In Vivo Cortical Bone MRI with Bound and Pore Water-Discrimination

R. Adam Horch[1,2], Mary Kate Manhard[1,2], Daniel F. Gochberg[2,3], Jeffry S. Nyman[4], and Mark D. Does[1,2]

[1]Biomedical Engineering, Vanderbilt University, Nashville, TN, United States, [2]Vanderbilt University Institute of Imaging Science, Vanderbilt University, Nashville, TN, United States, [3]Radiology & Radiological Sciences, Vanderbilt University, Nashville, TN, United States, [4]Department of Orthopaedics & Rehabilitation, Vanderbilt University, Nashville, TN, United States

Target Audience: clinicians and researchers investigating human cortical bone and other tissues with short T_2 components, as well as investigators utilizing ultrashort-echo time imaging and similar methods

Purpose

Ultrashort-echo time (UTE) imaging[1] and related methods have become practical tools for visualizing human cortical bone[2], which contains signals primarily from collagen-bound water ($T_2 \approx 400$ μs) and pore space water (T_2 = 1ms-1s). Importantly, the net UTE signal is poorly correlated to bone mechanical properties, but bound and pore water-discriminated signals are each strongly correlated to mechanical properties[3]. UTE methods for discriminated bound or pore water imaging were previously evaluated in cadaveric cortical bone[4] but have not yet been translated to *in vivo* MRI. Herein we implement these methods on a clinical scanner and demonstrate quantitative bound and pore water maps obtained from human cortical bone *in vivo*. These maps have potential for robust bound/pore water quantitation in a clinical setting, which would enhance the diagnostic utility of cortical bone MRI.

Methods

MRI was performed on three human subjects (ages 24-60) with a 3T Philips Achieva scanner. Quantitative MRI methods utilized T_2-selective adiabatic full passage (AFP) pulses to image either bound or pore water and consisted of MP-RAGE 3D UTE sequences (70 μs TE, isotropic 1.5mm resolution over a 200mm^3 FOV) with one of the following preparations: 1) a 360° double-AFP pulse, which isolated long-T_2 pore water by saturating short-T_2 bound water (2 x 10ms/2kHz hyperbolic secant AFPs, 400 ms TR, 14 min scan time), and 2) a single AFP pulse, which isolated short-T_2 bound water by selectively inverting and then nulling the pore water (10ms/2kHz hyperbolic secant AFP, 300ms TR, 80ms TI, 10 min scan time). $CuSO_4$ phantoms (10% H_2O, 90% D_2O) were included for quantifying bone signals in units of absolute concentration (mol $^1H/L_{bone}$).

Results and Discussion

Fig. 1 shows a representative slice though conventional (non-prepared) 3D UTE, along with quantitative bound and pore water concentration maps calculated from the two AFP-prepared MP-RAGE uTE methods described above. The average signal-to-noise ratio across the tibial cortex was approximately 40 in both bound and pore water maps, indicating potential for scan time acceleration or resolution enhancement. Bound and pore water concentrations were negatively correlated in all subjects (Fig 2), which agrees with *ex vivo* studies[4] and indicates appropriate contrast generation in the bound/pore water maps. Challenges with these bound/pore water discriminated imaging methods *in vivo* include 1) trade-off between scan time and high specific absorption rate adiabatic pulses, which must have sufficiently wide bandwidths to encompass the line-broadened broad pore water resonance (> 2kHz); 2) sensitivity to B_1 calibration/variation, which is inherent to most quantitative MRI methods; 3) selection of an inversion-recovery time to null pore water signals during bound water-selective imaging; and 4) validation of signal quantitation. These challenges were addressed in phantom and *ex vivo* bone testing and *in vivo* optimization is underway.

Conclusions

Quantitative bound and pore water concentration maps were demonstrated in cortical bone *in vivo*, with useful SNR obtained in clinically-compatible scan times. Such *in vivo* bound/pore water discrimination provides diagnostic information on bone quality by way of established mechanical property correlations, potentially improving the clinical utility of cortical bone UTE MRI.

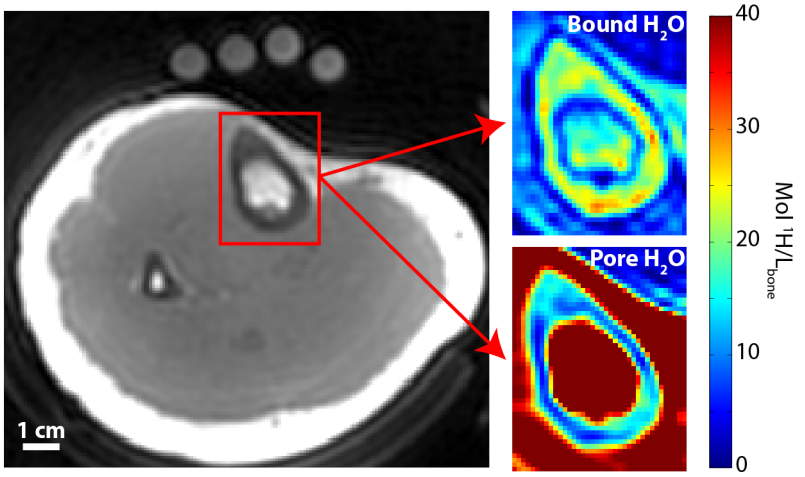

Fig 1. UTE of mid-calf (left) with bound and pore water concentration maps of the tibia (right). Phantoms used for quantitation are visible at left.

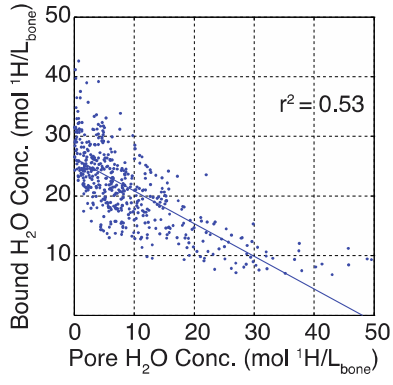

Fig 2. Negative correlation between bound and pore water proton concentrations in a representative subject, indicating successful bound and pore water discrimination.

References:

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