Water and Fat Suppressed Proton Projection MRI (WASPI) of Rat Femur Bone with Sub-millimeter Resolution

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Introduction

Rats are one of the most commonly used animal models to investigate the pathogenesis and treatment of skeletal disorders occurring in humans, due to many similarities between rat and human skeletons, and cost effectiveness of studies conducted on rats. Rat bone specimens are widely studied by the X-ray based modality of micro computed tomography (μCT). However, since the X-ray beam is primarily attenuated by calcium, the constituent with the highest atomic number and concentrated in bone mineral, μCT measurement of bone only reflects the mineral content of bone, but not the solid matrix content (mostly collagen) of bone. In this study, we explored the feasibility of water and fat suppressed proton projection MRI (WASPI) [1] to image the solid matrix content of rat whole bone specimens, meeting the challenges of small sample size and the demanding sub millimeter resolution.

Materials and Methods

Four-month-old virgin female NIHRNU rats (Charles River Laboratories, Charlestown, MA) were used in this study. The femurs were disarticulated from the hip and knee. Chicken bone marrow was used as reference of water and fat suppression. Two capillary tubes (outside diameter: 1.5 mm, inside diameter: 1.1 mm, wall thickness ~ 0.2 mm) were filled with saline to serve as phantoms.
MRI data were acquired with a Bruker 4.7 T scanner under fixed 160 mT/m gradient magnitudes in 2934 directions at a sampling rate of 5 μs per complex point. The short hard pulse used to excite the signal was 8 μs in duration. Receiver dead time was 10 μs. The two data points lost in this dead time were recovered by an additional acquisition with gradients of half strength and in 20 directions. Repetition time TR was 0.15 sec and the FIDs were averaged over 16 acquisitions. The measurement time was approximately 2 hours. Eighty complex points of the FID were used in the reconstruction, effectively creating a 12 mm FOV in a 64 x 64 x 64 cubic lattice. WASPI data were acquired with pairs of π/2 pulse of 2 – 2.5 ms in duration, with frequencies set at water and fat respectively.

Figure 1. ^{1}H SMRI of two tightly bound saline capillaries. The space between the two saline tube images was 0.4 mm.

Results and Discussions

Projection pixel size (digital resolution) (Δx_p) < 0.4 mm of solid state MRI (SMRI) was demonstrated in the experiment of imaging two sealed 1.5 mm outside diameter capillaries filled with saline (Figure 1). The total thickness of the adjacent walls of the capillaries is 0.4 mm. In either the longitudinal or axial direction, there is a clear dark gap between the two saline tube images, which corresponds to the adjacent walls of the capillaries.

Figure 2. Proton spectra of rat femur bone specimen. **Left:** non-suppression one pulse (8 μs) spectrum; **Center:** water and fat suppressed proton spectrum ; **Right:** vertical scale increased (x10) water and fat suppressed proton spectrum, in which the full width of the observed resonance at half height was ~ 1.2 kHz .

Figure 2 shows the proton spectra of a rat femur bone. The single pulse (8 μs) spectrum was contributed from soft and solid components of bone (Figure 2 left). The water and fat suppressed spectrum shows a broad resonance with reduced intensity, the line width of which measured at half height was around 1.2 kHz (Figure 2 center and right). This signal was contributed from the solid components of bone matrix and observed in WASPI images. This measurement implies that the intrinsic resolution that could be achieved is as small as ~0.17mm with projection gradient of 160 mT/m magnitude.

Figure 3 shows non-suppressed MRI (upper) and WASPI (middle) images of a rat femur with a tube of chicken marrow. The dark features in non-suppression images were graphically corresponding to the bright features in WASPI images of the specimen. This observation clearly demonstrates that WASPI provides the solid-bone-matrix-only images of the sample, which was further confirmed by the μCT images (bottom) of the same specimen.

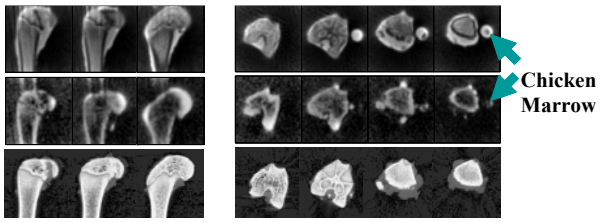

Figure 3. Non-suppressed (**upper**) and WASPI (**middle**) of rat femur imaged with a tube of chicken marrow. μCT (**bottom**) images of the same rat femur.

Conclusion

Proton solid-bone-matrix-only MR images with 0.4 mm resolution of rat femur were obtained for the first time to the best of our knowledge. This method provides a non-invasive means to study bone matrix in small animals.

References

1. Wu Y, Ackerman JL, Chesler DA, Graham L, Wang Y, Glimcher MJ. Magn Reson Med. 50, 59-68 (2003).