Estimation of spinal bone density using conventional MRI

Comparison between MRI and DXA in 32 subjects

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We evaluated the usefulness of MRI T1 and T2 relaxation times in assessing bone mineral status. T1 and T2 relaxation times of L3 were measured in 16 pairs of identical twins (24 men, 8 women), aged 25–69 years. Bone mineral density (BMD), bone mineral content (BMC) and apparent volumetric bone mineral density (BMDvol) of L3 were measured from the same subjects using dual x-ray absorptiometry (DXA).

T2 relaxation time correlated inversely with BMD and BMC (r –0.40 and r –0.47, respectively), whereas a significant positive correlation between T1 relaxation time and BMDvol was found (r 0.36). The measurement of T1 may give some information on bone mineral status in clinical MRI measurements when DXA is not available. It is possible that T1 and T2 reflect not only bone density, but also other factors related to bone structure.

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Dual x-ray absorptiometry (DXA) is a precise method for measuring axial bone mineral density (BMD). Recent prospective studies suggest that there is a significant inverse relationship between BMD and fracture risk (Black et al. 1992, Cummings et al 1993, Kröger et al. 1995). In addition to BMD, bone microarchitecture (bone quality) and trauma are related to fracture pathogenesis. Conventional densitometry techniques provide no information on bone quality, however.

Recently, the value of MRI in assessing osteoporosis has been studied. Several reports suggest that MRI may produce information about trabecular structure and bone quality (Wehrli et al. 1991, Ito et al. 1993). As part of a larger project investigating spinal bone density among twins, T1 and T2 relaxation times were measured to evaluate the usefulness of conventional MRI of vertebral bodies in assessing bone mineral status.

Patients and methods

16 pairs of identical twins (24 men, 8 women), aged 25–69 years, were selected for the study (Table 1). The study was approved by the Ethics Committee of Kuopio University Hospital, and subjects gave their informed consent.

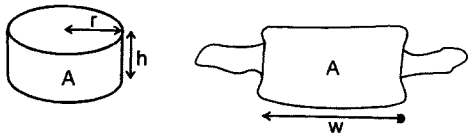
DXA (Lunar DPX, Lunar Radiation Corporation, Madison, WI) was used for measurement of bone mineral density (BMD, g/cm^2), bone mineral content (BMC, g) and the projected area of lumbar vertebrae L3. The precision of the method was 0.9% for spine measurements (Kröger et al. 1992a). In order to reduce the influence of bone size, we have previously developed a method for calculating apparent volumetric bone mineral density (BMDvol) (Kröger et al. 1992b) (Figure 1).

Initially, MRI investigations of the lumbar spine were done to evaluate disc degeneration. MR imaging was performed with a whole-body system operating at 1.5 T (Siemens Magnetom 63SP, Erlangen, Germany) by using a standard oval spine coil placed

Table 1. Characteristics of study subjects and the results of DXA and MRI measurements of vertebrae L 3. Mean *SD*

	Men (n 24)		Women (n 8)	
Age	48	*12*	42	*4*
Weight, kg	78	*11*	64	*17*
Height, cm	175	*5*	160	*7*
BMI (kg/m^2)	25.3	*3.1*	24.9	*4.8*
BMD (g/m^2)	1.173	*0.163*	1.153	*0.150*
BMDvol (g/cm^3)	0.328	*0.036*	0.381	*0.037*
T1 (ms)	600	*76*	784	*132*
T2 (ms)	43.2	*2.6*	47.1	*3.5*

Figure 1. The model for calculation of volumetric bone mineral density (BMDvol).



The lumbar body was hypothesized to have a cylindrical shape and the volume of the cylinder and BMDvol were calculated as follows:

Volume = $\pi \cdot r^2 \cdot h = \pi \cdot (width/2)^2 \cdot (area/width)$

Thus, BMDvol = BMC/volume = BMD • [4/(π • width)

where width (W) = mean width of vertebral body
area (A) = mean area of vertebral body.

Table 2. Correlations between DXA and MRI (T1 and T2) data of L3 vertebrae

	T1	T2
BMC	–0.23	–0.47**
BMD	0.01	–0.40*
BMDvol	0.36*	–0.04
Age	–0.28	–0.07
Height	–0.56***	–0.59***
Weight	–0.50**	–0.43*
BMI	–0.29	–0.17

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

under the lumbar region. Lumbar vertebrae were imaged in two orientations. T1-weighted spin-echo images at the repetition time (TR) of 650 ms and echo time (TE) of 22 ms were taken in the sagittal plane. Two double spin-echo sequences with the repetition time of 2600 ms and echo times of 22 and 90 ms yielded T2-weighted and proton density-weighted (ρ) images in sagittal and axial planes. The field of view was 260 mm and the matrix size 256 × 256. Slice thickness was 4 mm in all sequences. The functional dependence of signal intensity on the tissue parameters in the spin-echo image was modeled by

$$S = \rho \cdot [1 - e^{(-TR/T1)}] \cdot e^{(-TE/T2)}$$

T1 relaxation time of vertebral body L3 was calculated by using the equation

$$S = 1 - e^{(-TR/T1)}$$

A region of interest was manually drawn inside the vertebral body in two images with different TR and the mean signal intensity was determined. T1 relaxation time was solved from the above equation by using a table. T2 relaxation times were calculated by obtaining signal intensities from two images with different echo times (22 and 90 ms) and solving the equation

$$S = e^{(-TE/T2)}$$

Statistics

Linear regression analysis was used to determine the relations between continuous variables. Results were regarded as significant if $p < 0.05$.

Results

T2 relaxation time correlated inversely with BMD and BMC, whereas a positive correlation between T1 relaxation time and BMDvol were found (Table 2). However, the standard errors of estimate (SEE%) for the regression equations were relatively high (e.g., between T1 and BMDvol 12%; between T2 and BMD 13%). Both relaxation time parameters were inversely related to body size variables (Table 2).

Discussion

MRI evaluation of bone is mainly dependent on the signal characteristics of bone marrow tissue. Differences in magnetic susceptibility of trabecular bone and bone marrow produce distorsions in the magnetic lines of force. These effects are manifested as a decrease in signal intensity in gradient echo MR images (Wehrli 1993). Recently, significantly prolonged true transverse relaxation time (T2*) relative to normals has been found in osteoporotic patients (Wehrli et al. 1991). Significant correlations have been found between T2* and bone density measured by QCT (Majumdar et al. 1991), and experimental data suggest that T2* provides information on trabecular architecture (Ford et al. 1993). Unfortunately, T2* was not measured in the present study.

In our study, T1 relaxation time decreased with age, but the decrease did not reach significance, possibly owing to the small sample size. A decrease in T1 relaxation time with age may be due to a corresponding replacement of trabeculae and red marrow by fatty tissue in the vertebral bodies (Laval-Jeantet et al. 1986). T1 relaxation time has been shown to decrease with increasing fat concentration (Ito et al. 1993). Jenkins et al. (1989) studied vertebral bodies of 66 patients with degenerative disc-disease (aged 14–70 years) and could not find significant age- or sex-related T1 or T2 relaxation time changes in vertebral bodies. However, large variations in relaxation times, even within age and sex groups, were detected.

An inverse correlation between MRI relaxation

times and body weight contrasts with the positive correlation found between BMD and body weight (Kröger et al. 1992a).

BMC and BMD correlated inversely with T2. Thus, a high T2 relaxation time of bone tissue indicates a low BMC and BMD. However, T2 may rather reflect bone size than true bone density, since no correlation between BMDvol and T2 was found. In fact, T2 is unaffected by magnetic field inhomogeneities, and is not expected to be a probe for trabecular microarchitecture either. In contrast, T1 relaxation time correlated more strongly with BMDvol. Our results agree with the study by Ito et al. (1993), who examined excised human vertebrae using MRI and found a good correlation between T1 relaxation time and BMD measured by QCT.

Although the correlation between T1 relaxation time and BMDvol was significant, the standard error of estimate (SEE%) was relatively large (12%). T1 reflected better volumetric or true bone mineral density than T2. The detected correlation may reflect marrow fat content, which is inversely related to bone content in osteoporosis. Although the prediction of bone mineral density using conventional MRI data is not sufficiently good, the measurement of T1 may give some information about bone mineral status in clinical MRI measurements, when DXA is not available.

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