Comparison of Two MRI-UTE Sequences for the Quantification (T1) of the Human Achilles Tendon

P. Wright1, R. Hodgson2, V. Jellus3, L. Lauer3, and M. Robson4
1LMBRU, Leeds Teaching Hospitals NHS Trust, Leeds, Yorkshire, United Kingdom, 2LMBRU, University of Leeds, United Kingdom, 3Siemens AG, Erlangen, Germany, 4University of Oxford, United Kingdom

INTRODUCTION: The Achilles tendon is commonly involved in both degenerative and inflammatory tendinopathies. The short T2 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 T1 relaxometry. T1 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 T1 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 T2 phantoms with an assumed ‘gold standard’ inversion recovery spin echo (IR-SE) sequence.

METHOD Phantom Calibration: 4 phantom tubes with various measured T1 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 = 2.2 s; SR delay = 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 s; TE = 0.07 ms; matrix = 256x256x256 and voxel size 0.625 mm3 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 Ŝ0 for T1 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, B0, 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 T1: 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 T1 using a 3 parameter fit for T1, F and Ŝ0 to Sr(TSR) = Ŝ0(1-(1-F)*exp(-Tsr/T1))). VFA-UTE data was fitted for T1 using a 2 parameter fit for T1 and Ŝ0 to Sr(α) = Ŝ0(sin(α)(1-exp(-TR/T1)))/(1-cos(α)*exp(-TR/T1))). Simulations were run to obtain the most accurate combination of 2 and 3 flip angles using a model with target T1 = 600 ms [4] with added randomly generated Gaussian noise at 0.05 x Ŝ0 for 1000 runs per flip angle combination. 4 volunteers were imaged using VFA-UTE and optimised flip angles for T1 calculated for ROI in the Achilles tendon.

RESULTS: The phantom calibration T1 measurement results showed good comparison between the ‘gold standard’ IR-SE and SR- and VFA-UTE sequences with correlations of r² = 0.9985 [p<0.02] and r² = 0.9993 [p<0.01] respectively. The T1 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 T1 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. T1 measurements for 4 subjects using optimised flip angles are shown in figure 3.

DISCUSSION AND CONCLUSION: T1 measurements of fat are comparable to those previously reported [2]. T1 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 T1 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 T1 (it has also been shown that T2 differs depending on location [6]) or differences in the subject population. T1 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.