Imaging in the presence of Motion with Sliding Slice Distortions

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TARGET AUDIENCE: Scientists and clinicians interested in free breathing and motion robust imaging.

PURPOSE: Respiratory motion remains a major challenge to the use of MRI in the body and techniques that restrict intra-scan motion utilizing breath-holding or gating are prone to error. For example, dynamic contrast enhanced (DCE) imaging of the liver requires images collected over a span of 30-90s to capture both arterial and portal venous blood delivery. Thus, breath-held and respiratory gated approaches yield data with significant gaps in time. In this work, we investigate the use of a T1 weighted sliding slice approach that casts intra-scan motion as geometric distortion rather than aliasing, in order to address breathing related artifacts.

METHODS: The proposed data sampling strategy is shown in Fig. 1, and is based off sliding 2D radial sampling with similarities to past sliding slice and moving table approaches (1-3). Data are collected with the excitation frequency linearly varying over each time frame such that the slice is swept from superior to inferior achieving contiguous volumetric coverage. During this sweep, in-plane k-space data are collected utilizing golden angle radial sampling. For the next frame, the excitation frequency is reset, however, the golden angle sampling is maintained such that adjacent time frames have unique sampling patterns. Prior to slice selection, a non-selective pulse is applied to impart a 3D T1 steady state. This RF energy is only used to establish T1 weighting with an optimal flip angle that much smaller than if it was used for both imaging and contrast. Data are reconstructed in a least squares sense on an oversampled 3D grid with resampling operations in all three dimensions and resampling kernel in the sliding dimension matching that of the expected excitation profile.

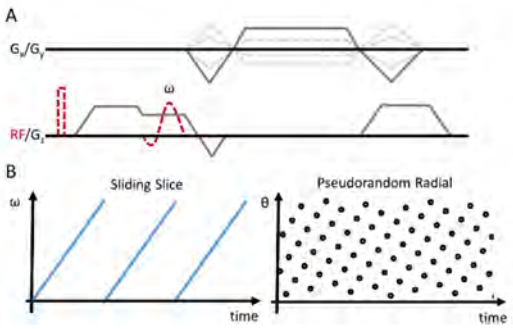

Figure 1. *Pulse sequence diagram (A) and excite frequency and radial view angle (B) for T1 weighted sliding slice.*

EXPERIMENTS: To assess feasibility, phantom and healthy volunteers (after IRB approval and informed consent) were imaged on a clinical 3.0T system (MR750, *GEHC*, WI, USA). Images collected with the sliding slice encoding in the S/I dimension were compared to a 3D stack-of-stars sequence with Fourier phase encoding in the S/I dimension. Common imaging parameters include, ~3.5s per frame, FOV =32x32x25.6cm^3, Resolution=1.4x1.4x4mm^3. Both sequences utilized golden angle view ordering. 3D stack-of-star sampling acquired all phase encodes for each projection before incrementing. Sliding slice resulted in a TE/TR of 1.6/4.9ms utilizing $flip_{sat}$=5°, $flip_{imaging}$=18°. Stack-of-stars had a shorter TE/TR of 1.3/3.6ms with a flip angle of 10°. For each case, data were collected for 1:32. In phantom scans, cyclic motion was simulated utilizing table motion, with 30mm of translation over a 4s period, data were reconstructed at 3.5s frames with a parallel imaging framework. In-vivo images were collected without contrast with the both acquisition triggered to start at end-expiration with a 70% acceptance window. In this manner, sliding slice acquisition moves from the diaphragm inferiorly and geometric distortions anchored by a consistent diaphragm position. In-vivo cases were averaged to a single frame.

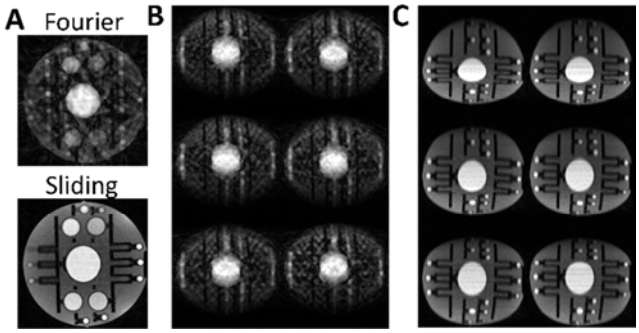

Figure 2. *Axial images demonstrating through plan motion (A) and coronal reformats of 6 time frames of Fourier (B) and sliding slice (C). As seen in coronal images, the motion (up/down images) in Fourier encoding leads to significant ghosting artifacts. In sliding slice the motion manifests as geometric distortion demonstrated by the changing shape of the phantom, which depending the timing of the motion relative to acquisition.*

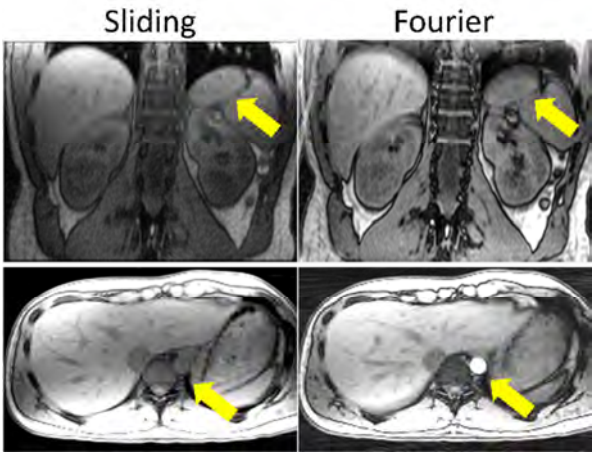

Figure 2. *Coronal reformats (top) and axial slices (bottom) of sliding slice and Fourier encoded.*

RESULTS: Fig. 2 shows images comparing axial and coronal reformats of Fourier and slicing slice S/I encoding approaches. In Fourier encoding, artifacts manifest as destructive ghosting and blurring due to the non-local nature of Fourier transform. However, in the dynamic sliding slice approach, artifacts manifest as geometric distortions. Figure 3 shows preliminary human. Due to near continuous breathing, both images have significant motion; however, geometric distortions in the sliding slice approach are not readily visible (top-arrows). The sliding approach is also notably less sensitive to inflow, demonstrated by low signal intensity in the aorta (bottom-arrows).

DISCUSSION AND CONCLUSION: The feasibility of a dynamic acquisition using 2D radial sliding slice is presented. This approach is quite insensitive to motion artifacts assuming the velocity of the motion is lower than that of the sliding. Given the recent advances in reconstruction and the prospect for further acceleration utilizing dynamic regularization, it is likely that such a velocity is achievable for dynamic contrast enhanced (DCE) applications. The proposed 2D sampling of a 3D steady state avoids severely mitigates artifacts arising from inflowing blood and motion, which have typically plagued 2D imaging. **ACKNOWLEDGMENTS**: We gratefully acknowledge GE Healthcare for their assistance and support. **REFERENCES**: 1. Shankaranarayanan et al. 03' MRM (50):5 2. Rasche et al. 94' SMRM(3):787 3. Scheffler et al 94': ISMRM 9:17