Quantification of bone water in the human tibia *in vivo* by ultra-short TE radial MRI at 3T

A. Techawiboonwong[1], H. Song[1], C. E. Jones[1], M. B. Leonard[2], and F. W. Wehrli[1]
[1]Laboratory for Structural NMR Imaging, Department of Radiology, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania, United States,
[2]Children's Hospital of Philadelphia, Philadelphia, Pennsylvania, United States

Introduction: Cortical bone contains approximately 20% water [1], which resides mostly in the microscopic pores of the haversian and the lacuno-canalicular system. A measure of bone water (BW) may provide a surrogate for cortical porosity, which correlates strongly with bone's mechanical strength [2]. Pore water has extremely short T_2 and thus exhibits solid-like behavior with a linewidth on the order of 1kHz, therefore requiring ultrashort-echo time (UTE) MRI techniques. Here, we developed and evaluated a method for quantification of BW content in human cortical bone *in vivo* and applied it to a pilot study comprising three groups of subjects.

Materials and Methods: Cortical BW content was determined with a custom-designed 3D UTE imaging sequence [3] at 3T (Siemens Trio™). In brief, excitation was accomplished with a 100µs rectangular pulse followed by a time-incremented slice-encoding gradient. This approach ensures minimum TE for all encoding steps [4]. The sequence used radial readout with ramp sampling and the data were regridded before being Fourier reconstructed. To enhance visualization of the proton signal from bone, the dominant soft-tissue signals were suppressed using two 5ms T_2-selective RF excitation pulses centered at the methylene lipid and water resonance frequencies [5]. The proton density of water in bone was computed from the ratio of signal intensities of the reference (10% H_2O in D_2O doped with 27mM $MnCl_2$ yielding T_1 of 3.5ms, T_2 ~300µs) and bone, with the relaxation of short T_2* of BW (~300-500 µs) during the RF pulse taken into consideration (Eq. 1):

$$\rho_{bone} = \rho_{ref} \frac{I_{bone} F_{ref}}{I_{ref} F_{bone}} \exp\left(-TE\left(R^*_{2ref} - R^*_{2bone}\right)\right) \quad \text{Eq. 1}$$

Here, ρ_{bone} and ρ_{ref} are the proton densities of bone and reference; I_{bone} and I_{ref} are the respective image intensities; factors F_{bone} and F_{ref} represent the available magnetizations for a given set of scan parameters, T_1 and τ/T_2 values (τ is the RF duration) [5]; and $R_2^* \equiv 1/T_2^*$ is the effective transverse relaxation rate in the two phases. The intensity-based quantification was previously validated *ex vivo* by exchange of the native water with D_2O [6].

BW content was measured at the tibial mid-shaft with an eight-element transmit/receive knee array (Invivo, Pewaukee, WI) in two groups of healthy women (mean age 34.6 and 69.4 years, N=5 each) and a group of women renal osteodystrophy (ROD, mean age 51.8, N=6). The resulting data were compared with pQCT volumetric bone mineral density (vBMD). Radial images were acquired with the following parameters: TE 110µs-230µs, TR 70ms, flip angle 41°, readout bandwidth 700 Hz/pixel, nominal voxel size 0.3x0.3x8mm^3, number of views over 2π radians 256 with 30 slice encodings in 9 min scan time.

Results and Conclusion: BW content in the older age group was greater by 65% (29±2% v/v, versus 18±2%, $p<0.0001$) and ROD patients had higher BW than either healthy reference group by 135 and 43% (39±8%, $p<0.0005$ and 0.02, respectively). VBMD at the same location showed an opposite behavior but group differences were much smaller. Since the majority of BW is pore water, this parameter may provide a surrogate for cortical porosity.

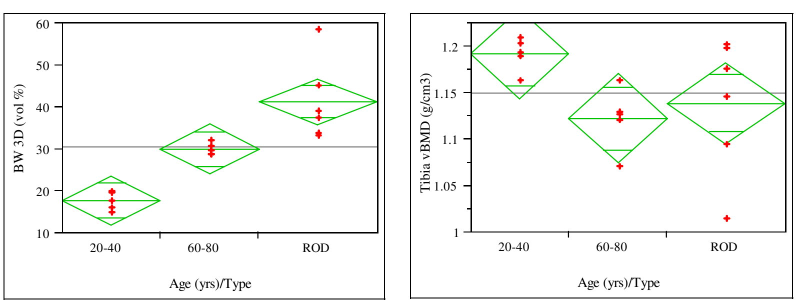

Fig. 2 Scatter plots showing differences between groups for BW (left) and vBMD (right). The data indicate lower BW and higher vBMD in the younger age group. Note also abnormally high bone water concentration in the ROD patients.

References: 1. Mueller KH *et al*., JBJS **48**: 140 (1966). 2. McCalden RW *et al.*, JBJS **75**: 1193 (1993). 3. Techawiboonwong A *et al.*, NBM In press (2007). 4. Song HK *et al.*, MRM **39**:251 (1998). 5. Sussman MS *et al.,* MRM **40**:890 (1998). 6. Techawiboonwong A *et al.*, Proc ISMRM 14th, 3620 (2006).

Acknowledgment: NIH RO1 AR49553 and RO1 AR50068

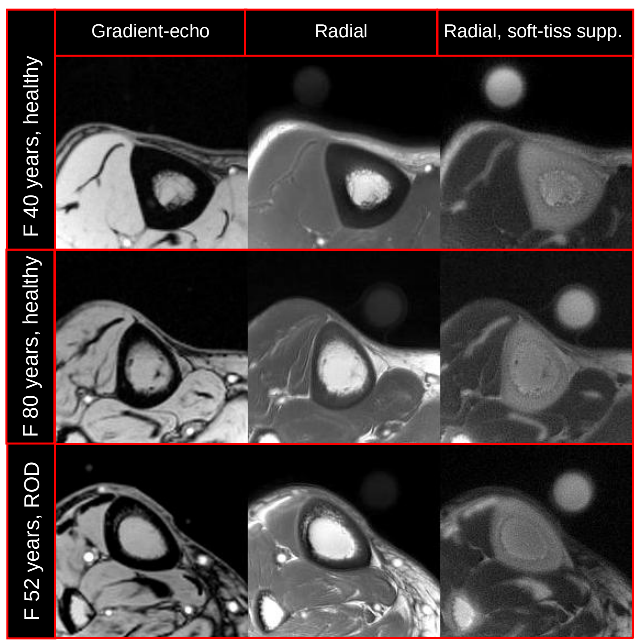

Fig. 1 MR images of tibial mid-shaft of each of the three groups studied: gradient-echo (left column); UTE (middle column); UTE with soft-tissue suppression (right column). Circular structure is the reference sample with T_2 ~ 300 µs which, similar to bone, is only visible in the UTE radial images. Images obtained from 40-year old healthy subject (top row), displays noticeably thicker cortex than 80-year old subject (middle row) or 52-year old ROD patient (bottom row). Images of ROD patient also display effect of increased cortical bone porosity.