Measurement of Water Content in Normal and Osteomalacic Rabbit Bone by Solid-State 3D Radial Imaging

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Introduction

About 10-15% of bone volume is accupied by water. A significant fraction occupies the haversian and lacuno-canalicular space, while the remainder is bound to collagen. During mineralization the collagen-bound water is gradually replaced by the mineral. Conversely, in osteomalacia – a disease of hypomineralization of the bone – bone water content is increased under retention of the total bone volume [1]. In this work we designed and implemented a 3D radial imaging sequence for measuring the water content *ex vivo* in bone specimens and we compared the method with single point imaging (SPI) [2]. We show that the hypothesized increase in water content in osteomalacic bone relative to normally mineralized bone can be detected and quantified.

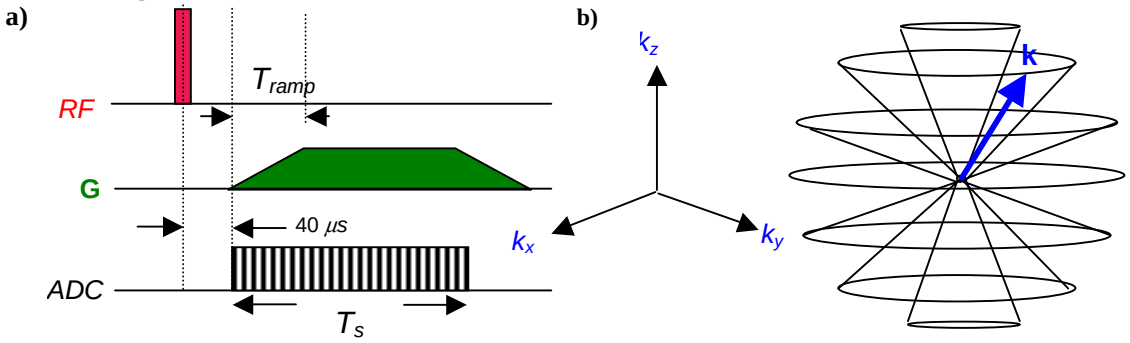

Fig.1 a) 3D radial projection imaging sequence using ramp sampling. b) sampling on concentric cones for uniform mapping of k-space.

Materials and Methods

The difficulty of imaging bone water is its extremely short T_2 (~250 μs). While single-point imaging (SPI) is suited to image solid–like materials, it is very inefficient [2]. Wu et al [3] have previously shown radial scanning to be useful for proton imaging of solid bone. In order to accurately measure bone water content a 3D radial projection reconstruction (PR) sequence was designed for operation at 400 MHz (Fig. 1). It consists of a nonselective 90^0 pulse followed 40 μs later by FID sampling in the presence of projection readout gradients. The FID sampling necessitates sampling during the gradent ramp-up in order to capture the center of k-space. The nonuniform sampling during the ramp time of the gradients is compensated by resampling during reconstruction. 2626 gradient directions were sampled uniformly distributed on a series of parallel rings, equally spaced in 65 azimuthal angle increments. This yields uniform coverage of 256 complex sampling points per view on a sphere with equal solid angles [4]. Imaging parameters used were: TR=1*s*; FOV=2.5 x 2.5 x 2.5 cm^3; Sweep width = 200*kHz*; acquisition time ~ 45 *min*. The images were reconstructed by regridding onto a matrix 137 x 137 x 137 (after taking into account the number of points on the linear gradient ramp), yielding an isotropic resolution of 183 x183 x183 μm^3. In addition, SPI was performed by acquiring a single point per TR after the application of a 15 μs hard 90^O pulse in the presence of three frequency encoding gradients. Imaging parameters used were: TR = 500 ms, matrix size = 32 x 32 x 16, FOV 2.5 x 2.5 x 2.5cm^3, yielding a resolution of 0.78 x 0.78 x 0.16 mm^3 (scan time 2hrs. 27 min). Both pulse sequences were implemented on a 9.4T (DMX-400, Bruker Instruments, USA) vertical-bore superconducting system equipped with standard 100G/cm gradients, allowing for a ramping time of ca. 100µs and using a 10 mm i.d. rf coil.

Six female New Zealand White rabbits were obtained at the age of 5 weeks and divided into two groups, treated (TR) and control (CO). The TR group was fed a low phosphorus diet (0.09%) to induce osteomalacia. The CO received the same diet supplemented with sodium phosphate to 0.5% P (normal). After 8 weeks the animals were euthanized and 1.5 *cm* long cortical bone specimens were harvested from the right tibiae were harvested and external soft tissue and marrow were removed. To determine whether the bone water content was increased in TR animals the relative signal intensity was computed as the mean from the center 6 slices in all images. Noise was measured as the mean value from signal-free regions in the same slices and SNR computed.

Results and Discussion

Cross-sectional images obtained with the 3D PR and SPI sequences for one specimen are given in Fig.2(a) and (b). The 3D-surface rendered image of one of the specimens clearly showing the bone's tubular structure at this mid-diaphyseal location is displayed in Fig.2(C). The mean difference in water proton density between the two groups was 5% (being larger in the TR group) although this difference did not quite reach statistical significance yet. However, it is notable that the data from this preliminary study are in good agreement with those obtained by NMR exchange experiments [4]. Finally, the present data indicate that subtle differences in bone water content and thus mineral density (due to the inverse relationship between the two quantities) can be obtained *ex vivo* in small animal bone and likely *in vivo* in conjunction with soft-tissue suppression techniques [3].

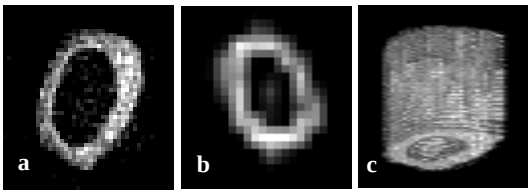

Fig.2. Typical axial slices obtained with the 3D PR (a) SPI sequence (b) and 3D surface-rendered image of one of the tibial specimens (c).

References

1. Robinson RA,et.al., J Bone Joint Surg 1957; **39A;**167-188. **2**. Emid S et.al., Physica 1985; **128B**; 81-83. **3**. Wu Y et.al., Magn Reson Medicine 2003; **50**; 59-68. **4**. Fernandez-Seara MA,et.al., Biophys J 2002; **82**; 522-529.