



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



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Introduction

One of the crucial parameters for bone quality is the degree of bone mineralization, which is determined by the ratio of bone mineral density (BMD) over bone matrix density. The widely used micro-CT in rat bone studies can provide BMD, but not the solid matrix content. Here we explore the feasibility of water and fat suppressed projection MRI (WASPI) to image the solid matrix content of rat bone specimens, in order to determine the matrix density.

Solid State MRI (SMRI)

To image very short T_2 subjects, our approach of solid state MRI (SMRI) is to utilize the projection reconstruction imaging method emphasizing the start of the FID: fast sampling and recovering data lost in the receiver dead time (Figure 1). Slowly ramped, medium strength gradients in three dimensions are applied to provide the desired spatial resolution (Figure 2) [1].



Figure 1. Effect of recovering missing data in receiver dead time: ^1H SMRI of rat femur. Sampling dwell time was $5 \mu\text{s}$ per complex point and the receiver dead time was $20 \mu\text{s}$. Four points were lost in the receiver dead time. **A:** Image was reconstructed without correcting the data position in the k-space, resulting in severe distortion. **B:** Image was reconstructed by zero filling of the missing points, and shifting data to the correct k-space position. Most of the artifacts were corrected, but a dark ring surrounds the image. **C:** Image was reconstructed with the addition of a second set of data acquired under 4 times lower gradient, which approximated the lost data close to the origin of the k space. The artifacts are corrected.



Figure 2. ^1H SMRI of saline in bonded capillaries. The total thickness of the adjacent walls of the capillaries is 0.4 mm . In either the longitudinal (**A**) or axial direction (**B**), there is a clear dark gap between the two saline tube images, showing the achieved projection pixel size $< 0.4 \text{ mm}$. **C:** Photograph of the capillaries. The overall resolution of SMRI is limited by number of projections, whenever the projection gradient is large enough to overcome the intrinsic spectral width of the imaged material. The data were acquired with 2934 projections, gradient strength of 160 mT/m , on a 4.7 T Bruker scanner. FOV was 12 mm in a $64 \times 64 \times 64$ cubic lattice.

Water and Fat Suppressed Projection Imaging (WASPI)

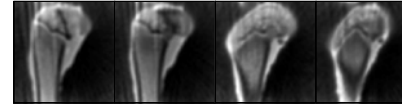
In addition to regular SMRI, a specially designed water and fat suppressed proton projection imaging pulse sequence utilizes the large difference between the proton T_2^* 's of the solid organic matrix and the fluid constituents of bone tissue to suppress the fluid signals while preserving solid matrix signals [2].



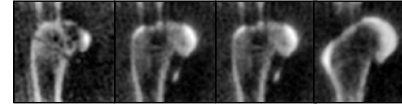
Figure 3. Proton spectra of rat femur bone specimen. **Left:** non-suppression one pulse ($8 \mu\text{s}$) spectrum; **Right:** water and fat suppressed proton spectrum, in which the full width of the observed resonance at half height was $\sim 1.2 \text{ kHz}$.

SMRI, WASPI and μCT Images of Rat Femur Specimen

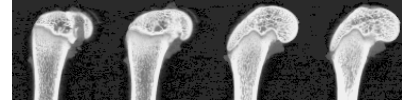
SMRI



WASPI

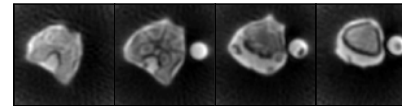


μCT

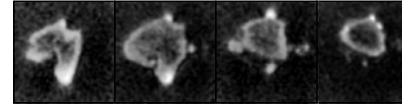


Longitudinal View

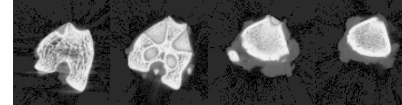
SMRI



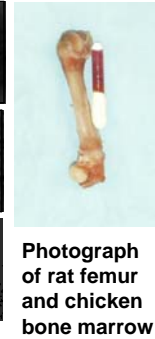
WASPI



μCT



Axial View



Photograph of rat femur and chicken bone marrow

Figure 4. SMRI experiments were carried out as described in Figure 2 on femur specimens of two-month-old virgin female NIHHRNU rats.

WASPI was carried out with suppression pulses of 2 ms (90°) and hard pulse of $8 \mu\text{s}$ (16°). Chicken bone marrow extracted from chicken radii was imaged at the same time as a reference for water and fat suppression.

In all experiments, $\text{TR} = 150 \text{ ms}$, $\text{NS} = 16$, total scan time = 2 hr . μCT imaging was performed on a $\mu\text{CT}40$ system (Scanco Medical AG) using the following parameters: $30 \mu\text{m}$ isotropic resolution, 200 ms integration time, 55 kVp energy, 0.145 mA current and 1024×1024 array size. The μCT images were coarsened to an isotropic resolution of $400 \mu\text{m}$ to match SMRI and WASPI images.

The correlation between the dark regions in non-suppression SMRI images and the bright regions of WASPI and μCT images of the rat bone specimens justifies the assignment that these regions represent solid bone.

Conclusions

SMRI method faithfully collects all proton signals from both solid and fluid constituents of bone specimens. The WASPI method, built on SMRI, and including a water and fat suppression preamble which minimizes the perturbation of the solid signal, yields an image of only the solid constituents. In this study, the solid matrix of rat bone was imaged directly by WASPI with 0.4 mm resolution for the first time to the best of our knowledge. This method provides a means to measure bone matrix density in small animals.

References

- Wu Y, Chesler DA, Glimcher ML, Garrido L, Wang J, Jiang HJ, Ackerman JL. Proc Natl Acad Sci USA. 96, 1574-8, (1999).
- Wu Y, Ackerman JL, Chesler DA, Graham L, Wang Y, Glimcher MJ. Magn Reson Med. 50, 59-68 (2003).