Propeller techniques for pediatric exams in the presence of large motion

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Introduction Propeller MRI was first introduced for T2-w imaging (1), and today T2-FLAIR, T1-FLAIR, and diffusion contrasts are commercially available. Success factors for propeller MRI include its single-shot full-FOV blades and its 2D self-navigating property, where rotational and translational motion between blades may be estimated in sequence on the k-space data. Motion correction of propeller data can also be performed in the image domain, accounting for the nominal blade angle differences. For large head movements in multiple directions, a standard 2D (in-plane) correction is less suitable. Moreover, partial or complete signal dropouts of individual slices can lead to bias in the estimates, and as the slices are registered independently, the corrected slices may not correlate anatomically with each other. These effects are avoided by 3D motion correction. However, registering 3D blade volumes (i.e. stack of 2D slices) assumes minimal intra-blade volume motion. With a temporal footprint (i.e. TR) of several seconds per blade volume, rapid head motion will result in anatomically inconsistent blade volumes that are difficult to realign to each other. In this work, the aim was to develop a multi-contrast propeller sequence with an image reconstruction chain that is robust enough to consistently produce diagnostic images on pediatric patients, even in the presence of very large head movements during the examination.

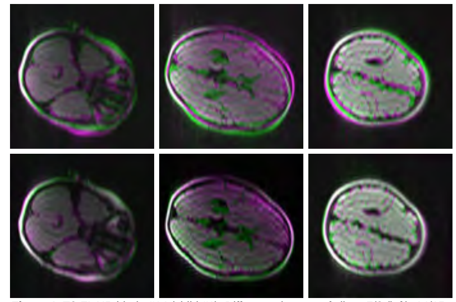

Figure 1. T2-FLAIR blade #14 (child #1). Difference images of slices 7/8 (left), 14/15 (center), 24/25 (right) - before (top) and after (bottom) intra-blade volume correction.

Methods *Acquisition:* All scans were performed on a GE 3T DV MR750W system using a 32-ch Nova head coil (Nova Medical Inc., MA, USA). A 17-min brain protocol dominated by propeller sequences was run on three pediatric patients. These patients were already scheduled for a clinical MRI under general anesthesia (GA) at the hospital and were scanned unsedated ahead of their appointment using this motion robust protocol. Relevant sequence parameters (T2-w/T2-FLAIR prop.): # blades = 30/16, blade size = 288x32/40, TE = 90/112 ms, TR = 7500/8000 ms, FOV = 20 cm. 30-40 4 mm adjacent slices were acquired, depending on the scan plane. All scans were accelerated by R = 2 without ACS lines, cross-calibrated by an orthogonal propeller blade acquired next in time. For all pulse sequences in this protocol, the acoustic noise was substantially reduced via gradient derating and the children watched a cartoon movie for motivation during the examination. Child #1 (6Y), having a spastic cerebral palsy (continuous head motion during the entire examination), was evaluated for periventricular leukomalacia (PVL). For child #2 (7Y), an MR was requested for ADHD evaluation. Child #3 (4Y), recently having a longer seizure and put on antiepileptica, was examined to rule out any structural pathology.

Image reconstruction: After parallel imaging reconstruction and a conservative phase correction of the blade data, intra-blade-volume motion was first performed by in-plane alignment to the average of the two neighboring slices (above and below), from the center slice outwards in the slice stack. This procedure was aborted in either slice direction due to lack of information if a dropout slice was found. This was repeated a second time starting with one slice offset (acquired TR/2 later in time). Next, the blade volumes were sorted in order of similarity (accounting for nominal rotations), allowing the first sorted blade volume (reference) to have minimal signal dropouts from motion, but also be in a space similar to most other blades to reduce blurring from excessive data interpolation through slices. First, the blade volume being the least similar to the mean of all blades was placed last in the sorted list, after which a new mean was taken for the remaining blades, etc. This was followed by 3D registration to the first blade volume. From the same propeller raw data, images were also reconstructed using only 2D realignment in k-space/image space for comparison, as well as without motion correction.

Results Across all scans and patients, rotational blade motion per scan was found to be ~15±5 degrees, with varying rotation axes and frequency. For the first patient, having spastic motion patterns, intra-blade volume motion was prominent. Fig. 1 (top) shows the amount of slice-to-slice movements for the one of the T2-FLAIR blades. After the proposed intra-volume correction step, the slice-to-slice variations were reduced (Fig 1, bottom) making each blade volume anatomically consistent and better suited for 3D image realignment. Fig. 2 shows the same T2-FLAIR data after gridding. For the 2D corrections, used as comparison, the k-space based correction (Fig. 2b) performed worse than the image space correction (Fig. 2c) in the presence of the frequent motion and variable degree of dropout slices. The initial intra-blade correction step was necessary for successful 3D registration (Fig. 2d vs. Fig. 2e). The need for 3D registration becomes apparent in Fig. 3, showing two coronal T2-w slices of the 4-year old patient, who was observed to occasionally looking away from the movie, corresponding to nearly 20º of rotation (nodding). While 2D image domain MoCo improves the image appearance, it does not yield anatomically correct data (Fig. 3b, arrows).

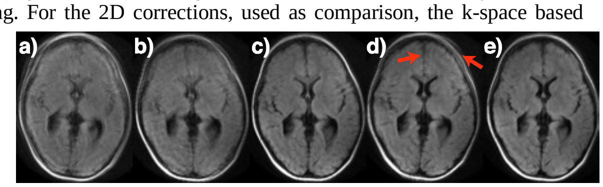

Figure 2. T2-FLAIR image (child #1), slice 14. a) No correction, b) 2D k-space MoCo, c) 2D image space MoCo, d) 3D image space MoCo, e) Intra-blade corr. + 3D image space MoCo. K-space 2D MoCo (b) performed worse than image domain 2D MoCo (c) (consistent for all slices). Arrows show that intra-blade motion needs to be addressed before 3D MoCo, (d) vs. (e).

Discussion The T2-w and T2-FLAIR propeller data acquired on these pediatric patients contained sometimes up to 15-20% of dropout slices and often large motion with major through-plane components during one TR. We find this very challenging for the standard 2D MoCo that is widely used today. While we believe propeller MRI using 3D image registration is entirely necessary for reliable scans of unsedated pediatric patients, the move from 2D to 3D registration introduces the demand to control intra-blade volume motion. Our way to address this was simple but effective, but further work may also borrow ideas from e.g. slice-to-volume matching in fetal MRI (2). One should note that it is insufficient to first perform a slice-independent 2D registration across blades followed by 3D registration as this does not drive the slices to their proper place in each blade volume. Finally, for regular propeller scans, having slice thicknesses around 4-5 mm, the proposed blade sorting will aid aligning the data in a reference space that reduces through-plane interpolation effects.

With the proposed steps for propeller motion correction, the clinical questions could be answered for all three patients, and no further MR examination under general anesthesia was necessary.

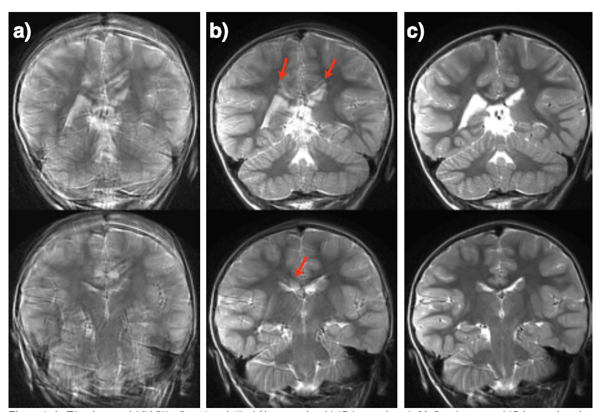

Figure 3. Ax T2-w images (child #3), slice 13 and 17. a) No correction, b) 2D image domain MoCo, c) proposed 3D image domain MoCo. With head rotations up to about 20° in the through-plane direction, 2D image domain MoCo converges (b) but produces data with mixed anatomy (arrows) and significant residual artifacts. This is not the case for the proposed 3D approach (c).

References 1. Pipe J, Magn Reson Med 42:963-69 (1999). 2. Rousseau Acad Radiol 13:1072-1081 (2006)