Human Imaging of Phosphorus in Cortical and Trabecular Bone Using Ultrashort TE Pulse Sequences

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Synopsis:
In this work we present the first images of the 31P content of human bone obtained in-vivo. Phosphorus in bone has a very short T2 (here measured at 176 µs), consequently it has been necessary to image with an ultra-short TE (80 µs). The radio frequency excitation is performed using a half pulse and k-space sampling is radial. Images have been acquired of human bone with a true in-plane resolution of 2.9mmx2.9mm yielding a high SNR for cortical bone. There is significant clinical interest in bone metabolism and access to phosphorus imaging may provide a new method for demonstrating bone disease.

Materials and Methods:
All data were acquired on a 1.5T system (Siemens Sonata) equipped with multi-nuclear capabilities and 40mT/m gradients. In this work a 31P Heart/Liver optimised coil (Siemens, Erlangen) was used. This included a large relatively homogeneous RF transmit field and a smaller, more localised, quadrature reception region. The imaging sequence employed is based on the half-pulse method described for proton imaging of lungs [1]. The radio frequency (RF) excitation is performed using a half pulse with the data acquisition beginning at the centre of k-space and extending radially. A second RF half pulse excitation is then performed with a reversed slice selection gradient. This was used at the 31P operating frequency of 25.4MHz. Reconstruction was performed off-line. The technique is described in more detail elsewhere where it was used for imaging of protons in cortical bone and other ultra-short T2 structures [2]. We used a minimum echo time (TE) of 80 µs. This TE was progressively increased for studying the T2 of cortical bone. The RF pulse length was optimised for amplitude and duration, with the optimum found at 200 µs, using a flip angle from the surface transmitter coil of approximately 12 degrees and a TR of 300ms. This corresponds to the Ernst angle (in general terms) in relation to the published T1 of phosphorus in bone of 16s [3]. The sampling rates used were between 2 and 8 µs per point (faster sampling yielding less T2 blurring, but lower SNR). Given the T2, the optimum sampling rate for a 20minute scan (and the coil that we used) was determined using a simulation. This calculation is non-trivial owing to the increased SNR at low frequency, and modified sampling of the T2 decay function that are due to ramp sampling. The optimum sampling rate for this resolution was determined as being ~3 µs/point.

Results:
A 31P image of cortical bone is shown (fig. 1) in the left lower leg of a normal volunteer. This image has a pixel dimension of 0.3mm but a true resolution (FWHM of point spread function from simulation) of 2.9mm. The slice thickness is 60mm in this case. The difference in thickness of different aspects of cortical bone in the tibia is shown in this image. The SNR for cortical bone here is 19. Trabecular bone has also been visualised using this technique (fig. 2). The T2 of cortical bone was measured as 176 µs.

Fig.1 Cortical bone of the tibia in a 58 year old male volunteer (transverse images). Proton image (left), 31P image (right). The signal intensity in the phosphorus image corresponds closely to the thickness of bone seen in the proton image.

Fig.2 Trabecular bone in the upper end of the femur in a 58 year old male volunteer (coronal images). TE>1ms 1H image (left), TE=80µs 1H image (centre), TE=80µs 31P image (right)

Orienting the bone to 55° was performed to assess any magic angle effect. No significant signal change was observed.

Discussion:
We conclude that cortical and trabecular bone 31P imaging is possible in-vivo; voxel sample sizes of around 0.5ml and a SNR of 19:1 are obtainable in 20minutes for cortical bone. Although the MR experiment is less sensitive to 31P than to 1H, and 31P in bone has very short T2, it is still possible to obtain signal from 31P in bone and to image it with reasonable spatial resolution because 31P is present in relatively high (i.e. 4-5Molar) concentrations in the bone. This compares with 31P concentration of around 10mM for the metabolities ATP, PCr, Pi etc. the molecules conventionally observed with 31P (although these possess shorter T1’s and longer T2’s). All the work performed here has been on standard clinical hardware, with a novel pulse sequence. In this case the RF coil is optimised for cardiac imaging and, hence, is not optimised for bone imaging, so improvements in the RF coil would greatly improve this method.

References: