ASSOCIATION BETWEEN T2* RELAXATION TIME AND THE MECHANICAL PARAMETERS OF THE ACHILLES TENDON IN TRAINED AND UNTRAINED POPULATIONS: PRELIMINARY DATA

Andrea Monte[1], Jiri Skypala[1], Jaroslav Uchytil[1], Vladimir Juras[2], Daniel Jandacka[1]

1 Human Motion Diagnostic Center, Department of Human Movement Studies, University of Ostrava, 70200 Ostrava, Czech Republic
2 High Field MR Centre, Department of Biomedical Imaging and Image-guided Therapy, Medical University of Vienna, Austria

The purpose of this study was twofold: 1) to investigate the association between T2* relaxation time and Achilles tendon mechanical/material parameters (e.g., stiffness, Young's modulus and hysteresis); and 2) to check the sensibility of the T2* in determining the differences among population, providing important insight for sports scientist and clinicians. Thirty participants (10 power athletes, 10 endurance athletes and 10 healthy participants) participated in this study. Magnetic resonance imaging (MRI) was used to quantify T2* relaxation time at rest. Ultrasound, kinetics, EMG and kinematics data were used to calculate Achilles tendon mechanical/material parameters during maximum voluntary contractions of the plantar-flexor muscles. Preliminary data on power athletes and healthy controls suggest that the Achilles tendon Young's was higher in power athletes compared with healthy control, whereas tendon hysteresis and T2* relaxation time were lower in power athletes. Tendon stiffness was similar between populations. Our preliminary data suggest that T2* can be utilised to investigate the differences between the population in terms of material parameters (Young's modulus and hysteresis) but not in mechanical ones (e.g. stiffness).

KEYWORDS: relaxation time, Achilles tendon, mechanical parameter, athletes

INTRODUCTION: The mechanical properties of the tendon are highly involved in muscle tension transmission to the skeleton and in the storage-recoil process of elastic potential energy, playing an important role in daily activities (Roberts & Azizi, 2011). Hence, the correct quantification of the tendon's mechanical parameters represents an important point in the scientific community. T2* relaxation time is a new magnetic resonance imaging (MRI) technique that provides a non-invasive evaluation of the soft tissues, such as tendons (Fouré, 2016). T2* relaxation time provide information about the tendon's water content and collagen orientation (Juras et al., 2013). It was observed that trained middle-distance runners had longer T2* relaxation time when compared to healthy inactive controls (Devaprakash et al., 2020). Longer T2* relaxation time was also correlated with clinical scores in the pathologic population (Juras et al., 2013). However, the association between T2* relaxation time and the mechanical parameters of the Achilles tendon is still not understood. Since tendon mechanics is affected by the training stimuli, it can be possible to argue that subjects with different mechanical properties will exhibit different T2* relaxation time. Hence, the aims of the project were: 1) to investigate the association between T2* relaxation time and the Achilles tendon mechanical/material parameters (e.g., stiffness, Young's modulus and stress); and 2) to check the sensibility of the T2* in determining the differences among population, providing important insight for sports scientist and clinicians.

METHODS: Three groups of subjects were involved in this study: healthy active subjects (n=10), endurance athletes (n=10) and power athletes (n=10). The participants visited the laboratory on one single occasion.

After 20 min rest in a lying position, the Achilles tendon of the right leg was analysed using a 1.5 T Siemens Magnetom Sempra Scanner (Siemens, Erlanger, Germany). The ankle joint scan with the main focus on the Achilles tendon is performed in a 16-channel head coil with the designed device for fixing the leg at a 90-degree angle. The protocol includes five sequences: SAG T1-weighted spin-echo (SE), TRA T2-weighted TSE, COR T1-weighted TSE, SAG and TRA PD-weighted TSE FS, and SAG T2* mapping. The acquisition time is approximately 20 min. Finally, T2* relaxation time was calculated using a customised MATLAB program as described by Juras et al. (2013).

The Achilles tendon mechanical parameters were evaluated after 10 min of warm-up, using 6 maximum-voluntary contractions (MVC). During each contraction, the participants were seated in an isometric chair with the hip, knee, and ankle at 90° with the same set-up proposed by (Couppé et al., 2016). A transversal ultrasound image was acquired at the level of malleolus for determining tendon cross-sectional area (CSA) (Couppé et al. 2016), using an ultrasound apparatus (Mindray Z5, Shenzhen, China). During each contraction, a motion capture system (Qualysis) and an EMG apparatus (Delsys Trigno Research+) were utilised to obtain the coordinates of 7 reflective markers and the EMG activity of the tibialis anterior, soleus and gastrocnemius muscles. Markers positions were used to obtain the Achilles tendon moment arm and the joint angles (Monte & Zignoli, 2020). Finally, using an ultrasound apparatus (Mindray Z5, Shenzhen, China), the displacement of the gastrocnemius medialis muscle-tendon junction was calculated to quantify the elongation of the Achilles tendon; whereas a force plate (Kistler, 9287CAQ02) was used to collect the force generated by the ankle muscles. During the post-processing analysis, for each contraction, Achilles tendon stiffness was calculated as the slope of the force-elongation curve over 20% force-intercept. Young's modulus was calculated by multiplying the stiffness values obtained by the ratio of tendon length to tendon CSA. An example of these data are reported in Figure 1. The energy stored and released by the Achilles tendon during each contraction was calculated as the area under the force-tendon elongation curve in the ascending and descending phases, respectively. Tendon hysteresis was computed as the ratio between the energy stored and released (Maganaris & Paul, 2002). Mean values of the 6 contractions were used.

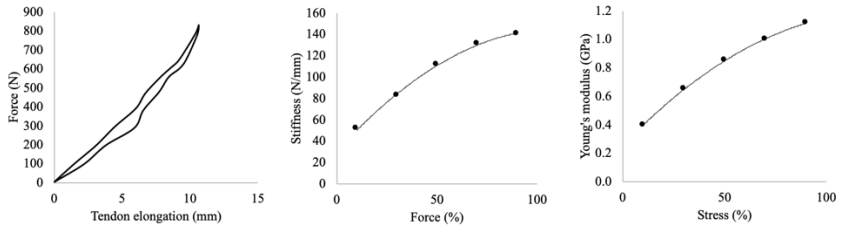

Figure 1: Tendon force-elongation relationship (left panel), tendon stiffness (middle panel) and Young's modulus (right panel) for a typical subject.

RESULTS: In this abstract, preliminary data of six subjects (3 power athletes: 25±2 years 75±6 kg, 1.73±5.5 m and 3 healthy: 24±2 years 76±5 kg, 1.71±6.2 m) were analysed and reported in Table 1.

Table 1: Achilles tendon parameters for each subject.

	Healthy			Power Athletes		
Stiffness (N/mm)	S1	S2	S3	S4	S5	S6
10%	61	63	67	37	40	43
30%	93	85	94	77	85	84
50%	121	130	131	140	140	142
70%	141	164	155	167	158	175
90%	151	170	169	171	163	185
Young's Modulus (Gpa)						

10%	0.40	0.55	0.47	0.42	0.48	0.45
30%	0.65	0.75	0.70	0.74	0.8	0.77
50%	0.85	1.01	0.93	0.91	0.97	0.99
70%	1.00	1.06	1.03	1.18	1.16	1.2
90%	1.12	1.13	1.12	1.22	1.19	1.26
Hysteresis (%)	19	21	20	15	18	16
T2* (ms)	1.12	1.20	1.15	1.01	1.08	1.05

For simplicity, the average values of stiffness and Young's modulus among the percentage of force were calculated for each subject and utilised for a preliminary comparison. In Figure 2, the Achilles tendon parameters for healthy and power groups are reported.

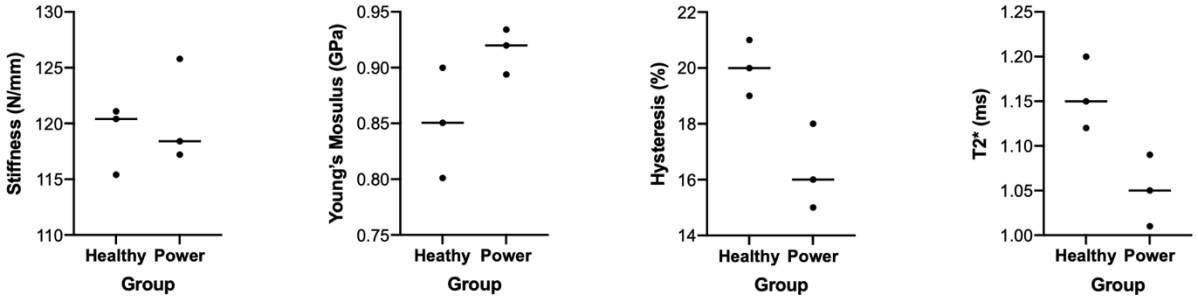

Figure 2: Achilles tendon parameters of health subjects and power athletes. Dots refer to induvial data and horizontal line to the mean values among subjects.

The statistical analysis was not performed, due to the small number of subjects. However, whereas the values of Young's modulus, hysteresis and T2* were "different" between groups, stiffness values were similar.
Figure 3 shows the preliminary association between parameters: Achilles tendon stiffness, Young's modulus and hysteresis were plotted as a function of T2*.

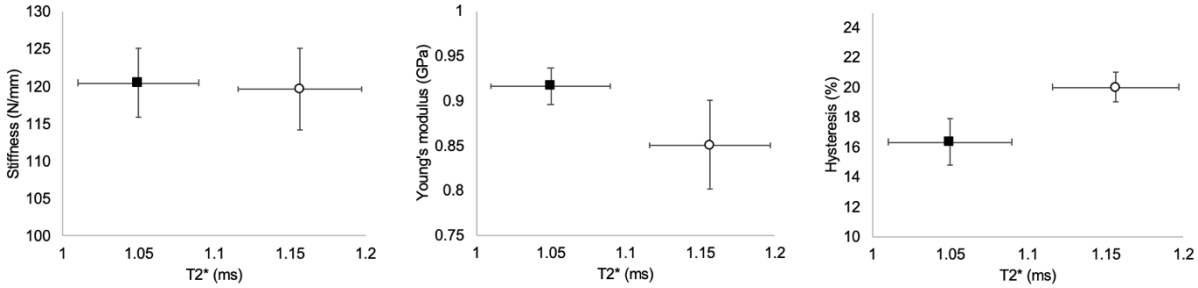

Figure 3: Mean values of Achilles tendon stiffness (left panel), Young's modulus (middle panel) and hysteresis (right panel) as a function of T2* relaxation time. Black square refers to power athletes, while with dot to healthy subjects.

Figure 3 suggests a possible association between Young's modulus, tendon hysteresis and T2* relaxation time.

DISCUSSION: In this study, we investigated the possible association between T2* relaxation time and Achilles tendon mechanical/material parameters as well as the possibility of the T2* in determining the differences between populations.
Consistent with the literature, our preliminary data suggested that the Achilles tendons material parameter (Young's modulus and hysteresis) differed between populations (Kubo et al., 2011), while mechanical parameters (e.g. stiffness) can be similar among them (Kubo et al., 2017). In this regard, our data suggest that power athletes had lower values of tendon hysteresis and higher Young's modulus compared with healthy subjects, suggesting that power athletes had

superior Achilles tendon material properties (Malmgaard-Clausen et al., 2021). Training stimuli such as strength or power training can indeed increase collagen synthesis, affecting tendon material properties without changes in tendons' mechanical modification.
Longer T2* relaxation time in tendons has been suggested to represent greater amount of free water protons between collagen fibres that could reflect increased water content and/or disorganised collagen alignment (Juras et al., 2013). Our preliminary data suggest that the T2* relaxation time is longer in healthy subjects compared to power athletes, reinforcing the idea of superior tendon material properties in power athletes. Finally, as reported in figure 3, the preliminary data suggest a possible association between T2*, Young's module and tendon hysteresis, but not with the Achilles tendon stiffness.

CONCLUSION: Based on these preliminary data, T2* relaxation time seems to be sufficiently sensitive to detect differences between populations. These differences can be due to the materials properties (e.g. Young's modulus).

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