Potential Diagnostic Role of the MRI-Derived Internal Magnetic Field Gradient in Calcaneus Cancellous Bone for Evaluating Postmenopausal Osteoporosis at 3T
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Target audience: Translational researchers interested in noninvasive assessment of bone quality

Purpose: Even though bone mineral density (BMD) has been the accepted standard for osteoporosis diagnosis, BMD has a low predictive value on patients’ risk for future fractures. Thus, new approaches for examining patients at risk for developing osteoporosis would be desirable. Magnetic Resonance (MR) T2* measurements have been shown to yield quantitative information on trabecular-bone density as well as on bone micro-architecture. T2* probes trabecular-bone microstructure by virtue of its sensitivity to magnetic susceptibility differences (ΔX) between bone and marrow. Therefore, an increase in inter-trabecular space, which typically occurs in osteoporosis, prolongs T2*. A new potential surrogate marker for osteoporosis, the internal magnetic field gradient (IMFG), has recently been proposed. In cancellous bone, the susceptibility mismatch between the solid matrix and interstitial liquid marrow generates internal gradients at the interface between bone and marrow. It has recently been shown that water IMFG measured in cancellous bone axially is strongly associated with trabecular-bone density. Furthermore, preliminary data obtained in vivo from the human calcaneus at 3T indicate a progressive reduction of IMFG with age, suggesting IMFG to parallel the physiological reduction of trabecular-bone density.

Here, we assessed the potential of the effective IMFG to evaluate cancellous bone quality in the calcaneus of postmenopausal women. Toward this goal we examined the calcaneus of healthy, osteopenic and osteoporotic subjects at 3T, as classified by quantitative computed tomography (QCT) BMD, by measuring IMFG at various calcaneal sites and assessing associations between BMD and T2*.

Methods: Model: The cancellous bone model used here is based on recent evidence from experiments done in vivo indicating that the water component in cancellous bone-marrow is prevalent in the boundary zone of the pores, while fat is mainly occupies the central intertrabecular space. An estimate of IMFG can be obtained from the spin-echo (SE) signal by quantifying the additional decay of the echo amplitude due to diffusion of water in local magnetic field gradients (Fig.1). The local magnetic field gradient obtained in this manner is a function of temporal averaging governed by the water dynamics confined to the interface between fatty marrow and bone. Imaging Protocol: MR relaxation and diffusion-weighted MR imaging (DWI) of the heel was performed in fifty-five women (mean age, 62.9±6.6 years) at 3T. The study protocol was approved by the local Ethics Committee. QCT of the L1-L3 vertebral segments was performed. The subjects were classified into three groups according to BMD: healthy (n=8); osteopenic (n=25); and osteoporotic (n=22). A fat-suppressed multi-contrast spin-echo (MCSE) sequence (TR/TE=15000/30-40-50-80-100 ms; FOV=192x192 mm2; matrix, 256x256; BW=130 Hz/pixel; NS=1) was used to obtain the SE decay from which the IMFG was extracted. To minimize the number of fitting parameters of the function:

\[ (S(TE) = S(0) - \Delta S)[1 - \frac{1}{2}(\frac{T2*}{TE})^{4}] - \frac{1}{2}(\frac{T2*}{ADC})^{4}] \]

(where S(0) is the signal intensity at TE=0, T2* is the spin-spin relaxation time, apparent diffusion coefficient (ADC) was evaluated from DWI images acquired in a single sagittal section of the calcaneus. A spin-echo segmented echo-planar imaging (EPI) sequence (TR/TE=15000/86 ms; FOV=192x192 mm2; matrix, 128x128; BW=1954 Hz/pixel; epi factor, 7; diffusion sensitization along the anterior-posterior direction) at two different b-values (b=0 and 8000 sec/mm2) was run (20). T2* was obtained with a FLASH sequence (TR/TE=1500/5-7-10-20 ms; flip angle, 30°; FOV=192x192 mm2; matrix, 128x128; BW=260 Hz/pixel; NS=1). In all subjects, BMD T-scores, T2* and IMFG were assessed in the whole calcaneus (CALCA) as well as in calcaneal subregions: subtalar (ST), tuber calcaneus (TC), and cavoos calcaneus (CC). Between-group comparisons to assess group differences and Pearson correlation analysis were performed.

Results: An example of the fitting procedure used to compute IMFG from the SE decay as a function of time is displayed in Fig. 1. IMFG in the ST region was found to be greatest in healthy, intermediate in osteopenic, and lowest in osteoporotic subjects (Table 1). IMFG values were significantly lower in osteoporotics and more so in osteoporotics, paralleling T-scores for the ST region but not for all other regions examined (Fig.2). IMFG was significantly different between healthy and osteoporotic subjects in the TC, CC, and CALCA regions, but between osteopenics and osteoporotics for the CALCA region only. Furthermore, preliminary data obtained in vivo from the human calcaneus at 3T indicate a progressive reduction of IMFG with age, suggesting IMFG to parallel the physiological reduction of trabecular-bone density.

Conclusion: BMD provides limited information on the two key properties that determine cancellous bone strength: bone’s material composition and microstructural rearrangement. In contrast, IMFG reflects changes in both bone microarchitecture and composition that occur in osteoporosis. Our preliminary results suggests the ability of IMFG evaluated in the ST region to discriminate healthy subjects from those with osteopenia and osteoporosis. Therefore, IMFG in the calcaneus obtained in large populations might allow establishment of a threshold on a single subject basis to determine whether intervention is indicated. Reference: Kanis JA. Diagnosis of osteoporosis and assessment of fracture risk. Lancet 2002;359:1929-1936.