz-duvar çömelme testi sırasında ölçüldü.

Bulgular: Ayak bileği mobilitesi mekanik özelliklerle korelasyon göstermedi (p>0,05). AT sertliği, AT elastisikiyeti ile zayıf negatif korelasyon gösterdi (r=-0,46). Dominant olmayan tarafta ITB sertliği, ITB elastikiyeti ile orta düzeyde negatif, AT sertliği ile zayıf pozitif korelasyon gösterdi (r=-0,65,0,44). AT elastikiyeti, AT ve PF sertliği arasında orta ve zayıf negatif korelasyon bulundu (r=-0,63,-0,41). Dominant tarafta ITB sertliği ile ITB elastikiyeti arasında zayıf negatif korelasyon vardı (r=-0,36). Koşucuların dominant taraf AT ve dominant olmayan taraf ITB elastikiyeti ve basketbolcuların dominant olmayan ve dominant taraf ITB sertliği daha yüksek bulundu (p<0.05).

Sonuç: Ayak bileği mobilitesi ile ITB-AT-PF' nın mekanik özellikleri arasında ilişki yoktu. Elde edilen bulgular rehabilitasyon ve kondisyon programlarının planlamasında yaralanmaların önlenmesi açısından yarar sağlayabilir.

Anahtar Sözcükler: *Sertlik, elastikiyet, ayak bileği mobilitesi, ilişki, sporcular*

INTRODUCTION

Fascia and tendons are important structures responsible for transmitting the force created by the muscles. They store and release elastic energy (1). This physical feature is essential for the effective functioning of human movement, and efficiency in athletic performance (2). The characterization of athletic movement is associated with the spring-like mechanism of musculotendinous units. The mechanical properties of musculotendinous units are stiffness and elasticity which transmit strength or power during sprinting, jumping or cutting (3). Stiffness is defined by the slope of a

Received / Geliş: 07.06.2022 · **Accepted / Kabul:** 22.08.2022 · **Published / Yayın Tarihi:** 03.01.2023

Correspondence / Yazışma: Serkan Usgu · Hasan kalyoncu Üniversitesi, Fizik Tedavi ve Rehabilitasyon Anabilim Dalı, Gaziantep, Türkiye · serkan.usgu@hku.edu.tr

Cite this article as: Usgu S, Ulusahin S, Gonen T. The association between ankle mobility and Achilles tendon, plantar fascia, iliotibial band stiffness and elasticity in athletes. *Turk J Sports Med.* 2023 58(1):8-14; https://doi.org/10.47447/tjsm.0701

force-displacement curve for a given body and/or material (e.g., a tendon) (4). Elasticity is a mechanical feature that describes an ability of a material to recover its previous configuration after it has been deformed by an applied load (5). If a structure becomes too elastic, overloading may occur with the reduction of force. If it becomes too stiff, there may be an increase in forces in the kinetic chain.

Also, the range of motion is very important for force transmission or absorption in the kinetic chain. The restriction of ankle movements leads to undesired alignments and loads on the knee, hip and even upper segments (6) and can affect mechanical features of soft tissue, alter athletic performance, and cause musculoskeletal injuries, e.g. ankle sprains, knee and hip injuries as well as reinjuries including plantar fasciopathy, Achilles tendinopathy (7) and iliotibial band syndrome (8).

Some studies, including tasks such as sprinting, landing and single-leg stance have tried to explain the connection between ankle mobility and stiffness (9, 10). However, the surrounding soft tissue structures of joints such as muscles, tendon, fascia, and ligament contributing to the passive joint stiffness and it is difficult to detect isolated muscle or tendon stiffness due to joint torque change (11). Therefore, it is not clear whether specific soft tissues differ in terms of joint mobility. Myotonometry is a novel and noninvasive technique that provides an objective measure of mechanical properties of soft tissue such as compliance, stiffness, tone, elasticity, relaxation time and creep. But there were limited studies investigating the relationship between the mechanical properties of soft tissues and ankle mobility such as muscle, tendons and fascia in healthy sedentary participants (12, 13).

The decrease in ankle mobility may alter the mechanical properties of the muscle-tendon-fascia, especially the stiffness, and it may restrict the ankle joint movement. Decreased ankle dorsiflexion is known to cause decreased flexibility of the gastrocnemius/soleus complex and restriction of the posterior talar glide (14). Also, decreased dorsiflexion is seen as an important risk factor for excessive knee valgus and may affect the ITB stiffness and elasticity in the kinetic chain. The knee valgus is compensated by increased knee flexion in the sagittal plane or increased hip internal and adductor moment in the transverse/frontal plane (15). To the best of our knowledge, there are no studies assessing stiffness and elasticity of iliotibial band (ITB), Achilles Tendon (AT) and plantar fascia (PF) and the relation with ankle mobility in sport.

Investigating the relationship between ankle mobility and soft tissue mechanical properties may provide a better understanding of possible injuries. Furthermore, ankle mobility and soft tissue mechanical properties may alter with the type of sports itself. Therefore, identifying the possible relationship between these parameters and the type of athletic activity may help us to develop proper training or rehabilitative exercises. The aim of this study was to demonstrate the mechanical properties of ITB, AT and PF, and ascertain their relation with ankle mobility in athletes with different training characteristics. We hypothesized that limited ankle-dorsiflexion would be related to increased stiffness and decreased elasticity of ITB, AT and PF in athletes.

MATERIALS and METHODS

Participants

The minimum total number of participants required for each group was calculated as 10 (α=0.05) in order to determine a possible significant difference with an acceptable effect size (f=0.70) G-power program version 3.9.1.7 was used in power analysis. This study included a total of 39 professional runners, basketball and volleyball players between the ages of 19 and 32 years. It was reported that leg dominance affected weight-bearing mobility performance (16). This study was carried out only with male athletes having right lower extremity dominance and normal body mass index (BMI); because dominancy, sex and obesity could affect joint mechanical properties. The dominant leg was determined by asking the athletes to kick the ball.

The athletes underwent a clinical interview to determine eligibility. Exclusion criteria were being female, left side dominance, history of ankle injury or surgery in the last 6 months, any neurological or systemic disease, acute pain or/and inflammation on ITB, AT and PF or disclosure of anabolic drug abuse.

30 professional male athletes who met the inclusion criteria (n=10 basketball, n=10 volleyball, n=10 running) participated in the study. The physical characteristics of athletes are given in Table 1. All measurements were performed bilaterally during the off-season in the afternoon, at the appropriate temperature (22-24 °C) and humidity (%45-60) in the same environment. Athletes were asked to refrain from high-intensity exercise for 48 hours before testing. The participants provided their signed informed consent before participating in this study, which was approved by Hasan Kaloncu University Noninvasive Clinical Ethics Committee and numbered 2020-100. Clinical Trial İdentifier Number: NCT04737226.

Table 1. Demographic characteristics of athletes

	Mean ± SD	Min-Max
Age (year)	26.07 ± 4.41	18-35
Height (cm)	188.40 ± 12.93	157-211
Weight (kg)	81.73 ± 18.24	51-116
Sport age (year)	12.37 ± 4.33	5-22

Assessments

Myotonometric Measurements

Bilateral ITB, AT and PF stiffness and elasticity were evaluated with MyotonPro device (Myoton Ltd, Estonia). The measurement method of the device is based on the free oscillation technique. Firstly, the probe of the device is placed perpendicular to the skin and a pre-pressure (0.18 N) is applied to compress the subcutaneous tissue. Then, a short (15 ms) mechanical impulse (0.40 N) is applied, causing damped oscillation on the tissue and the co-oscillation is recorded by an accelerometer. The raw signal is then processed to filter the frequencies that are not the natural oscillation of the tissue. Finally, the filtered acceleration curve is used to calculate the mechanical properties of the tissue by the formula below (17).

$$\text{Stiffness k} = \frac{a_0 \text{ x } m_{\text{prob}}}{\Delta l}.$$

a_0; maximum acceleration, mprob; probe mass of the device and Δl; is the maximum displacement of tissue.

The MyotonPro device provides data on three different mechanical properties. Stiffness and elasticity were used in this study. Stiffness (N/m) indicates resistance to any contraction or external intervention. Elasticity (log) is obtained as a logarithmic reduction of the natural oscillation of soft tissues. The MyotonPro can reliably assess the stiffness and elasticity of AT and PF (18, 19). Also, it has good to excellent test-retest reliability and repeatability that has been established in previous studies (18).

Athletes were placed in a prone position on a massage table and the feet hanging freely over the edge and advised to stay and relax for 5 minutes in this position. After that, athletes were instructed not to move their feet during the measurement. The reference points were marked with a skin marker. The AT was assessed at 4 cm above the distal insertion of the tendon (calcaneal tubercle) (Figure 1a) (18). The PF was measured in the middle of the foot, intersecting with the lateral basis of the fifth metatarsal bone (Figure 1b) (20). The ITB was assessed at 3 centimeters (cm) above of lateral femoral condyle (Figure 1c). Each measurement was repeated 3 times bilaterally and average was recorded.

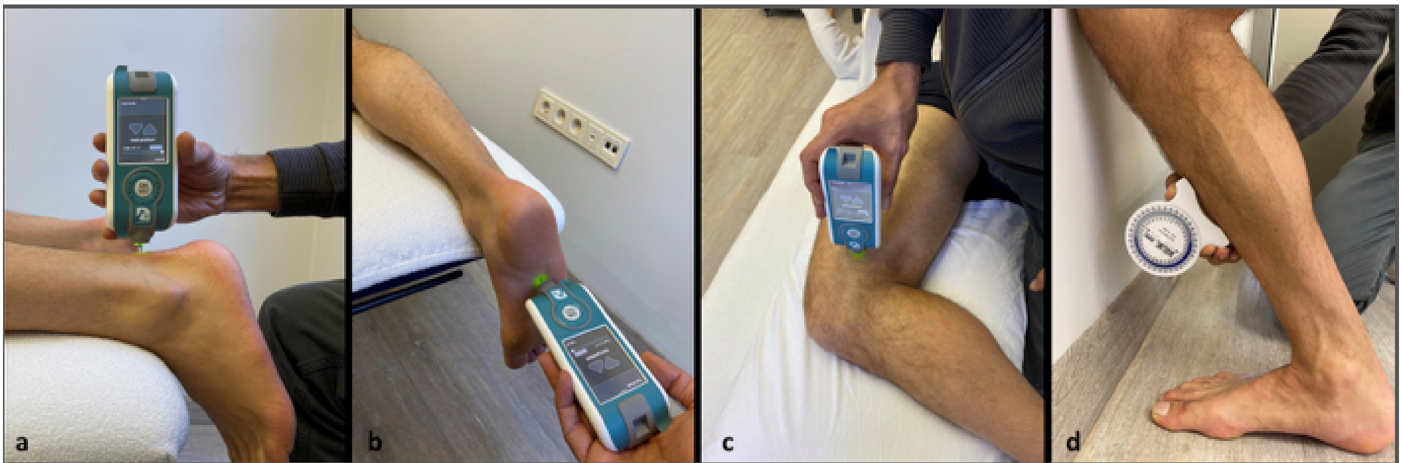

Figure 1. a) AT measurement, b) PF measurement, c) ITB measurement, d) Knee to wall lunge test

Ankle Mobility Assessment

The mobility assessment was performed after myotonometric measurements. Ankle mobility was measured with the use of a fluid-filled inclinometer while a knee-to-wall lunge test was performed. The knee to wall lunge test was performed in a standing position while the heel was in contact with the ground and the knee was in line with the second toe. The athlete was asked to lunge forward without lifting the heel off the floor. Once maximal dorsiflexion was reached, the inclinometer was placed at the middle anterior tibial crista and the dorsiflexion angle was recorded. The test was repeated 3 times and the average value was calculated (Figure 1d) (21). The inter-reliability and intra-reliability of knee-to wall test have been previously reported as excellent (22).

Statistical Analysis

Descriptive statistics were summarized as mean ± standard deviation for numerical data. The Shapiro-Wilk test was used to check whether the data were normally distributed. Kruskal-Wallis test was used for comparison of the groups. If the Kruskal-Wallis test yielded a significant p-value, posthoc pairwise comparisons (after Dunn correction) were used to determine the source of the difference. Pearson correlation coefficient was used to determine correlations between numerical variables. The magnitude of the correlations was interpreted as follows: below 0.499, poor, 0.500 to 0.699, moderate, 0.700 to 0.899, good, and 0.900 to 1.000, excellent (22). The effect size was defined according to Cohen, with the standardized effect (ηp^2) being small for $\eta p^2 > 0.1$, medium for $\eta p^2 > 0.25$ and large for $\eta p^2 > 0.4$. The SPSS (Windows version 24) was used for statistical analyses and a p-value less than 0.05 was considered statistically significant.

RESULTS

The descriptive statistics of ankle mobility and AT, PF and ITB mechanical properties concerning extremities are shown in Table 2. Dominant side AT elasticity and ankle mobility were lower than nondominant side. Nondominant side ITB stiffness was higher than dominant side ($p<0.05$). There was no significant correlation between nondominant side ankle mobility and mechanical properties ($p>0.05$). AT stiffness had weak negative correlation with AT elasticity (r= -0.46), ITB stiffness had moderate negative correlation with ITB elasticity and moderate positive correlation with AT stiffness on the nondominant side (r= -0.65 and 0.44, respectively) (Table 3).

Table 2. The comparison of mechanical properties and mobility values.

	Nondominant side (Mean ± SD)	Dominant side (Mean ± SD)	z	p
Ankle Mobility (°)	127.00 ± 4.26	125.33 ± 4.71	-1.98	**0.04***
AT Stiffness (N/m)	781.05 ± 110.87	772.99 ± 82.67	-0.46	0.64
AT Elasticity (log)	0.85 ± 0.15	0.90 ± 0.15	-2.18	**0.03***
PF Stiffness (N/m)	502.42 ± 78.96	506.29 ± 64.34	-1.13	0.26
PF Elasticity (log)	1.15 ± 0.20	1.17 ± 0.12	-0.03	0.97
ITB Stiffness (N/m)	504.69 ± 133.07	474.05 ± 123.61	-2.60	**0.01***
ITB Elasticity (log)	1.15 ± 0.21	1.14 ± 0.24	-0.34	0.73

AT; Achilles tendon. PF; Plantar fascia. ITB; Iliotibial band. N/m; Newton/meter. log; logarithmic decrement. * p<0.05

Table 3. Ankle mobility and mechanical properties of the nondominant side

		Ankle Mobility	AT Stiffness	AT Elasticity	PF Stiffness	LPF Elasticity	ITB Stiffness	ITB Elasticity
Ankle Mobility	r	1.00	-0.07	0.01	0.32	0.18	-0.07	0.06
	p		0.71	0.95	0.08	0.34	0.69	0.75
AT Stiffness	r	-0.07	1.00	**-.46***	-0.18	-0.01	**.44***	-0.27
	p	0.71		0.01	0.34	0.94	0.02	0.15
AT Elasticity	r	0.01	**-.46***	1.00	0.13	-0.15	0.03	-0.11
	p	0.95	0.01		0.48	0.42	0.86	0.57
PF Stiffness	r	0.32	-0.18	0.13	1.00	0.33	0.04	-0.07
	p	0.08	0.34	0.48		0.07	0.82	0.72
PF Elasticity	r	0.18	-0.01	-0.15	0.33	1.00	-0.18	0.27
	p	0.34	0.94	0.42	0.07		0.33	0.15
ITB Stiffness	r	-0.07	**.44***	0.03	0.04	-0.18	1.00	**-.65****
	p	0.69	0.02	0.86	0.82	0.33		0.00
ITB Elasticity	r	0.06	-0.27	-0.11	-0.07	0.27	**-.65****	1.00
	p	0.75	0.15	0.57	0.72	0.15	0.00	

AT; Achilles tendon. PF; Plantar fascia. ITB; Iliotibial band. * p < 0.05, ** p < 0.01

There was no significant correlation between dominant side ankle mobility and mechanical properties ($p>0.05$). AT elasticity had a moderate and weak negative correlation between AT and PF stiffness (r= -0.63 and -0.41, respectively), ITB stiffness had weak negative correlation with ITB elasticity on the dominant side (r= -0.36) (Table 4).

The descriptive statistics of age, height, body weight and sport age values with respect to sports discipline are shown in Table 5. Significant differences were found between the groups in age, height, weight and sport ages ($p<0.05$). Basketball players were older and more experienced than runners and volleyball players; however, runners were shorter and lighter than basketball and volleyball players ($p<0.05$). The dominant and nondominant side ankle mobility were similar between the groups ($p>0.05$). Dominant side AT and nondominant side PF elasticity were significantly different between the groups. Dominant-nondominant side ITB stiffness and nondominant side ITB elasticity were significantly different between groups. Dunn's posthoc test showed; the dominant side AT and nondominant side ITB elasticity of runners were lower than basketball and volleyball players. Nondominant side PF elasticity of volleyball players was lower than others ($p<0.05$). Nondominant and dominant side ITB stiffness of basketball players was higher than the others ($p<0.05$).

Table 4. Ankle mobility and mechanical properties of the dominant side

		Ankle Mobility	AT Stiffness	AT Elasticity	PF Stiffness	PF Elasticity	ITB Stiffness	ITB Elasticity
Ankle Mobility	r	1.00	-0.10	0.07	0.02	0.08	-0.05	0.24
	p		0.59	0.72	0.92	0.69	0.80	0.19
AT Stiffness	r	-0.10	1.00	**-.63****	-0.24	-0.16	0.31	0.01
	p	0.59		0.00	0.20	0.39	0.10	0.94
AT Elasticity	r	0.07	**-.63****	1.00	**-.41***	0.05	0.14	-0.19
	p	0.73	0.00		0.02	0.79	0.45	0.32
PF Stiffness	r	0.02	-0.24	**-.41***	1.00	0.23	0.07	-0.04
	p	0.92	0.20	0.02		0.23	0.70	0.83
PF Elasticity	r	0.08	-0.16	0.05	0.23	1.00	-0.28	0.22
	p	0.69	0.39	0.79	0.23		0.13	0.24
ITB Stiffness	r	-0.05	0.31	0.14	0.07	-0.28	1.00	**-.36***
	p	0.80	0.10	0.45	0.70	0.13		0.04
ITB Elasticity	r	0.24	0.01	-0.19	-0.04	0.22	**-.36***	1.00
	p	0.19	0.94	0.32	0.83	0.24	0.04	

Abbreviations; AT; Achilles tendon. PF; Plantar fascia. ITB; Iliotibial band.* $p < 0.05$, ** $p < 0.01$

Table 5. Group comprasion of characteristics and mechanical properties

	Runner (Mean ± SD)	Basketball P (Mean ± SD)	Volleyball P (Mean ± SD)	X^2	P	ηp^2
Age (year)	24.8 ± 3.29	29.4 ± 3.63	24.0 ± 4.45	8.52	**0.01**	0.29
Height (cm)	174.6 ± 9.11	196.0 ± 9.32	194.6 ± 7.09	17.74	**0.00**	0.61
Weight (kg)	61.3 ± 5.27	97.7 ± 11.25	86.2 ± 12.15	19.35	**0.00**	0.67
Sport age (year)	11.3 ± 3.27	15.5 ± 3.87	10.3 ± 4.24	8.11	**0.02**	0.28
ND Ankle Mobility (°)	123.9 ± 4.51	124.8 ± 5.63	127.3 ± 3.53	2.47	0.29	0.09
D Ankle Mobility (°)	125.1 ± 3.48	127.9 ± 6.03	128.0 ± 2.00	3.18	0.20	0.11
D AT Stiffness (N/m)	763.5 ± 67.73	764.7 ± 93.25	790.8 ± 90.61	0.98	0.61	0.03
D AT Elasticity (log)	**0.8 ± 0.14**	1.0 ± 0.15	0.9 ± 0.13	7.36	**0.02**	0.25
ND AT Stiffness (N/m)	730.9 ± 48.03	822.1 ± 104.84	790.2 ± 146.82	4.77	0.09	0.17
ND AT Elasticity (log)	0.8 ± 0.15	0.9 ± 0.17	0.8 ± 0.14	0.71	0.70	0.02
D PF Stiffness (N/m)	507.6 ± 68.37	519.5 ± 53.34	491.8 ± 73.44	1.18	0.55	0.04
D PF Elasticity (log)	1.2 ± 0.10	1.1 ± 0.15	1.2 ± 0.11	1.09	0.60	0.04
ND PF Stiffness (N/m)	491.6 ± 65.01	537.2 ± 85.77	478.5 ± 79.99	3.11	0.21	0.11
ND PF Elasticity (log)	1.2 ± 0.07	1.2 ± 0.15	**1.0 ± 0.28**	6.05	**0.04**	0.21
D ITB Stiffness(N/m)	417.0 ± 103.02	**566.8 ± 102.30**	438.3 ± 116.40	7.55	**0.02**	0.26
D ITB Elasticity (log)	1.2 ± 0.29	1.0 ± 0.21	1.2 ± 0.21	2.77	0.25	0.10
ND ITB Stiffness (N/m)	426.1 ± 83.79	**609.8 ± 134.39**	478.2 ± 109.86	10.54	**0.01**	0.36
ND ITB Elasticity (log)	**1.3 ± 0.26**	1.0 ± 0.13	1.1 ± 0.17	6.15	**0.04**	0.21

Abbreviations; AT; Achilles tendon, PF; Plantar fascia, ITB; Iliotibial band, P; player, N/m; Newton/meter, log; logarithmic decrement, D; dominant side, NS, nondominant side. Values in bold letter show significant differences.

DISCUSSION

There are several studies investigated the AT stiffness (18, 23-26). AT stiffness of elite soccer players were higher in the study conducted by Cristi-Sánchez et al. (23) than AT stiffness values found in our study. Sakalauskaitė&Satkunskienė analyzed PF, AT stiffness and elasticity of 21 soccer players with Myoton (27), and they found slightly lower values than our results. In another study, AT stiffness of female netball players was measured in the lying and standing positions (28). In the lying position, AT stiffness values were found to be lower than our results. In another study conducted with basketball players, AT stiffness values were similar with the results of basketball players participated to our study, whereas the elasticity of AT was higher than ours (24).

Ankle mobility restriction can affect the biomechanical chain and athletic performance, joint mobility reduction may increase joint and muscle stiffness, muscle activity patterns, impair the efficiency of movements (6, 29, 30). Limited dorsiflexion was demonstrated with the higher projection of the knee in the frontal plane during dynamic tasks (squatting, jumping, single-leg squatting) and large frontal and transverse knee motions (internal rotation and adduction) in several studies (6, 31, 32). The foot-ankle is a region where many joints and muscles interact dynamically. The tightness of the PF or the AT leads to limited ankle dorsiflexion and injuries (31). Both structures (AT and PF) are associated anatomically and functionally during the stance phase and dynamic gait. Increased active or passive tension of the AT can cause increased plantarflexion moment of hindfoot and dorsiflexion moment of the forefoot. These moments also may increase tension in the PF for stabilizing the foot arch (32). Therefore, a positive correlation has been demonstrated between the mechanical properties of both structures dynamically in another study (20). If the dorsiflexion of the ankle was increased via strain or force, the PF and AT stiffness were raised similarly (30). A restriction of dorsiflexion limits the anterior translation of the tibia over the fixed foot and this restriction is compensated with foot pronation. When the foot pronation increases, PF and AT can be overloaded and get stiffer because of calcaneus rotation. We found weak negative correlation between AT elasticity and PF stiffness on the dominant side. A strong negative correlation has been demonstrated between AT stiffness and PF elasticity in hyperpronated ankles (27). We did not find any relation between ankle mobility and mechanical properties.

Lumbar spine stiffness and mobility of lumbar spine assessments revealed a discrepancy (33). We observed that nondominant and dominant side AT stiffness had strong and moderate negative correlations with AT elasticity. Weak and moderate negative correlations were detected in ITB stiffness and elasticity, respectively. If the stiffness increased in a tissue, elasticity would decrease; which has been supported by researches (34).

Ankle hypermobility may cause delayed hip abductor muscle firing patterns (35). In the lower extremity chain, the increase in adduction moment may result in a weakness of the proximal antagonistic muscle groups (36). This uncontrolled femoral adduction and internal rotation due to hip weakness cause an increase in the ITB tightness (37). The strengthening of proximal kinetic chain musculature, specifically gluteus medius has been recommended for controlling ankle motion. We postulated that the moderate positive correlation between nondominant side ITB and AT stiffness which may also prove this inefficiency in the kinetic link.

Our results showed that mechanical properties of the AT, PF and ITB, especially stiffness and elasticity, vary among different sports disciplines. The right AT and left ITB elasticity of runners were greater than others. Volleyball players had higher PF elasticity on the nondominant side. Besides, basketball players had stiffer ITB, bilaterally. These differences among different sports may be related to adaptation to the needs of the sport itself and the physical characteristics of the athlete. The adaptation of the tendon to training has been explained with scientific evidence but there is not enough information about which training methods (eg; strength, plyometric or endurance) could affect tendon stiffness. One of the studies revealed adaptation over time (38). The adaptation of AT to short or long-term training and its relation to sportive performance is controversial. Runners with the best performance in a 5000-meter marathon have been reported to have lower AT stiffness than those with worse performance (39). On the contrary, in different studies, medium and long distance runners with the best running economy or performance have higher AT stiffness (40).

The AT stiffness has been found to be similar for different positions in the same sport (23). It is well-known that midfield footballers run more than those playing in other positions and are exposed to extra workload. Therefore, adaptations are expected in the tendon and soft tissue because of the mechanical demands of the sport and long-term training. It is possible to see these kind of adaptations in karate or netball players as demonstrated in previous studies (25, 28). AT, PF and ITB might have been adapted mechanically according to the specific needs of sports or training regimes.

Limitations

Several limitations have hindered our ability to draw definitive conclusions. First, we did not assess the adipose tissue of the athletes that may affect the interpretation of the results. The second limitation of the study was lack of EMG measurement which might have revealed the relaxation of the muscles to perform a better assessment.

CONCLUSION

This study revealed that ankle mobility was not correlated with AT, PF and ITB mechanical properties. Mechanical properties might differ according to sports discipline. The data related to joint mobility and mechanical properties may provide useful information in planning rehabilitation or conditioning programs in terms of injury prevention.

Acknowledgements

The author would like to thank all athletes who participated in this study

Ethics Committee Approval / Etik Komite Onayı

This study was approved by the Ethics Committee for Non-Invasive Research Studies of Hasan Kaloncu University Faculty of Health Sciences (approval number 2020/100).

Conflict of Interest / Çıkar Çatışması

The authors declared no conflicts of interest with respect to authorship and/or publication of the article.

Financial Disclosure / Finansal Destek

The authors received no financial support for the research and/or publication of this article.

Author Contributions / Yazar Katkıları

Concept: SU; Design: SU; Supervision: SU; Materials: SU; Data Collection and Processing: SB, TGB; Analysis and Interprepation: SB; Literature Review: SU; Writing Manuscript: SU; Critical Reviews: SU.

Additional information

All methods were carried out in accordance with relevant guidelines and regulations.

REFERENCES

1. Magnusson SP, Narici MV, Maganaris CN, Kjaer M. Human tendon behaviour and adaptation, in vivo. *J Physiol.*2008;586(1):71-81.
2. Fukunaga T, Kawakami Y, Kubo K, Kanehisa H. Muscle and tendon interaction during human movements. *Exerc Sport Sci Rev.* 2002;30(3):106-10.
3. Biewener AA, Roberts TJ. Muscle and tendon contributions to force, work, and elastic energy savings: a comparative perspective. *Exerc Sport Sci Rev.* 2000;28(3):99-107.
4. Gleim GW, McHugh MP. Flexibility and its effects on sports injury and performance. *Sports Med.* 1997;24(5):289-99.

5. Kocur P, Tomczak M, Wiernicka M, Goliwąs M, Lewandowski J,Łochyński D. Relationship between age, BMI, head posture and superficial neck muscle stiffness and elasticity in adult women. *Sci Rep.* 2019;9(1):8515.
6. Macrum E, Bell DR, Boling M, Lewek M, Padua D. Effect of limiting ankle-dorsiflexion range of motion on lower extremity kinematics and muscle-activation patterns during a squat. *J Sport Rehabil.* 2012;21(2):144-50.
7. Rabin A, Kozol Z, Finestone AS. Limited ankle dorsiflexion increases the risk for mid-portion Achilles tendinopathy in infantry recruits: a prospective cohort study. *J Foot Ankle Res.* 2014;7(1):48.
8. Kaufman KR, Brodine SK, Shaffer RA, Johnson CW, Cullison TR. The effect of foot structure and range of motion on musculoskeletal overuse injuries. *Am J Sports Med.* 1999;27(5):585-93.
9. Jeon K, Kim K, Kang N. Leg stiffness control during drop landing movement in individuals with mechanical and functional ankle disabilities. *Sports Biomech.* 2022;21(9):1093-1106.
10. Mao M, Yin Y, Luo D, Liu H, Yu B. Evaluation of dynamic postural control during single-leg landing tasks using initial impact force, landing leg stiffness and time to stabilisation. *Sports Biomech.* 2021;1-14.
11. Riemann BL, DeMont RG, Ryu K, Lephart SM. The effects of sex, joint angle, and the gastrocnemius muscle on passive ankle joint complex stiffness. *J Athl Train.* 2001;36(4):369-75.
12. Liu CL, Zhou JP, Sun PT, Chen BZ, Zhang J, Tang CZ, et al. Influence of different knee and ankle ranges of motion on the elasticity of triceps surae muscles, Achilles tendon, and plantar fascia. *Sci Rep.* 2020;10(1):6643.
13. Hug F, Lacourpaille L, Maïsetti O, Nordez A. Slack length of gastrocnemius medialis and Achilles tendon occurs at different ankle angles. *J Biomech.* 2013;46(14):2534-8.
14. Dill KE, Begalle RL, Frank BS, Zinder SM, Padua DA. Altered knee and ankle kinematics during squatting in those with limited weight-bearing–lunge ankle-dorsiflexion range of motion. *J Athl Train*. 2014;49(6):723-32.
15. Lima YL, Ferreira VMLM, de Paula Lima PO, Bezerra MA. de Oliveira RR, Almeida GPL. The association of ankle dorsiflexion and dynamic knee valgus: A systematic review and meta-analysis. *Phys Ther Sport.* 2018;29:61-9.
16. Rabin A, Kozol Z, Spitzer E, Finestone AS. Weight-bearing ankle dorsiflexion range of motion can side to side symmetry be assumed? *J Athl Train.* 2015;50(1):30-5.
17. Gapeyeva H, Vain A. Methodological guide: principles of applying Myoton in physical medicine and rehabilitation. Tartu, Estonia: Muomeetria Ltd. 2008.
18. Liu CL, Li YP, Wang XQ, Zhang ZJ. Quantifying the stiffness of Achilles tendon: intra-and Inter-Operator reliability and the effect of ankle joint motion. *Med Sci Monit.* 2018;24:4876-81.
19. Schneebeli A, Falla D, Clijsen R, Barbero M, Myotonometry for the evaluation of Achilles tendon mechanical properties: a reliability and construct validity study. *BMJ Open Sport Exerc Med*. 2020;6(1):e000726.
20. Orner S, Kratzer W, Schmidberger J, Grüner B. Quantitative tissue parameters of Achilles tendon and plantar fascia in healthy subjects using a handheld myotonometer. *J Bodyw Mov Ther.* 2018;22(1):105-11.
21. Hall EA, Docherty CL. Validity of clinical outcome measures to evaluate ankle range of motion during the weight-bearing lunge test. *J Sci Med Sport.* 2017;20(7):618-21.
22. Domholdt E. *Physical therapy research, principles and applications*. 2nd ed. Philadelphia: WB Saunders; 2000.
23. Cristi-Sánchez I, Danes-Daetz C, Neira A, Ferrada W, Yáñez Díaz R, Silvestre-Aguirre R. Patellar and achilles tendon stiffness in elite soccer players assessed using myotonometric measurements. *Sports health.* 2019;11(2):157-62.
24. Pożarowszczyk B, Gołaś A, Chen A, Zając A, Kawczyński A. The impact of post activation potentiation on Achilles tendon stiffness, elasticity and thickness among basketball players. *Sports.* 2018;6(4):117.
25. Pożarowszczyk B, Pawlaczyk W, Smoter M, Zarzycki A, Mroczek D, Kumorek M, et al. Effects of karate fights on Achilles tendon stiffness measured by myotonometry*. J Hum Kinet.* 2017;56(1):93-7.
26. Usgu S, Yakut Y, Cinar MA. The comparison of Achilles tendon viscoelastic properties in elite runners and soccer players. *Turk J Sports Med.* 2020;55(4):276-83.
27. Sakalauskaitė R, Satkunskienė D. The foot arch and viscoelastic properties of plantar fascia and Achilles tendon. *J Vibroeng.* 2012;4(4):1751-59.
28. Pruyn EC, Watsford ML, Murphy AJ. Differences in lower-body stiffness between levels of netball competition. *J Strength Cond Res.* 2015;29(5):1197-202.
29. Cook G, Burton L, Hoogenboom BJ, Voight M. Functional movement screening: the use of fundamental movements as an assessment of function-part 1*. Int J Sports Phys Ther.* 2014;9(3),396-409.
30. Leardini A, Stagni R, O'Connor JJ. Mobility of the subtalar joint in the intact ankle complex. *J Biomech.*2001;34(6):805-9.
31. Patel A, DiGiovanni B. Association between plantar fasciitis and isolated contracture of the gastrocnemius. *Foot Ankle Int*. 2011;32(1):5-8.
32. Huerta JP. The effect of the gastrocnemius on the plantar fascia. *Foot Ankle Clin.* 2014;19(4):701-18.
33. Tennant LM, Nelson-Wong E, Kuest J, Lawrence G, Levesque K, Owens D, et al. A comparison of clinical spinal mobility measures to experimentally derived lumbar spine passive stiffness. *J Appl Biomech.* 2020;1(aop):1-11.
34. Gavronski G, Veraksitš A, Vasar E, Maaroos J. Evaluation of viscoelastic parameters of the skeletal muscles in junior triathletes. *Physiol Meas.* 2007;28(6):625-37.
35. Beckman SM, Buchanan TS. Ankle inversion injury and hypermobility: effect on hip and ankle muscle electromyography onset latency. *Arch Phys Med Rehab.* 1995;76(12):1138-43.
36. Fredericson M, Cookingham CL, Chaudhari AM, Dowdell BC, Oestreicher N, Sahrmann SA. Hip abductor weakness in distance runners with iliotibial band syndrome. *Clin J Sport Med.* 2000;10(3):169-75.
37. Noehren B, Davis I, Hamill J. ASB Clinical Biomechanics Award Winner 2006: Prospective study of the biomechanical factors associated with iliotibial band syndrome. *Clin Biomech.* 2007;22(9):951-6.
38. Bohm S, Mersmann F, Arampatzis A. Human tendon adaptation in response to mechanical loading: a systematic review and meta-analysis of exercise intervention studies on healthy adults. *Sports Med Open.* 2015;1(1):7.
39. Kubo K, Miyazaki D, Shimoju S, Tsunoda N. Relationship between elastic properties of tendon structures and performance in long distance runners. *Eur J Appl Physiol.* 2015;115(8):1725-33.
40. Ueno H, Suga T, Takao K, Tanaka T, Misaki J, Miyake Y, et al. Potential relationship between passive plantar flexor stiffness and running performance. *Int J Sports Med*. 2018;39(3):204-9