

Simultaneous fat, water and T2* mapping of trabecular bone and comparison with high resolution MRI in the hip

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Introduction: Destruction of trabecular bone can result from osteoporosis or infiltrative processes such as malignancy or infection, and is difficult to detect using conventional imaging techniques. The standard methodology for quantifying bone loss in osteoporosis is dual-energy X-ray absorptiometry (DXA), but this suffers from several limitations. As a projection technique, its accuracy is affected by bone size, cortical thickness and soft tissue composition. Furthermore, since it provides minimal spatial resolution, it cannot be used in the diagnosis of infiltrative disorders. The purpose of this study was to compare two novel MRI approaches for regional assessment of trabecular bone in the hip, which is one of the primary sites of fracture risk. The first is a high resolution technique [1] that provides detailed visualization of trabecular microarchitecture but requires long scan times. The second is a multiple gradient echo technique with simultaneous mapping of T2* and fat/water ratio. T2* is sensitive to trabecular density since the magnetic susceptibility of mineralized bone differs from that of marrow [2]. The latter approach offers the benefit of relatively short scan times and simultaneous quantification of fat content. This could potentially allow discrimination of osteoporosis from early malignancy, since trabeculae lost through osteoporosis are usually replaced by fat, while those destroyed by malignant processes are replaced by neoplastic cells.

Methods: Thirty patients (29F/1M, aged 22 – 89 years) with osteoporosis or osteopenia as determined by DXA were prospectively included. All provided informed consent to participate. High resolution imaging was performed unilaterally over the proximal femur at 3T (Skyra, Siemens) using a standard body phased array coil wrapped around the hip. An imaging slab was prescribed in an oblique sagittal plane aligned with the femoral neck. Data were acquired using a 3D gradient echo sequence with an echo time TE = 4.92ms chosen to satisfy the second in-phase condition. Spatial resolution was 0.24mm x 0.24mm in plane, and 1.5mm in the slice direction. Other parameters included: FOV = 124mm x 124mm, 60 slices, BW = 200 Hz/pix, 100% phase oversampling, FA = 25° and TR = 37ms, giving an acquisition time of 29min 43sec. Parallel imaging was applied in 6 of the exams, which shortened the acquisition time to 15min 16 sec but reduced SNR. Simultaneous fat, water and T2* mapping was conducted at 1.5T (Aera, Siemens) during a separate visit, with a time interval not exceeding two months. A 3D multiple gradient echo sequence was applied bilaterally over both proximal femora in an axial imaging slab with isotropic 1.8 x 1.8 x 1.8mm³ spatial resolution. 12 echoes were collected with monopolar readout gradients, minimum TE = 1.85ms and echo spacing = 1.99ms, over an acquisition time of 6min 21sec. Other parameters included: FOV = 400mm x 225mm, 72 slices, receiver BW = 890 Hz/pix, TR = 42ms and FA = 18°. This FA was chosen as a compromise between maximizing SNR and minimizing T1 weighting. Maps of fat, water and T2* were generated by performing a pixel-by-pixel fit of the complex-valued image data as a function of echo time. The model used for the fitting procedure assumed a single relaxation rate R2* (= 1/T2*) for water and lipid components within the same voxel, and incorporated a 10-peak spectrum for marrow fat [3]. The fat fraction was calculated as (fat signal)/(fat + water signals). This ignores the effect of slight T1 weighting in the signal, which will introduce a small positive bias into all the estimates of fat fraction. The 3D maps were reformatted in the plane of the high resolution images to facilitate visual comparison between T2* and trabecular structure. Trabecular paucity in the region of greatest bone loss was graded on a 4-point scale by a board-certified radiologist who was blinded to the patient's identity and the T2* results. Spearman's rank correlation coefficient was used to compare trabecular paucity with T2* values.

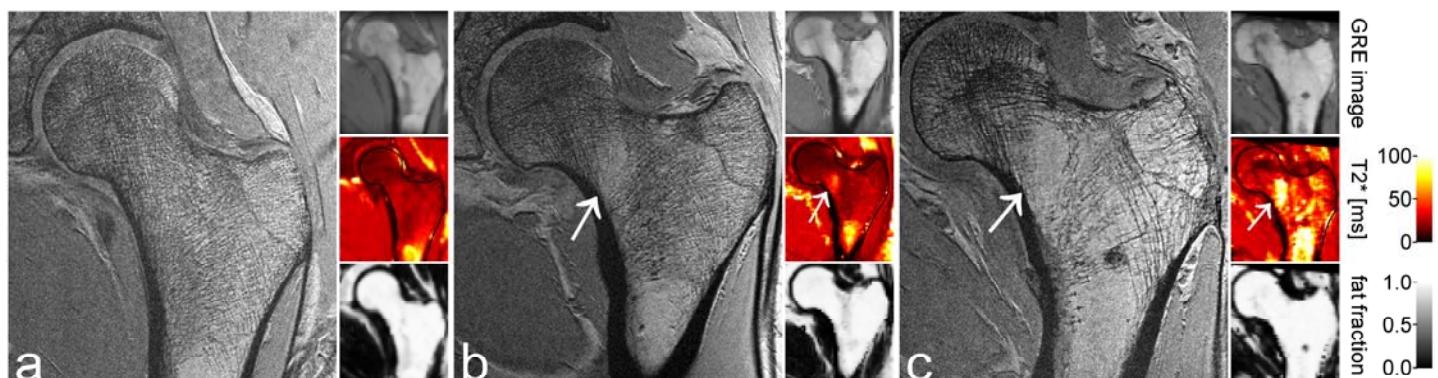


Fig. 1: Comparison between high-resolution images and results of simultaneous fat, water and T2* mapping in (a) a patient with no apparent microarchitectural deterioration, (b) a patient with focal trabecular destruction and (c) a patient with advanced bone loss. The insets show the first image from the multiple gradient echo acquisition (TE = 1.85ms) as well as maps of T2* and fat fraction, all of which have been reformatted in the plane of the high resolution images.

Results: 29 patients completed both MRI scans. 28 subjects underwent high resolution imaging of a single hip, while one person had high resolution exams of both hips. A total of 30 hips were therefore assessed. Image quality in 7 of the high resolution exams was compromised by low SNR or motion. Visual comparison of the T2* maps and high-resolution images revealed close anatomical agreement between regions of high T2* and areas of low trabecular density. Figure 1 shows examples in three patients. In all cases, T2* is high in the femoral shaft, which is devoid of trabeculae. By contrast, T2* is low in the presence of normal trabecular microarchitecture (Fig. 1a). T2* is locally elevated in regions of focal trabecular destruction (Fig. 1b, arrow) and greatly increased in cases of severe bone loss (Fig. 1c). Over all 30 hips, T2* was positively correlated with trabecular paucity as assessed from the high resolution images (Fig. 2). There was considerable overlap in T2* values among patients with different severity scores, but the correlation was highly significant ($r = 0.64$, $p = 0.00014$).

Discussion: The close anatomical agreement between the distribution of elevated T2* values and the pattern of trabecular loss suggests that T2* is sensitive to regional variations in trabecular structure. Although T2* mapping does not provide the microarchitectural detail offered by high resolution imaging, it can be performed in a fraction of the scan time and is less sensitive to motion and low SNR. The overlap in T2* values among patients with different trabecular paucity scores may be due in part to poor image quality in 7 of the high resolution exams and in part to the comparatively large slice thickness of the high resolution images, which could have reduced visibility of the trabeculae in some patients. Further validation of the T2* technique against micro-MRI with isotropic resolution [2] would address this issue. Other future work includes application of these techniques to different pathologies, such as multiple myeloma and osseous carcinomatosis.

References: [1] Chang G, JMRI 2013 [2] Wehrli FW, NMR Biomed. 2006;19:731 [3] Ren J, J Lipid Res. 2008;49:2055

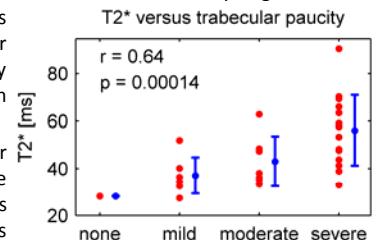


Fig. 2: Correlation over all patients between T2* and trabecular paucity as graded from the high resolution images in the region of greatest bone loss. Bars represent mean \pm standard deviation.