Six-degree of Freedom Retrospective Motion Correction using Spherical Navigator Echoes (SNAV)

Patricia Johnson[1,2], Junmin Liu[1], Trevor Wade[1], and Maria Drangova[1,2]
[1]*Imaging Research Laboratories, Robarts Research Institute, London, Ontario, Canada,* [2]*Dept. of Medical Biophysics, Schulich School of Medicine & Dentistry, Western University, London, Ontario, Canada*

TARGET AUDIENCE: MR scientists developing and applying motion correction techniques.

PURPOSE: To implement and evaluate retrospective motion correction using SNAVs interleaved within a 3D imaging pulse sequence.

INTRODUCTION: Spherical navigator echo (SNAV) techniques are promising for measuring rigid body motion in all 6 degrees of freedom.[1-4] However, the original method for motion extraction from SNAVs is iterative and time consuming – severely limiting their potential for prospective motion correction.[2] To overcome this drawback, a pre-rotated-baseline SNAV technique (PreRot-SNAV) was proposed and demonstrated improved speed and accuracy, making real-time prospective motion correction with SNAVs feasible.[3] Unfortunately, the PreRot-SNAV technique requires a baseline prescan that can be prohibitively long (25.6 s). A modification of this method employed an under-sampling and simulation technique to reduce this baseline acquisition time to only 4.2 s while maintaining the accuracy of motion measurements.[4] In this abstract we demonstrate – for the first time - the accuracy of retrospective preRot-SNAV-correction of motion by interleaving the SNAVs *within* a 3D imaging pulse sequence

METHODS: ***SNAV-interleaved imaging sequence.*** The navigated sequence used in this study is a modified fast gradient echo sequence (efgre-SNAV).The image sequence has a TR and RF pulse that match those of the SNAV; this implementation strategy was previously used with vNAVs[5] and ensures that the steady state of the image sequence is preserved. The efgre-SNAV sequence used in this study alternates between an image RF pulse and an SNAV RF pulse, with the full SNAV acquisition requiring 2 shots, thus a full navigator is acquired for every four RF pulses of the sequence. The built-in SNAV (a radius of 0.40cm^{-1}) samples 1254 points per shot; to match this, the image readout was extended.

Data acquisition. An agar-filled skull phantom was used for all experiments. A baseline set of 82 pre-rotated SNAVs[4] was first acquired with the phantom at a reference position (4.2s scan time). The rotation range about X and Y was ±6°. The efgre-SNAV sequence was then executed; the imaging parameters were TR/TE = 50/7.2 ms, flip angle =5°, bandwidth = 125 kHz, FOV = 20×20×20 cm^3, matrix size 1254x128x40 (reconstructed matrix size: 128x128x40) slice thickness =5 mm and scan time = 9 mins. The phantom was manually rotated to a trial position and another efgre-SNAV image was acquired. In order to evaluate the performance of the efgre-SNAV, a set of stand-alone SNAVs (32 non-prerotated) were also acquired at the trial position, the motion parameters extracted from the stand-alone and the baseline SNAVs were used as the gold standard.

Table 1. Mean motion parameters (max, min) measured by SNAVs

	θ_x (°)	θ_y (°)	θ_z (°)	X (mm)	Y (mm)	Z (mm)
Interleaved Navigators	-1.5 (-1.5, -1.5)	-4.0 (-4.0, -4.0)	10.0 (10.0 10.0)	-8.71 (-8.70, -8.72)	-0.47 (-0.46, -0.50)	-13.09 (-13.00, -13.16)
Stand-alone Navigators	-0.5 (-0.5, -0.5)	-4.0 (-4.0, -4.0)	10.0 (10.0 ,10.0)	-9.14 (-9.13,-9.15)	-0.33 (-0.31,-0.35)	-12.68 (-12.64, -12.72)

Motion extraction. A hybrid baseline dataset was generated, as previously described,[4] by combining the 82 acquired baselines with a set of simulated pre-rotated SNAVS. From these acquired templates, simulated templates were generated with rotations about the Z axis from -20° to 20° in 1° steps. The motion parameters were extracted from the 2432 interleaved navigators as well as the 32 stand-alone navigators. The mean, standard deviation, and extremes of all six motion parameters were calculated for each set of navigators.

Motion correction. In order to investigate the feasibility of retrospective motion correction, the raw k-space data of the image was transformed based on the efgre-SNAV determined motion parameters, θ_z, X, Y and Z. First, phase shifts were applied in order to correct for the measured translations, next, the 3D coordinates of the phase corrected data were rotated based on the measured axial rotation. The data were then interpolated at the transformed coordinates using cubic spline interpolation. The transformed k-space data were then Fourier transformed and the resulting image was compared to the reference image using a pixel-by-pixel image subtraction.

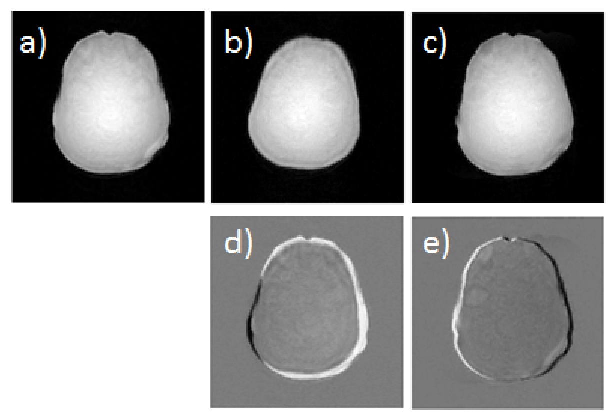

Figure 1. Single axial slice of the 3D image acquired at the reference position (a) and the trial rotation position (b). Acquisition following rotation and translation correction is shown(c). The reference image is subtracted from the uncorrected (d) and corrected (e).

Results: The motion parameters extracted from the interleaved and stand-alone navigators are shown in Table 1. The values presented are the mean of all repeated measurements along with the maximum and minimum measured values. The interleaved navigators performed comparably to the stand-alone navigators for all 6 motion parameters. The rotations estimates agree within 1.0° and the translation estimates, agree within 0.43 mm. Retrospective motion correction was successfully performed based on the motion measurements as shown in Fig. 1. Qualitatively, the image subtraction shows that the corrected image is better aligned with the reference than the uncorrected image. Motion measurement and retrospective correction were performed in approximately 4 mins.

Discussion & Conclusions: In this preliminary work we have successfully incorporated SNAVs into an image sequence for the first time. The interleaved and stand-alone navigators performed comparably for both rotations (within 1.0°) and in-plane translation estimates (within 0.43 mm). The results of the retrospective motion correction are promising; the transformed image is much better aligned than the uncorrected image with the reference image. Previous investigations have demonstrated the feasibility of using partial SNAVs to measure motion;[3-4] this will be incorporated with the efgre-SNAV sequence in the future in order to reduce the SNAV readout and thereby the minimum TR, while also allowing for a flexible matrix size for the image in the readout direction. The efgre-SNAV sequence is a promising tool for motion correction in MRI. The current method of interleaving the SNAVs in the 3D sequence doubles the scan time; in the future we will investigate alternative strategies for interleaving the navigators. Future work will also involve assessment of retrospective correction of in-vivo images as well as the implementation of a prospective motion correction technique using the sequence.

References: (1) Welch et al., MRM 47:32-41, 2002. (2) Welch et al., MRM 52:1448-52, 2004. (3) Liu and Drangova, MRM 65:506-14, 2010. (4) Johnson et al. Proc ISMRM, Motion Correction in MRI Workshop 2014; 30 (5) Tisdall et al., ISMRM 22, Milan, p0882, 2014.