Free-Breathing Pediatric Imaging with Nonrigid Motion Correction and Parallel Imaging

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PURPOSE: MR is a compelling imaging modality for children, free of risks of ionizing radiation of CT and nuclear scintigraphy studies. However, motion corrupts MR images, so children often undergo deep anesthesia and periods of suspended respiration, particularly for body MR exams. This prolongs studies and has its risks. Leveraging recent advancements in accelerated imaging and motion correction, we developed a novel method aimed to eliminate the need for deep anesthesia and breath-holds via a high-resolution motion-free volumetric MR scan acquired free-breathing with contrast-enhancement.

METHOD: *Data Acquisition:* A standard 3D spoiled gradient echo sequence was modified to monitor motion using Butterfly navigation, a self-navigated Cartesian trajectory [1]. We developed and integrated a variable-density radial (VDRad) view-ordering to undersample k-space for a shorter scan time, and to efficiently acquire data throughout k-space with the golden-angle (~137.5°) ordering [2] of each radial train (Fig. 1).

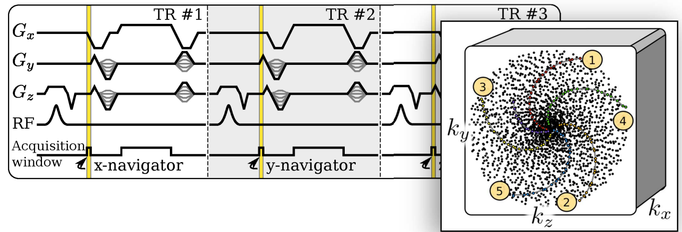

FIG. 1: *Data acquisition.* **left:** 3D spin-warp sequence modified to acquire Butterfly navigators in *x* (TR #1), *y* (TR #2), and *z* (TR #3). **right:** Example VDRad view-ordering where each point is a (k_y,k_z) view with a full k_x readout. Each radial spiral is a train acquired according to the golden-angle. The spiral-twist can be exaggerated to better randomize the view-ordering.

Image Reconstruction:

<u>*Step 1 – Motion Estimation:*</u> The motion estimated from each coil-array element yields weights $w[n]$ that correspond to the amount of corruption for each acquisition echo and motion paths $\mathbf{d}[n]$ that each image voxel may exhibit – where n is the TR number (Fig. 2).

<u>*Step 2 – Parallel Imaging:*</u> We modified ESPIRiT [3], a compressed-sensing/parallel-imaging algorithm, to include $w[n]$ – the data-consistency weights [4]. The wESPIRiT (weighted ESPIRiT) method "soft-gates" the acquired data and estimates missing or overly corrupt values.

<u>*Step 3 – Motion Correction:*</u> Residual motion-artifacts are corrected using an autofocusing (AF) algorithm [1].

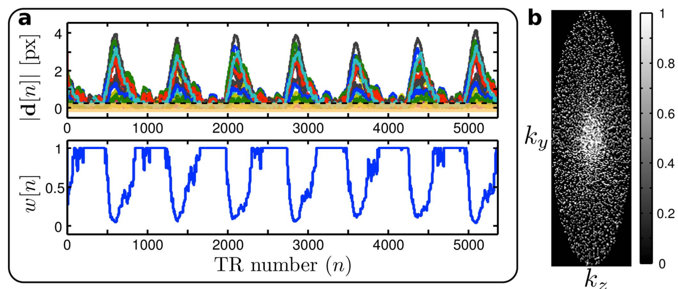

FIG. 2: *Image reconstruction example.* **a:** Magnitude of the estimated motion $\mathbf{d}[n]$ from each coil-receiver (each channel represented by a different color), and the derived data-consistency weights $w[n]$. **b:** Resulting k-space weighting mask that is used for the wESPIRiT reconstruction. In our experiments, we found it sufficient to accept a motion of 0.25 pixels, and exponentially weight the data with more motion.

Experiments: Free-breathing abdominal studies were performed on pediatric subjects in a 3T GE MR750 scanner. Data was acquired using a 32-channel torso coil, flip angle = 15°, and bandwidth = ±62.5 kHz. *Additional Scan Parameters:* <u>*Study 1:*</u> TE/TR = 1.4/3.9 ms, resolution = 1.0×1.3×3.0 mm^3, FOV = 34×27.2×18 cm^3, navigation time per TR = 0.096 ms, and an acceleration ~2.27 with two phases. <u>*Study 2:*</u> TE/TR = 1.4/3.6 ms, resolution = 0.88×1.4×2.0 mm^3, FOV = 28×22.4×16 cm^3, navigation time per TR = 0.12 ms, and a total acceleration of ~3.

RESULTS: Weighted reconstruction delineates more anatomic structures, and AF resolves additional structures. Overall, diagnostic image quality is obtained despite the free-breathing (Fig. 3). The view-ordering and weighting reduces the severity of the motion artifact. This aids ESPIRiT's performance because the aliasing noise from motion is minimized. Also, the AF correction is more effective because the method depends on local linear corrections.

DISCUSSION: Even if entire radial trains have to be discarded, the proposed VDRad view-ordering maintains the sampling density necessary for an ideal undersampling point-spread-function. This property makes the view-ordering useful for k-space weighting and also useful for 4D techniques.

Two components to compensate for motion are presented: wESPIRiT and AF; they can be used individually or together depending on the reconstruction quality desired versus the computation time allotted. The weights $w[n]$ can be adjusted to accept more samples and tolerate more data-corruption; the AF algorithm will correct the remaining motion artifacts.

CONCLUSION: We present a practical free-breathing method for children or other patients incapable of performing breath-held scans. For future research, we will explore the limits of the algorithm, such as how much we can increase the acceleration factor.

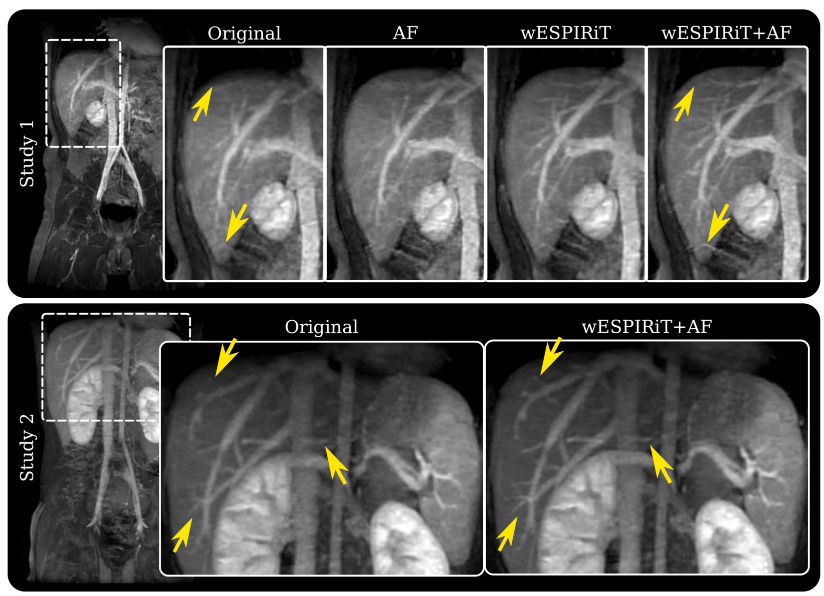

FIG. 3: *Results.* **top:** Study 1 – post-contrast scan of a 3 year old patient. **bottom:** Study 2 – post-contrast scan with fat-saturation of a 5 year old patient (motion and weights are shown in Fig. 2). Only the original (normal ESPIRiT reconstruction) and wESPIRIT with AF are displayed for Study 2 to better show the details. For all images, maximum intensity projection (MIP) is used to highlight the vessels. Motion blurring is most obvious in the original image. The AF image shows some improvement. Next, "noise" is reduced in the wESPIRiT image, because the corrupted acquisitions that contribute to extra aliasing noise are weighted down. Lastly, with the two methods combined, the large vessels are sharpened and finer vessels are recovered. Diagnostic image quality is obtained despite the free-breathing.

REFERENCES: **[1]** JY Cheng et al, MRM 2012; Early View. **[2]** M Doneva et al, ISMRM 2011, p3057. **[3]** M Uecker, P Lai et al, MRM 2012, preprint. **[4]** KM Johnson et al, MRM 2012; 67:1600-1608.