MRI Characterization of Trabecular Bone Structure by Exploring Bone Microscopic Susceptibility Effect

S. C. Cheung[1], J. Yang[1], S. K. Hui[1], E. X. Wu[1,2]

[1]Dept. of Electrical & Electronic Engineering, The University of Hong Kong, Pokfulam, Hong Kong, [2]The Jockey Club MRI Centre, The University of Hong Kong, Pokfulam, Hong Kong

Introduction

It is well known that MRI may provide information on trabecular bone structure as well as trabecular bone density. Two major methods are quantitative magnetic resonance (QMR) and high resolution magnetic resonance imaging (HR-MRI). QMR measures the relaxation times T2, T2* of bone marrow to assess the inhomogeneities in trabecular bone structure while HR-MRI directly look at the 2D or 3D trabecular bone network with high spatial resolution. The former method can be performed using standard imaging techniques on conventional MR systems with relatively short time while the latter method requires very long scan time. In this study we hypothesize that trabecular bone structure or distribution can serve as an endogenous contrast agent whose effect is expected more prominent at high field. The aim of this study is to extract bone structural information from various MRI measurements.

Methods

The complex trabecular bone structure can be considered as an endogenous contrast agent (CA). It causes microscopic magnetic field perturbation and alters the apparent relaxation properties in bone tissue. Previous simulation and experimental studies have characterized such susceptibility effects in various scenarios, such as randomly distributed microvascular structure or spheres with susceptibility difference $\Delta\chi$ for mechanistic study of fMRI and exogenous contrast agents [1]. The influence of this susceptibility effect on R2* and R2 depends not only on the concentration or volume fraction occupied by the contrasting structures, but also on their structural parameters, as well as MRI acquisition sequence types and parameters. For example, Boxerman et al. show that for a given concentration of CA, the larger the size of the CA, the higher the R2'(≡ R2* - R2) (see Fig. 1 [1]). Note that the plateau saturation in R2* curve here can be modified by amount of intravoxel dephasing or voxel size selection. These relationships have been utilized to determine structural parameters related to microvasculature, i.e., microvessel density and size [2,3].

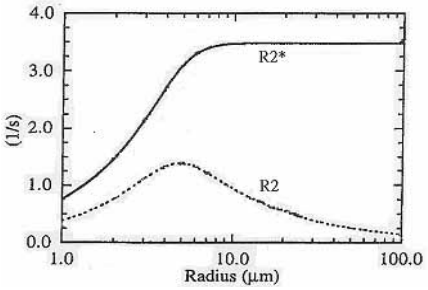

Fig.1 R2* and R2 vs. geometric size of the susceptibility contrasting medium assuming the constant volume fraction occupied by the contrasting medium [1].

In this preliminary study, data was collected at 3T Philips scanner in the calcanei of two healthy men (age of 21 and 34). Calcaneus was chosen because of its heterogeneity of trabecular bone structure. R2* maps were computed from dual-echo GE images at TE=2.4/4.8 ms with TR=300 ms, flip angle=70° and NSA=4 on a pixel-by-pixel basis. R2 maps were computed by dual-echo SE images at TE=15/50 ms with TR=300 ms, NSA=6. Proton-density weighted images with TR=2000ms, TE=10ms, NSA=1 were acquired for the absolute calculation of bone volume fraction (BVF). That is, BVF = 1 – MVF = 1 – (A/A_o) where MVF is the marrow volume fraction, A is the signal amplitude from a trabecular marrow voxel and A_o is the signal amplitude from a reference voxel. All images were acquired with FOV=128 mm, data matrix=128X128, number of slices=8, slice thickness=2.5 mm and were smoothed by a 5X5 averaging window before computing the relaxation maps. Total scan time for these 3 acquisitions was ~15 minutes. R2'' maps (defined as R2'' ≡ R2' / BVF) were computed. Because R2" is a measure of susceptibility effect exhibited per unit of BVF, it may reflect and correlate with the size (or coarseness) of the bone structures. High-resolution 3DGE images (0.25 X 0.25 X 1.25 mm^3) were also acquired at the same slice locations for structural visualization.

Results

The mean values of R2, R2* and R2' of calcanei measured in the 2 subjects are 28.6±0.4 s^{-1}, 170.6±3.4 s^{-1} and 142.0±3.3 s^{-1} respectively. They are substantially higher than those reported for 1.5 T (17.5 s^{-1}, 87.7 s^{-1}, and 70 s^{-1}, respectively [5]). Fig. 3 shows the correlation between measured R2' and BVF in various ROIs with calcaneus (10 circular ROIs with radius of 30 pixels in different regions of calcaneus on each slices, total 60 ROIs). The significant linear correlation was found between R2' and BVF. This is consistent with Boxerman theory [1], stating that the relaxation effect is approximately proportional to the CA concentration. Table 1 compares the mean values of R2' and R2'' computed from three different calcaneus regions to the μCT and histomorphometric measurements of calcaneus structural parameters by others [4]. Reasonable correlation was found between R2' and BMD, R2" and trabecular thickness (Tb. Th).

Discussion

The preliminary data suggests the potential of MRI to examine not only the bone volume fraction but also bone structural information. However, the MRI measurement paradigm remains to be refined by fully characterizing the contrast mechanisms (possibly through simulation studies) and validations by μCT measurement. Study is underway to compare the measurements by such MRI paradigm with those by μCT in bone samples, and results will be reported.

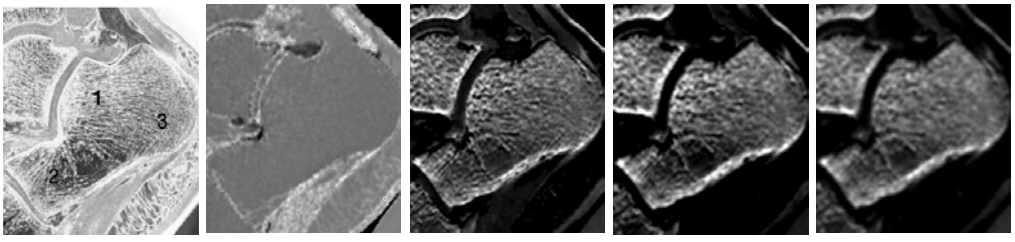

Fig.2 Left to right: Inverted HR image, R2, R2*, R2' and R2'' map of calcaneus.

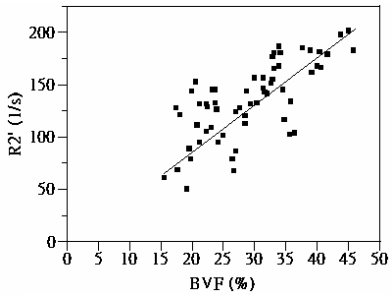

Fig.3 R2' vs. BVF (r^2=051,p<0.001).

	Subtalar Region 1	Cavum Region 2	Tuber Region 3
R2' (s^{-1})	170.7±5.8	93.0±3.3	150.0±3.3
BMD(gm/cm^2)[4]	0.87	0.55	0.68
R2'' (s^{-1})	251.5±6.2	155.0±6.0	178.7±4.8
Tb.Th (mm)[4]	0.26	0.21	0.19

Table 1 Mean value of R2', BMD, R2'', Tb. Th in three different regions of calcaneus (marked in HR image in Fig. 2).

References [**1**] Boxerman JL et al. MR Contrast due to Intravascular Magnetic Susceptibility Perturbations. *MRM*. 1995;34:555-566. [**2**] Jensen JH et al. MR imaging of microvasculature. *MRM*. 2000;44:224-230. [**3**] Tropres I et al. Vessel size imaging. *MRM*. 2001;45:397-408. [**4**] Lin JC et al. Heterogeneity of Trabecular Bone Structure in the Calcaneus Using Magnetic Resonance Imaging. *Osteoporosis Int*. 1998;8:16-24. [**5**] Kang C., et al. In Vivo MRI Measurements of Bone Quality in the Calcaneus: A Comparison with DXA and Ultrasound. *Osteoporosis Int*. 1999;9:65-74.