PROPELLER and Turboprop Acquisition Parameters for Optimal Motion Correction

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Introduction: PROPELLER-MRI[1] and Turboprop-MRI[2] are considerably less sensitive to motion than their precursors, multi-shot fast spin echo (FSE) and gradient & spin-echo (GRASE) respectively. In the PROPELLER family of sequences, data are collected along blades centered at the origin of k-space. The amount of translation and rotation of the object is estimated for each blade through comparison of the common low spatial frequency information between blades, and subsequently corrected[3]. In this study, the effects of PROPELLER and Turboprop acquisition parameters on motion correction were investigated.

Methods: Human brain PROPELLER image acquisitions were simulated. For this purpose, a high-resolution (512x512) low-noise T_2-weighted image from a slice of the brain of a healthy volunteer was obtained on a GE 3T scanner, using a conventional spin-echo sequence. Signals outside of the brain were set to zero. The image was then rotated, and inverse-Fourier-transformed to simulate k-space blades at the corresponding angles. Gaussian noise was added in k-space (in both the real and the imaginary components). Random in-plane rotations within a range of ±5°, and translations within ±5 voxels were simulated in each k-space blade. Rotations were estimated using data from a number of the outer lines of each blade. Translations were estimated using published methods[1]. The absolute value of the residual rotation and translation error after motion correction was estimated for each blade. The same process was repeated 100 times and the mean rotation and translation errors per blade were calculated for each sampling pattern. All of the procedures above were used in a downhill simplex algorithm in order to determine: a) the total number of lines acquired per blade, and b) the number of lines used for correction in each blade, that minimize the mean rotation and translation errors. The number of blades was excluded from the minimization process since it was shown to have little effect on motion correction (see Results). Motion correction was also tested on selected sampling patterns with {24, 40, 56, 72, 88, 104, 120} lines per blade, {24, 26, 28, 30} blades, and 192 samples per line. In addition to the techniques used in the simplex algorithm, rotation correction was also performed using information from all lines in each blade weighted by the square of their distance from the center of the blade[1]. Finally, Turboprop acquisitions were simulated for white matter tissue with T_2=90ms and T_2*=40ms. Motion correction was tested for Turboprop acquisitions with turbofactors {5, 7, 9} and number of spin-echoes per blade equal to {4, 8, 12, 16, 20}.

Results and Discussion: From the simplex algorithm, the number of lines per blade and the number of outer lines used for motion correction that minimized the mean rotation and translation errors were equal to 104 and 84 respectively. However, this number of lines per blade is not feasible in PROPELLER due to T_2 signal decay. Mean rotation and translation errors were found to be independent of the number of blades of the sampling pattern. Hence, the total number of blades was selected such that full sampling of k-space was maintained. Nonetheless increasing the number of blades enhanced SNR in the expense of acquisition time. For the selected sampling patterns, a valley of low mean rotation and translation errors was reached for more than approximately 40 lines per blade (Fig.1). When only outer lines of each blade were used for rotation correction, the residual errors increased for blades with high total number of lines. This was probably due to the low k-space signal to noise ratio for lines quite distant from the center of k-space. In contrast, when all lines of each blade were used for rotation correction, then the residual errors remained low even for blades with a large total number of lines. However, this technique provided inferior rotation correction for small numbers of lines per blade (see result for 40 lines per blade in Fig.1a). Thus, from Figure 1a, approximately 40 lines per blade and rotation correction using the 20 outer lines of each blade provide motion correction similar to that of the optimal sampling pattern suggested by the simplex algorithm. However, even acquisition of 40 lines per blade is not feasible with PROPELLER-MRI. This can only be achieved with Turboprop. A plot of the mean rotation error versus the number of spin-echoes per blade and the turbofactor is shown in Figure 2 (accounting for T_2 and T_2* decay). Combinations of numbers of spin-echoes and turbofactors that correspond to the dark region of Figure 2 produced the lowest rotation and translation errors. Approximately 40-90 lines per blade correspond to that region (in agreement with findings presented in Figure 1). These numbers of lines per blade can be achieved by various combinations of numbers of spin-echoes and turbofactors. However, high turbofactors will increase susceptibility-related artifacts, and large numbers of spin-echoes per blade will lead to significant T_2 decay. Figure 3 demonstrates the effects of the number of spin-echoes per blade on motion-corrected images.

Based on the findings of this study, Turboprop acquisitions with 8-9 spin-echoes, and a turbofactor of 5-9 will allow for optimal motion correction. The number of blades can be adjusted to achieve the desired SNR and acquisition time. To our knowledge, this is the first study to propose PROPELLER and Turboprop acquisition parameters that ensure optimal motion correction.

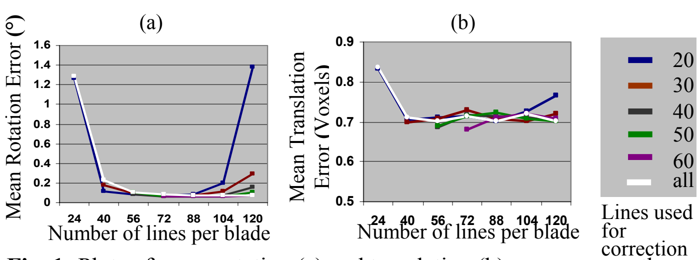

Fig. 1: Plots of mean rotation (a) and translation (b) errors versus the number of lines per blade (for sampling patterns with 24 blades).

References: **1)** Pipe JG, et al., Magn Reson Med 2002;47:42-52. **2)** Pipe JG. ISMRM 2002, p. 435. **3)** Pipe JG. ISMRM 2001, p. 743.

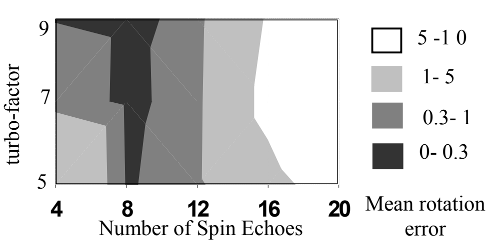

Fig. 2: Plot of mean rotation error in Turboprop-MRI versus the number of spin-echoes and turbofactor. Nonlinear greyscale is used.

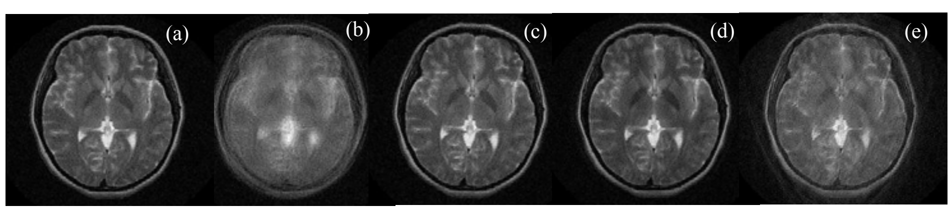

Fig 3: (a) and (b) are images reconstructed for 8 spin echoes per blade without and with simulated motion respectively. (c), (d) and (e) show the images after motion correction for 8, 12, 16 spin echoes per blade respectively. A turbofactor of 7 was used in all cases.