MECHANICAL PROPERTIES OF THE ACHILLES TENDON IN RUNNERS WITH TENDINOPATHY: A PILOT STUDY

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The aim of this study was to compare the dimensions of Achilles tendon, Achilles tendon moment arm and foot lever ratio between runners with tendinopathy and healthy control runners. We paired 12 runners diagnosed with baseline tendinopathy with 12 healthy control runners. The dimensions of Achilles tendon, Achilles tendon moment arm and foot lever ratio were measured using kinematic analysis and ultrasound imaging. Based on the parametric paired-samples T-Test, we compared the dependent variables measured on the affected lower limb. No differences were found between the groups for Achilles tendon length, Achilles tendon moment arm and foot lever ratio. Runners diagnosed with tendinopathy had thicker Achilles tendons than healthy control runners.

KEYWORDS: Achilles tendon length, Achilles tendon moment arm, Achilles tendon thickness, foot lever ratio.

INTRODUCTION: The Achilles tendon (AT) is the longest and strongest tendon of the human body (Benjamin et al., 2009). Due to its resilience and high tensile strength, it is well adapted to transmit forces from muscles to the bones (Doral et al., 2010). Recently, there has been an increasing incidence of AT ruptures in western population (Lantto et al., 2014). In addition, tendinopathy is one of the most common running injuries, with an incidence of up to 9% per year in recreational and performance runners (Carcia et al., 2010).

Based on ultrasound measurements, research has shown significant differences in AT cross-sectional area (CSA), AT thickness, and Kager's fat pad length between patients with tendinopathy and healthy people (Morales et al., 2019). Furthermore, runners with tendinopathy have significantly different running biomechanical parameters than healthy runners, especially greater eversion range of motion of the rearfoot, reduced ankle joint dorsiflexion velocity and knee flexion between heel strike and midstance (Munteanu & Barton, 2011).

Research evidence indicates that the differences in AT length and calcaneus are related to running economics, as shorter AT moment arm and longer AT reduces running energy costs (Scholz et al., 2008; Ueno et al., 2018). The study of Scholz et al. (2008) explains that AT force is inversely related to its moment arm. The authors postulate that a shorter AT moment arm can store more elastic energy, which can lead to a better running economy. A study by Kunimasa et al. (2014) suggests that the foot lever ratio (ratio of the forefoot length divided by the AT moment arm) may also influence force production and muscle contraction rate. If a shorter AT moment arm can cause more energy production and storage in the tendon (Baxter et al., 2012), could there be greater risk of AT injury?

The aim of the present study was to compare the dimensions of AT, AT moment arm and foot lever ratio between runners with tendinopathy and healthy control runners. We expected a group of runners with tendinopathy (ATG) to have shorter AT length, shorter AT moment arm, thicker AT, and greater foot lever ratio compared to healthy control runners (CTRL).

METHODS: The runners tested in this pilot study were selected from a prospective study which attempts to identify the risk factors for running injuries, especially those affecting the AT. In a prospective study, we measured 108 healthy recreational runners. The mechanical properties of AT and foot were measured in all participants. Furthermore, the biomechanics of running at their preferred endurance speed and the biomechanics of running on the treadmill at 3.5 $m \cdot s^{-1}$ were measured. Subsequently, the participants' physical activity and the incidence of running-related injuries were observed for one year.

Participants: From the prospective study, we paired 12 runners diagnosed with baseline tendinopathy with 12 healthy control runners; they were paired based on age, weight and height (Table 1). In the ATG group, 7 participants had been diagnosed with tendinopathy on the right lower limb and 5 participants had been diagnosed with tendinopathy on the left lower limb.

Table 1. Participants characteristics

	ATG		CTRL		p-value	ES
	Mean	SD	Mean	SD		
Age [years]	41.57	8.93	40.70	7.60	0.401	0.105
Mass [kg]	74.98	11.36	75.68	11.20	0.521	0.062
Height [m]	**1.74**	**0.11**	**1.76**	**0.10**	**0.016***	**0.190**
BMI [kg/m^2]	24.79	3.49	24.28	2.79	0.276	0.161
Right Shank Length [mm]	**411.28**	**34.35**	**423.32**	**29.04**	**0.011***	**0.379**
Left Shank Length [mm]	**410.47**	**33.82**	**422.99**	**31.07**	**0.008***	**0.386**
Run volume [km/week]	29.73	17.05	21.00	10.95	0.118	0.609
VISA-A Score [%]	**75.73**	**15.87**	**92.18**	**7.01**	**0.004***	**1.341**

ATG – Tendinopathy group; *CTRL* – Control group; *ES* – Effect size; *SD* – Standard deviation; *BMI* – Body Mass Index; *VISA-A* – Victorian Institute of Sport Assessment-Achilles questionnaire (Score 100 % is maximum score associated with healthy AT)
* Significant difference between groups (0.05)

Experimental set-up: The system of 10 infrared cameras with a recording frequency of 240 Hz (Qualisys, 9 x Oqus 700, 1 x Oqus 510, Sweden) and high precision pearl reflective markers of 9.5 mm were used for the kinematic analysis. A diagnostic ultrasound system Mindray (Mindray Z5, Shenzhen, China) with a 50 mm electronic linear ultrasound transducer probe (Mindray 75L38EA, Shenzhen, China) was used for ultrasound imaging. The diagnostic ultrasound system was set up in orthopaedic mode at 10 MHz.

Protocol: Each participant completed the VISA-A questionnaire (validated in the Czech version) and subsequently visited the biomechanical laboratory. First, the AT length was measured using a combination of kinematic analysis and ultrasound imaging. The AT length was determined from the calcaneus osteotendinous junction to the musculotendinous junction of mid-point of the medial and lateral heads of the gastrocnemius and from the calcaneus osteotendinous junction to the musculotendinous junction of the soleus (Skypala et al., 2019). The AT thickness was detected using the ultrasound image at a distance of 2 cm from the insertion of AT to the calcaneus (Cassel et al., 2017). Both the AT length and the AT thickness were measured three times on the affected lower limb in ATG and on the contralateral lower limb in CTRL. AT moment arm, Forefoot length, Foot lever ratio and Lunge test were measured using kinematic analysis (Bennell et al., 1998; Kunimasa et al., 2014; Scholz et al., 2008). Lateral femoral epicondyle, medial femoral epicondyle, lateral malleolus, medial malleolus, distal fifth metatarsal head, distal first metatarsal head and point on the AT (perpendicular distance to medial and lateral malleoli) were labelled with high precision pearl reflective markers.

Data analysis: AT thickness was determined directly in the diagnostic ultrasound system. The dimensions for determining AT length, AT moment arm, forefoot length and foot lever ratio were detected in Qualisys Track Manager (Qualisys, Gothenburg, Sweden) and Visual3D (C-Motion, Rockville, MD, USA). The determination of AT length was performed according to Skypala et al. (2019). The AT moment arm was determined by the perpendicular distance between the reflective marker on the AT and the joint centre of the ankle. Forefoot Length was determined by the perpendicular distance between the lateral malleolus and the distal fifth metatarsal head. Foot lever ratio was calculated by forefoot length divided by AT moment arm.

The output of the lunge test was given by the angle value between the ground and the shank (Bennell et al., 1998). The AT length was also normalized to the length of the shank (*Shank length/AT Length*).

Statistical analysis: We compared the dependent variables measured on the affected lower limb between ATG and CTRL. First, we determined the normality of the data using the Shapiro-Wilk test. Subsequently, we chose a parametric paired-samples T-Test for comparison, and the effect size was calculated (Becker, 1999). The statistical analysis was conducted using the IBM SPSS Statistics 24.

RESULTS: Table 2 provides the mean values and standard deviations of the measured mechanical properties on the affected lower limb, and the comparison between ATG and CTRL. Only the AT thickness on the affected lower limb was significantly greater in runners with tendinopathy.

Table 2. Comparison of variables between ATG and CTRL

	ATG		CTRL		p-value	ES
	Mean	SD	Mean	SD		
AT to Gas Length [mm]	215.67	29.36	220.79	25.00	0.514	0.188
AT to Sol Length [mm]	61.73	16.66	57.50	15.03	0.542	0.267
AT to Gas Length Normalized	1.88	0.16	1.92	0.14	0.583	0.266
AT to Sol Length Normalized	6.91	1.74	7.52	1.47	0.451	0.379
AT Thickness [mm]	**6.24**	**0.50**	**5.50**	**0.42**	**0.011***	**1.602**
AT Moment Arm [mm]	52.04	3.94	53.06	4.22	0.520	0.250
Forefoot Length [mm]	119.38	10.69	118.56	8.77	0.763	0.084
Foot Lever Ratio	2.31	0.29	2.25	0.27	0.607	0.214
Lunge Test [°]	56.95	5.56	57.97	5.79	0.728	0.180

ATG – Tendinopathy group; *CTRL* – Control group; *ES* – Effect size; *SD* – Standard deviation; *AT to Gas Length* – AT length from the calcaneus to the musculotendinous junction of the gastrocnemius; *AT to Sol Length* – AT length from the calcaneus to the musculotendinous junction of soleus; * Significant difference between groups (0.05)

DISCUSSION: The aim of this study was to compare the dimensions of AT, AT moment arm and foot lever ratio between runners with tendinopathy and healthy control runners. Shorter AT may have a lower ability to store and produce elastic energy during running (Kunimasa et al., 2014). During the run, the triceps surae performs near isometric contractions and the AT operates in dynamic mode and delivers 53 – 75% of the total mechanical work within the running gait cycle (Lai et al., 2014). We assumed that ATG would have a shorter AT moment arm and a shorter AT length than the CTRL. However, no significant differences were found between ATG and CTRL. This result may mean either that there is no relationship between the AT length, AT moment arm and tendinopathy, or it is possible to understand this potential relationship only through multifactorial interdisciplinary research which combines running biomechanics, anthropology, physiology, physical activity, psychosocial aspects of running. For example, in our group we do not analyzed footfall pattern and AT load due to running technique. Although ATG were on average 2 cm smaller than CTRL, they showed significantly thicker AT on the affected lower limb than runners from the control group (p = 0.011, es = 1.602). This finding of thicker AT in the ATG is consistent with the finding in Morales et al., (2019), which investigated the mechanical properties of AT among people with chronic mid-portion AT (n = 71) and a group of healthy people (n = 72). In this study, we extended the research evidence to findings on a group of runners.
The limitation of this study is that in this cross-sectional design it is unclear whether thicker AT is the cause or the effect of the injury (tendinopathy). Moreover, another limitation of this research is that biomechanical variables were not controlled. For example, the AT load is up to 19 % higher for forefoot runners than rearfoot runners (Kulmala et al., 2013). Further

research might investigate the association of AT dimensions and the incidence of running injuries, especially in non-rearfoot runners. These runners show an increased incidence of AT injury (Daoud et al., 2012).

CONCLUSION: We found no differences in AT lengths, AT moment arm and foot lever ratio between runners with tendinopathy and healthy control runners. Runners with tendinopathy have a thicker AT than healthy runners. Further research should focus on understanding the relationship between the mechanical properties of AT, biomechanical loading and tendinopathy.

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