Density, Structure and Texture Quantitation of Bone Trabeculae at 3.0 Tesla

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Introduction: Previous studies have established that bone strength is a multi-factorial parameter depending both on bone density and architecture. Currently, the gold standard for determining bone mineral density is either aerial measurements from dual energy absorptiometry (DEXA) or volumetric measurements from quantitative computer tomography (QCT). However, MRI offers advantages in terms of lack of ionising radiation and the ability to examine both trabecular structure [1] and marrow composition [2]. If MRI is to be used clinically to provide a density measure, its concordance with QCT must be established. Furthermore, architectural and structural variation will inherently depend on resolution and contrast, making the choice of clinical protocols a crucially important factor. This study examines bone volume fraction (BVF) obtained from MRI and compares these data to volumetric density measurements from QCT images. Secondly, the relationship between bone structural and textural parameters was investigated in a bovine sample for various sequences and protocols using three different RF coils typically used in extremity imaging. The optimised imaging scheme was then adopted in preliminary in vivo imaging of the wrist.

Materials & Methods: All examinations were performed on a 3.0 Tesla whole-body GE Signa system (HDx). Three RF coils routinely used in extremity studies were assessed: (i) a small diameter general-purpose flexible coil (GP), (ii) a quadrature knee/ankle coil (QK), and (iii) a dedicated wrist-only coil (WR). BVF was examined for various sequences (including SE, FIESTA) and imaging protocols using signal-averages between 2 and 6 in each RF coil. In each case scan time was restricted to clinically suitable times and ranged from 4 to 14 minutes. Spatial resolution ranged from 0.12 to 0.31 mm. To determine BVF, software was developed to process and analyse the MR images. This was initially tested using four stereolithographic (STL) phantoms which had been manufactured from micro-CT data (University of Wales, Cardiff) and had known volume fractions varying from 0.09 to 0.26. These were immersed and de-gassed in water/oil emulsion to simulate in vivo images. Bovine samples were subsequently investigated with MRI and density-calibrated CT scans (Philips Brilliance). Image processing included using Otsu's histogram segmentation algorithm to binarise the image (giving an effectiveness metric, $0 < \mathrm{EM} < 1$) and skeletonised to one pixel width. Structural parameters of trabecular thickness (Tb.Th), number (Tb.N) and spacing (Tb.Sp) were calculated using the plate model prior to skeletonisation [3]. Textural parameters were also computed from the gray level co-occurrence matrix (GLCM), calculated from the original images having first been reduced to 32 grey levels. An average of four orientations was recorded for each parameter. These included the commonly used indices of angular second moment (f1), contrast (f2), correlation (f3), and inverse difference moment (f5) [4]. The software also permitted an examination of the effects of step-wise image decimation on each parameter. Additionally, synthetic images were produced to investigate the behaviour of textural measures in a standardised manner. Finally, preliminary data from normal subjects were collected using the optimum coil and imaging protocol combination.

Results: For the STL phantoms, the BVF algorithm was in good agreement with known values ($r^2 = 0.99$). In studies of bovine specimen, BVF varied from 0.06 to 0.29 and corresponding volumetric density varied from 97 to 309 g/cm^3. BVF demonstrated a sequence and protocol dependence on the correlation of this data with volumetric density. To summarise: data acquired with the WR coil provided consistently higher correlations with density and in shorter examination times ($r^2 = 0.93$, $p = 0.002$). BVF from QK coil required 6 averages to achieve the same significance ($p = 0.002$). Data obtained with the GP coil correlated less well irrespective of protocol ($p < 0.03$). Images acquired with the best FIESTA data did not represent density as effectively ($r^2 = 0.77$, $p = 0.021$). In textural analysis, the WR coil demonstrated correlations between BVF, Tb.N and Tb.Sp with f2, f3, and f5. However, data with other coils showed correlations with f3 only and protocol dependence (e.g. $0.75 < r^2 < 0.49$ for GP). Tb.N and Tb.Sp correlated with texture better than BVF. Tb.Th did not correlate with any texture parameter in any case. FIESTA images showed significantly better correlations with f3 than spin-echo images. Image decimation resulted in larger changes in BVF (40%) than the other structural measures studied (18-26%). In-vivo wrist data using the optimum protocol showed significant correlation between BVF (0.12 to 0.24) and f3.

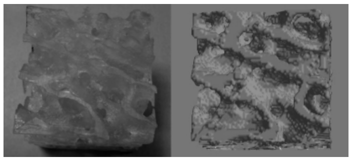
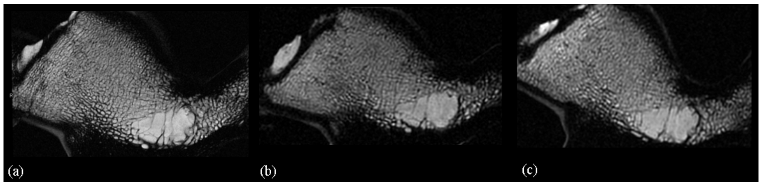


Figure 1: (left) Photograph and 3D reconstruction of an STL phantom used to test the BVF algorithm.
Figure 2: (below left) Example bovine images acquired in (a) WR, (b) QK and (c) GP extremity coils.



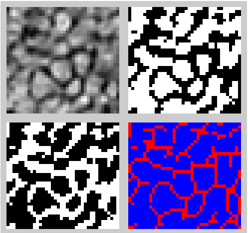


Figure 3: (above left) Processing steps from ROI selection to production of the final trabecular map in red/blue. (EM = 0.76)
Figure 4: (above right) In vivo wrist image optimised for BVF.

Discussion: MR-derived BVF may be used as a surrogate measure of volumetric bone density in each of the coils studied when an optimised protocol is adopted. Furthermore, certain textural and structural measures demonstrated correlations that were dependent on specific imaging protocols. The FIESTA sequence appears more suited to textural rather than structural quantitation. Certain structural parameters (Tb.N and Tb.S) seem to provide additional information to BVF and are more resilient to resolution variation. This data has been used to optimise our wrist imaging, and preliminary work shows important structural/textural characteristics in vivo. In future we intend to examine these parameters in a longitudinal clinical study.

References: [1] FW Wehrli, Journal of Bone and Mineral Research 2001;16:1520, [2] GP Liney et al. J Magn Reson Imag 2007;26:787-293, [3] A Parfitt et al. Journal of Bone and Mineral Research 1987;2:595-610, [4] RM Haralick et al. IEEE Trans Syst Man Cybern SMC 1973;3:610-621.