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FASCIA SCIENCE AND CLINICAL APPLICATIONS: PROSPECTIVE STUDY

Quantitative tissue parameters of Achilles tendon and plantar fascia in healthy subjects using a handheld myotonometer

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A R T I C L E I N F O

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A B S T R A C T

Objective: The aim of the study was to examine the quantitative tissue properties of the Achilles tendon and plantar fascia using a handheld, non-invasive MyotonPRO device, in order to generate normal values and examine the biomechanical relationship of both structures.
Design: Prospective study of a large, healthy sample population.
Participants: The study sample included 207 healthy subjects (87 males and 120 females) for the Achilles tendon and 176 healthy subjects (73 males and 103 females) for the plantar fascia. For the correlations of the tissue parameters of the Achilles tendon and plantar fascia an intersection of both groups was formed which included 150 healthy subjects (65 males and 85 females).
Interventions: All participants were measured in a prone position. Consecutive measurements of the Achilles tendon and plantar fascia were performed by MyotonPRO device at defined sites.
Results: For the left and right Achilles tendons and plantar fasciae all five MyotonPRO parameters (*Frequency* [Hz], *Decrement*, *Stiffness* [N/m], *Creep* and *Relaxation Time* [ms]) were calculated of healthy males and females. The correlation of the tissue parameters of the Achilles tendon and plantar fascia showed a significant positive correlation of all parameters on the left as well as on the right side.
Conclusions: The MyotonPRO is a feasible device for easy measurement of passive tissue properties of the Achilles tendon and plantar fascia in a clinical setting. The generated normal values of the Achilles tendon and plantar fascia are important for detecting abnormalities in patients with Achilles tendinopathy or plantar fasciitis in the future. Biomechanically, both structures are positively correlated. This may provide new aspects in the diagnostics and therapy of plantar fasciitis and Achilles tendinopathy.

1. Introduction

The Achilles tendon and plantar fascia are both important structures for the static and dynamic functionality of the foot. The plantar fascia connects the calcaneal bone to the distal aspect of the metatarsophalangeal joints. It consists of a tough sheet of dense connective tissue connected to the skin and underlying structures and protects the underlying blood and lymph vessels and nerves from compression (Benjamin, 2009). As the plantar fascia inserts distally into the metatarsophalangeal joints, the plantar fascia winds around the heads of the metatarsophalangeal bones during dorsal extension of the toes. In doing so, the plantar fascia becomes shortened and the medial longitudinal foot arch can be stabilized and raised. This is called the windlass mechanism. The longitudinal arch of the foot is raised without muscular effort and can resist loads up to 3.4 times the body weight (Hicks, 1954; Benjamin, 2009). Another function of the plantar fascia is shock absorption during walking. When the foot hits the ground the plantar fascia is stretched and the longitudinal arch is flattened, thus enabling the walker to accommodate to uneven surfaces (Singh et al., 1997). The Achilles tendon transfers load from the gastrocnemius muscle to the bones of the foot and enables plantar flexion of the hind foot. Both structures, the Achilles tendon and plantar fascia, interact and play an important role in walking. Non-specific foot pain is a common symptom among primary care patients. In a survey of 5109 subjects older than 50 years, 13% (n = 675) of the subjects affirmed posterior heel pain (Chatterton et al., 2015). Chronic heel pain has a negative influence on a patient's quality of life. For this reason, patients not only have a poorer foot-specific quality of life

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but also a poorer quality of life in terms of general health, including their physical activities and social life (Irving et al., 2008). The cause of chronic heel pain can be very extensive and includes Achilles tendinopathy and plantar fasciitis, plantar fasciitis being the most common cause (Tu and Bytomski, 2011). A recent increase in the level of activity is often observed in the patient's case history. This includes an increase in walking or running distance and standing times (McPoil et al., 2008). After medial tibial stress syndrome, Achilles tendinopathy and plantar fasciitis are the main running-related musculoskeletal injuries, with an incidence ranging from 9.1% to 10.9% for Achilles tendinopathy and 4.5%–10% for plantar fasciitis (Lopes et al., 2012). Multiple risk factors can promote plantar fasciitis and include obesity (Riddle et al., 2003), limited ankle dorsiflexion (Riddle et al., 2003), as well as anatomical changes such as Pes planus, Pes cavus or increased pronation of the foot (Young et al., 2001). Individuals who spend most of their workday on their feet and individuals with a recently increased level of activity are also at risk of developing plantar fasciitis (Riddle et al., 2003; McPoil et al., 2008). Degenerative changes of the Achilles tendon lead to Achilles tendinopathy, which in the acute state can also result in an Achilles rupture. There are multiple extrinsic and intrinsic risk factors similar to those of plantar fasciitis. The risk factors include, amongst others, obesity (Franceschi et al., 2014), dysfunction of the M. gastrocnemius and M. soleus (Kader et al., 2002), foot deformities (Kader et al., 2002), tendon vascularity (Kader et al., 2002) and overuse (Glazebrook et al., 2008). Mechanical overload can lead to microtraumas and inflammatory reactions. Due to an incomplete healing process, Achilles tendinopathy occurs, resulting in a degeneration of collagen fibrils and proliferation of extracellular matrix and blood vessels (Scott et al., 2015; Franceschi et al., 2014; Khan et al., 2000). For Achilles tendinopathy, as well as for plantar fasciitis, a change in the elastic properties can be observed in their respective structures. In both disease scenarios, there is a decrease in stiffness of the two structures (Scott et al., 2015; Arya and Kulig, 2010; Wu et al., 2011). These changes can be detected using imaging technologies such as ultrasound elastography (Aubry et al., 2015; Wu et al., 2015; Klauser et al., 2013). However, the acquisition costs for sonoelastography devices are high and the examiners need special training. A new approach for measuring tissue stiffness is the examination of musculoskeletal structures by a small, handheld, non-imaging device called MyotonPRO. The application is easy to learn and the device can measure five tissue parameters (Frequency [Hz], Decrement, Stiffness [N/m], Creep and Relaxation Time [ms]) of the underlying structure simultaneously. All five parameters describe biomechanical tissue properties that can be altered in pathological states, sports-related injury or therapeutic intervention. Examining the tissue properties of muscles, fascia or tendons in relaxed or contracted state by a Myoton device can easily generate objective information that cannot be provided by clinical examination or dynamic tests. By manual palpation only superficial structural changes like indurations or calcifications and trophic changes can be detected. Passive, quantitative tissue parameters such as stiffness or tone can only be measured by technical imaging or non-imaging devices. In the current literature, there are few studies that examine the Achilles tendon and plantar fascia using the MyotonPRO device. A baseline of normal values of healthy subjects measured by the MyotonPRO device is important for detecting abnormalities in tissue properties of the Achilles tendon and plantar fascia in the fields of sports medicine, therapeutic interventions or detection of pathologies. Studies using the MyotonPRO device have often been conducted on a small sample of less than 50 subjects (Pruyn et al., 2015; Agyapong-Badu et al., 2013; Mooney et al., 2013; Aird et al., 2012). To generate normal values representative of the population, a large sample of healthy subjects is necessary. The aim of this study was to measure the quantitative tissue parameters of the Achilles tendon and plantar fascia of a large, healthy sample population using the MyotonPRO device and to correlate the tissue parameters of both structures. In future research, the MyotonPRO device can be tested on a population of patients with Achilles tendinopathy or plantar fasciitis in order to facilitate the diagnostics of these clinical manifestations.

2. Methods

2.1. Design

The study was designed prospectively. With the MyotonPRO device the relaxed Achilles tendons and plantar fasciae of healthy participants of all age groups were measured. The MyotonPRO (Myoton AS, Tallinn, Estonia) is a small, handheld, non-invasive device. The measuring tip is placed perpendicularly on the skin above the muscle or fascia to be measured. After pre-compression of the subcutaneous tissue (0.18 N), the tip oscillates via an electromagnetic mechanism for the duration of 15 ms (0.58 N). The consecutive oscillations of the skin and the underlying muscle or fascia are registered by the device. From the damping of the oscillation curve over 400 ms, five quantitative parameters are computed. All five parameters describe biomechanical tissue characteristics that provide quantitative information about passive muscle properties. *Frequency* [Hz] is the oscillation frequency of the oscillation curve and characterizes the tone of the tissue in a relaxed state. The higher the value, the higher the tone. *Decrement* describes the logarithmic decrement of the natural oscillation. *Stiffness* [N/m] represents the capability of tissue to resist external, deforming forces. A higher value indicates stiffer tissue. *Relaxation Time* [ms] characterizes the time to shape recovery after a deformation of tissue, whilst *Creep* describes the non-elastic deformation of tissue over time (Myoton AS Revision No. 14 12th February 2016; Schneider et al., 2014).

2.2. Participants

All subjects in this study met the inclusion criteria (age > 18 years; body-mass-index < 30 kg/m^2; no pregnancy; no chronic diseases affecting the musculoskeletal system such as diabetes mellitus, osteoporosis or rheumatism; no surgery or injuries of the lower limb and the foot; no skin lesions above the measuring sites; no intake of anabolics or other drugs affecting the musculoskeletal system). The study sample population for the measurements of the Achilles tendon included 207 healthy subjects (87 males and 120 females). For these subjects the mean age was 33.15 (standard deviation (SD) 13.66) years (range 18–75 years), and the mean body mass index was 22.73 (SD 2.47) kg/m^2 (range 17.58 kg/m^2 to 29.7 kg/m^2). The plantar fascia sample population included 176 healthy subjects (73 males and 103 females). The mean age was 35.53 (SD 15) years (range 18–75 years), and the mean body mass index 23.05 (SD 2.63) kg/m^2 (range 17.58 kg/m^2 to 29.53 kg/m^2). As an intersection of both groups, the study population of the correlations of the Achilles tendon and plantar fascia measurements included 150 healthy subjects. In total 65 males (43.3%) and 85 females (56.7%) formed the common intersection (mean age 34.5 (SD 14.4) years, mean body mass index 22.9 (SD 2.5) kg/m^2). The study was conducted by the Elastography Study Group Ulm at the Department of Internal Medicine I at the University Hospital of Ulm in accordance with the Declaration of Helsinki. All subjects were informed about the procedures and privacy policy and gave their written informed consent. None of the involved investigators has any business relationship or affiliation with the company Myoton AS.

2.3. Procedures

For all measurements, the subjects lay in a prone position on a massage table with their feet hanging over the edge of the table at an angle of 90°. The subjects were instructed to relax completely so that both structures could be measured in a relaxed state. After a relaxation phase the measurement started. The Achilles tendon was measured centrally between the malleoli medialis and lateralis. The measuring site of the plantar fascia was positioned on the sole of the foot on a level with the lateral basis of the fifth metatarsal bone in the middle of the foot. To support the contact of the MyotonPRO probe with the skin, two sided medical stickers were used for the measurements. These stickers do not influence the results to any significantly statistical extent and were recommended by the Myoton AS company (Myoton AS Revision No. 14 12th February 2016). Three consecutive measurements with the MyotonPRO device were carried out at every measuring site, each comprising a series of 10 measurements of all five MyotonPRO parameters. After every measurement, the Coefficient of Variation of every parameter was calculated automatically by the device and shown on the screen indicating the variability of the measurement. It can be influenced by the subject, operator, device accuracy or environment. In accordance to the recommendations of the Myoton AS company the Coefficient of Variation of every parameter was lower than 3%. When it was higher, the measurement was repeated under better examination conditions (Myoton AS Revision No. 14 12th February 2016).

2.4. Statistical analyses

Sample size planning and calculation was performed with G*Power Version 3.1. A priori type of power analysis and sample size calculation according to a power (1-β err prob) of 0.95 and an effect strength of 0.3 at $\alpha = 0.05$ was calculated. SAS 9.2 software was used for the statistical analysis. (SAS Institute Inc., Cary, North Carolina, USA). Testing the normality of data was performed using the Shapiro-Wilk-Test. The data were first analyzed descriptively. The mean, standard deviation, median, minimum, maximum and 95% confidence interval of each MyotonPRO parameter were calculated out of 30 single values from 3 consecutive measurements of every measuring site. The correlation of the MyotonPRO values of the Achilles tendon and plantar fascia were calculated using the Spearman's rank correlation coefficient. The α significance level was set at 0.05.

3. Results

Table 1 shows the descriptive statistics of the measured tissue parameters for the left and right Achilles tendon for both males and females. For the Achilles tendon, there was a significant difference in all measured parameters between males and females. The mean values (SD) of the left and right Achilles tendon of healthy males (n = 87) and healthy females (n = 120) are shown in Table 2.

The descriptive statistics of the measured tissue parameters of the left and right plantar fascia for both gender are shown in Table 3. The mean values (SD) of the left and right plantar fascia for healthy males (n = 73) and healthy females (n = 103) are shown in Table 4.

Table 5 and Table 6 show the correlation results of the Achilles tendon and plantar fascia. All five MyotonPRO parameters of both structures correlated significantly for the left and right side. Thereby all correlation coefficients were positive, indicating a positive relationship of both structures. For example, the higher the tone of the Achilles tendon, the higher the tone increases in the plantar fascia and vice versa.

4. Discussion

To our knowledge, this is the first study examining the Achilles tendon and plantar fascia in a large, healthy sample population using the MyotonPRO device. In the study of Pruyn et al. (2015), the Achilles tendons of 15 female netballers were assessed using MyotonPRO. In a lying and standing position as well as in a contracted state, only the stiffness value of the Achilles tendon was measured (Pruyn et al., 2015). Comparing the results from the lying position, the stiffness value deviates from our results (393.2 (SD 55.9) N/m for the left and right Achilles tendons of the female netballers compared to our results of 826.53 (SD 95.51) N/m for the left and 824.36 (SD 99.14) N/m for the right Achilles tendon of healthy females (n = 120)). However, it must be mentioned that both studies cannot be compared directly. In Pruyn et al. (2015), only 15 female participants between the ages of 18 and 35 years were examined. Furthermore, all participants exercised the same

Table 2
MyotonPRO parameters of the Achilles tendons of healthy males and females.

Achilles tendon	Left	Right
Males (n = 87)		
Frequency [Hz]	35.96 (SD 2.90)	35.95 (SD 2.99)
Decrement	0.86 (SD 0.14)	0.85 (SD 0.13)
Stiffness [N/m]	877.62 (SD 88.31)	879.01 (SD 96.57)
Creep	0.39 (SD 0.04)	0.39 (SD 0.05)
Relaxation [ms]	5.79 (SD 0.65)	5.83 (SD 0.77)
Females (n = 120)		
Frequency [Hz]	35.05 (SD 3.04)	34.95 (SD 3.08)
Decrement	1.03 (SD 0.21)	1.01 (SD 0.19)
Stiffness [N/m]	826.53 (SD 95.51)	824.36 (SD 99.14)
Creep	0.41 (SD 0.05)	0.41 (SD 0.04)
Relaxation [ms]	6.17 (SD 0.76)	6.19 (SD 0.74)

Table 1
Results of the MyotonPRO measurements of the left and right Achilles tendon (n = 207).

Achilles tendon (n = 207)	Mean	95% Confidence Interval	Standard deviation	Median	Minimum - Maximum
Left					
Frequency [Hz]	35.44	35.02–35.85	3.01	35.37	25.89–48.55
Decrement	0.96	0.93–0.99	0.2	0.93	0.36–1.82
Stiffness [N/m]	848	834.88–861.12	95.73	846.47	584.57–1156.57
Creep	0.4	0.40–0.41	0.04	0.4	0.25–0.57
Relaxation [ms]	6.01	5.91–6.11	0.74	5.93	3.44–8.64
Right					
Frequency [Hz]	35.37	34.95–35.79	3.08	35	25.81–43.76
Decrement	0.94	0.92–0.97	0.19	0.91	0.48–1.65
Stiffness [N/m]	847.32	833.42–861.23	101.5	841.37	535.97–1111.33
Creep	0.41	0.37–0.38	0.05	0.4	0.31–0.65
Relaxation [ms]	6.04	5.93–6.14	0.77	6	4.53–9.88

Table 3
Results of the MyotonPRO measurements of the left and right plantar fascia (n = 176).

Plantar fascia (n = 176)	Mean	95% Confidence Interval	Standard deviation	Median	Minimum - Maximum
Left					
Frequency [Hz]	25.06	24.73–25.38	2.2	24.92	20.27–33.12
Decrement	1.17	1.14–1.19	0.17	1.14	0.82–1.83
Stiffness [N/m]	511.71	501.52–521.90	68.51	506.87	368.10–832.17
Creep	0.68	0.67–0.69	0.09	0.68	0.42–0.90
Relaxation [ms]	10.51	10.30–10.72	1.43	10.45	6.11–14.30
Right					
Frequency [Hz]	25.94	25.63–26.25	2.11	25.85	20.65–30.76
Decrement	1.16	1.14–1.18	0.14	1.16	0.83–1.63
Stiffness [N/m]	533.18	523.58–542.79	64.56	533.72	365.57–706.43
Creep	0.65	0.64–0.67	0.08	0.65	0.49–0.89
Relaxation [ms]	10.09	9.89–10.29	1.34	9.99	7.38–14.16

Table 4
MyotonPRO parameters of the plantar fasciae of healthy males and females.

Plantar fascia	left	right
Males (n = 73)		
Frequency [Hz]	25.29 (SD 2.30)	26.27 (SD 1.96)
Decrement	1.11 (SD 0.16)	1.12 (SD 0.13)
Stiffness [N/m]	518.89 (SD 72.33)	545.69 (SD 59.61)
Creep	0.67 (SD 0.08)	0.64 (SD 0.07)
Relaxation [ms]	10.38 (SD 1.38)	9.81 (SD 1.12)
Females (n = 103)		
Frequency [Hz]	24.89 (SD 2.12)	25.71 (SD 2.19)
Decrement	1.21 (SD 0.16)	1.19 (SD 0.13)
Stiffness [N/m]	506.62 (SD 65.55)	524.31 (SD 66.72)
Creep	0.68 (SD 0.09)	0.67 (SD 0.09)
Relaxation [ms]	10.60 (SD 1.46)	10.29 (SD 1.45)

sport. Our sample size was bigger and the age range was wider. The differing results could provide an indication that the stiffness of the Achilles tendon varies with the exercise of sport.

Using a Myoton-3 device in a different study, 42 Achilles tendons of soccer players were examined. The results for the Achilles tendons of participants with a normal foot arch in a relaxed state were 32.59 (SD 2.91) Hz for Frequency, 0.97 (SD 0.15) for Decrement and 676.59 (SD 44.41) N/m for Stiffness (Sakalauskaite and Satkunskiene, 2012). The results of Frequency and Decrement were close to ours. Compared to our results the Stiffness value of this study was lower. However, all participants exercised the same sport and, again, the results indicate a correlation of the stiffness value of the Achilles tendon to the performance of sport. In the same study, the 42 plantar fasciae of 21 soccer players were examined. The Myoton values for the plantar fascia in a relaxed state with a normal foot arch were 25.01 (SD 3.09) Hz for Frequency, 1.65 (SD 0.16) for Decrement and 446.4 (SD 46.17) N/m for Stiffness (Sakalauskaite and Satkunskiene, 2012). The Frequency value was very close to our result. The Decrement value of our male participants (n = 73) was a little lower (1.11 (SD 0.16) for the left plantar fascia and 1.12 (SD 0.13) for the right plantar fascia) and our Stiffness value was higher (518.89 (SD 72.33) N/m for the left plantar fascia and 545.69 (SD 59.61) N/m for the right plantar fascia). It must, however, be kept in mind that the study sample was different. In addition, their measuring position was different from ours. The authors measured the plantar fascia on the sole of the foot with a knee flexion of 90°. Furthermore, Sakalauskaite and Satkunskiene (2012) could discover a statistically significant difference between the relaxed and strained state of the Achilles tendon and plantar fascia plus a statistically significant higher elasticity of the relaxed plantar fascia for participants with a normal foot arch compared to a low foot arch. Testing the effects of karate fights, the authors Pozarowszczyk et al. (2017) measured Achilles tendon stiffness by a MyotonPRO device before and after competitive fights. They showed that Achilles tendon stiffness of the dominant leg of eleven male participants increased significantly from 751.6 (SD 123.5) before fights to 809.4 (SD 160.4) after fights. They could show no effect for the non-dominant leg (Pozarowszczyk et al., 2017). Their results before fights are lower than ours with a greater standard deviation. However, the study population differ in size and age range. Our study population of the Achilles tendon includes 87 males and the range of age is wider. The lower stiffness value of participants performing the same competitive sport may provide an indication that training has effects on the Achilles tendon stiffness that can be quantified by a myometry device. These findings should be evaluated in further

Table 5
Correlation results of the Achilles tendon and plantar fascia on the left side of both gender.

R (correlation coefficient)	Achilles Tendon				
P − value (n = 150)	Left				
Plantar Fascia	Frequency [Hz]	Decrement	Stiffness [N/m]	Creep	Relaxation [ms]
Left					
Frequency [Hz]	0.30018 **0.0002**				
Decrement		0.32067 <**0.0001**			
Stiffness [N/m]			0.28086 **0.0005**		
Creep				0.2872 **0.0004**	
Relaxation [ms]					0.28075 **0.0005**

P-values under 0.05 were interpreted as statistically significant.

Table 6
Correlation results of the Achilles tendon and plantar fascia on the right side of both gender.

R (correlation coefficient)	Achilles Tendon				
P – value (n = 150)	Right				
Plantar Fascia	Frequency [Hz]	Decrement	Stiffness [N/m]	Creep	Relaxation [ms]
Right					
Frequency [Hz]	0.28075 **0.0005**				
Decrement		0.30931 **0.0001**			
Stiffness [N/m]			0.32331 <**0.0001**		
Creep				0.27292 **0.0007**	
Relaxation [ms]					0.28974 **0.0003**

P-values under 0.05 were interpreted as statistically significant.

studies comparing athletes with non-athletes in the same study protocol.

There are several studies testing reliability of the Myoton device at different measuring sites. Repeated measurements of the rectus femoris muscle showed very high within-day and high between-day reliability in healthy older males for Frequency, Stiffness and Decrement (Aird et al., 2012). Mullix et al. (2012) demonstrated similar results in reliability measurements of rectus femoris and biceps femoris muscles in healthy young males. Reliability of Frequency, Stiffness and Decrement was excellent within-sessions and good between-days (Mullix et al., 2012). Further, interrater reliability was tested showing excellent reliability for Frequency, Stiffness and Decrement of the rectus femoris and biceps brachii muscles of healthy young males. In older males interrater reliability was excellent for all rectus femoris parameters and for Decrement of the biceps brachii muscle. For Frequency and Stiffness of the biceps brachii muscle interrater reliability was good (Agyapong-Badu et al., 2013). MyotonPRO measurements of Achilles tendon and calf muscles showed moderate to very high reliability. Moreover, measurements performed in lying and standing positions indicate a higher level of relative reliability compared to measurements in a contracted condition (Pruyn et al., 2015). Gavronski et al. (2007) could measure a significant difference of the Frequency, Stiffness and Decrement values of relaxed and contracted muscles of the arm. Those changes were muscle-specific and the contracted muscles became generally more elastic, stiff and tense (Gavronski et al., 2007). In another study, the Stiffness value of the soleus muscle was measured in a relaxed state and during increasing contraction conditions by Myoton-3-device. The muscle stiffness was lowest in relaxed state and showed a significant increase during plantar flexion. The authors conclude that an increased number of activated cross-bridges during contraction causes increased muscle stiffness (Juhart and Strojnik, 2011).

The Achilles tendon and plantar fascia are closely associated anatomically. Both structures are composed mostly of type I collagen fibers that are orientated longitudinally (Stecco et al., 2013; Scott et al., 2015). As a thin band, the fibers of the plantar fascia blend over the calcaneal bone. They interact with the periosteum of the calcaneal bone and are connected continually to the paratenon of the Achilles tendon (Stecco et al., 2013). The paratenon is a structure surrounding the Achilles tendon. It contains nerve fibers and lymphatic vessels and represents the main vascular supply for the Achilles tendon (van Sterkenburg and van Dijk, 2011). The continuity of the plantar fascia and Achilles tendon varies with age. The investigation of cadaveric feet of different age groups shows that the connection of both structures diminishes with age. In neonate feet there is a thick continuation of fibers. The feet of cadavers in the mid-20s show a superficial periosteal connection of the fibers, and for the feet of the elderly the fibers of the Achilles tendon and plantar fascia both insert into the calcaneal bone with the periosteum in between (Snow et al., 1995). Both structures, the Achilles tendon and plantar fascia, are not only associated anatomically, but also functionally. This is proposed in the model of Pascual Huerta (2014): The external forces acting on the foot during normal stance are gravity and opposing ground reaction forces in the calcaneus and metatarsals. Increased active or passive tension of the Achilles tendon induces a plantar flexion moment to the hind foot. As a consequence, there is more load on the forefoot. The forefoot tends to equalize these forces by increasing the dorsiflexion moments of the forefoot to the hind foot with a tendency to arch flattening. In order to stabilize the foot arch, tension in the plantar fascia increases. This functional relationship occurs during static stance and dynamic gait (Pascual Huerta, 2014). In another study, the force transmission of the Achilles tendon to the plantar fascia was examined during the stance phase of gait in a cadaveric model. The authors demonstrated that the plantar fascia plays an important role in the force transmission from the Achilles tendon to the forefoot. With increased force of the Achilles tendon, the tension in the plantar fascia increases (Erdemir et al., 2004). Many studies point out that tightness of the posterior muscles of the leg is associated with plantar fasciitis. Bolivar et al. (2013) determined that tightness of the posterior muscles of the lower limb was present only in the group of patients with plantar fasciitis but not in the healthy control group (Bolivar et al., 2013). Tightness of the M. gastrocnemius and the Achilles tendon and the subsequent plantar flexion can lead to prolonged forefoot loading. This results in an increased passive mechanical tension of the plantar fascia in order to counteract the flattening of the foot arch by the plantar flexion moments in the hind foot and dorsiflexion moments in the forefoot (Pascual Huerta, 2014). In a prospective study of 254 patients with plantar fasciitis, 83% of the patients had limited ankle dorsiflexion due to an isolated contracture of the gastrocnemius (57%) or a contracture of the gastrocnemius-soleus complex (26%). Only 17% of the patients had no limitation in ankle dorsiflexion (Patel and DiGiovanni, 2011). In their study, Riddle et al. (2003) describe reduced ankle dorsiflexion ($\leq 0°$), besides obesity and work-related weight-bearing, as being the most important independent risk factor for plantar fasciitis, with an odds ratio of 23.3 in comparison to the control group with an ankle dorsiflexion of $>10°$ (Riddle et al., 2003). Furthermore, patients with hamstring tightness are 8.7 times more likely to sustain plantar fasciitis on the same side compared to the control group (Labovitz et al., 2011). Hamstring tightness increases knee flexion. This leads to a prolonged forefoot loading and windlass mechanism whereby the plantar fascia is in a prolonged tensional state. Additionally, tight posterior leg muscles limit ankle movement. Due to this, excessive pronation of the subtalar joint and consequently a higher tension in the plantar fascia occur (Bolivar et al., 2013). These impairments in the functionality of the plantar fascia can thus lead to plantar fasciitis. Conservative treatment including stretching exercises is based on this issue and can correct functional risk factors such as hamstring tightness or tightness of the gastrocnemius muscle (Young et al., 2001). In a prospective, randomized study by DiGiovanni et al. (2003), the outcomes of stretching exercises of the plantar fasciae and Achilles tendons of patients with chronic plantar fasciitis were compared. One group performed a structure-specific plantar fascia-stretching program, while the other group performed a standard Achilles tendon-stretching program. After a duration of eight weeks a greater improvement with respect to pain, activity limitations, and patient satisfaction was determined in the plantar fascia treatment group (DiGiovanni et al., 2003). In a two-year follow-up, no significant differences between the two treatment groups were observed regarding pain (DiGiovanni et al., 2006). The present results show that the plantar fascia-stretching program is a key component in the treatment of chronic plantar fasciitis; however, the posterior muscles of the leg should also be examined and included in the treatment concept (DiGiovanni et al., 2006; Bolivar et al., 2013). The results of the above-mentioned studies show an anatomical, functional and pathophysiological relationship of the Achilles tendon and plantar fascia. Furthermore, the results of our study show a biomechanical relationship of both structures. All five MyotonPRO tissue parameters of the Achilles tendon and plantar fascia of both gender correlate significantly on both the left and right sides, whereby all correlations are positive. This illustrates that both structures are also connected biomechanically. Sakalauskaite and Satkunskiene (2012) reached a similar result. The authors could also determine significant, positive correlations for the parameters Frequency, Stiffness and Decrement of the Achilles tendon and plantar fascia measured with Myoton-3 (Sakalauskaite and Satkunskiene, 2012). The biomechanical relationship of both structures that can be quantified by a myometry device may provide new aspects in the diagnostics and therapy of plantar fasciitis and Achilles tendinopathy. Both structures should be regarded and treated as a unit and not separately.

Our study was conducted on a healthy population. To the best of our knowledge, there are no existing MyotonPRO studies of patient groups for symptoms of the plantar fascia or the Achilles tendon. Different sonoelastography studies showed a decrease in stiffness of the Achilles tendon or plantar fascia in patient groups suffering from Achilles tendinopathy or plantar fasciitis respectively (Aubry et al., 2015; Wu et al., 2011, 2015). Because of its smaller size and lower acquisition cost compared to sonoelastography devices, the MyotonPRO has great potential to establish in the clinical setting of primary care. The MyotonPRO device allows the user to collect quantitative tissue parameters easily and fast in addition to the clinical examination. Studies with groups of patients should be conducted in future research. The application of a myometry device could provide additional information and therefore facilitate the diagnostics of Achilles tendinopathy and plantar fasciitis. Especially, when the sole clinical examination is inconclusive. The most common localization for abnormalities of the plantar fascia is close to the origin of the plantar aponeurosis to the calcaneus bone (McPoil et al., 2008). Sullivan et al. (2015) detected differences in foot loading during normal walking for participants with plantar heel pain (Sullivan et al., 2015). These changes in the functional gait cycle could also result in changes of the biomechanical parameters of the plantar fascia and should be examined in future studies. In a magnetic resonance imaging study, Stecco et al. (2013) compared the thickness of the plantar fascia between patients with and without Achilles tendinopathy. The results show that the plantar fascia of patients with Achilles tendinopathy is significantly thicker than in patients with no signs of tendinopathy (Stecco et al., 2013). Future research could examine the MyotonPRO parameters of symptomatic Achilles tendons and plantar fasciae as well as the correlation of the quantitative tissue parameters of both structures in patients with Achilles tendinopathy and/or plantar fasciitis. As the thickness of the plantar fascia varies between patients with and without Achilles tendinopathy, it should also be investigated whether the quantitative tissue parameters of the plantar fascia vary between patient groups with and without symptoms of the Achilles tendon. Additionally, the indication that the stiffness value of the Achilles tendon may vary with the exercise of sport is very interesting and should be examined in groups of athletes. This study has several limitations. Although the subjects were instructed to relax completely, the state of relaxation of the Achilles tendon and plantar fascia was not checked by electromyography. The sample population was very large and therefore heterogeneous. However, the goal of the study was to establish normal values for a very broad spectrum of participants in order to realize the conditions of a routine clinical setting.

5. Conclusion

The MyotonPRO is a feasible device for measuring the quantitative tissue parameters of the Achilles tendon and plantar fascia easily and fast. The calculated normal values of males and females are important to facilitate the detection of abnormalities in the Achilles tendon and plantar fascia in a clinical setting. The correlations of all five MyotonPRO values on both the left and right Achilles tendons and plantar fasciae are significant and positive. This illustrates the biomechanical relationship of both structures. Further research with the myometric device should include studies of patients suffering from Achilles tendinopathy and plantar fasciitis.

Conflicts of interest

None.

Declaration of interest

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Disclosure statement

None of the investigators was involved with the Myoton AS company. There are no conflicts of interest.

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