Measurements of Inter- and Intravoxel Dephasing of Trabecular Bone at 7T Field Strength using a Chemical Shift-Selective Asymmetric Spin-Echo (Chase) Sequence

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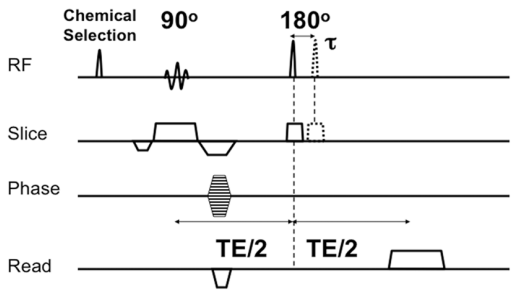
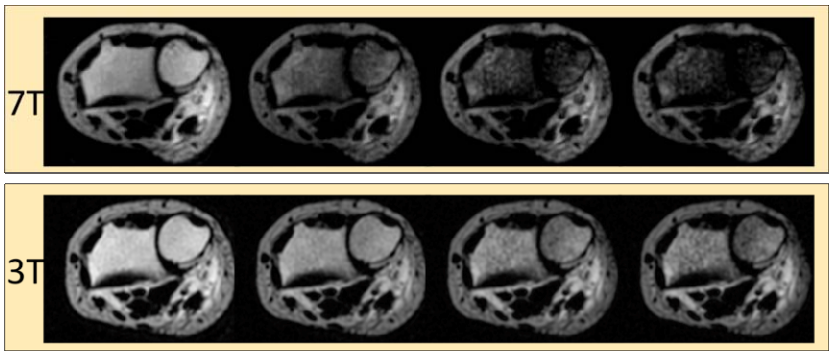
Introduction: Magnetic resonance imaging has increasingly become the method of choice to assess trabecular bone architecture *in vivo* non-invasively and without ionizing radiation to evaluate the progression of osteoporosis. This is commonly done by quantitative analysis of bone structural properties from high-resolution MR images. In this work, we hypothesized that measurements of inter- and intravoxel dephasing of the MR signal can provide information about the structural organization and topology of trabecular bone in addition to direct structural measurements. We studied these phenomenona using simulations, MR experiments at 7T and 3T as well as peripheral quantitative computed tomography (HR-pQCT) imaging. Due to differences in susceptibility between the more diamagnetic bone and the bone marrow interface, induced magnetism is generated leading to a variation of spin phases. This mechanism can be quantified as intervoxel dephasing (phase differences between the voxels) and intravoxel dephasing (T2* relaxation time measurements). Also, inter- and intravoxel phase measurements of trabecular bone have not yet been reported using high-field MRI (3T) and ultra high-field (UHF) MRI at 7T. In addition and in order to investigate the decay characteristics we simulated the T2* decay behavior of bone by using a magnetostatic model of trabecular bone (1). Furthermore, we measured the global magnetic field structure (B_0) within the region of interest (the trabecular bone) at both 7T and 3T field strength.

Theory: Trabecular structures with greater relative surface area (e.g. "rod-like") should exhibit increased inter- and intravoxel dephasing whereas structures with lower relative surface area (e.g. "plate-like") should exhibit decreased dephasing within a voxel. Intravoxel dephasing, leading to signal phase cancellation in the voxel, can be quantified by T2* relaxation measurements. Intervoxel dephasing can be characterized by the standard deviation of the phase image histogram.

Material and Methods: A Chemical Shift-Selective Asymmetric Spin-Echo (Chase) pulse sequence (2) was implemented at 7T and 3T. Using this sequence, the trabecular bone microstructure of the wrist was imaged in five intact human cadaveric arm specimens at both field strengths at spatial resolutions of 937µm and 625µm and 3mm slice thickness. For measurements of intervoxel dephasing a high-pass filter was applied to the unwrapped phase images (3) and standard deviations of the phases across the voxels were computed. A global magnetic field map was derived from the phase images. Regression analysis was used to investigate correlations between phase parameters and structural and topological measurements obtained from 3D HR-pQCT scans that were acquired at an isotropic voxel size of 41 µm. Additionally, we investigated the theoretical T2* decay behavior in trabecular bone at different field strengths based on a magnetostatic model of trabecular bone that simulates the susceptibility-induced inhomogeneities in a voxel comprised partly of bone and partly of bone marrow. The signal response of the CHASE sequence was simulated by numerical solution of the Bloch equation at each effective echo time TE and a decay curve was fitted to the simulated data points.



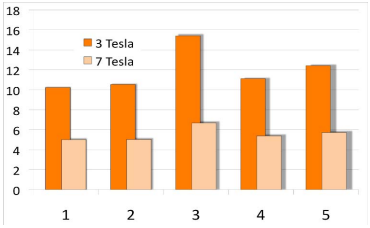
Pulse sequence diagram of CHASE



Representative images for T2* are shown acquired at effective echo times of TE_{eff}=2,4,6,8 ms

Results and Discussion: Highest correlations were found between the structure model index (SMI), a metric for topological classification and intravoxel phase measurements. Correlations with bone mineral density (BMD) as derived from HR-pQCT were also found to be high, while lower correlations were found for bone fraction and trabecular thickness at both field strengths. Correlations of T2* values between both field strengths were very high. Intervoxel phase variations were found to be less sensitive to structural and topological bone parameters. Absolute inter- and intravoxel dephasing was significantly enhanced at 7T and B_0 field inhomogeneities were more pronounced. From the simulations we found that a monoexponential decay function (4) is a valid assumption especially for the faster T2* decay in UHF-MRI. Our results indicated that intravoxel phase measurements of bone are well suited for UHF-MRI and correlate highly with topological and structural parameters as measured from HR-pQCT at high, isotropic resolution. The high correlations reflect a close relationship of T2* to bone structure and topology.

Conclusion: In summary, T2* has the ability to provide additional topological and structural information of bone architecture using UHF-MRI.



T2* [ms] values as measured from MRI at 7 Tesla and 3 Tesla field strength from 5 different radii.

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