Quantification of Bone Marrow Types from High-Resolution MR Images in the Proximal Femur using Three Class Clustering

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Introduction

The proximal femur is an anatomical site associated with high prevalence of osteoporotic fractures with high rates of morbidity and mortality. MRI has emerged as one of the leading *in vivo* methods for non-invasive imaging of the trabecular bone microstructure at peripheral sites. Recent improvements in image acquisition and processing technologies enables high resolution (HR) image analysis *in vivo* of deep seated regions such as the proximal femur[2]. The femur contains both red and yellow bone marrow (Figure 1), which requires enhanced image processing methods for the analysis of the different classes: two marrow phases and trabecular bone. Due to a longer T1 relaxation time, red marrow appears darker than fatty yellow marrow in HR bone images. The aim of this work was to evaluate the feasibility of simultaneous red marrow and trabecular bone from HR MRI.

Materials and Methods

HR proximal femur images (Fig. 1a) of 20 healthy females were acquired on a 3T GE MR750 system using an 8 channel phased array coil and a fully balanced steady state free precession pulse sequence (TR/TE 8.6ms/3.09ms, flip angle 60º, bandwidth ±62.5 kHz, voxel size 0.23×0.23×0.5 mm). Scan time was 13 minutes. Coronal 3-echo fast-gradient echo (FGRE) images employing IDEAL[3] (Iterative Decomposition of water and fat with Echo Asymmetry and Least-squares estimation) for water/fat separation (Fig. 1b) were acquired with half the spatial resolution. An IDEAL atlas was created by automatic 3D multi-resolution affine registration of 9 scans to a reference scan (age 50±19 years), followed by 3D free-form deformations[3]. Transformations were applied to create an HR atlas where a volume of interest (VOI) was prescribed in the central 16 slices, eroded 20 pixels from the boundary. Using affine registrations and free form deformations, the IDEAL atlas was automatically registered to the 10 remaining subjects (2 with vertebral fracture, age 70±3 years, 8 non-fracture, age 57±10 years).The outcome was used to transform and upsample the VOI's for HR image analysis. Images were partitioned using fuzzy C-means clustering with feature spaces built from the same scans as the atlas. HR images were clustered into 3 classes; trabecular bone and red and yellow marrow, using local bone enhancement fuzzy clustering[3]. For qualitative comparison reasons, IDEAL water images were also clustered as either red or yellow marrow based on intensity.
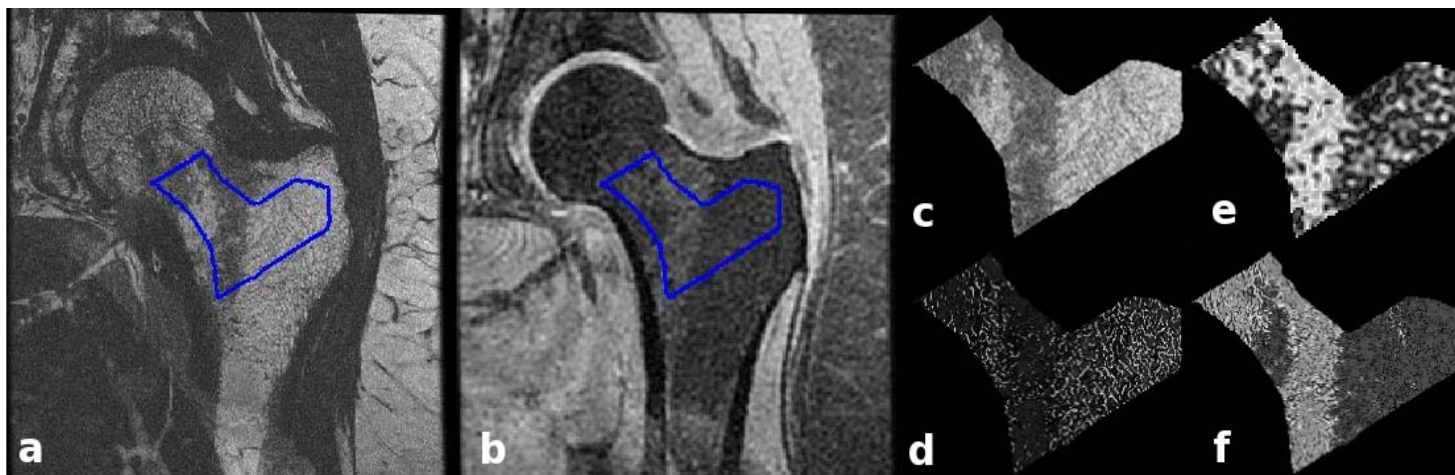

Figure 1: a) Slice from HR scan with automatically placed ROI. b) Corresponding slice from IDEAL scan. c) Enlarged HR slice around the ROI. d) Trabecular bone structure determined by 3-class fuzzy clustering. e) IDEAL red marrow content determined by 2-class clustering. f) HR red marrow contents determined by 3-class clustering.

Results and Discussion

We have successfully implemented a 3-class fuzzy C-means clustering for HR MR images of the proximal femur. As demonstrated in Figure 1, this technique is able to distinguish the 3 main classes of tissue in the proximal femur: trabecular bone, (Figure 1d), red (Figure 1f) and yellow marrow. The distribution of red marrow based on the HR image analysis (Figure 1f) agrees qualitatively with the distribution of red marrow based on the low resolution water-only FGRE image (Figure 1e).The HR image analysis showed lower red marrow fraction ($p<0.05$) in fracture subjects (0.42±0.01) compared to non-fracture (0.44±0.01). This is in accordance with previously published results using MR spectroscopy in subjects with osteoporosis[4].

There was no difference found in mean bone volume fraction in the HR analysis between fracture and non-fracture subjects (0.16±0.01 vs. 0.15±0.01) underlining the potential contribution of bone marrow to the assessment of femur fracture risk. Although the method needs to be evaluated on a larger, age matched cohort, these results suggest that marrow composition analysis is feasible using HR MRI. The methodology could potentially help understand the factors behind the red and yellow marrow conversion process in relation to aging and fracture history.

References

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