Combined Rotational/Translational Motion Correction using Autofocusing for High-Resolution Trabecular Bone Images

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Introduction

Due to the small voxel size (~140 µm) necessitated by the trabecular thickness (100-150 µm) and long scan time (~10 mins), involuntary patient motion, even on a sub-millimeter scale, could cause severe artifacts in high-resolution trabecular bone imaging. It has been shown recently [1] that motion alone could account for 4-10% variation in architectural parameters, which could severely limit the effectiveness of the micro-MRI technique to monitor the progress and effect of treatment in individual osteoporotic patients.

One useful post-processing technique previously proposed for motion correction is autofocusing [2-4], which optimizes an image quality metric against various trial motions applied to segments of acquired data. Although shown to achieve results similar to those of navigator echoes, combined translational/rotational autofocusing has not been demonstrated in a large set of clinical data, particularly when image SNR is limited. In this work, combined in-plane translational/rotational autofocusing is applied to a set of clinical high-resolution trabecular bone images acquired as part of a longitudinal study designed to assess drug response.

Theory

The hypothesis underlying combined rotational/translational autofocusing is that, among multiple trial motions (combined rotation/translation) applied to a k-space data segment, the global metric maximum (or minimum, depending on the metric) appears at a position where both rotation and translation are compensated. This is illustrated using an *ex vivo* trabecular bone specimen image (**Fig. 1**). Since the original data used in the figure was motionless, the maximum metric appears when the trial rotation θ=0.

We previously proposed an efficient search strategy for in-plane translation based on the pattern of metric cost functions vs. 2D trial translations. For combined rotation/translation, this strategy could still be applied at each trial rotation angle, with the global metric maximum occurring when both rotation and translation are properly compensated [5].

Methods

Combined rotational/translational autofocusing motion correction was applied to 26 clinical *in vivo* high-resolution MR images of trabecular bone (TB) from the distal radius, and the results compared with 2D in-plane translational correction only using 2D navigator echoes acquired during the scan [6]. Images were acquired with a 3D FLASE pulse sequence, with a 137x137x410μm^3 voxel size, 512x288x32 matrix, TR/TE=80/9.5 ms. Due to the limited SNR (~9), the summed metric values from the center 8 slices were used for the measure of image sharpness. The normalized gradient squared metric (NGS) [3] was chosen for optimization. Four-line segments were used for the central k-space region, while 8 and 16 were used in the outer regions where signal is lower. The maximum rotation and translation searched between two contiguous segments were (±1°,±2 pixels,±2 pixels) in increments of (¼ °, ¼ pixels, ¼ pixels). Images before and after motion correction were then submitted to a cascade of processing steps [1] to extract architectural parameters, including bone volume fraction (BVF), trabecular thickness (Tb.Th) and digital topological parameters.

Results and Discussion

The results from one subject, shown in **Fig. 2**, demonstrate that the autofocusing correction is superior to that of the 2D navigator, presumably due to the correction of rotational motion. The autofocusing processing times averaged approximately 10 minutes for each 3D dataset on a 3.0GHz Pentium computer. For the 26 *in vivo* clinical high-resolution MR images, autofocusing yielded increased NGS values compared to navigator (0.7 vs. 0.4% increase from that of motion-corrupted image), indicating sharper, more focused images. Digital topological analysis was conducted on the skeletonized TB images (where plates and rods are converted to surfaces and curves, respectively) and voxel densities were determined for the following topological types: curve (C), surface (S) and profile-edges (PE, essentially double-layered curves) [1]. For all parameters, autofocusing generated larger changes, consistent with those of reduced motion according to previous simulations (**Fig. 3**) [1]. The erosion index (a measure of bone loss) and S/C ratio demonstrate the largest difference, while smaller differences were seen in the BVF or Tb.Th.

Acknowledgements NSF BES-0302251, NIH T32DK07006.

References

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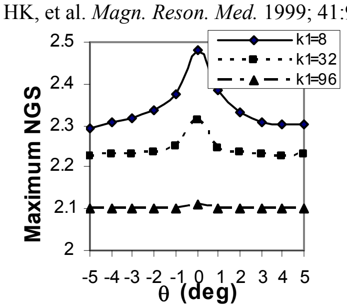

Fig. 1 Maximum metric values (NGS) of 2D trial translations for various rotation angles of a k-space segment which consists of 8 k-space lines and is located k1 lines from ky=0.

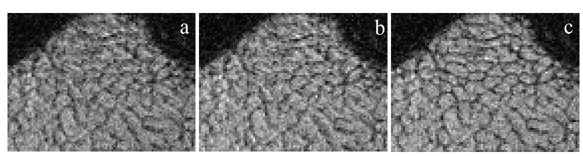

Fig. 2 *In vivo* high-resolution images of trabecular bone in the distal radius. (a) Motion-corrupted; (b) Navigator corrected; (c) Autofocused.

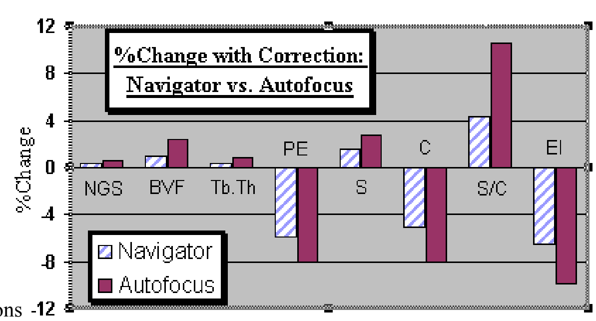

Fig. 3 Average percentage changes in metric (NGS) values, bone volume fraction (BVF), trabecular thickness (Tb.Th), profiles-edges (PE), surface (S), curve (C), surface to curve ratio (S/C) and erosion index (EI), after translational correction by navigator and combined rotational/translational correction with autofocusing from 26 clinical scans. The directions of change are all in agreement with those of reduced motion.