2D Fat Navigators (FatNav) for real-time correction of nodding motion of the patient's head

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Purpose Patient head motion is one of the leading sources of artifacts in brain MRI. In particular, it is difficult to restrain motion in the 'nodding direction' – a direction where motion naturally occurs due to the patient's breathing. Propeller based pulse sequences (1) have been proven clinically robust to motion. However, as only in-plane correction is performed, nodding motion is left uncorrected unless the slices are prescribed in the sagittal plane. Moreover, when retrospectively correcting any 2D imaging scan, spin-history effects cannot be addressed. Over the recent years, both hardware (video camera) and MR data (navigator) based prospective motion correction techniques have emerged (2). For example, the MR navigator based PROMO technique (3) uses three orthogonal excitations and spiral readouts to obtain three low-resolution images in parallel to the actual image acquisition. The flip angle of the three RF excitation pulses in PROMO has been reported to be 8° to minimally affect the longitudinal magnetization used for imaging. Nevertheless, the continuous use of about fifteen 8° RF pulses per second may saturate the brain signal by up to about ten percent, in particular in the ~1x1x1 cm^3 intersection point of the three orthogonal navigator planes. In quantitative or contrast sensitive applications, the PROMO technique may therefore not always be ideal. In the context of cardiac MRI, Nguyen et al. (4) presented a fat-selective pencil-beam navigator to estimate 1D motion based on the fat signal, while leaving water magnetization untouched for imaging. In this work, we propose a 2D fat-only (FatNav) navigator image for prospective correction of head nodding motion.

Methods A 2D FatNav pulse sequence module was implemented, consisting of a spectral spatial (SPSP) excitation RF pulse and an ARC accelerated GE-EPI readout played out as a single sagittal slice over the midline of the head (Fig. 1a-b) with a total sequence duration of ~20 ms. As the geometric distortions due to the EPI readout may interact and potentially bias the motion estimates, sensitivity to off-resonances were mitigated by using a low frequency encoding resolution and a high parallel imaging acceleration factor. The following pulse-sequence parameters were used: 10 ms SPSP excitation pulse tuned to fat, flip angle = 10°, slice-thickness = 30 mm, reduction factor R=4, acquisition matrix (freq x phase) = 48 x 96 (96/R = 24 lines acquired), zerofilling to 96 x 96, FOV = 28 cm, TE = 9.4 ms. The ARC weights were calculated from a fully sampled R-shot GE-EPI scan acquired once in the beginning of the experiment.

To investigate to what accuracy the FatNav images could estimate the motion and the effect of geometric distortions, 65 consecutive *sets* of scans were acquired. Each set contained three scans: i) FatNav with positive phase encoding blips (Fig.1a), ii) FatNav with negative phase encoding blips (leading to distortions in the opposite direction) (Fig. 1b) and iii) a high resolution 2D T1w FSE with same FOV and slice position as the FatNav scans (Fig. 1c). A highly skilled and motivated healthy volunteer was scanned and moved the head to a new pose *between* each set, after first remaining as still as possible during the first 20 sets. In-plane image registration was performed for each of the three scans independently, via a sum-of-squares metric and a rigid body model. All images were masked during the registration to exclude the neck and jaw area, which move non-rigidly (Fig. 1d). The motion estimates, $\mathbf{p} = [\Delta y, \Delta z, x_{rot}]$, derived from the T1w FSE time course were assumed as the gold standard because of the FSE images being distortion free, acquired at higher resolution and with the brain signal present for a more 'informed' realignment. All scans were performed on a GE Discovery MR750 3.0T scanner using an 8-channel head coil.

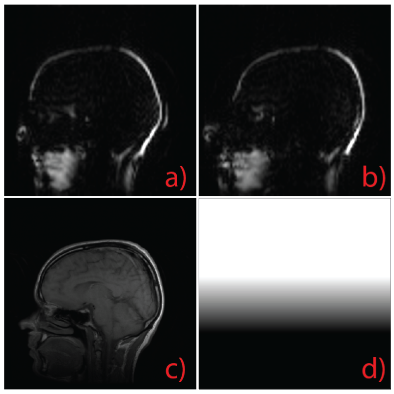

Figure 1. a) FatNav, positive blips, b) FatNav negative blips, c) T1w FSE, d) Mask used during registration

Results Fig. 1a and 1b show two FatNav scans acquired with the phase encoding blips in opposite directions. Note the difference in head shape due to off-resonance distortions. Fig. 1c shows the 2D T1w FSE and Fig. 1d shows the simplistic mask used to exclude the neck and jaw during the motion estimation. Fig. 2 shows the motion estimates for all three scans. A close correspondence between all three scans can be seen, indicating that; a) the geometric distortions had a low impact on the motion estimates; b) the estimates using the fat signal only are not too noisy or biased compared to the reference FSE scan. With the motion estimates from the FSE data assumed as gold standard, the standard deviation (std) and the root mean square (RMS) for both FatNav scans (blips up = +, blips down = -) were $\mathbf{\Delta p+}_{std}$ = [0.14, 0.15, 0.23], $\mathbf{\Delta p-}_{std}$ = [0.13, 0.28, 0.32], $\mathbf{\Delta p+}_{RMS}$ = [0.19, 0.34, 0.23] and $\mathbf{\Delta p-}_{RMS}$ = [0.13, 0.30, 0.42] [mm/deg], respectively. Note also that the discrepancies between the curves in part may be due to true unintended head motion between the scans within each set.

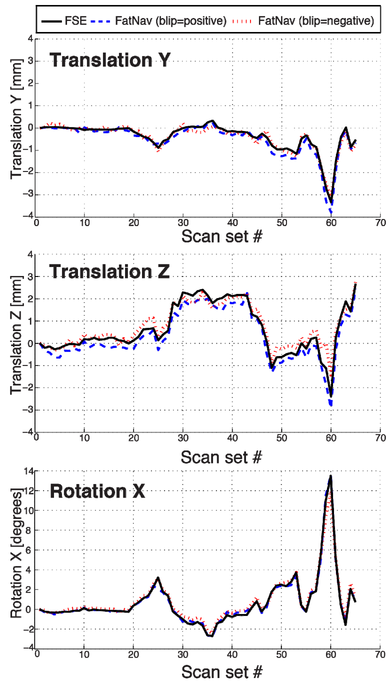

Figure 2. Motion estimates obtained after image registration. From top to bottom, translation Z, translation Y and rotation X, respectively

Discussion & Conclusion A new 2D navigator technique using only the fat signal of the brain to estimate nodding motion has been presented. We have shown that despite the some remaining EPI off-resonance distortions, the motion estimates using the FatNav images are close to those from the FSE reference data (Fig. 2). FatNav is advantageous as it leaves the brain water magnetization unaffected. As it corrects only for motion in the sagittal ('nodding') plane, the indented use of FatNav is foremost for axial/coronal PROPELLER or EPI based acquisitions where in-plane motion can be corrected retrospectively. One may extend this to a full 3D motion correction, and like PROMO excite three orthogonal planes, at the expense of longer navigation time. Next, this FatNav sequence module will be combined with other imaging sequences with an integrated real-time update of the gradients w.r.t the nodding motion. Compared to PROMO, the in-plane pixel size of the FatNav was 6 times smaller. Further work will investigate the need for Kalman filtering and the implementation of an adaptive mask for the sake of further registration accuracy.

References
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