A Review of the Recent Advances in Magnetic Resonance Imaging in the Assessment of Osteoporosis

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Abstract. Osteoporosis is a common metabolic disorder with considerable associated morbidity and mortality. The loss of bone mineral integrity and the resultant occurrence of atraumatic fractures are typically symptomatic of the disease. Currently skeletal status is commonly assessed using non-invasive conventional radiography and scintigraphy as well as densitometric techniques such as quantitative computed tomography and dual-energy X-ray absorptiometry. But, apart from gross bone mineral density, the fine structure of trabecular bone also plays an important role in defining the biomechanical competence of the skeleton. Recently attention has been focused on deriving measures that provide information not only about trabecular bone density but also microstructure. Magnetic resonance imaging (MRI) is one such new technique which potentially may provide information pertaining to bone density and structure as well as to occult fracture detection. Cortical bone produces a signal void in MR images, due to the fact that it contains very few mobile protons that give rise to a signal in MRI; also the MR relaxation time T2 of these protons is very short which produces a very fast decay of the MR signal during image acquisition. However, the trabecular bone network affects the MR properties of bone marrow. The difference in the magnetic properties of trabecular bone and bone marrow generates local imperfections in the magnetic field. The MR signal from bone marrow is modified due to these imperfections and the MR relaxation time T2* of marrow is shortened. The extent of relaxation time shortening and hence loss of signal intensity is proportional to the density of trabecular bone and marrow interfaces and their spatial architecture. Recent investigation in this area include studies aimed at quantifying marrow relaxation times and establishing their relationship to trabecular bone density and structure. In addition, with advances in imaging software and hardware, MR images at in-plane resolutions of 78–200 μm may be obtained. The trabecular bone structure is clearly revealed in such images and studies aimed at the development of high-resolution MRI techniques combined with quantitative image analysis techniques are currently under way. These potentially useful techniques for assessing osteoporosis and predicting fracture risk are reviewed in this paper.

Keywords: High resolution; Magnetic resonance; Microscopy; Osteoporosis assessment; Relaxation times; T2*; Trabecular structure

Introduction

Osteoporosis is a condition in which there is a deterioration in bone quality and quantity, and is characterized by the occurrence of atraumatic fractures. It is a major public health concern, contributing considerably to the socioeconomic costs in western countries [1–3].

Currently skeletal status is assessed non-invasively using conventional radiography, scintigraphy and computed tomography (CT), and the risk of osteoporotic fractures is assessed using bone densitometry techniques such as quantitative computed tomography (QCT) and dual-energy X-ray absorptiometry (DXA). It is also recognized that, apart from decreases in bone density, changes in the trabecular bone network, i.e. the thickness and spacing of the trabeculae, their connectivity and spatial geometry, are also important con-
sequences of osteoporosis. Recent research has thus been focused not only on techniques that provide information pertaining to gross structural status and trabecular bone density but also on methods that provide some measure of trabecular microarchitecture. Magnetic resonance imaging (MRI) is one such technique that is currently being used clinically to detect subtle osteoporotic fractures, and may potentially be used to measure trabecular bone density and quantify trabecular structure and hence to predict the risk of fracture occurrence.

Clinical Applications of MRI in Osteoporotic Fracture Assessment

Image intensity in MR images results from a complex interaction of several factors such as tissue relaxation times, the chemical environment and diffusion. Consequently, the signal intensity of MR images reflects characteristic tissue properties that provide unique diagnostic capabilities for the non-invasive evaluation of the musculoskeletal system, including assessment of compositional changes in the bone marrow and structural changes in osseous tissue. These qualitative applications of MRI are currently widely used and are having an impact on the clinical management of patients with osteoporosis.

Clinical fracture assessment using MR images is being applied in diagnostic radiology. Occult traumatic fractures or subtle atraumatic insufficiency fractures are common occurrences in the elderly osteoporotic population, and conventional radiographs are sometimes unrevealing while radionuclide bone scanning shows improved sensitivity but poor specificity. Axial imaging with CT provides improved specificity but only modest sensitivity for assessing occult fractures. Several authors [4-6] have documented an accuracy level approaching 100% for MRI in the detection of occult fractures of the proximal femur including the transcervical (Fig. 1) and intertrochanteric (Fig. 2) sites. MRI provides improved sensitivity and specificity compared with bone scintigraphy, particularly in the first several days following non-displaced hip fractures when scintigrams may be negative [6,7]. MRI characteristically demonstrates irregular linear signal alteration at the fracture site, typically low signal on T1-weighted images with adjacent high signal of normal fatty marrow, and high signal on T2-weighted images contrasted with low signal of adjacent marrow (Fig. 2). These MR signal changes reflect the focal hyperemic and reparative processes, as well as condensation of trabeculae and callus formation.

Fig. 1a, b. Occult femoral neck fracture demonstrated on T1-weighted coronal (a) and axial (b) images.

Fig. 2a, b. Subtle incomplete inter-trochanteric fracture demonstrated on coronal T1-weighted (a) and T2-weighted (b) scans.