T2 and T1ρ Quantification of Cortical Bone In Vivo Using Ultrashort TE (UTE) Pulse Sequences

J. Du[1], A. Takahashi[2], M. Carl[2], M. Bydder[1], N. Szeverenyi[1], C. Chung[1], and G. Bydder[1]
[1]Radiology, University of California, San Diego, CA, United States, [2]Global Applied Science Laboratory, GE Healthcare Technologies, Menlo Park, CA, United States

INTRODUCTION

Conventional magnetic resonance sequences produce a signal void from cortical bone. Detectable signal can be obtained from bone using ultrashort TE (UTE) sequences which combine half pulse excitation, radial ramp sampling, and fast transmit receiver switching to reduce TE to less than 100 μs (1-3). Although high contrast imaging of cortical bone is available with UTE sequences combined with efficient long T2 suppression techniques, quantitative relaxation time evaluation has been limited to T1 and T2*. Signal from bone is subject to strong bulk susceptibility effects (4), and these may significantly reduce T2* but are likely to have less effect on T2. T1ρ has been proposed as an attractive approach to probe biochemical changes in cartilage (5, 6). It reflects slow interactions between motion-restricted water molecules and their local macromolecular environment, and provides unique biochemical information in the low frequency region ranging from a few hundred Hertz to a few kiloHertz. Measurement of T2 and T1rho relaxation times in cortical bone may help evaluate bone quality. Here we describe the use of techniques to quantify T1rho and T2 relaxation times of the cortical bone in vivo at 3T.

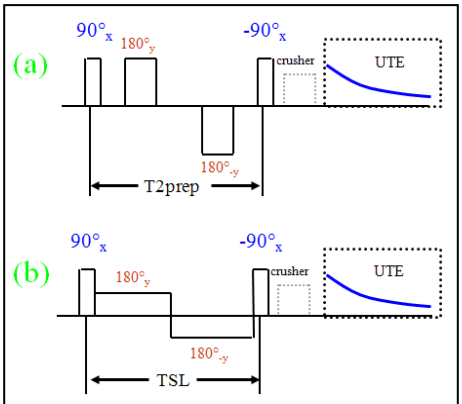

Fig 1 *UTE sequences combined with T1ρ (a) and T2 (b) preparation pulses. These allow quantification of T1ρ and T2 of cortical bone.*

MATERIALS AND METHODS

The UTE T1ρ sequence combines a 2D UTE sequence with a spin-lock preparation pulse (Fig 1a). The spin-lock pulse consists of a hard 90° to tip the spins to the transverse plane, followed by a spin locking pulse and another 90° pulse to tip the spins back into longitudinal axis. UTE acquisitions are used after a series of spin-lock times (TSL) to detect the recovery of bone magnetization in the rotating frame (T1ρ). The T2-prepared UTE sequence combines a T2-preparation pulse cluster (Fig 1b) consisting of a short hard 90° pulse (256 μs in duration) followed by a short hard 180° pulse (512 μs in duration) and a hard -90° pulse with a UTE acquisition. UTE images acquired with a series of T2 preparation times can be used to detect the transverse decay of bone magnetization (T2). Fat signal was suppressed with either a fat saturation pulse or an adiabatic inversion pulse. Typical acquisition parameters are as follows: FOV = 15 cm, TR = 300 ms, TSL = 0.02/0.6/1.5/5 ms (for T1ρ), T2 prep time = 0.5/1.5/3/10 ms (for T2), TE = 8 μs, bandwidth = ±125 kHz, readout = 256, slice thickness = 7 mm, 255 half projections, NEX = 2, 2.5 minutes for each scan. T1ρ was derived by exponential fitting of the following equation: $S(TSL) \propto \exp(-TSL/T1\rho)*(1-\exp(-(TR-TSL)/T1))/(1-\exp(-TSL/T1\rho)*(\exp(-(TR-TSL)/T1)))$, which accounts for T1 relaxation effects (1). T2 was derived through the same equation except that T1ρ was replaced by T2. T1 is required in the fitting and was measured with a saturation UTE acquisition at a series of saturation recovery times (TSR). The techniques were applied to 10 healthy volunteers.

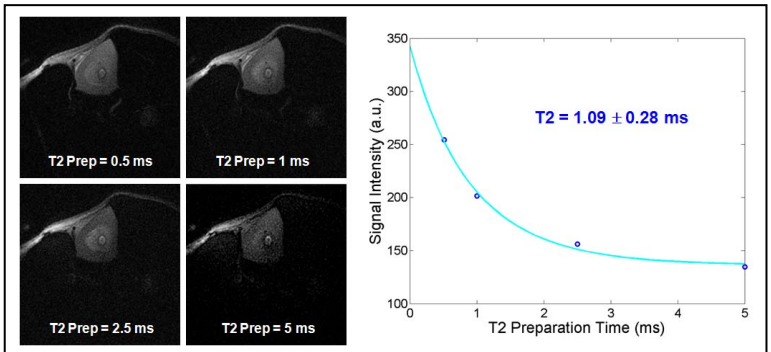

Fig 2 *IR-prepared UTET2 imaging of the tibia of a 36-year old healthy volunteer at a series of T2 preparation times of 0.5 ms, 1 ms, 2.5 ms and 5 ms, as well as curve fitting which shows a short T2 of 1.09 ± 0.28 ms for the tibia of this volunteer. There is significant residual bone signal at long T2 preparation time probably due to significant transverse relaxation during the relatively long 180° refocusing pulse.*

RESULTS AND DISCUSSION

Figure 2 shows UTE T2 images of cortical bone of a 36 year old healthy male volunteer with an adiabatic IR pulse to suppress signal from long T2 muscle and fat. High contrast images were achieved with excellent curve fitting. This showed a short T2 of 1.09 ± 0.28 ms for tibia of this volunteer. Figure 3 shows UTE T1ρ images of cortical bone of the same volunteer with an adiabatic IR pulse for long T2 suppression. Curve fitting shows a short T1ρ of 894 ± 63 μs. Both T2 and T1ρ are significantly longer than T2* for this volunteer, which was 412 ± 19 μs. In the future we will investigate T1ρ dispersion (T1ρ as a function of the spin locking field strength), and the relation between T2/T1ρ/T1ρ dispersion and bone quality, such as bone porosity, proteoglycan content, and bone water in cadaveric bone samples and patients with osteoporosis.

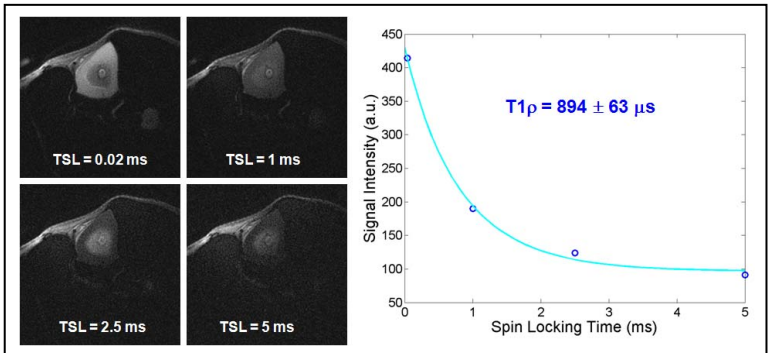

Fig 3 *IR-prepared UTET1ρ imaging of the tibia of a 36-year old healthy volunteer at a series of TSLs of 0.02 ms, 1 ms, 2.5 ms and 5 ms, as well as the curve fitting which shows a short T1ρ of 894 ± 63 μs for the tibia of this volunteer.*

CONCLUSIONS

Bone T2 and T1ρ relaxation times can be quantified with UTE sequences combined with appropriate preparation pulses. These techniques may allow quantitative evaluation of bone quality in vivo using clinical MR systems.

REFERENCES

1. Reichert ILH, et al., MRI 2005; 23:611-618.
2. Du J, et al., MRM 2007; 58:1001-1009.
3. Techawiboonwong A, et al., NMR in Biomed 2008; 21:59-70.
4. Wehrli FW, et al., NMR in Biomed 2006; 19:731-764.
5. Duvvuri U, et al., MRM 1997; 38:863-867.
6. Li X, et al., Osteoarthritis Cartilage 2007; 15:789-797.