Predicting Whole Bone Strength in Radii Using MRI Measurements of Bound and Pore Water

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Target Audience: Scientists and clinicians interested in imaging cortical bone using MRI for diagnosing fracture risk.

Purpose

Current clinical methods for diagnosing fracture risk include Dual X-ray Absorptiometry (DXA) to measure areal bone mineral density (BMD) and quantitative computed tomography (qCT) to measure volumetric BMD and other structural properties. These measurements only give information about the mineral tissue properties and do not give information about the soft tissue characteristics of bone such as collagen or water bound to the collagen matrix, which is known to have significant contributions to fracture risk[1]. MRI has been shown to produce quantitative measures of both water bound to the collagen matrix (bound water) and water residing in the pores (pore water) in cortical bone using T_2 selective preparation pulses[2]. In previous studies, NMR measurements of bound and pore water in small samples of cortical bone have been shown to correlate with the mechanical properties of these samples, such as bending strength and flexural modulus[3]. In this study, whole cadaveric radii were imaged with previously presented 3D UTE sequences using clinically practical parameters to acquire bound and pore water maps. Images were also acquired with DXA and μCT as a comparison to current gold standard measurements. Lastly, mechanical data was obtained from three-point bend testing for the purpose of comparing MRI and X-ray contrasts. We hypothesized that bound water and pore water are more predictive of the biomechanical properties of the radius than X-ray based techniques.

Methods

The Vanderbilt Donor Program supplied cadaveric arms (mean age=82, M/F=4/7) from elbow to fingertip. DXA measurements (GE Lunar iDXA) were obtained on intact arms to find areal BMD at the distal third site of the radius. The arms then underwent MRI scans using a 3T Philips Ingenia system with an 8-channel knee coil for the receive signal. Pore water maps were obtained using the Double Adiabatic Full Passage (DAFP) sequence, and the Adiabatic Inversion Recovery (AIR) sequence was used to acquire bound water[4]. A reference marker with known concentration was used to convert signal into absolute units of mol H^1/L. After MRI measurements, the radii were dissected out of the arms and the distal third region was scanned using a Scanco μCT50 (40 μm voxel size, 80keV, 200 μA) and evaluated to find tissue mineral density (TMD) and structural properties. After imaging, a 3-point bend test[5] at the distal third site was performed using an MTS Bionix 858 bi-axial Test System to obtain force displacement curves. From these curves, mechanical properties such as strength and toughness were calculated. These measures were then correlated to the imaging results to assess the relative contribution of bound water, pore water and mineral density measurements to the strength and brittleness of the radius at the fracture site.

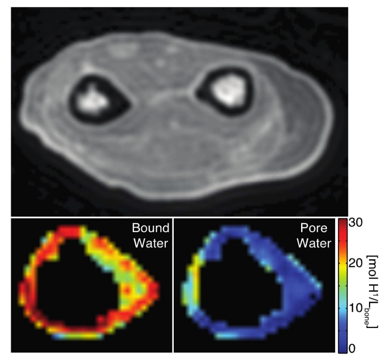

Figure 1: (Top) A conventional UTE image from the distal third slice of a cadaveric arm. (Bottom left) Corresponding bound water map from the radius in this slice from an AIR imaging sequence. (Bottom right) corresponding pore water map from the radius in this slice from a DAFP imaging sequence.

Results and Discussion

Fig.1 shows a slice from a conventional UTE image of a representative cadaveric arm, with the corresponding bound and pore water maps of the cortical bone in the radius at the distal third location. Results are shown in Fig. 2 of bending strength correlations with bound and pore water, along with correlations with BMD from DXA at the distal third site and TMD from μCT at the distal third site. Bound and pore water correlate strongly with both yield and bending strength (r^2 = 0.51 and 0.43 respectively). The DXA- and μCT-derived properties gave similar correlations (r^2 = 0.59 and 0.45, respectively). Stepwise multiple linear regression analysis found that bound and pore water together provided a higher explanation of the variance in strength (r^2 = .68) than individual imaging properties. Bound water also has strong correlations to toughness (r^2 = .39), while no other imaging properties are significantly correlated. As the number of samples studied increases, multiple regression analysis may provide greater insight. These MRI imaging methods show promising results for bound and pore water mapping as a predictor for fracture risk. Measuring both bound and pore water has the potential to increase the information obtained to more fully evaluate fracture risk.

Conclusion

These results validate the potential of MRI for yielding diagnostically useful information for clinical bone imaging to determine fracture risk across the cortical bone volume. MRI can obtain structural information from anatomical images in addition to the bound and pore water measures, giving it an advantage over current bone imaging methods. MRI methods offer a new diagnostic measure for fracture risk, which may be valuable in both researching the mechanisms of increased fracture risk and following treatment of fracture or response to drugs.

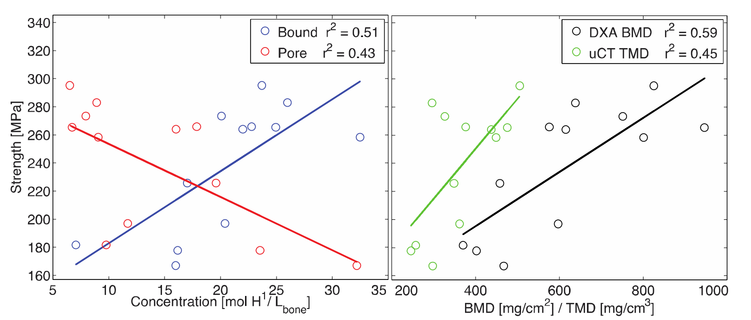

Figure 2: Correlations between bending strength and bound and pore water (left) as well as DXA BMD and uCT TMD (right)..

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