Decay from Diffusion in Internal Field (DDIF) and R2* contrast in Bovine Tibiae Samples at 3 T and 7 T

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Background

Trabecular bone (TB) demonstrates more rapid turnover and has greater import than cortical bone regarding risk of fragility fractures. While bone mineral density (BMD) predicts up to one half of fracture risk, structural properties are also important[1, 2]. Many MR techniques incorporate structure into fracture risk, including structurally-dependent contrasts[3-6] and direct microimaging[7, 8]. Recent work demonstrated a new structural contrast using the decay from diffusion in the internal field (DDIF)[9]. Studies both at low[10, 11] and high[12] resolution indicate that DDIF probes the projected surface-to-volume ratio along the applied field. The present study implemented this technique in clinical scanners (3 T and 7 T), tested its anisotropic sensitivity, and compared it with R2* contrast for in vitro bone samples.

Methods

Bovine tibiae core samples (6 mm diameter) were cleaned of their marrow, water saturated, and placed in 8 mm NMR tubes, separated by susceptibility plugs. The tubes were mounted in a holder with two axes of rotation for use in full body clinical scanners (Figure 1B); an 8 channel head coil and a CP head coil were used at 3 T and 7 T, respectively. A gradient echo (GRE) sequence (α = 25°, TR = 500 ms, 144x192x15 matrix,1.1 x 1.1 x 3 mm resolution) was used to collect images with R_2* contrast at echo times TE = (3.7, 5,10,15,20,25,30) ms at 3 T and TE = (3.7, 5,7,9,11,13,15) ms at 7 T. A stimulated-echo prepared single-shot BURST sequence (α = 20°, interpulse spacing TR = 30 ms, 96x128x15 matrix,1.7 x 1.7 x 3 mm resolution) was used to collect DDIF-encoded images at a series of 17 diffusion times 12 ms < Td < 1000 ms for a fixed encoding time te = 13.2 ms at 3 T and te = 9 ms at 7 T. These scans were performed for different orientations θ of the samples' axis with the applied field. ROIs enclosing each sample were used to calculate amplitudes for each sample and contrast level. Decay curves were analyzed with single exponential forms, and the resulting R2* and DDIF decay rates were tabulated for each sample and field angle. The yield stress (YS) of each sample, measured along the load-bearing axis in a previous study, parametrized the sample batch.

Results

Figure 1A shows example GRE and DDIF images at each field strength. Figure 1C shows the field dependence of R2* for two field angles; the fitted slopes (m = 2.31±0.03, m=2.24±0.02) confirm the expected R2* linear field scaling (7 T / 3 T = 2.33). Figures 1D,1E show the variation of the R2* and DDIF decay rates with yield stress at two field angles. Two regimes are evident: (1) a weak regime (YS< 6 MPa) of very porous and nearly isotropic bones, and (2) a strong regime (YS > 6 MPa) with negative strength correlation and larger anisotropy. These behaviors are also evident in the angle dependencies of the rates in Figures 1F and 1G, where the strongest bone (C) shows higher anisotropy than the intermediate strength sample (B). The DDIF results are qualitatively similar to the R2* behavior, with less overall quantitative contrast.

Discussion

The contrast behavior shown in Figure 1 is consistent with previous studies of this sample batch[11]. However, the expectation of the DDIF contrast was that it scales more exactly with surface-to-volume than R2*, due to the sharper variation of gradient fields. The SNR of the STE-BURST implementation is limited by the low flip angles in the single shot echo train required to avoid excessive blurring. This feature ultimately limits the spatial resolution and analysis complexity of the DDIF scan, as models beyond single exponentials were not supported by the data SNR. Future implementations will incorporate the DDIF contrast in a higher SNR sequence that is also compatible with musculoskeletal imaging, such as the turbo spin echo (TSE) sequence.

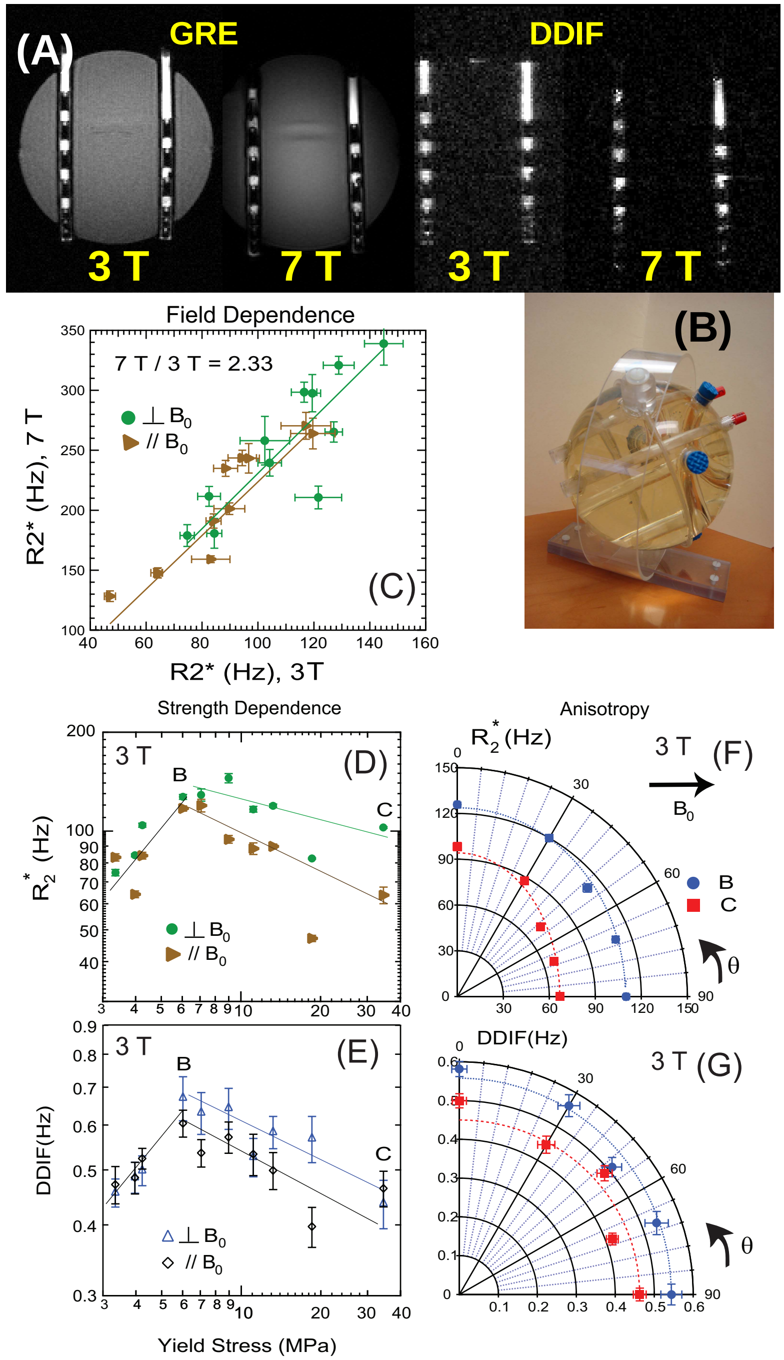

Figure 1: In vitro bovine tibiae MRI results. (A) Gradient echo (GRE) and Decay from diffusion in internal field (DDIF) images at 3 T and 7 T. (B) Sample holder with two rotation axes. (C) Field dependence of R2* for two orientations. (D,E) T2* and DDIF decay rates at 3 T as a function of sample mechanical yield stress. (F,G) Decay rates as a function of orientation at 3 T. Lines are guides to the eye. Both contrasts display sensitivity to scale and anisotropy features of the trabecular structure.

References

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