

Validation of Quantitative Bound and Pore Water Imaging in Cortical Bone

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Target Audience: Scientists and clinicians interested evaluating bone fracture risk with MRI.

Purpose

The soft-tissue characteristics of bone, including water bound to collagen and pore water can be quantitatively imaged using ultra-short echo time (UTE) MRI^{1,2}, and recent work has shown that distinguishing pore-water ($T_2 = 1\text{ms}-1\text{s}$) and bound-water ($T_2 \approx 400\ \mu\text{s}$) signals based on T_2 is necessary in predicting fracture risk³. Clinically-compatible UTE pulse sequences for quantitative bound and pore water imaging, based on T_2 -selective magnetization preparation, have been proposed and preliminarily shown effective in isolated bone samples⁴. This work demonstrates implementation of these methods in 3D radial UTE imaging, and validation against previously-established non-images measures of bound and pore water.

Methods

The previously-proposed Adiabatic Inversion Recovery (AIR) and a Double Adiabatic Full Passage (DAFP) magnetization preparation schemes were integrated into 3D radial UTE sequences on a 3T (Philips) human scanner and an 4.7T (Agilent) small bore system. The DAFP sequence saturates the short T_2 signal from bound water, resulting in a pore water image, and the AIR sequence T_2 -selectively inverts and nulls pore water signal, resulting in a bound-water image³. Images were acquired at 3T and 4.7T from three human cadaveric femur mid-shafts, using clinically practical gradient amplitudes/slew-rates and specific RF absorption rate (SAR), with 1.5 mm nominal isotropic resolution. Reference phantoms (120 mM CuSO_4 in 10/90% $\text{H}_2\text{O}/\text{D}_2\text{O}$) were placed around the bone during imaging to i) define a B_1 map using the Bloch-Siegert method⁴, and ii) convert the bound- and pore-water signals into to absolute concentrations of proton density ($\text{mol } ^1\text{H}/\text{L}_{\text{bone}}$). After imaging, samples of cortical bone were extracted from four locations around each bone and evaluated with previously-establish CPMG measures of bound- and pore-water.

Results & Discussion

Representative bound and pore water images from 3T and 4.7T are shown in Fig 1. As expected, there is a negative correlation of bound and pore water concentrations across the bone. Figure 2 shows the imaging measures of bound and pore water compared to “gold-standard” CPMG measures from small bone samples. Both 3T and 4.7T imaging data correlate well with the gold standard measures, although some systematic biases are apparent.

These imaging methods show promise for clinically relevant bound and pore water mapping. At both 3T and 4.7T, the sequences were run with clinically practical parameters, taking into account limitations such as SAR, B_1 , slew rates, and gradient amplitudes. Several key steps are necessary for accurate absolute quantitation: correction for relaxation during the RF pulse and acquisition needs, B_1 mapping to accurately account for flip angle variation, and use of suitably broad bandwidth adiabatic pulses to invert all pore water magnetization.

Conclusion

These results validate the potential for yielding diagnostically useful information from clinical bone imaging to determine fracture risk across the cortical bone volume. MRI methods that can measure soft tissue characteristics of bone offer a fundamentally new diagnostic measure, which may be valuable in both researching the mechanisms of increased fracture risk and in developing new drugs to mitigate these fracture risks.

References 1. Rad HS, et al. NMR in Biomedicine. 2011;24(7):855–64. 2. Du J, et al. Journal of Magnetic Resonance 2010;207(2):304–11. 3. Horch RA, et al. Magnetic Resonance in Medicine 2012 early view. 4. Sacolick LI et al. B Magnetic Resonance in Medicine 2010;63(5):1315–22.

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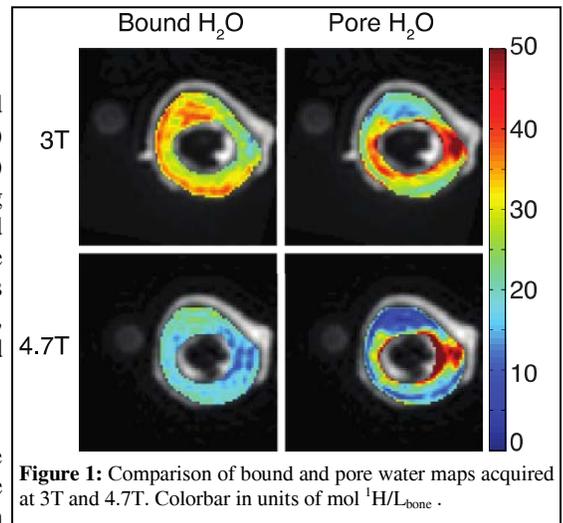


Figure 1: Comparison of bound and pore water maps acquired at 3T and 4.7T. Colorbar in units of $\text{mol } ^1\text{H}/\text{L}_{\text{bone}}$.

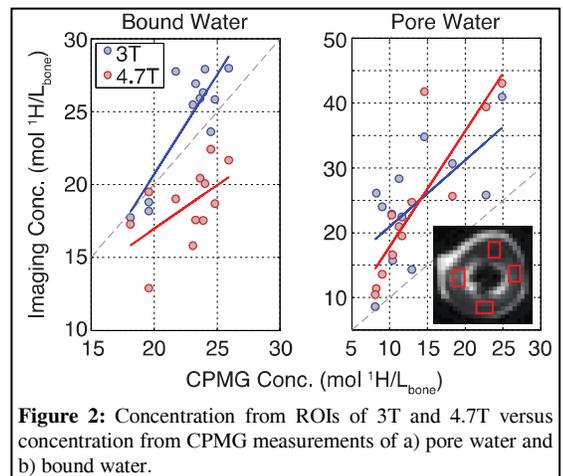


Figure 2: Concentration from ROIs of 3T and 4.7T versus concentration from CPMG measurements of a) pore water and b) bound water.