
● Short Communication

TRABECULAR BONE CHARACTERIZATION WITH LOW-FIELD MRI

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Multiple-echo (ME) T_2 measurements were performed in vitro at 0.1 T on a series of human trabecular bone samples filled with water and compared to site-matched bone density measurements. Multiple-echo T_2 is strongly correlated to bone density and allows distinction between samples of equivalent bone density. Multiple-echo T_2 is also dependent on the trabecular orientation with respect to the direction of the main field. © 1998 Elsevier Science Inc.

Keywords: Low-field magnetic resonance imaging; Multiple-echo T_2 ; Trabecular bone.

INTRODUCTION

Trabecular bone is a porous structure made up of bone rods and plates and saturated by bone marrow. Its biomechanical strength is dependent on bone mineral density (BMD) as well as on bone microstructure. Both are altered in case of osteoporosis¹ which increases the risk of atraumatic fractures. At present, clinical diagnosis by x-ray absorptiometry evaluates BMD but gives no information about microstructure. However, no significant difference in BMD but different microstructure were observed between two groups of postmenopausal women with and without fractures.² Some authors^{3–5} have found a relationship between T_2^* and bone density at 1.5 T, but at low field we do not observe this dependence. However, global multiple-echo T_2 (ME- T_2) is qualitatively correlated to the bone microstructure, as observed in a previous study.⁶ We examine the possibilities of bone characterization in vitro using ME imaging at low field.

MATERIALS AND METHODS

Quantitative computed tomography (QCT) and nuclear magnetic resonance (NMR) experiments were performed on 15 human bone samples from which marrow was removed and replaced by water. The samples are 1-cm-thick sagittal slices cut from calcaneus. QCT im-

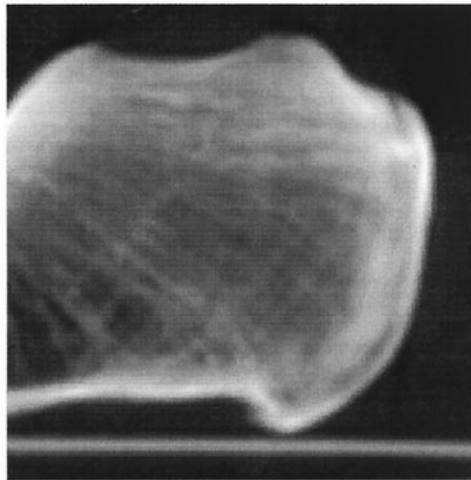
ages were used as a reference measurement of BMD. NMR images were obtained on a 0.1 T whole-body scanner. The XY-4 sequence (ME sequence with π pulses of alternate phases) was chosen for its ability to derive quantitatively significant T_2 maps without any spoiler gradients.⁷ The inter- π -pulse delay TE was 200 ms. The ME- T_2 was calculated using a monoexponential fit of the first 10 echo amplitudes. NMR images were acquired for two different orientations of the samples in the magnet. The ME- T_2 s and BMDs were averaged on site-matched 9-mm² regions of interest (ROIs), and correlation between the two parameters was calculated using a standard least square method.

RESULTS

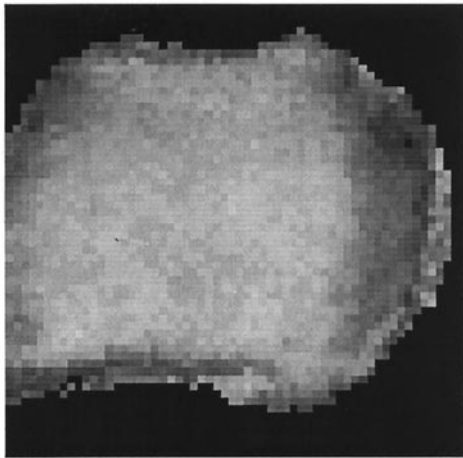
An example of QCT and NMR images obtained on the same sample is shown in Fig. 1. Figure 2 shows experimental measurements and regression lines for four samples. A strong linear negative correlation exists between ME- T_2 and BMD for each sample (the correlation coefficients R lie between 0.749 and 0.937, with a mean value of 0.837). The regression lines corresponding to different samples are not superimposed; this means that at equivalent BMD, ME- T_2 allows a distinction between samples. Moreover, ME- T_2 is shorter when trabeculae

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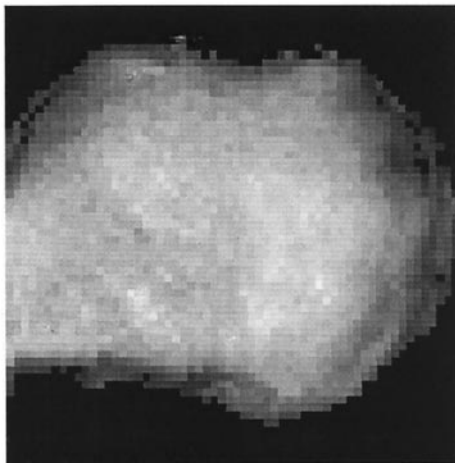
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(A)



(B)



(C)

Fig. 1. Images obtained on the same bone sample by QCT (A) and NMR:XME- T_2 image (B) and equilibrium magnetization image (C). The in-plane resolution is $256\ \mu\text{m}$ for QCT images and $1\ \text{mm}$ for NMR images. In the NMR images, the contrast is reversed compared to the QCT image.

are perpendicular to the direction of the main magnetic field $\vec{B}_0$, in the posterior region of the calcaneus (Fig. 3).

DISCUSSION

In regions of high trabecular density, the static magnetic field inside the bone tissue is less homogeneous due to the magnetic susceptibility difference between bone and water. Local field gradients cause phase shift between protons, and so ME- T_2 decreases when bone density increases. Moreover, ME- T_2 is dependent on the amount of local field gradients, explaining why different samples of equivalent BMD can be distinguished by their ME- T_2 values.

The equivalent surface charge density σ accumulated at the interfaces between bone and water is given by Eq. (1):⁸

$$\sigma = \Delta\chi \times \vec{B}_0 \cdot \vec{n}, \quad (1)$$

where $\Delta\chi_{\vec{n}}$ is the susceptibility difference between the two media, and $\vec{n}$ is the normal to the interface. Thus, when trabecular orientation is perpendicular to $\vec{B}_0$, the magnetic field inside the tissue is less homogeneous, and ME- T_2 is shorter. This effect has been quantitatively simulated on model systems.⁹

CONCLUSIONS

Our results show that ME- T_2 measured in vitro at low field is representative of bone density and is also dependent on the trabecular microstructure. Indeed, ME- T_2 allows distinction between different bone samples that have the same BMD and depends on trabecular orientation with respect to the main field B_0 . In vivo experiments on the calcaneus are now in progress to evaluate bone strength by ME- T_2 .

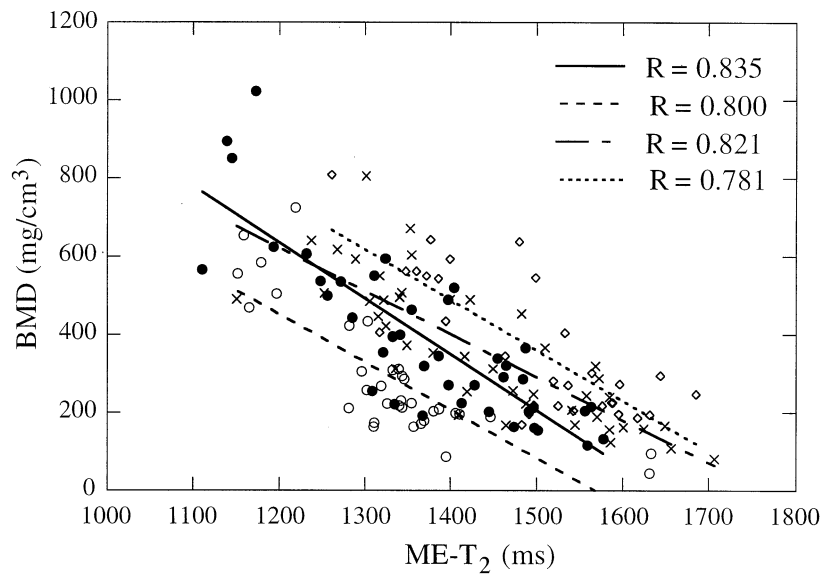


Fig. 2. Correlation between ME- T_2 and BMD for four samples. The regression lines shown were calculated separately for each sample, with the corresponding correlation coefficients R .

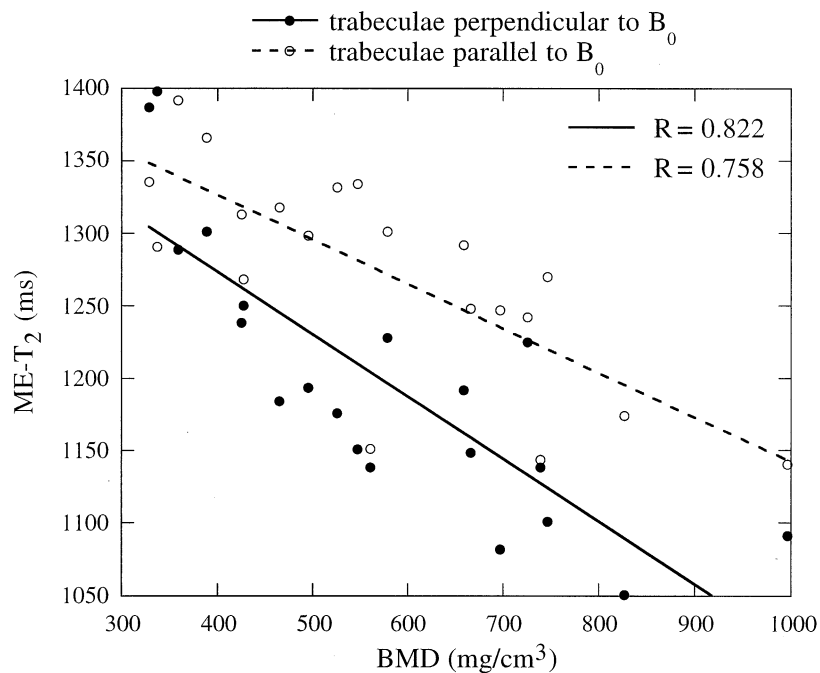


Fig. 3. ME- T_2 vs. BMD for two different orientations of the same sample in the magnet. The data shown were taken from the same regions of interest in the posterior region.

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