Measurement of Trabecular Bone Quality In Vivo using Decay due to Diffusion in the Internal Field (DDIF) MRI

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Target Audience Musculoskeletal radiologists, Metabolic bone disease specialists, Diffusion MR specialists, MR physicists

Purpose The technique currently used to assess bone health is dual energy x-ray absorptiometry (DXA) [1], which assesses the bone mineral density (BMD). However, BMD is just one of several factors contributing to bone quality. The microstructural geometry of bone is another, very important, factor in determining bone strength. An MR technique that provides information on the microarchitecture of trabecular bone is Decay due to Diffusion in the Internal Field (DDIF) MRI, which extracts information about the porosity, surface-to-volume ratio and related parameters describing the internal geometry of a porous material [2, 3]. DDIF effectively reflects statistical measures of the trabecular microarchitecture, and resolving individual trabeculae in the image is therefore not required, reducing the need for high spatial resolution. In a recent clinical study DDIF MR readily detected age-related changes in trabecular bone of the lumbar spine [4]. The current work was aimed at forging an enhanced understanding of the relationship between the DDIF decay time and BMD assessed by DXA. The DDIF technique was applied in the lumbar spine of healthy controls and patients with anorexia nervosa and compared to BMD measurements obtained using DXA measurements.

Methods *Study population* The study population consisted of healthy controls (male and female, age 18-45y, ideal body weight of 90-130%) and anorexia nervosa patients (female, 18-45y, ideal body weight less than 85%). All subjects could not be pregnant or breastfeeding, not be on hormones, not have a history of diabetes and any disease known to affect bone metabolism or take any medication known to affect bone metabolism. *MRI data* Pulse sequences sensitive to the DDIF effect are based on the STimulated Echo (STE) sequence, which consists of a series of three successive 90° radiofrequency pulses. The DDIF technique involves the acquisition of a stimulated echo for a range of diffusion (mixing) times TM and records the MR signal decay as a function of TM. A spectroscopic DDIF sequence was designed so as to select the STE signal while minimizing the dephasing effects of the gradients [4]. Patients were placed supine, head first in a 3T MR scanner (Siemens) and scanned using a dedicated spine coil. A volume of interest (VOI, 15x15x15 mm^3) was positioned in the lumbar spine. DDIF MRS scan parameters: TE = 15 msec; BW = 3000 Hz, TM = 20, 50, 100, 200, 400, 800 msec, TR = 2500 msec, total scan time 2 min 33 sec. The water and fat peak areas of all DDIF spectra were determined using a Lorentzian/Gaussian curve fitting tool (MATLAB peakfit.m). The DDIF decay time T_{DDIF} of the water was found by a monoexponential fit to the normalized signal decay over TM using: $S = a_1 + a_2 e^{-\frac{t}{T_{DDIF}}}$. The bone marrow fat percentages were calculated from the DDIF spectrum with the shortest TM (20 ms) by dividing the area of the fat peak by the sum of the areas of the water and fat peaks. *DXA for BMD* Lumbar spine areal BMD was measured from a PA lumbar spine (L1–L4) in all subjects using DXA (Hologic Discovery A densitometer, Hologic Inc). T-scores were calculated from the BMD values and subjects were divided into two groups based on the T-score: normal bone quality (T-score > -1) and osteopenic/osteoporotic bone (T-score < -1).

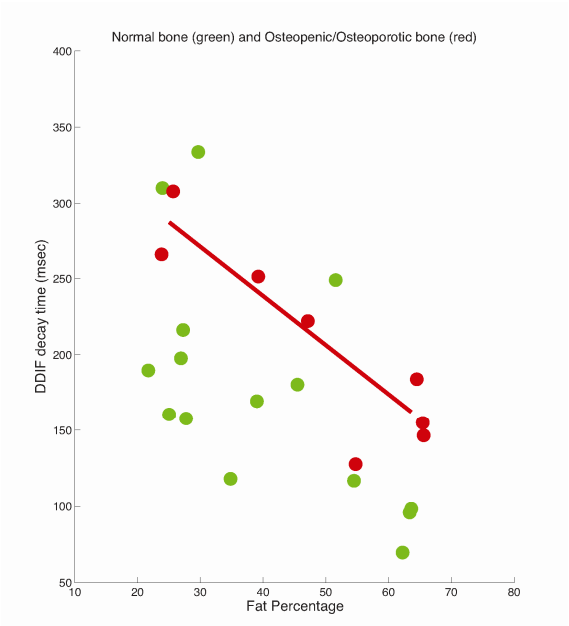

Figure 1. DDIF decay times versus bone marrow fat percentage for normal bone (T-score > -1; green) and osteopenic/osteoporotic bone (T-score < -1; red).

Results DDIF decay times are plotted against bone marrow fat percentage and color coded by their bone quality in Fig. 1. The decreasing trend of DDIF decay times with increasing fat percentage is expected based on the influence of fat magnetic susceptibility on the field distribution in the pore spaces [4]. The group with osteopenic/osteoporotic bone (shown in red) are related to longer DDIF decay times, as is expected in trabecular bone with enlarged pore spaces [4]. In the healthy bone group (shown in green) a similar trend is clear, however, a larger variability in DDIF decay times is observed.

Discussion & Conclusion The data shows that for the osteopenic/osteoporotic group, DDIF decay follows the expected relation with bone marrow fat percentage and are overall longer, an indication of large pore sizes. Most of the healthy bones exhibit a DDIF decay time which is significantly lower than that of the osteoporotic/osteopenic patients, consistent with the diagnostics made based on BMD. Furthermore, the larger variability in DDIF times for normal healthy bone shows the variation of pore size among the individual that is not fully accounted for by BMD. Continuing study with a larger healthy/osteoporosis population is currently ongoing to validate the observation.

References 1. Genant, H.K., et al., Osteoporos Int, 1999.10(4): 259-64. **2**. Song, Y.-Q., Concepts in Magnetic Resonance Part A, 2003.18A(2):97-110. **3.** Song, Y.-Q., et al., Nature, 2000. 406(6792):178-181. **4.** Sprinkhuizen S.M. et al. Influence of Bone Marrow Composition on Measurements of Trabecular Microstructure using Decay due to Diffusion in the Internal Field (DDIF) MRI: Simulations and Clinical Studies Magn Reson Med. 2013 (in press) **Support** Schlumberger-Doll Research, Martinos Center for Biomedical Imaging, NIH grant P41EB015896, NIH grant R24 DK084970