Bone Marrow Fat Content in Osteoporosis: Evaluation with Localized Proton MR Spectroscopy

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BACKGROUND

Osteoporosis is a metabolic bone disease characterized by low bone mineral density (BMD) and micro-architectural fragility of bone tissue, with a resultant increased susceptibility to fracture. The risk of fracture increases with age and as such, the magnitude of health problems associated with osteoporosis is expected to increase as the average world's population ages. Dual energy x-ray absorptiometry (DXA) and quantitative CT (QCT) are accepted methods of assessment for osteoporosis. The development of alternative or complementary assessment methods based on magnetic resonance may be important not only because they involve no ionizing radiation but also, because they could potentially provide additional information currently not obtainable by means of DXA or QCT.

OBJECTIVES

In vitro (1) and recent in vivo (2,3) studies have shown that there is a direct relationship between age and vertebral bone marrow fat content. Osteoporosis has also been shown to be associated with increased fat content in the bone marrow (4) but it is still unclear whether the observed increase in fat content is related to the normal aging process or is associated with bone weakening (2,3). The purpose of this study was to use proton MR spectroscopy to measure differences in vertebral bone marrow fat content in elderly subjects with normal and reduced BMD.

MATERIALS AND METHODS

Forty-six consecutive women above 60 years old with documented BMD measured by DXA (T-score) were examined with localized ^{1}H MR spectroscopy at 1.5 T on a whole-body MRI system (Gyroscan ACS-NT, Philips, Best, the Netherlands). All subjects were free from vertebral fractures, metabolic disease or bone tumors. A 20-cm diameter circular surface coil centered at the third lumbar vertebra (L3) spine was used to optimize sensitivity. Conventional scout MR images along the axial, coronal and sagittal planes were acquired to locate the L3 vertebral body and to guide the positioning of a volume of interest (VOI) in the center of the vertebral body. The width (w), length (l) and height (h) of the vertebral body were first measured on MR images and the VOI dimensions for each subject was given by $w/2 \times l/2 \times h/2$ mm^3. After local shimming and gradient adjustments, 64 non-water suppressed signals were acquired using a PRESS sequence (TR/TE 3,000/25 msec).

The averaged spectra were analyzed using magnetic resonance user interface (MRUI) in the time domain (5). As starting values in the non-linear least squares fitting algorithm, manually selected resonance frequency and linewidth of water (4.65 ppm) and fat (1.3 ppm) peaks were used. Prior knowledge incorporated into the fitting procedure consisted of the following: linewidth of water equal to that of fat; zero and first-order phase correction estimated by AMARES were fixed to zero; the resonance relative phase was also set to zero; and a Lorentzian model function was assumed. The calculated water (I_{water}) and fat (I_{fat}) amplitudes were used to determine fat content expressed as relative fat signal intensity in percentage of total signal intensity ($I_{fat}/(I_{fat} + I_{water}) \times 100$ [%]). A scatter plot of fat content against T-score was obtained and the correlation between the two measurements was evaluated using Spearman's correlation test. The mean fat content between subjects with normal BMD (T-score $\geq$ -1) and reduced BMD (osteopenia (T-score < -1 and > -2.5); osteoporosis (T-score $\leq$ -2.5); severe osteoporosis (T-score < -2.5 with pre-existing fractures)) were compared using the Student's t-test. The differences were considered significant when P values were less than 0.05.

RESULTS

There were 14 subjects with normal BMD (mean age, 69 years) and 32 subjects (13 osteopenia, 14 osteoporosis and 5 severe osteoporosis) with reduced BMD (mean age, 70 years). A typical ^{1}H MR spectrum from a vertebral body with osteoporosis (T-score –3.1) is shown in Fig. 1. The correlation coefficient between fat content and T-score was – 0.34 (P = 0.02), implying an increasing bone marrow fat content with reducing BMD (Fig. 2). The mean fat content for the group with normal BMD was 59.7 ± 10.6 % and the group with reduced BMD was 68.8 ± 9.7 (Fig. 3). The difference between these two means was significant (P = 0.007).
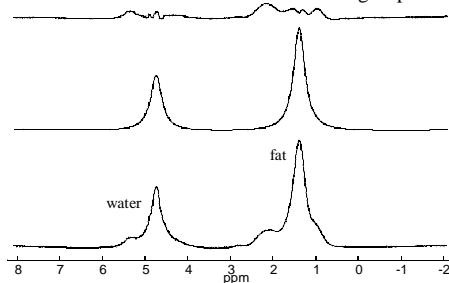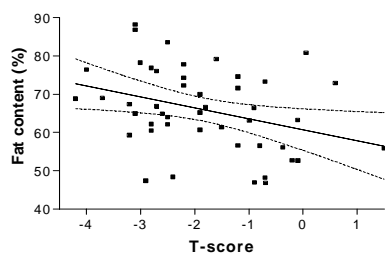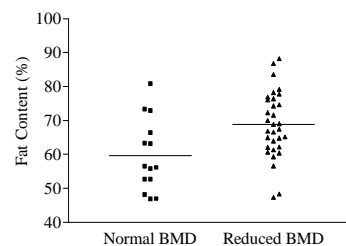

Fig.1

Fig.2

Fig.3

DISCUSSION

A recent report based on small number of subjects (N=11) was unable to find any relationship between DXA and bone marrow fat content (4). Our results showed that there was an inverse relationship between T-scores and bone marrow fat content (Fig.2). In addition, we found a significantly higher mean fat content among subjects with reduced BMD than those with normal BMD (Fig.3). Age was unlikely to be a confounding factor of our results since all our subjects were of the same age group. Our results for subjects with normal BMD (59.7%) were in good agreement with reported figures (53.8%) for females $\geq$ 61 years (2). The higher fat content found among subjects with reduced BMD (68.8%) may reflect an abnormally high fatty marrow accumulation within vertebral bone marrow. In other words, as trabecular bone volume diminishes because of osteoporosis, the amount of marrow fat correspondingly increases.

CONCLUSION

Fat marrow content as measured by localized ^{1}H MR spectroscopy could not only demonstrate that there is an accumulation of fatty marrow among elderly subjects but also that those with reduced BMD have a significantly higher degree of fatty marrow accumulation. Proton spectroscopy does correlate with DXA findings. Additional information provided by ^{1}H MR spectroscopy may be useful to complement DXA, may enable in vivo study of the physiological changes associated with bone weakening and may be useful for longitudinal population-based analysis following therapeutic intervention for osteoporosis.

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