In Vivo Measurement of Fast Transversal Relaxation Times of Achilles Tendon Using Ultra-High Field MRI

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Abstract. *The aim of the study was to investigate proton transverse relaxation times combined with local magnetic field non-uniformities (T_2*) of human Achilles tendon in vivo as a prospective marker for diagnosis of early pathological changes. Achilles tendon consists mainly of highly oriented collagen fibres resulting in lower water mobility, and therefore fast relaxation processes of protons. Mapping of ultra-short T_2* using conventional MR techniques is considered challenging using conventional sequences. Ten volunteers and two patients with chronic tendonitis were included in the study. 3D ultra-short time echo (TE) sequence with radial sampling was used. From the images acquired at different TEs (0.07, 0.20, 0.30, 0.46, 0.59, 0.74, 1.00, 1.50 ms), T_2* map was constructed by pixel-by-pixel fitting of signal intensities to mono-exponential function. Resulting maps were evaluated in various anatomical regions (tendon-muscle junction, medial part and insertion). Mean bulk T_2* in volunteers was 0.56 ± 0.18 ms. In patients with chronic Achillotendonitis, T_2* values were higher in comparison to healthy volunteers. Advanced quantitative imaging of human Achilles tendon has a potential to benefit from early diagnosis of degenerative processes and so prevent the development of serious tendon damage, such as partial tear or rupture.*

Keywords: MRI, Achilles tendon, T_2, ultra-short*

1. Introduction

The conventional clinical MRI sequences are predominately used for visualizing the tissues with relatively long transversal T_2 relaxation times. In the human body, however, there are some tissues characterized by a very short T_2. These highly oriented tissues, such as tendons (T_2~1.5ms), menisci (T_2~5ms), ligaments (T_2~5-10ms) or cortical bone (T_2~0.5ms), give little to no signal using conventional sequences so they appear black on standard MR images [1].

Considering the relaxation times in Achilles tendon (AT) to be in order of 1 ms, a very short echo time (TE) must be used to acquire signal directly from the tendon. Recent developments of UTE made this sequence to be clinically applicable in a whole variety of cases. UTE pulse sequences have TEs (in sense of ultra-short imaging, TE is often referred to as 'time of encoding') about 10 to 20 times shorter than the shortest generally available on modern clinical systems. Signal is produced by half-radiofrequency excitation with radial sampling from the centre of the k-space. Using UTE imaging, it is possible to come to a detectability of tissues with T_2 relaxation times of 0.1 to 0.01 ms [2].

The aim of this study was to investigate ^{1}H transverse relaxation times combined with local magnetic field non-uniformities (T_2*) of Achilles tendon in vivo in healthy volunteers with 3D-UTE sequence. T_2* may prospectively serve as a marker for diagnosis of early pathological changes in Achilles tendon.

2. Subject and Methods

Ten volunteers (5 males, 5 females, mean age of 25 +/- 3 years, free of any pain and any abnormality in the Achilles tendon in the past) and 3 patients (1 male, 2 females, mean age of 28 +/- 4 years) with chronic Achillotendinitis were included in the study. The ankle of each subject was placed within the coil in the way that the foot platform and the axis of tibia created 110º angle and the Achilles tendon was parallel to the static magnetic field B0 as much as possible (taking into account a natural curvature of the tendon). Volunteers underwent MRI examination at 7T, (Siemens Healthcare, Erlangen Germany). The investigational 7T MR system is equipped with the same gradient strength. Twenty-eight channels transmit/receive knee coil (QED, Quality Electrodynamics, Mayfield Village, OH, USA) with diameter of 18 cm was used. To acquire a signal from Achilles tendon, half-pulse 3D-UTE sequence with radial k-space sampling was used. The data were sampled on the projection originating from the center of the k-space and the ending points of all projections covered a spiral on a sphere. The reconstruction was performed using regridding algorithm and 3D-iFFT to produce resulting images [3].

Eight different TEs were used [0.07, 0.20, 0.30, 0.46, 0.59, 0.74, 1.00, 1.50] ms. The rest of the sequence parameters was the same in each scanning: TR, 400ms; averages, 2; bandwidth, 560 Hz/px; matrix, 256 x 256 x 256 (isotropic); flip-angle, 12°, FOV, 300mm, number of projections 12.000. Standard shimming method implemented on both scanners by manufacturers was used. Total scanning time was 12 min (8 x 1:30 min) at 7T.

T_2* maps were generating by mono-exponential three parameter fitting on pixel-by-pixel basis in custom-built IDL (Interactive Data Language, RSI, Boulder, CO) script using mpcurvefit routine (Craig B. Markwardt, NASA/GSFC Code 662, Greenbelt,MD20770) for each slice. Coefficient of determination (R^2) was stored for later T_2* correction [4].

3. Results

Mean bulk T_2* was 0.56 ± 0.18 ms; Example T_2* map and corresponding fitting curve are depicted on Fig. 1 and Fig. 2, respectively. The individual T_2* values for all subareas are summarized in the Table 3. When looking at the anterior-posterior differences of Achilles tendon in the sense of T_2*, statistically significant differences were observed for bulk values and so for individual subareas. Regarding the precision of T_2* calculation, R^2 was 0.90 ± 0.03 in average.

Table 1. The summary of T2* measured in healthy Achilles tendon

	T_2* [ms]	stdev	area [mm^2]	SNR
UA	0.495	0.153	93.73	137.17
UP	0.551	0.170	90.57	54.82
MA	0.452	0.180	35.20	131.65
MP	0.574	0.177	61.39	95.82
LA	0.448	0.184	27.10	118.14
LP	0.812	0.352	25.25	109.60
BULK	0.555	0.181	333.25	107.87

In patients with tendinitis (Fig. 3), significant increase of T_2* values was found in lower part of Achilles tendon (0.66 ± 0.09 ms in anterior region and 0.65 ± 0.15 ms in posterior region). In average, T_2* in patients was 0.80 ± 0.13 in anterior region and 0.73 ± 0.12 in posterior region. An example of MR examination of patient with Haglund's disease accompanied with Achillotendonitis and corresponding T_2* map are depicted on Fig. 3. Compared to healthy

volunteers, the T_2* were higher in patients of +42% (anterior), +11% (posterior) and +27% (bulk).

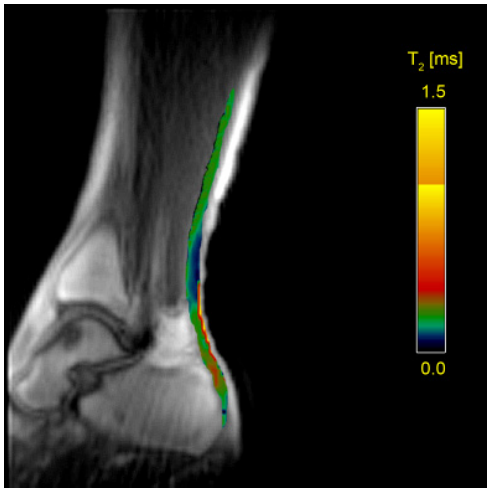

Fig. 1. Pseudo-color coded T_2* map of healthy 25 years old volunteer acquired by 3D-UTE at 7T (overlaid on image acquired at the minimum TE 0.07 ms).

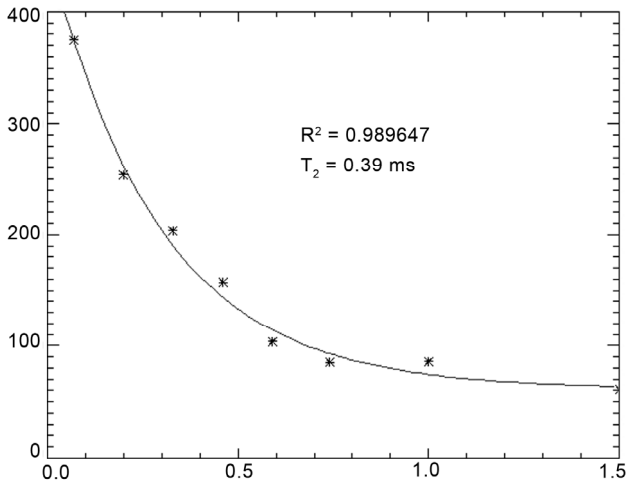

Fig. 2. Exponential decay from representative pixel selected in Achilles tendon of healthy volunteer. On both images, stars represent the measured intensity values, while the solid line is the mono-exponential fitting curve. Offset of the curve is caused by the hardware noise.

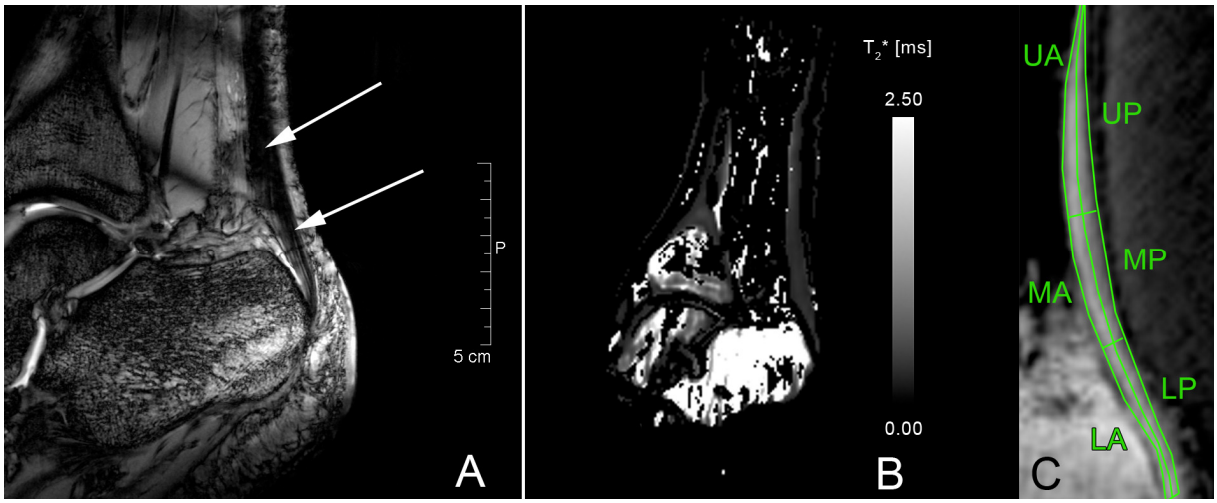

Fig. 3. A) 3D TRUFI T_2-weighted morphological image of 26 years old patient with Haglund's disease and tendonitis measured at 7T. The thickening of the Achilles tendon is obvious (upper arrow) and hyper-intense signal in the lower region signalizes the inflammation process. B) T_2* values in Achilles tendon in patients were considerably increased in comparison to healthy volunteers. The definitions of ROI segmentation are sketched on the C) with this meaning of labels: UA: upper anterior, UP: upper posterior, MA: medial anterior, MP:medial posterior, LA: low anterior, LP: low posterior.

4. Discussion and Conclusion

In this study, the first results of the quantitative assessment of Achilles tendon at ultra-high field MR are presented. 3D-UTE sequence used at ultra high-field provided a remarkable contrast of Achilles tendon by acquiring the signal directly from tissue.

To compare our results with already published studies at different field strength, Du et al. observed T_2* of 0.78 ± 0.07 ms at 3T using 2D-UTE sequence [5]. Robson et al. demonstrated region-dependent T_2* values in Achilles tendon - in anterior region 88% of

short component (T_2* ~ 0.53 ms) and 12% of long component (T_2* ~ 4.80 ms), and in posterior region 70% of short component (T_2* ~ 0.60 ms) and 30% of long component (T_2* ~ 4.20 ms) [6]. Filho et al. reported the T_2* values in lateral, central, medial and bulk region of 2.10 ± 0.43, 2.23 ± 0.31, 1.89 ± 0.34 and 2.18 ± 0.30, respectively [7]. These values are different from those measured in our study which may be caused by tissue changes in cadaver samples and non-physiological tense. Henkelman et al. used CPMG sequence for T_2 mapping; they measured relatively high values - 7.2 ± 0.6 ms at 0° (angle between tendon and static magnetic field) and 23 ± 2 ms at 55°.27 T_2 and T_2* effects cannot be distinguished using the UTE sequence [8]. One of the limitations of the study is the in-plane resolution of images. The used matrix was 256 x 256 and FOV 300 x 300 mm which leads to resolution of 1.17 mm per pixel. This limits the examination of some clinically interesting areas, such as tendon insertion. Theoretically, it would be possible to increase the resolution, but this would cause even stronger k-space undersampling and therefore stronger artefacts and in addition the total acquisition time would dramatically increase. For the investigation of the Achilles tendon at higher resolution, the 2D-UTE sequence is more suitable.

In conclusion, advanced qualitative and quantitative imaging of human Achilles tendon using 3D-UTE sequence may provide additional information to standard clinical imaging in reasonable scan times. It has the potential to provide early diagnosis of degenerative processes and so prevent the development of serious tendon damage, such as partial tear or rupture.

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