Methods for robust quantification of trabecular bone parameters from highly accelerated in vivo MR images obtained by GRAPPA based techniques at 3 Tesla and 7 Tesla

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Introduction: The potential of parallel imaging in the area of in vivo high resolution (HR) MRI of trabecular bone has recently been shown in the literature [1]. However the authors observed that trabecular structural parameters such as apparent trabecular number (App. TbN) derived from the accelerated images had an increasing trend with the acceleration factor (R). Morphological metrics of trabecular bone such as App. TbN and trabecular bone fraction (TBF) derived from HR-MR images are crucial for evaluating the skeletal condition in osteoporosis patients. The purpose of this work is to identify the factors contributing to elevated structural measures in accelerated images and to formulate a robust GRAPPA based technique for quantitative HR-MRI of trabecular bone.

Hypothesis: The image processing technique generally employed to quantify trabecular bone structure from MR images involves a dual threshold- the bone intensity reference or lower threshold and the marrow reference intensity level or higher threshold which is empirically set to the higher value of the full-width-at half-maximum (FWHM) of the intensity histogram of the region of interest (ROI). Structural analysis is subsequently performed on binarized bone images [2] .In this work we hypothesize that elevation in App. TbN values in accelerated images might primarily be caused by spatially varying magnification of noise related to the geometry factor of parallel reconstruction [3]. Furthermore, in cases of high acceleration, the histogram characteristics of an accelerated image might be considerably altered compared to the conventional image such that the empirically set upper threshold might lead to overestimation of TBF measures. Since all structural analysis is performed on binarized bone images, the elevation of TBF would increase App. TbN values as well. The noise amplification might be mitigated to some extent by regularizing the inversion of the signal matrix in the GRAPPA reconstruction. The second probable cause of variation in structural measurements might be addressed by a modified thresholding strategy.

Methods: To test our hypothesis**,** we incorporated Tikhonov regularization using the L curve method for choice of regularization parameter in a modified GRAPPA reconstruction developed in our lab [1] in MATLAB 7.0. We acquired HR-MR images of trabecular bone from five healthy volunteers at several skeletal sites with a three dimensional (3D) multiple acquisition SSFP sequence 3D FIESTAc (cycled Fast Imaging employing Steady State Acquisition) with two phase cycles, partial echo and a 512x384 acquisition matrix. Two volunteers were scanned at the sites of the hip (proximal femur), one for a 32 slice dataset and one for a 48 slice dataset, and one at the knee (distal femur) for a 48 slice dataset with a custom built eight channel dual phased array coil [4] on the 3 T GE Signa Echospeed system (GE Healthcare). One volunteer each was scanned at the knee and the ankle (calcaneus) by a custom built eight channel phased array and a eight channel receiver from Nova Medical (Wilmington,MA) respectively, on the 7 Tesla GE EXCITE scanner. In-plane resolution of the images was 190 µm at the ankle and knee and 230 µm at the hip. Slice thickness was 500 µm at the ankle and 1000 µm at the knee and the hip. Acquisition time for R=1 32 slice hip, knee and ankle datasets was 7:07 mins, 10:45 mins and 9:19 mins respectively. To eliminate sources of variation in structural measurements other than that caused by the parallel reconstruction, such as motion between scans, accelerated acquisitions (R=1, 2..6) were simulated from the R=1 datasets and reconstructed once by regularized and once by unregularized GRAPPA reconstruction. Resulting images were subjected to thresholding based analyses [2] for quantification of trabecular micro-structural parameters

Figure 1: Representative images of the ankle acquired with normal and six times accelerated acquisition at 7 T. The R=6 image was reconstructed with regularized GRAPPA method

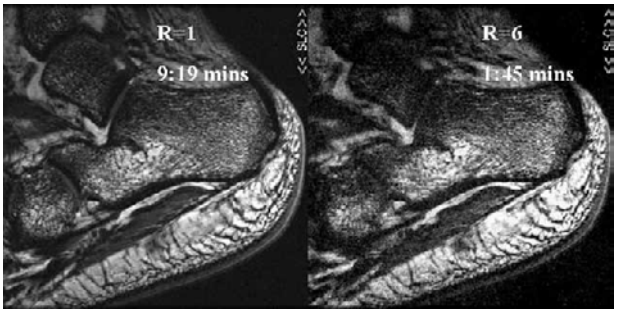
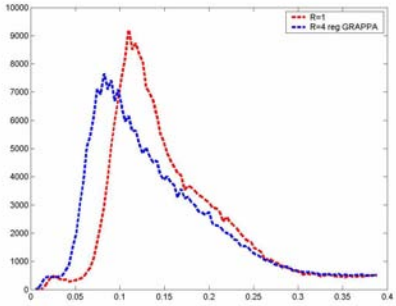
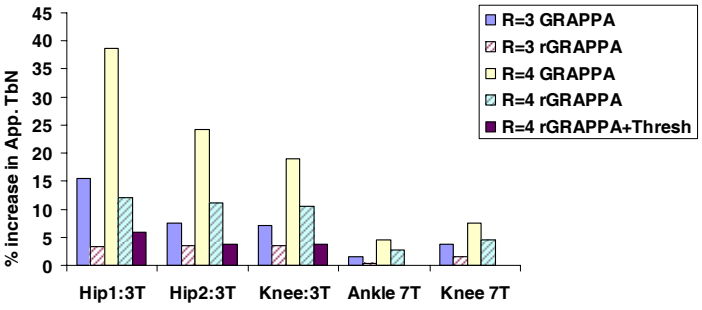


Figure 2: Intensity histogram of conventional and R=4 regularized GRAPPA reconstructed image



Results and Conclusion: A representative R=6 image of the ankle acquired at 7 T and reconstructed by regularized GRAPPA (rGRAPPA) based method is shown in Fig.1 along with the unaccelerated image. Increase in App. TbN measure with R reduced significantly in images reconstructed with rGRAPPA technique compared to the unregularized method. For R=4 datasets the variation in App. TbN measure could be further reduced when the threshold was adjusted for the larger FWHM of the intensity histogram of the accelerated image. The different histogram characteristics of an R=1 and R=4 image is shown in Fig. 2. Increase in App. TbN measures derived from accelerated images for each reconstruction method for 3 folds and higher acceleration for all the datasets is shown in Fig. 3. The standard deviation of structural measurement variation across all datasets was also observed to be remarkably lower for rGRAPPA compared to the unregularized method. The increase in structural measures from the R=1 image is much less at 7 T compared to 3 T for the same acceleration factor probably due to lower geometry factor at 7T. This implies great potential for rapid trabecular bone MRI at 7 T.

Figure 3: Percent change in App. TbN with acceleration factor for all reconstruction methods for all datasets



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