Performance of two spin-echo sequences for quantitative structure analysis of trabecular bone

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Introduction: The susceptibility difference between bone and bone marrow promotes the use of spin echo-based sequences for high resolution magnetic resonance imaging (μMRI) of trabecular bone (TB) [1], particularly for B_0>1.5T. At ultra high field strengths, specific absorption rate (SAR) limits for patient safety are breached by the fast large-angle spin-echo (FLASE) pulse sequence. Fast spin echo sequences, like fast spin-echo with out-of-slab cancellation (FSE-OSC) [2], offer the flexibility of reduced RF power via low refocusing flip angles with only minor penalty in SNR relative to a train of full 180° refocusing pulses [3,4]. FSE-OSC was developed to image TB microstructure within SAR limitations at 7T but has shown promise at lower fields strengths as well. Here, distal tibia specimens were scanned with FLASE and FSE-OSC pulse sequences at 1.5T to evaluate the pulse sequences' relative performance in terms of SNR efficiency and sensitivity to TB microstructure. TB structural parameters were computed and considered relative to those drawn from μCT images, a standard of reference.

Methods: Seven cadaveric distal tibia specimens, selected to provide a broad age range (55-83 years of age), were demarrowed using a water jet prior to imaging the central 10mm section at 25μm isotropic voxel on a Scanco μCT 80. Specimens were then fixed in 1 mM aqueous Gd-DTPA/10% formalin solution (T_1 =300 ms) and centrifuged to remove air bubbles and residual bone marrow. Each specimen was positioned within a two-channel phased-array ankle coil and consecutively imaged with FLASE and FSE-OSC sequences on a Siemens Sonata 1.5T scanner (Erlangen, Germany). A central 13 mm section from each specimen was acquired at a voxel size of 137x137x410 μm^3 with both pulse sequences and the following scan parameters: FLASE- TE/TR=11/80 ms, scan time=17 mins; FSE-OSC - τ/TR=20/500 ms, 8 shots/TR, scan time=19 mins.

SNR was measured at three locations within the doped water solution in the square-root sum-of-squares reconstructions and SNR efficiency computed as SNR/scan time$^{1/2}$. High resolution μCT data were downsampled to a 75 μm isotropic voxel size. A 20x20x5 mm^3 volume of TB was then extracted and bone volume fraction (BVF) mapped based on the bimodal intensity histogram. The same approximate regions of TB from the FLASE and FSE-OSC images were manually extracted and subjected to local thresholding to segment bone from marrow space [5], interpolation to a 69μm isotropic voxel, and contrast-inversion to create a BVF-map. BVF-maps from μCT and both μMR images were then subjected to digital topological analysis (DTA) [6] and fuzzy distance transform (FDT) [7] for the calculation of bone volume fraction (bone volume/tissue volume, BV/TV), surface-to-curve ratio (S/C – the ratio of plate-like to rod-like trabeculae), and trabecular thickness (Tb.Th).

Results and Conclusions: Measured SNR was comparable for the two sequences and FLASE achieved 10% higher SNR efficiency than FSE-OSC (0.56±0.15 versus 0.51±0.11). Trabeculae appeared thicker in FLASE images (Fig. 1b) relative to μCT (Fig. 1a) and FSE-OSC (Fig. 1c), the later attributed to the lower readout bandwidth in FLASE (±16 kHz vs. ±50 kHz for FSE-OSC) thereby causing greater signal attenuation of the higher spatial frequencies due to the longer readout time. FSE-OSC requires a greater readout bandwidth in order to acquire eight k_z encodings from a single echo-train considering the relatively short T_2 of fatty acid triglyceride protons. Shortened readout times also benefits image sharpness in the readout direction. Linear regressions (Fig. 2a & b) show BV/TV and S/C to be highly correlated between the two sequences (R^2 =0.98 and 0.99, respectively) and moderately for Tb.Th (R^2=0.78). Comparisons to μCT are summarized in Table 1. Whereas μMRI-derived parameters were strongly correlated with those obtained from the μCT images (R^2s of 0.72 to 0.93), slopes and intercepts varied widely. Specifically, μMRI overestimated BV/TV within the range of BV/TV detected although slopes were less than unity. μMRI-derived S/C was lower than that of μCT, likely due to the transition from surface voxels to curve voxels as the voxel size increases. The highest inter-modality agreement was relative to Tb.Th which had slopes of 1.3 (R^2=0.78) and 1.2 (R^2=0.93) for FLASE and FSE-OSC, respectively.

The data show excellent intra-modality agreement for both spin-echo-type pulse sequences. Even though the parameters were well correlated with those obtained by high-resolution μCT, there were large deviations in absolute values between modalities. The latter findings are similar to those reported by others [8].

References: [1] A. Techawiboonwong et al., *JMRI* 22, 647 (2005); [2] J. Magland et al., 17th ISMRM, Honolulu, 1948 (2009); [3] J. Hennig et al., *MRM* 49,527 (2003); [4] D. Alsop, *MRM* 37, 176 (2997); [5] B. Vasilic and F. Wehrli, *IEEE TMI* 24,1574 (2005); [6] B. Gomberg et al., *IEEE TMI* 19, 166 (2000); [7] P. Saha and F. Wehrli, *IEEE TMI* 23, 53 (2004); [8] Sell et al., *Calcif.Tissue Int.* 76, 355 (2005).

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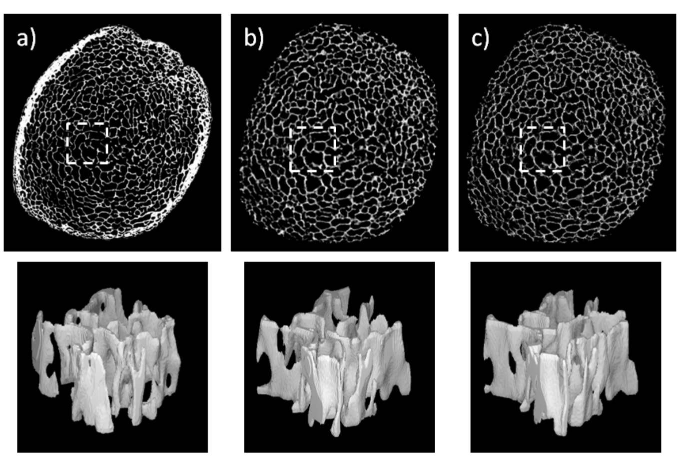

Fig. 1. BVF-maps of distal tibia specimens acquired using μCT (a), FLASE (b), and FSE-OSC (c). Surface-renderings of TB sub-regions show high degree of visual similarity among the three image datasets.

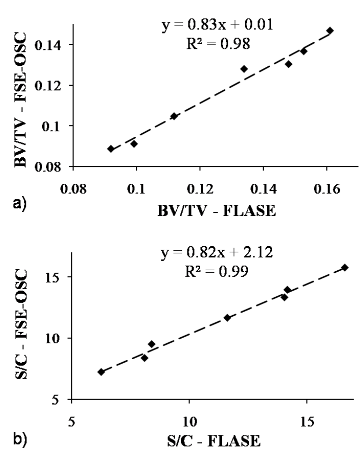

Fig. 2. Linear regressions of BV/TV (a) and S/C (b) between FLASE and FSE-OSC derived parameters. Tb.Th: y=0.79x+18.6, R^2=0.78 (not shown).

	Parameter	m	b	R^2
FLASE	BV/TV (%)	0.69	0.06	0.80**
	S/C	0.33	7.2	0.77**
	Tb.Th (μm)	1.3	-2.4	0.78**
FSE-OSC	BV/TV (%)	0.55	0.06	0.74*
	S/C	0.26	8.1	0.72*
	Tb.Th (μm)	1.2	-5.8	0.93***

Table 1. correlations between μMRI- and μCT-derived structural parameters (m=slope, b=intercept). *** p<0.001, ** p<0.01, * p<0.05.