Free-Breathing Pediatric MRI with Nonrigid Motion Correction and Acceleration

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PURPOSE: To obtain high quality images of uncooperative pediatric patients, MR exams often involve intubating these patients with deep anesthesia and temporarily suspending their respiration during the scan. At sites where breath-holding cannot be performed and for pediatric patients with high-risk profiles, the quality and reliability of the MR images are limited. Prospective respiratory triggering & gating is an effective solution, but this approach usually results in low scan efficiency. Thus, the goal of this work is to develop and assess motion correction techniques for high-resolution volumetric free-breathing pediatric MRI acquired with high scan efficiency.

MATERIALS & METHOD: First, a variable-density sampling and radial-like phase-encode ordering scheme (VDRad[1]) is incorporated into a 3D Cartesian acquisition. Second, intrinsic multi-channel Butterfly navigators[2] are incorporated to measure respiratory motion. Lastly, these estimates are applied for both motion-weighted data-consistency (or soft-gating[3]) in a parallel imaging and compressed sensing (PI&CS) reconstruction using ESPIRiT[4], and for nonrigid motion correction using a localized autofocusing framework[2,5] (illustrated in Fig. 1).

<u>*Setup:*</u> With IRB approval and informed consent/assent, studies were performed on 22 consecutive pediatric patients (13 females, 9 males, 2.2–10.7 years) referred for an abdominal MRI study on a GE MR750 3T scanner (Waukesha, WI) using a 32-ch cardiac coil. Parameters of the 3D spoiled GRE sequence include flip angle of 15°, bandwidth of ±100 kHz, partial readout (0.6 of full) to achieve TE of 1.2–1.3 ms, and TR of 3.0–3.4 ms. A resolution of 0.7–1.2 mm in S/I, 1.0–1.7 mm in R/L, and 1.6–2.6 mm in A/P was prescribed with modest acceleration factors (~3). A spectral fat-inversion pulse (TI of 9.0 ms) was applied every 24–27 TR's for fat-suppression. Data were acquired ~1.5 min after gadolinium contrast injection (venous phases). Images were reconstructed using Matlab & C/C++[6].

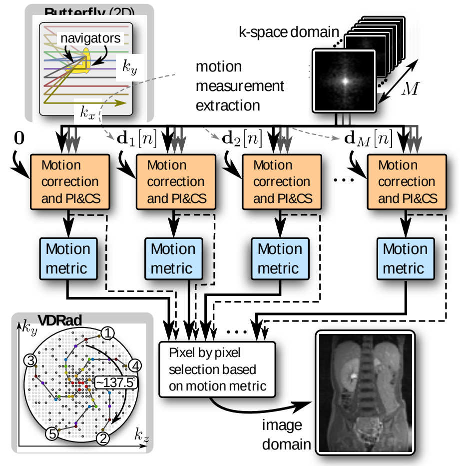

FIG. 1: *Method overview.* 2D Butterfly navigators (*top left*), VDRad scheme (*bottom left*), and nonrigid motion autofocusing framework (*center*) are depicted.

<u>*Image evaluation:*</u> The effects of sequentially adding different components to the reconstruction were investigated. The following methods were developed:

- **CS:** Reconstructing the free-breathing continuous VDRad acquisition using conventional PI&CS,
- **SG:** Reconstructing using soft-gated PI&CS,
- **wAF:** Using SG in an autofocusing framework, and
- **RT:** Prospective respiratory triggering & gating (window 30%) in a separate scan with conventional PI&CS.

Two radiologists independently scored the images for overall image quality, degree of motion artifacts, and representative anatomical features on a scale of 1 (nondiagnostic) to 5 (excellent). Paired Wilcoxon test evaluated comparisons, and weighted kappa evaluated inter-observer agreements.

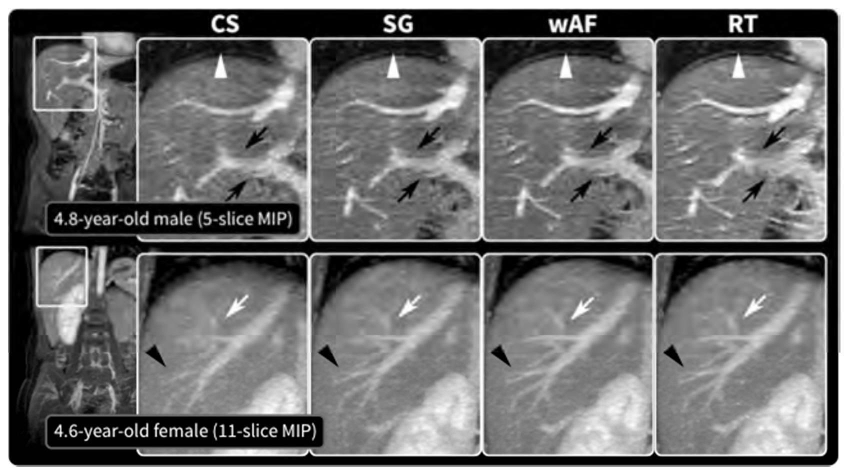

FIG. 2: *Representative images.* In the top row, hepatic arteries were recovered in SG with better delineation in wAF (*black arrow*). The diaphragm was also sharpened using wAF (*white triangle*). In the bottom row, the recovery of the 1st (*white arrow*) and 2nd-order (*black triangle*) hepatic veins can be appreciated in SG and more so in wAF. wAF achieved similar quality to RT.

RESULTS: Representative results are shown in Figs. 2 & 3. The complete procedure (wAF) yielded significantly better ($P<0.05$) overall image quality (mean score of 4.7) compared to CS (mean 3.4) and to SG (mean 3.9). The wAF (avg scan time 28 s) resulted in comparable image quality to RT (avg scan time 91 s) with a mean of 4.5. Since RT was performed after the first scan, hepatic arteries were not well delineated due to their reduced contrast enhancement. The majority of cases had fair to almost perfect agreement.

DISCUSSION: The lower mean scores of SG compared to RT can be attributed to insufficient motion-free data collected from a shorter scan. With autofocusing, there were no significant differences between wAF and RT: autofocusing enables a scan time reduction by accepting and correcting corrupted data. Also, with all techniques applied, wAF yielded statistically superior results compared to CS and SG. In conclusion, with the proposed methods, diagnosable high-resolution abdominal volumetric images can be obtained from free breathing scans.

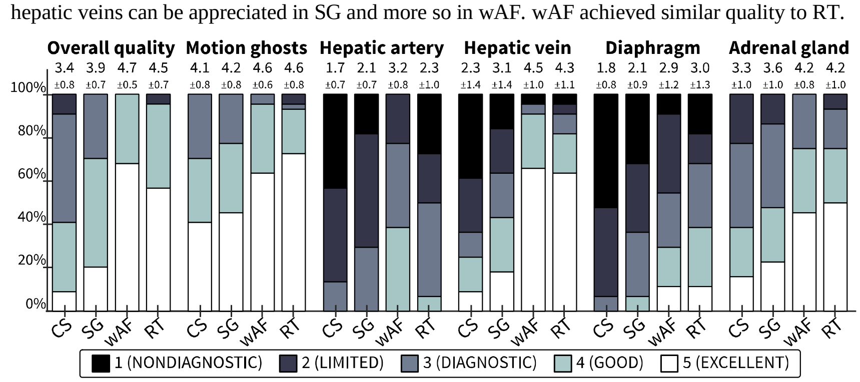

FIG. 3: *Image assessment results: scores from both readers combined for simplicity.* Each color bar represents the percent of cases with the same score. Mean ± standard deviation is annotated above each bar. There was significant improvement ($P<0.05$) for wAF over CS and SG for all features. Except for hepatic artery, there was no significant difference between wAF and RT.

REFERENCES:

[1] JY Cheng et al. JMRI; doi:10.1002/jmri.24785. **[2]** JY Cheng et al. MRM 2012; 68:1785–1797. **[3]** KM Johnson et al. MRM 2012; 67:1600–1608. **[4]** M Uecker et al. MRM 2014;71:990–1001. **[5]** JY Cheng et al. US 20140210469 A1, *patent pending.* **[6]** M Uecker et al. doi:10.5281/zenodo.12495.

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