

Quantitative Water and Fat Suppressed Proton Projection MRI (WASPI) Measurement of Bone Matrix Density Differentiates Normal, Osteoporotic and Osteomalacic Bone

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Introduction

Water and fat suppressed proton projection MRI (WASPI) has been developed to quantitatively image solid bone matrix, which cannot be detected in conventional MRI (1). WASPI measurement can be quantified by using a polymer blend calibration phantom as intensity reference (2). Bone matrix density, critically needed information for the study and diagnosis of metabolic bone diseases such as osteoporosis and osteomalacia, has long been obtainable only by bone biopsy. In this study, we report our preliminary results on quantitative WASPI measurement of bone matrix densities of normal, osteoporotic, and osteomalacic rat bone specimens.

Materials and Methods

Sprague-Dawley (SD) female rats (mass: 250-275 grams) were used in this study. Ovariectomy was utilized to induce osteoporosis in the OVX group of rats. Partial (5/6) nephrectomy and a modified diet containing 0.6% Ca and 1.2% P was utilized to induce severe secondary hyperparathyroidism and renal osteodystrophy, i.e., osteomalacia, in the NFR group of rats. The control group of rats (CON) was not subjected to any surgical or dietary interventions. At the end of week 7, the animals were sacrificed and both femurs were extracted from each rat. The external soft tissues and periosteum were completely dissected. Cortical specimens were cut from the diaphysis of the rat femur and trabecular bone specimens were cut from the femoral neck.

Three cylindrical pellets of the 20% poly(ethylene oxide) (PEO)/80% poly(methyl methacrylate) (PMMA) polymer blend powder diluted with silicon dioxide were used as the calibration phantoms. The polymer phantom densities were 1.17, 0.80, and 0.56g cm⁻³. A tube of pig bone marrow served as the reference for water and fat suppression. MRI density values of bone specimens and phantoms were calculated by summing all the pixel values above a threshold value in a rectangular volume of the 3D image containing each object to be analyzed and dividing by that volume. Non suppressed projection MRI (NSPI) and WASPI data were acquired and processed according to the previous description (1, 2) with a Bruker 4.7T 33cm scanner (Bruker Biospin, Billerica, MA, USA).

Results

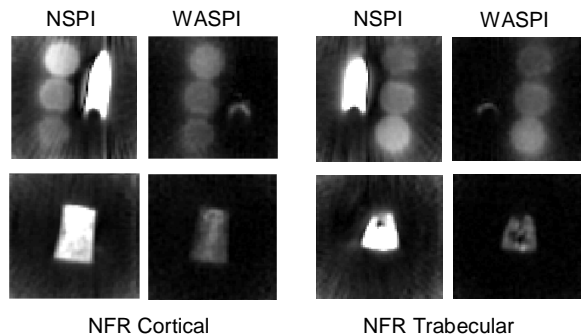


Figure 2. NSPI and WASPI images (at the same intensity scale) of NFR cortical and trabecular bone specimens, each of which is imaged together with 3 polymer phantoms and a tube of bone marrow (upper slices). In the WASPI (pure solid state) images, the bone marrow is invisible due to the suppression of the water and fat signals, indicating that the bone signals in WASPI come only from the solid bone matrix.

specimen was converted to the density in terms of polymer phantom g/cm³. The WASPI densities of bone specimens were then converted to the true bone matrix densities using the relationship: Gravimetric (g cm⁻³) = 0.44 WASPI (g cm⁻³) + 0.011, which was obtained from a previous study (2).

Figure 3 shows the bone matrix density results for the CON, OVX and NFR groups. The cortical bone matrix densities of both OVX and NFR were comparable to the CON. No significant changes of cortical bone matrix density were observed in both disease states. Decreased trabecular bone matrix density was observed in OVX relative to the CON (0.03±0.01 vs. 0.24±0.08 g/cm³, P=0.006), while there was no significant change of trabecular bone in NFR relative to CON.

Discussion

The WASPI data show that trabecular bone *matrix* density in osteoporosis was much lower than in normal and osteomalacic bone, while decreased trabecular bone *mineral* density is observed both in osteoporosis and osteomalacia using X-ray based densitometry. This indicates that osteomalacic bone matrix is undermineralized while osteoporotic bone matrix is close to normally mineralized, which agrees with the definitions of these diseases as well as observations by bone biopsy reported in literature (3). These results demonstrate that the method is capable of distinguishing the difference in trabecular bone matrix densities between osteoporosis and osteomalacia while micro-CT failed to detect it. The preliminary data in this study shows that WASPI quantitative bone matrix density measurement has potential for noninvasive quantitative characterization of bone matrix disorders in metabolic bone diseases such as osteoporosis and osteomalacia.

References

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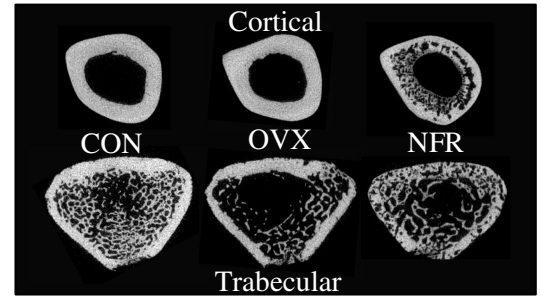


Figure 1. Representative micro-CT cross-sections from the mid-diaphysis and from the distal metaphysis illustrate cortical and trabecular bone morphologies respectively for CON, OVX and NFR groups. More significant cortical changes are observed in the NFR specimen, yet significant trabecular changes are observed in both the OVX and NFR specimen.

Figure 1 shows the representative micro-CT cross-sections of cortical bone from the mid-diaphysis and trabecular bone from the distal metaphysis of a rat femur from the CON, OVX and NFR groups. More significant cortical changes are observed in the NFR specimen. Decreased bone mineral densities are observed both in the OVX and NFR trabecular specimens. Micro-CT measurements do not provide information on the bone matrix densities and bone mineralization DM (chemical compositional changes).

Figure 2 shows the NSPI and WASPI images of a cortical specimen and a trabecular specimen from a NFR rat femur. Each specimen in this study was imaged together with 3 polymer phantoms and a tube of bone marrow.

The signal of bone marrow was suppressed in the WASPI images, indicating that the bone image in WASPI was non-marrow solid matrix component of bone. The measured WASPI intensity of each bone

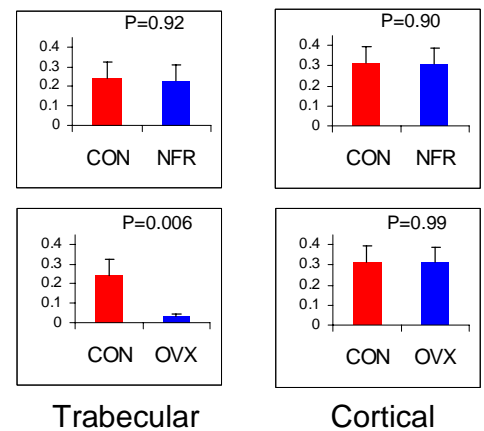


Figure 3. The true bone matrix densities of trabecular and cortical bones for CON, OVX and NFR groups. The number of samples N=3 for each group.