Actual Flip Angle Imaging to Improve T1 Measurement for Short T2 Tissues

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Target Audience: MRI physicists and clinicians who are interested in T_1 quantification for short T_2* tissues.

Introduction: A variable flip angle technique is a rapid T_1 mapping method that exploits steady-state signals at multiple flip angles [1]. This method can be used to measure T_1 of short T_2* tissues when combined with ultrashort echo-time (UTE) imaging. However, any flip angle errors due to miscalibration or B_1 inhomogeneities, and T_2* relaxation effects during RF excitation can degrade the accuracy of T_1 quantification. The actual flip angle imaging (AFI) technique is a recently proposed fast flip angle mapping method employing dual TR steady-state signal acquisitions [2]. In this work, we propose the use of the AFI technique to correct flip angles and improve accuracy in T_1 measurement for short T_2 tissues.

Methods: For variable flip angle T_1 mapping of short T_2 tissues, 3D UTE imaging consisting of a hard pulse excitation and 3D radial trajectories was performed at two flip angles. The AFI technique was also implemented in combination with 3D UTE imaging (Fig. 1). For both T_1 mapping and AFI acquisition, a hard pulse duration of 200 μs and a TE of 70 μs were used. The TR was 11 ms for UTE T_1 mapping; the TR_1/TR_2 was 7/35 ms and a nominal flip angle of 44° was used for the AFI technique.

An *ex vivo* study with diaphysis segments of a bovine femur was performed on a GE discovery MR750 3T scanner using an eight-channel wrist-array coil. The RF amplifier transmitter gain was manually set to three different values to vary the actually applied flip angle. For each gain, UTE imaging with optimized flip angles of 8° and 44° [3] (assuming a T_1 of 200 ms [4]) and AFI acquisition were performed with a 1.7 mm isotropic spatial resolution. For comparison, a saturation-recovery 3D UTE Look-Locker T_1 mapping method [5] was applied with an excitation flip angle of 20°, time interval between excitation pulses of 90 ms, and 16 excitations over a TR of 1.5 s. The mean T_1 value over the overall cortical bone volumes was measured by locating ROIs in cortical bone on each slice. *In vivo* T_1 mapping was performed for the Achilles tendon of one healthy volunteer on a GE MR750w 3T scanner using a 16-channel flex coil after informed consent. UTE imaging with 4.5° and 26° flip angles (assuming a T_1 of 600 ms [6]) and AFI acquisition were performed with a 1.7 mm isotropic resolution and 20 x 12 x 11 cm^3 FOV (in the sagittal plane).

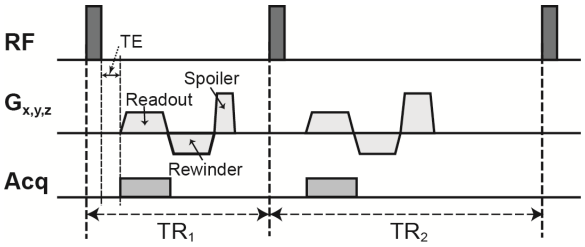

Figure 1. AFI utilizes interleaved acquisitions of the dual TR steady state to measure the actual flip angle. For short T_2* tissues, it was combined with 3D UTE imaging.

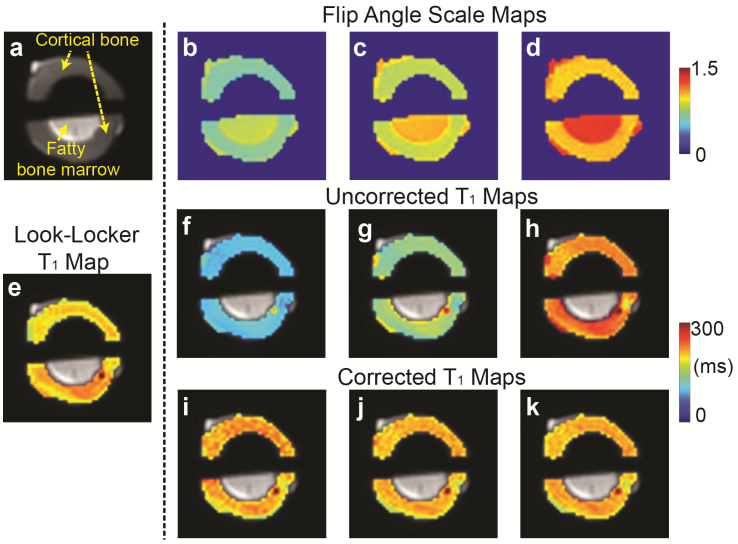

Figure 2. (a) UTE image from segments of a bovine femur. (b-d) Flip angle scale maps for the three different transmitter gains. Corresponding T_1 maps in cortical bone without and with flip angle correction are shown in (f-h) and (i-k), overlaid on UTE images. For comparison, (e) shows a T_1 map from the Look-Locker sequence.

Results: T_1 mapping on the *ex vivo* cortical bone is illustrated in Fig. 2. Figure 2b-d shows flip angle scale maps (ratio of the actual flip angle measured from AFI to the nominal flip angle) of one slice for the three different transmitter gains. The cortical bone regions have lower flip angles than bone marrow regions due to T_2* relaxation effects during excitation. For the three different transmit gains, the mean T_1 values were 98.4±3.5, 149.8±5.5, and 234.3±9.5 ms without flip angle correction and 214.5±4.9, 211.3±2.6, 213.8±3.4 ms with flip angle correction. Look-Locker T_1 mapping provided a mean T_1 of 205.1±9.5 ms. Figure 3 shows in vivo Achilles tendon T_1 maps with and without flip angle correction. With flip angle correction, the mean T_1 over the tendon volume (795.1±31.5 ms) was closer to the value reported in [6] while that without correction was 910.2±34.6 ms.

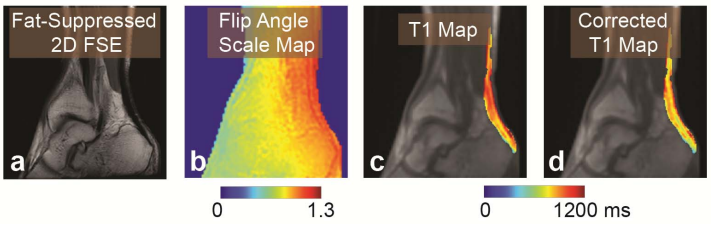

Figure 3. (a) Fat-suppressed 2D FSE image of an ankle. (b) Flip angle scale map. (c-d) T_1 maps in the Achilles tendon without and with flip angle correction, overlaid on UTE images.

Discussion: T_1 quantification in cortical bone and the Achilles tendon has a great potential to assess cortical bone porosity and tendon pathology. Our *ex-vivo* study demonstrates that variable flip angle T_1 mapping combined with flip angle correction can provide similar T_1 values in cortical bone over an actual flip angle variation in 0.65-1.1 times of the nominal flip angle, and the T_1 values are close to that from the Look-Locker method. In addition, variable flip angle T_1 mapping with flip angle correction is much more time-efficient than the look-locker T_1 mapping method (total 6 min versus 132 min scan time for our ex vivo study). By using an RF pulse equivalent to that of UTE T_1 mapping, the AFI technique can provide a flip angle accounting for the reduction of the flip angle due to T_2* relaxation effects during excitation, and can correct T_1 more appropriately [7].

Conclusion: AFI combined with UTE imaging can calculate flip angle maps on short T2* tissues such as cortical bone and tendon. As a fast flip angle mapping method, it can be used for 3D T_1 mapping of short T2* tissues in a clinically feasible scan time.

References

[1] Christenson KA, et al. J Phys Chem 1974;78(19):1971-1977.
[2] Yarnykh VL, et al. Magn Reson Med 2007;57(1):192-200.
[3] Deoni SCL, et al. Magn Reson Med 2003;49(3):515-526.
[4] Du J, et al. J Magn Reson 2010;207(2):304-311.
[5] Li W, et al. Magn Reson Med 2010;64(5):1296-1303.
[6] Filho GH, et al. Am J Roentgenol 2009;192(3):W117-124.
[7] Springer F, et al. Invest Radiol 2011;46(10):610-617.

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