Combined Rotational/Translational Motion Correction using EXTRACT for High-Resolution Trabecular Bone Imaging

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Introduction

In high-resolution trabecular bone imaging, involuntary patient motion is a major source of artifact due to the small voxel size (~140 μm) and long scan times (~10-15 mins). It has been shown recently [1] that motion alone could account for 4-10% variation in trabecular bone 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.

Recently we have proposed a rapid post-processing technique for motion compensation based on k-space extrapolation and correlation (EXTRACT) [2-3]. Starting from a small number of base views near the center of k-space (assumed to be motion-free), extrapolation is first performed to estimate "motion-free" reference segments on either side of the base. Translational shifts are then estimated by correlating the extrapolated segments with the acquired, motion-corrupted data (by simple multiplication in k-space). Rotations could be detected by first rotating the acquired data sets by various angles, correlating each with the extrapolated data, and determining that angle which yields the maximum correlation value. The detected motion is then used to correct the acquired data, which are then incorporated into the expanding motionless base. The algorithm continues until the entire k-space is motion compensated. The advantages of EXTRACT include rapid data correlation in k-space without the need for iterative searches.

In this work, it is shown that the robustness of the EXTRACT strategy is dependent on the k-space extrapolation technique, and a combination of two extrapolation methods provides superior performance. Combined rotational/translational motion correction with EXTRACT is then demonstrated in a set of clinical high-resolution trabecular bone images where SNR is limited (~10).

Methods

The method of k-space extrapolation is critical to the accuracy of subsequent motion estimation. We have investigated two extrapolation methods that have been reported in the literature: edge enhancement (EE) [4] and finite-support (FS) solution [5]. In the first method (EE), the base data is first multiplied by a high-pass ramp filter $|k_y/k_0|$ (k_0 is the maximum k_y value of the base) to reconstruct an image that mainly consists of edges. Then the adjacent higher spatial frequencies can be extrapolated by thresholding the *magnitude* of the high-pass filtered image, while maintaining its phase, followed by an inverse FT. In the second method (FS), a regularized matrix pseudo-inversion was used to extrapolate k-space, incorporating knowledge of spatial-zero locations. We have found that at low SNR, this is equivalent to the direct thresholding of an image reconstructed from only the k-space base zero-filled to full resolution, significantly reducing the computation cost. The relative performance of the two extrapolation methods was first examined in a motion-free dataset. Results show that FS performs better near k-space center while EE is superior in the outer k-space regions (**Fig. 1**). Therefore we propose to use FS for $k_y<k_1$ and EE for $k_y>k_1$. The crossing-point k_1, which is image-type dependent, was found to be consistently around 50 in the trabecular bone images examined in this report.

Both translation-only and combined rotation/translation correction with EXTRACT was applied to 26 clinical *in vivo* high-resolution MR images of the trabecular bone (TB) in the distal radius, and the results compared with 2D in-plane translation-only correction using navigator echoes acquired during the scan [6]. Images were acquired with a 3D FLASE pulse sequence [6], with a 137x137x410μm^3 voxel size, 512x288x32 matrix, TR/TE=80/9.5 ms. Due to the limited SNR, the summed correlation values from the center 16 slices were used to determine motion. At each step, data were extrapolated and correlated in a group of 4-line segments near the central k-space regions, and 8-lines in the outer regions (k_y>64) where signal is lower. The maximum rotation searched between two contiguous segments was ±1^o in increments of ¼ ^{o}. The translational motion search precision is ¼ pixels along both read-out and phase-encode axes. The processing times for EXTRACT averaged approximately 5 minutes for each 3D dataset on a 3.0GHz Pentium computer. Images before and after motion correction were then submitted to a cascade of processing steps to extract architectural and topological parameters [1].

Results and Conclusion

Figure 2 shows results from one of the subjects, where translational-only EXTRACT correction achieved an image quality similar to that of the 2D navigator technique. The motion determined with EXTRACT agrees well with that of navigators. In most of the scans, the effect of correction for rotation in addition to translation was subtle, nevertheless, the combined correction was on average superior, based on the average changes in bone structural parameters from the 26 datasets (**Fig. 3**). Paired t-tests shows that the improvements from combined rotation/translation EXTRACT over navigator is statistically significant (P<0.05) for all parameters, while the translation-only EXTRACT was significantly better than the navigator method in some of the parameters (BVF, Tb.Th and S). The direction and the relative magnitude of changes for the different parameters were consistent with those of reduced motion, according to previous simulation studies [1]. These results demonstrate that by optimizing the extrapolation procedure, the EXTRACT technique may be an effective motion correction tool for high resolution MR imaging under limited SNR conditions.

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References

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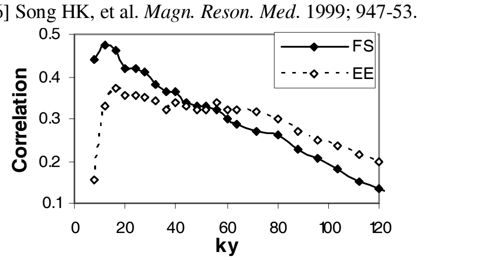

Fig. 1 Correlation values of extrapolated and actual k-space data segments using finite-support (FS) and edge-enhancement (EE) methods.

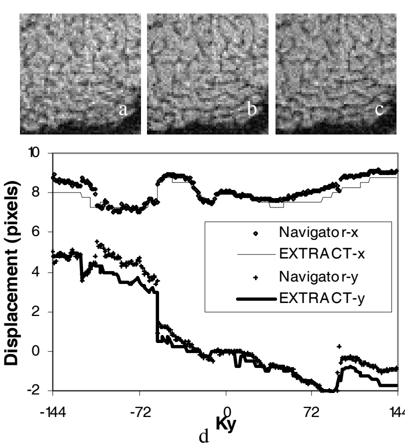

Fig. 2 (a) Motion-corrupted image; (b) Navigator corrected; (c) EXTRACT corrected. (d) Motion trajectories.

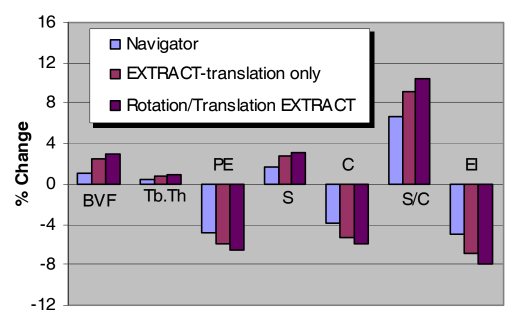

Fig. 3 Average percentage changes in bone volume fraction (BVF), trabecular thickness (Tb.Th), profiles-edges (PE), surface (S), curve (C), surface to curve ratio (S/C) and erosion index (EI), after translational correction by navigator and EXTRACT corrections from the in vivo scans. The directions of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