Mapping Bone Marrow Composition in the Lumbar Spine at 3.0 Tesla

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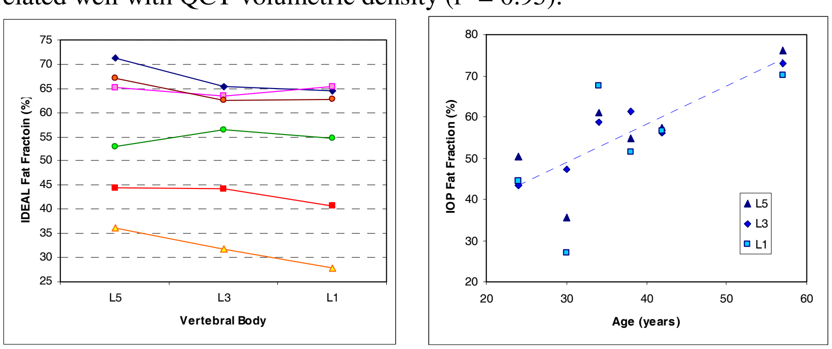
Introduction: Bone marrow consists of both red and yellow components, the proportions of which are thought to be related to the remodelling capacity of bone with implications for osteoporosis and the late effects of cancer treatment. Previous work has used MR Spectroscopy (MRS) to infer yellow:red content from fat fraction measurements and shown marrow differences due to age, gender, skeletal site and bone pathology [1,2]. Fat fraction (FF) has also been examined with respect to bone density although results appear inconclusive [3]. If fat fraction is to be utilised as a clinical parameter its relationship with bone density must be understood and measurements obtained at high spatial resolution. The purpose of this study was two fold: first, to compare two quantitative fat mapping techniques in normal subjects to assess whether differences seen with MRS could be reproduced with imaging. Secondly, porcine spines were imaged with both MRI and quantitative CT (QCT) to examine the relationship between FF and volumetric density.

Materials & Methods: All examinations were performed on a 3.0 Tesla whole-body GE Signa system (HDx) using a CTL phased array or extremity coil. Six subjects aged between 24 and 57 years were imaged using two different techniques for fat measurement. The first method utilised in and out-of-phase imaging (IOP) following a methodology previously used in the liver [4]. The IOP acquisition used two FGRE sequences with TE either in (2.1 ms) or out (3.2 ms) of phase and flip angles of 20° and 70° to identify the dominant component. Secondly, fat content was assessed using the proprietary IDEAL pulse sequence using TE/TR = 60/3000 ms [5]. Slice thickness/gap was 3/1 mm with an in-plane resolution of 0.9 × 1.3 mm. Software was written (MATLAB) to produce pixel-by-pixel maps of FF in each case to quantify vertebral body composition (VB). A Bland-Altman plot was used to evaluate the differences between the two techniques. Age and vertebral body differences were also assessed, the latter examining VBs at L1, L3 and L5, which have been most commonly investigated. In a parallel study, three porcine spines (6, 18 and 30 months old) were also examined with QCT and MRI to compare volumetric density and FF values. Water/oil test-tubes were placed in situ to use as an MRI signal reference and MR-derived density calculated from the proton-density weighted signal intensity (SI) ratio between VB regions and the reference. Bone volume fraction (BVF) was then inferred from this marrow fraction as $1\text{-}SI_{marrow}/SI_{ref}$.

Results: The IOP and IDEAL fat methods produced values that were statistically similar (mean difference -3.3%, $p = 0.116$). Mean FF values in the vertebral bodies were as follows (%): L5: 56.0 ± 13.3, L3: 56.6 ± 10.6, L1: 52.9 ± 15.9 (IOP) and L5: 56.2 ± 14.0, L3: 54.0 ± 13.3, L1: 52.7 ± 15.2 (IDEAL, shown in Figure 1). In 4/6 subjects fat fraction was greater in L5 compared to L1. However, inter-vertebral body differences were not statistically significant using either imaging technique. IOP showed significant age ($p = 0.001$) and sex ($p = 0.017$) variations in values at L3 and borderline significant age variation at L5 (also shown in Figure 1). In the porcine spines (Figure 2), FF values demonstrated a trend L5 > L1 and no correlation with QCT values. The dynamic range, expressed as coefficient of variance, was significantly higher for FF (26%) than density (11%). MR-derived BVF from total marrow fraction correlated well with QCT volumetric density ($r^2 = 0.95$).



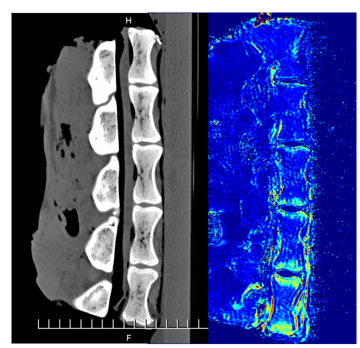


Figure 1: (left) FF data acquired in normal VBs for both imaging methods. Figure 2: (right) Example QCT image and FF map in a porcine lumbar spine showing significant variation in FF but little change in density between vertebra.

Discussion: Results suggest that the mapping methods investigated are not biased with respect to one another. The IOP method has reproduced significant age and sex related variations that had only previously been established using spectroscopy. Neither method was able to confirm inter-vertebral variations although clear trends with IDEAL were evident; this could be due to the low number of subjects compared to previous MRS data. In the porcine spine, bone density showed a weak negative trend with fat fraction. BVF derived from total marrow fraction correlated well with QCT density and could prove a valuable MRI surrogate for density in the spine. FF appears to provide additional information, possibly predicting future density changes due to remodelling capacity rather than absolute density. We believe that high resolution fat mapping may be of clinical benefit and further studies are warranted.

References: *[1] F Schick et al. Magn. Reson. Med. 1992; 26:207-217, [2] GP Liney et al. J Magn Reson Imag 2007;26:787-293, [3] D Schellinger et al. AJR,2004;183:1761-1765 [4] HK Hussain et al. Radiology 2005;237:1048, [5] SB Reeder et al . J Magn Reson Imag 2006;24:825-832.*