Comparison of Two MRI-UTE Sequences for the Quantification (T_1) of the Human Achilles Tendon

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INTRODUCTION: The Achilles tendon is commonly involved in both degenerative and inflammatory tendinopathies. The short T_2 of the normal tendon makes early changes difficult to assess with conventional MR sequences. Ultrashort echo time imaging (UTE) [1] can directly visualize the tendon signal allowing quantification, such as T_1 relaxometry. T_1 measurements may be useful for assessing Achilles disease directly or for other techniques such as pharmacokinetic modelling of contrast enhancement. The aim of this work was to compare the T_1 measurements in human Achilles tendon obtained from a saturation recovery (SR-) UTE and variable flip angle (VFA-) UTE sequence where these sequences were initially corroborated in long T_2 phantoms with an assumed 'gold standard' inversion recovery spin echo (IR-SE) sequence.

METHOD Phantom Calibration: 4 phantom tubes with various measured T_1 values from a Eurospin QA phantom were scanned using a Siemens 3T Verio system and 4 cm loop coil. Single slice SR-UTE sequence parameters were: TR = 2.2s + SR delay; TE = 0.07 ms; in-plane matrix = 128x128; voxel size = 0.8x0.8 mm; slice thickness = 3 mm and a 90° saturation pulse. 7 SR delay times of 100, 200, 400, 600, 800, 1000 and 1200 ms were acquired. 3D VFA-UTE sequence parameters were: TR = 6 ms; TE = 0.07 ms; matrix = 256x256x256 and voxel size 0.625 mm^3 with 26 flip angles between 1° and 26° in steps of 1°. The SE-IR sequence used parameters: TR = 4 s; TE = 9.6 ms; in plane matrix = 128x128; voxel size = 0.8x0.8 mm; slice thickness = 3 mm and IR-delays of 50, 100, 200, 400, 600, 800, 1000 and 1200 ms. Data from the SE sequence using no IR pulse was acquired to provide S_0 for T_1 fitting. **In vivo**: 8 healthy asymptomatic subjects (5 male; 3 female; age 35 ± 9 yrs [mean ± stdev]) were scanned using a Siemens 3T Verio system and 4 cm loop receive coil. The Achilles tendon was scanned parallel to the main magnetic field, B_0, using SR-UTE with 4 SR delay times of 100, 400, 800 and 1200 ms and VFA-UTE with flip angles of 3, 5, 10, 15, 20 and 25° and TR = 8 ms. The VFA-UTE scan session lasted 24 mins and the SR-UTE scan session lasted 60 mins. **Measurement and Fitting of T_1:** ROI were drawn in phantom tube intensity images and within the Achilles tendon and bone marrow fat anterior to the Achilles tendon (shown in figure 1). SR-UTE data was fitted for T_1 using a 3 parameter fit for T_1, F and S_0 to $S(T_{SR}) = S_0(1-(1-F)*\exp(-T_{SR}/T_1))$. VFA-UTE data was fitted for T_1 using a 2 parameter fit for T_1 and S_0 to $S(\alpha) = S_0(\sin(\alpha)(1-\exp(-TR/T_1)))/(1-\cos(\alpha)\exp(-TR/T_1))$. **Simulations** were run to obtain the most accurate combination of 2 and 3 flip angles using a model with target T_1 = 600 ms [4] with added randomly generated Gaussian noise at 0.05 x S_0 for 1000 runs per flip angle combination. 4 volunteers were imaged using VFA-UTE and optimised flip angles with T_1 calculated for ROI in the Achilles tendon.

RESULTS: The phantom calibration T_1 measurement results showed good comparison between the 'gold standard' IR-SE and SR- and VFA-UTE sequences with correlations of $r^2 = 0.9985$ [$p<0.02$] and $r^2 = 0.9993$ [$p<0.01$] respectively.

The T_1 measurements for all subjects are shown in figure 2, with the mean for Achilles tendon for SR- and VFA-UTE being 725 ± 42 ms and 698 ± 54 ms respectively. Bone marrow fat T_1 was 374 ± 28 ms and 301 ± 35 ms respectively. Saturation was found to be imperfect in SR-UTE with F = 0.15 ± 0.07 (mean ± stdev) for the Achilles tendon. The optimised flip angles for VFA-UTE were found to be 4 and 18° and 4, 19 and 24° for 2 and 3 flip angle combinations with total scan time of 8 and 12 mins respectively. T_1 measurements for 4 subjects using optimised flip angles are shown in figure 3.

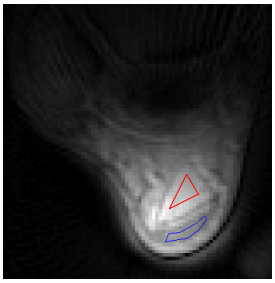

Figure 1. SR-UTE image (SR delay = 800 ms). Blue ROI = Achilles tendon; red ROI = fat

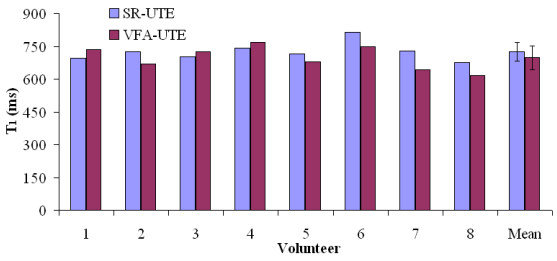

Figure 2. T_1 measurements for human Achilles tendon

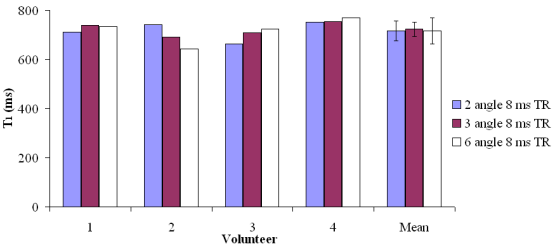

Figure 3. Optimised T_1 measurements for human Achilles tendon using VFA-UTE

DISCUSSION AND CONCLUSION: T_1 measurements of fat are comparable to those previously reported [2]. T_1 measurements of the Achilles tendon have previously been reported in cadaveric specimens at 3 T [3, 4] and in-vivo at 1.5 T [5] using a UTE sequence. This study differs in that the T_1 values of the Achilles tendon presented here are in-vivo and the values measured here are somewhat higher than those reported ex-vivo at 3 T (621 ms and 598 ms respectively) [3, 4]. This could be due to differences between cadaveric and in-vivo tissues (such as level of hydration, temperature, or whether the tendon is under load) or imperfect RF saturation; other factors could be regional differences in T_1 (it has also been shown that T_2 differs depending on location [6]) or differences in the subject population. T_1 measurements are feasible within 8 mins using optimised flip angles for VFA-UTE and may be useful for quantifying Achilles tendonopathy as well as for other techniques such as quantitative contrast enhancement.

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