Demonstration of FatNavs to correct for microscopic involuntary head-motion at 7T

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Introduction: We recently introduced the concept of exploiting the natural sparsity of volumes acquired with a fat excitation in the human head to achieve very high parallel acceleration factors, and proposed that this could be used as a motion-navigator for high-resolution imaging applications (FatNavs) [1], and successfully demonstrated an implementation of 64-times accelerated FatNavs using conventional GRAPPA to exploit the natural sparsity of the fat images [2]. Here we present the latest results from this novel concept, using retrospective motion-correction for striking improvements in image quality in very high-resolution MP2RAGE [3] data where the healthy volunteer moved less than ±0.5 mm and ±0.5° during a 37 minute scan.

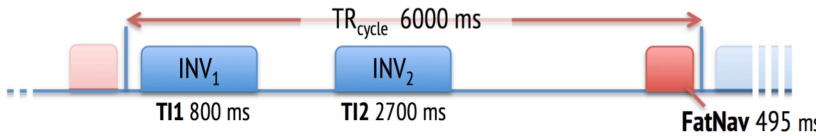

Figure 1: MP2RAGE pulse sequence, showing relative timing of FatNav motion navigator

Method: Imaging was performed on a 7T head-only Siemens MR scanner with a 32-channel RF coil (Nova Medical Inc.). A healthy adult volunteer was instructed not to move during the scan. A high-resolution MP2RAGE slab (330 µm × 330 µm ×1.00 mm, 488×492×80 matrix, TE/TI$_1$/TI$_2$/TR = 6.06/800/2700/6000 ms, BW=280 Hz/Px, FA = 7°/5°, total scan time ~37 mins) was acquired, with the insertion of a full 3D FatNav volume-navigator for motion correction within each MP2RAGE TR. The FatNav was a 2mm isotropic 3D-GRE dataset acquired with 8×8 acceleration and a binomial RF pulse for fat excitation (88×128×128 matrix, TE/TR = 1.35/3.0 ms, BW = 1950 Hz/Px, FA = 7°) which could be acquired in 495 ms (relative timing shown in Fig. 1). In order for the GRAPPA kernel estimation to remain an overdetermined problem, a large number of ACS lines are required – we used the maximum offered by the system for this matrix size: 81×113. This introduces an additional 32 s to the total scan time. After offline 2D GRAPPA reconstruction (following 1D FFT in readout direction), each of the FatNav volumes was co-registered (rigid-body) using SPM *realign* [4] to the time-point corresponding to the acquisition of the centre of the 3D k-space of the host sequence. The motion parameters obtained in this manner were then applied separately to the k-space data of each corresponding TR of the host MP2RAGE sequence to perform retrospective motion correction (3D gridding performed using 3D NUFFT [5]). Assuming small motion, no density compensation was applied. In addition to the low-bias T1-weighted image, the INV$_2$ image from MP2RAGE is also suitable for maximum and minimum intensity projections (MIP and MinIP) to visualize arteries and veins.

Results and Discussion: The top row of Fig. 2 shows the estimated motion parameters from the FatNavs indicating total motion of less than ±0.5 mm and ±0.5°. As each FatNav was independently co-registered to the reference, the small oscillations observed in these plots (~50 µm or ~0.05°) give an indication of the precision obtainable by co-registration of the FatNavs. It should be noted that this does not indicate the accuracy, which future work still needs to address as currently no compensation has been made for distortions due to gradient non-linearities, or to attempt to mask regions of the image subject to non-rigid motion. Fig. 2 also shows a zoom of one part of the low-bias T1-weighted image before and after application of the retrospective motion-correction where there is a clear improvement in image sharpness and contrast following the correction (although this is difficult to appreciate in a small figure). The MinIP of INV$_2$ over a 15 mm slab gives good vein contrast, and the MIP of INV$_2$ over the full 80 mm slab gives good arterial contrast, making the very high-resolution improvement with motion-correction more visible. The improvement is comparable to high-resolution examples of existing motion-correction methods which rely on external hardware [6,7]. Initial results have also recently been presented for high-resolution applications using an EPI-navigator for prospective motion correction [8], but the FatNavs offer the advantage of having a negligible effect on the signal of the host sequence. It would also be possible to use an EPI readout for the FatNavs to further shorten the time of each navigator, allowing easier incorporation into a variety of host sequences. There is also potential for using FatNavs for prospective motion correction, but this would be restricted by the reconstruction time of the highly accelerated 3D volume. As application of a GRAPPA kernel is highly parallelizable, however, fast reconstructions are technically feasible.

Conclusion: We have successfully demonstrated use of a very highly accelerated 3D volume as a high-resolution motion-navigator, capable of tracking very small involuntary motion of a compliant subject over a 37 minute scan. This offers the potential to better exploit the SNR of ultra-high field to push the spatial resolution of MRI acquisitions without the need for additional hardware.

[1] Gallichan et al, proc. ISMRM 2013, p309; [2] Gallichan et al, proc. ISMRM 2014, p4345; [3] Marques et al, NeuroImage (2010) 49:1271-81; [4] www.fil.ion.ucl.ac.uk/spm; [5] Fessler et al, IEEE TSP (2003) 51(2):560:74; [6] Maclaren et al, PloS one (2012) 7:e48088; [7] Schulz et al, MAGMA (2012) 25:443-53; [8] Tisdall et al, proc. ISMRM 2013, p268;

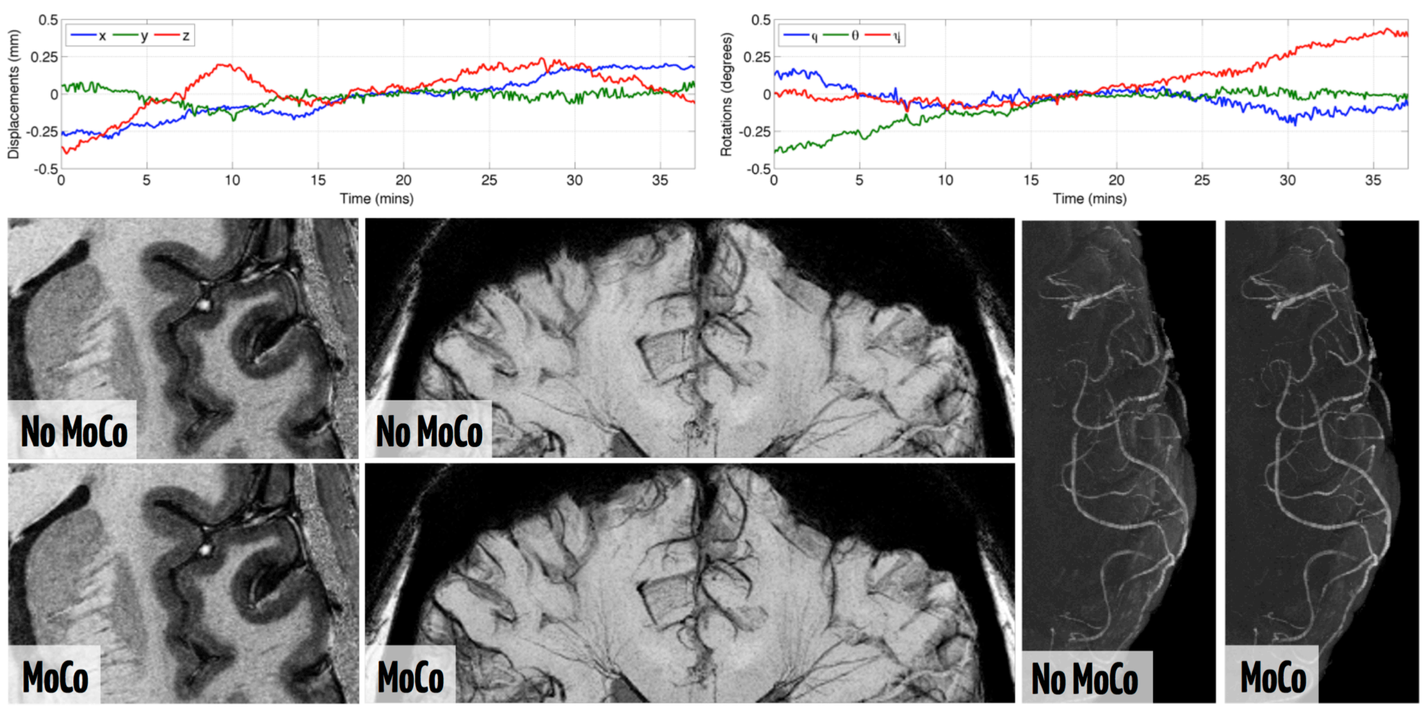

Figure 2: Top – estimated motion parameters from FatNavs. Bottom – (left) zoom of low-bias T1-weighted contrast; (middle) zoom of minimum intensity projection of INV$_2$ over 15 mm thickness to visualize veins; (right) maximum intensity projection of INV$_2$ over whole 80 mm slab to visualize arteries.