Fast Spatially Resolved Measurement of R2' and R2 of each component of Cancellous Bone Marrow and Correlation of R2' with Trabecular Bone Volume Fraction (BVF)

C. E. Jones[1], J. F. Magland[1], A. Techawiboonwong[1], F. W. Wehrli[1]

[1]Laboratory for Structural NMR Imaging, Department of Radiology, University of Pennsylvania Medical Center, Philadelphia, PA, United States

Introduction

The difference in magnetic susceptibility between bone and bone marrow causes local perturbations of the magnetic field in the marrow spaces of cancellous bone. These, in turn, cause broadening of the marrow proton resonances of each spectral component from R_2/π to $(R_2+R_2')/\pi$ (in Hz). Since R_2' increases with the density of trabeculae and their orientation relative to the polarizing field B_0[1] it has potential diagnostic value for diagnosing pathologies such as osteoporosis where trabecular architecture deviates from the architecture of healthy cancellous bone. Measurement of R_2^* can be ambiguous as R_2 depends on marrow composition[2]. Further, analysis in the time domain is confounded by the multiple resonances that cause a modulation of the signal decays. In this work we acquire spectra by mapping the evolution of the signal before and after a phase-reversal RF pulse using a multiple-interleave GESFIDE[3] sequence. However, in distinction to earlier work, we generate spectra as the Fourier transform of the descending and, and separately, the ascending portion of the signal. From the resulting linewidths in the two sets of spectra, R_2' can be computed. As a means to examine the effectiveness of the technique, the trabecular bone volume fraction (BVF) was measured from high-resolution anatomic images acquired with the FLASE[4] sequence, and correlated with R_2' measurements.

Methods

Both spectroscopic and high-resolution anatomic images were acquired with a custom-built dual phased-array coil, as sagittal slices of human radius and tibia specimens. Spectroscopic images were acquired with an interleaved GESFIDE[3] sequence, with the parameters: FOV = 72 × 54 mm^2, matrix = 64 × 48, slice thickness = 4 mm, pre-refocusing ETL = 16, post-refocusing ETL = 16, echo spacing = 6 ms, number of interleaves = 6, TR = 1 s. Echo time of the initial gradient echo was 4 ms and the echo time of the final gradient echo (which coincided with the spin echo) was 200 ms. The effective inter-echo time was 1 ms, resulting in a spectroscopic bandwidth of 1 kHz. Final voxel size after averaging 3x3 pixels was 3.375 × 3.375 × 4 mm^3. High-resolution anatomic images were acquired with a fast large-angle spin echo (FLASE)[4] sequence (matrix = 512 × 384 × 32 slices of 0.4 mm thickness, and 137x137 μm^2 in-plane pixel size, TR = 110 ms, acquisition time = 16 min). The center of the FLASE slab was chosen coplanar with the center of the GESFIDE slice. Only the 10 FLASE slices located within the volume of the GESFIDE slice were included in BVF calculations.

Data were processed in IDL (Research Systems Inc, Boulder, CO). On a pixel by pixel basis, the pre- and post-refocusing time domain data were separated and Fourier transformed (FT), the post-180º data being reversed and complex-conjugated prior to transformation. When the irreversible portion of the transverse relaxation rate (R_2) is less than the reversible portion (evolving as R_2') (a requirement verified experimentally for the dominant bone marrow component (Fig. 1)), the FT of post-refocusing pulse signal provides a spectrum of the bone marrow component whose linewidths are equal to $R_2^-/\pi = (R_2 - R_2')/\pi$. For each voxel of interest (VOI) R_2^* and R_2^- were calculated from spectra corresponding to the pre- and post-refocusing signals, respectively. The reversible transverse relaxation rate was then calculated as $R_2' = \frac{1}{2}(R_2^* - R_2^-)$.

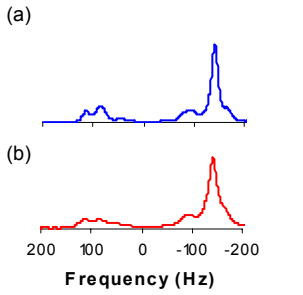

Fig. 1 R_2^* = R_2' + R_2 spectra obtained from FT of FID, from voxel corresponding to blue (a) and red (b) ROIs indicated in Fig. 3.

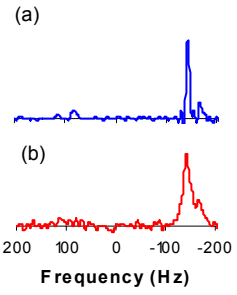

Fig. 2 R_2^- (= R_2' - R_2) spectra obtained by FT of post-refocusing time domain data (see Methods), from voxels corresponding to blue (a) and red (b) ROIs indicated in Fig. 3.

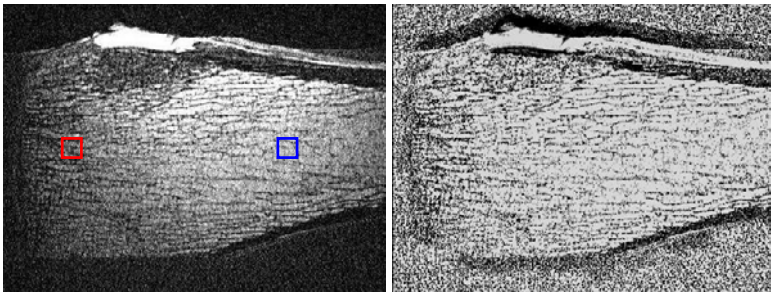

Fig. 3 3D high resolution sagittal image of a human tibia specimen, the red and blue ROIs correspond to the spectra shown in Figs. 1,2 (a); BVF map of the same slice (b).

Results and Discussion

The spectra shown in Figs. 1 and 2 correspond to the VOI indicated in Fig. 3 (red and blue squares). Clearly, the R_2^* spectrum corresponding to the blue ROI located in the metaphysis (Fig. 1a) is narrower than the spectrum corresponding to the red ROI in the distal epiphysis (Fig. 1b), reflecting less dense trabecular architechure at this location[5]. The R_2^- spectra (Fig. 2) are noticeably narrower than their R_2^* counterparts, consistent with the linewidth of the former being proportional to $R_2 - R_2'$, while the linewidth of the latter is proportional to R_2+R_2'. Notice also the absence of components in the R_2^- spectra (Fig. 2) that are present in the R_2^* spectra (Fig. 1), a consequence of their higher irreversible transverse relaxation rate. Fig. 4 displays a correlation between R_2' and BVF the human tibia bone showing the expected strong relationship between line broadening and trabecular density.

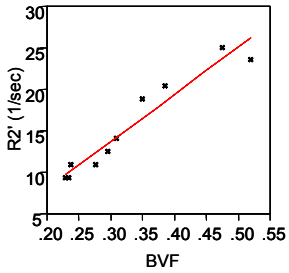

Fig. 4 R_2' versus BVF for a human tibia specimen (r^2=0.93, p=0.0001). Symbols represent values from 10 individual regions.

Conclusion

Cancellous bone marrow R_2' can be directly measured from GESFIDE spectra acquired in a 5 minute acquisition time under *in vivo* conditions. Spectroscopic R_2' mapping of cancellous bone may provide a time efficient alternative to high-resolution imaging for assessment of bone quality.

References: (1) Yablonskiy D, *MRM* 1997;214-221 (2) Ma J and Wehrli FW. *JMR B* 1996;111:161. (3) Ma J et al., *MRM B*1996;61:69. (4) Ma J et al., *MRM* 1996;903-10. (5) Majumdar M & Genant H, JMRI 1992: 209-219.

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