3D PROMO MRI with Online Automatic Slice Positioning

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INTRODUCTION

The image-based "PROspective MOtion correction" (PROMO) technique [1,2] is an effective and flexible method for real-time correction of *within*-scan motion artifacts in 3D MRI sequences. Here, we present an extension to the PROMO method for online correction of *between*-scan motion in the same sequences through automated scan plane positioning. Consistent alignment of MRI slice acquisitions is desirable for many research and clinical MRI applications, particularly when investigating longitudinal changes in patient anatomy and physiology. Several, automated approaches for setting the scan plane prescription have been proposed over the years, including using spherical navigator echos [3] and 3D localizers [4]. In our approach, a series of quick three-orthogonal spiral navigator images, collected during the initial pre-scan phase of PROMO, are used to register the patient anatomy to a fixed spiral navigator atlas. The resultant registration information is then carried though during the PROMO-enabled pulse-sequence to allow for consistent and automatic real-time motion tracking and slice plane positioning in atlas space.

METHODS

Image Acquisition: All data were collected on a GE 1.5T Signa HDx system (Waukesha, WI) using an 8 channel head coil. Following informed consent, three sets of three scans were acquired on a single volunteer on three separate scanning days, totaling 27 acquisitions. Each set of three images contained 1) an initial 3-plane localizer, 2) a 2D (non-PROMO-enabled) fast spin echo (FSE) sequence with a fixed slice prescription across scans, and 3) a 3D inversion recovery spoiled gradient echo (IR-SPGR) sequence equipped with PROMO motion correction and automated slice prescriptioning. Pulse sequence parameters for the 2D FSE scans were: TE = 103 ms, TR = 10s, FOV = 24cm, Flip = 90°, BW=±162kHz, acq. matrix = 128 x 128, slice thickness = 4 mm, # of slices = 44, total scan time = 1.2 min. Pulse sequence parameters for the 3D IR-SPGR scans were: TE = 2.9 ms, TR = 7.3, FOV = 24cm, Flip =8°, BW=±162kHz, acq. matrix = 128 x 128, slice thickness = 2 mm, # of slices = 166, total scan time = 5 min. The subject was instructed to remain fixed during the collection of each image set (all three scans), but to shift his/her position in between each set (i.e. prior to the start of each localizer).

Spiral Navigators and Atlas Construction: The PROMO motion correction framework utilizes repeated sets of three-orthogonal, low-flip, thick-slice, single-shot spiral navigator images (SP-Nav) (collected every ~100ms) in conjunction with the Extended Kalman Filter (EKF) algorithm for real-time 3D rigid-body motion measurement [1]. The SP-Nav parameters used here were: TE/TR=3.4/14 ms, Flip=5°, 2048 points, FOV=30cm, slice thickness=19mm, BW=±125kHz. A preliminary 3D spiral navigator atlas was created by extending the spiral sequence to acquire 10 stacks of axial, sagittal, and coronal slices on the same subject (totaling 30 volumes). The image volumes were then registered, smoothed with a Gaussian kernel (5° FWHM), and averaged offline to form the final atlas.

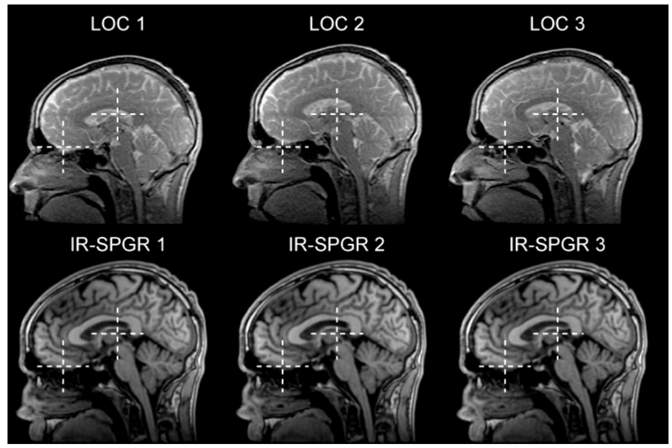

Figure 1 Initial localizers (top row) and automatically aligned, real-time motion corrected PROMO IR-SPGR scans (bottom row) across each of the three separate scan days. Crosshairs show the same location in image space across scans. Note the consistent alignment of the PROMO scans compared to that of the localizers.

Pre-scan Atlas Registration: In the original PROMO approach, an initial set of 20 SP-Navs are acquired every ~700ms during an initial pre-scan phase (lasting ~14s) to align a 3D navigator atlas and tracking region-of-interest (ROI) to the patient in navigator space via the EKF. Here, the initial pre-scan phase is modified such that spiral atlas remains fixed and the SP-Navs are acquired with recursive feedback from the EKF to update their respective geometries in real-time. Thus, provided convergence of the EKF registration, the last SP-Nav of the sequence will be acquired in atlas space. To allow for real-time prospective motion correction and automatic slice plane positioning in atlas space, the prescription of the last SP-Nav is carried through during the PROMO-enabled IR-SPGR pulse sequence. To improve the initial pre-scan registration, a ROI was applied during the last 10 SP-Navs to focus the registration on the head only, ignoring the neck and jaw regions.

Offline Quantification of Alignment Precision: To quantify the precision of the automatically aligned 3D IR-SPGR volumes, the residual motion was assessed offline by registering each IR-SPGR volume to the first volume of the first day. As a comparison, and to quantity the overall *between*-scan motion of the subject, the same registration was performed on the 2D FSE volumes (acquired with a fixed prescription). The offline registration yielded the six 3D rigid-body motion parameters that best aligned the image volumes in terms of minimizing their sum-of-squared voxel intensity differences.

RESULTS

Figure 1 shows the sagittal localizer for the first scan acquired on each of the three separate scan days, along with a mid-sagittal slice through the respective automatically aligned 3D IR-SPGR volumes (prior to offline registration). The minimum (min), maximum (max), and root-mean-squared (rms) residual motion across all 9 IR-SPGR and FSE volumes are shown in Table 1.

		Translation [mm]			Rotation [deg]		
		x	y	z	θ_x	θ_y	θ_z
IR-SPGR (PROMO AA)	min	-0.747	-0.154	-0.150	-0.301	-0.002	-0.400
	max	0.698	0.402	0.700	0.650	0.400	0.350
	rms.	0.472	0.249	0.303	0.421	0.242	0.246
FSE	min	-1.415	-0.677	-1.003	-1.190	-1.517	-2.200
	max	1.146	0.407	13.884	1.696	0.910	3.864
	rms.	0.686	0.374	8.999	2.054	0.780	2.153

Table 2 Residual motion statistics (min, max, root-mean-squared) for the automatically aligned (AA) PROMO IR-SPGR volumes and standard non-auto-aligned 2D FSE volumes.

DISSUSION

This study demonstrates the feasibility of extending the real-time image-based 3D PROMO technique for mitigation/correction of *between*-scan patient motion / differences in position through automatic alignment of the slice prescription. The PROMO alignment procedure showed a precision of better than 1 mm/deg, despite initial position / landmark differences of over 13 mm (c.f. Table 1). While the current pre-scan alignment routine takes about 14 seconds, it should be possible to reduce this time to about a second or two (given current scanner hardware and software capabilities), making it suitable for integration as part of a routine pre-scan procedure. Future work is needed to test the robustness of the method for automatic alignment across individuals.

REFERENCES

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