k-space Sampling Approaches Using TWIST: Implications for Dynamic Contrast Acquisitions

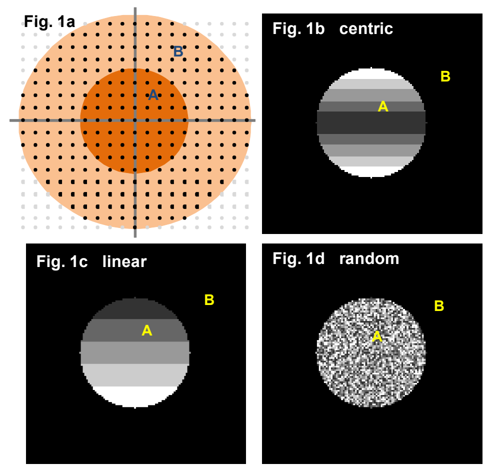
X. Li[1], J. W. Grinstead[2], C. V. Bishop[3], I. J. Tagge[1], R. L. Stouffer[3,4], W. D. Rooney[1], and G. Laub[5]

[1]Advanced Imaging Research Center, Oregon Health & Science University, Portland, Oregon, United States, [2]Siemens Healthcare, Portland, Oregon, United States, [3]Division of Reproductive Sciences, ONPRC, Oregon Health & Science University, Portland, Oregon, United States, [4]Department of Obstetrics and Gynecology, Oregon Health & Science University, Portland, Oregon, United States, [5]Siemens Healthcare, San Francisco, CA, United States

Introduction. Time-resolved angiography with stochastic trajectories (TWIST) package [1] offers a practical and flexible way to perform sub-second, time-sequential 3D measurements. It is often used in combination with contrast injection to provide dynamic clinical information, including the evaluation of abnormal vascular anatomy as well as vascular hemodynamics, and contrast enhanced measurements. Using a primate model (rhesus macaque) and simulated data therein, we investigated TWIST center of k-space updating strategy on Dynamic-Contrast-Enhanced (DCE) MRI signal time-course and image.

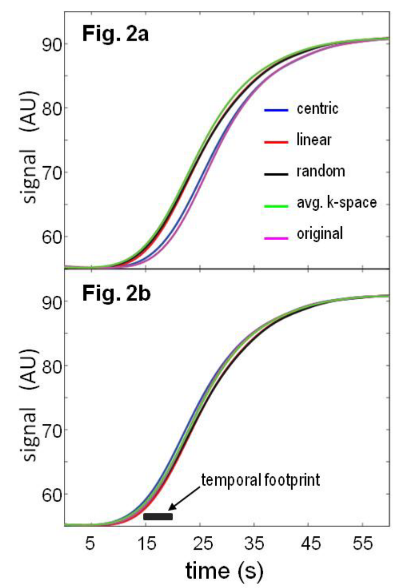
Methods. DCE-MRI data were obtained from adult, female macaques (n = 3) with a Trio 3T (Siemens) using an 8-channel knee coil. Single slice DCE series acquired 400 images with a 0.83 s temporal resolution. A CR bolus (Prohance, 0.2 mmol/kg I.V. at 0.5 mL/s) was administered ~40 s after MRI acquisition initiation. Other parameters are: square FOV and 128^2 matrix size, TR/FA: 6.5 ms/30°. Siemens RHP tool was used to retrieve the full k-space data.

Fig. 1a briefs a 2D k-space TWIST [1] plane where center of k-space region (**A**) is acquired most frequently and the higher spatial frequency region (**B**) is updated less often. The optimal sampling strategy for the ratio of regions **A** and **B** and how large a portion of **B** to be updated each time with the fully sampled region **A** during a dynamic multi-frame scan was investigated for contrast enhanced renal application [2]. Since DCE or angiography time-course signal can change rapidly and image contrast is mostly defined by the low spatial frequency k-space region (**A** region), we conceptually investigate the optimal pathway for updating region **A** of the 3D TWIST during a dynamic scan using our 2D data. Compared to the reference images, the preferred pathway should produce the least overall difference on dynamic signal time course and maintain the highest fidelity of image quality. The choice of 2D acquisition is to achieve sub-second temporal resolution and full k-space sampling with one echo during each read-out.



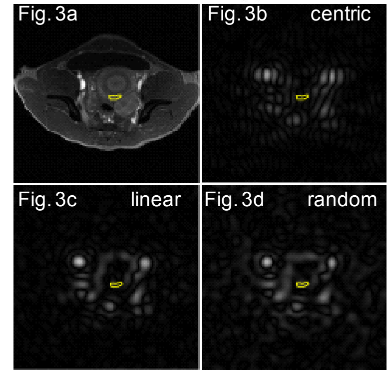
To capture a time varying event and mimic region **A** updating pattern, a temporal footprint for **A** region is defined by the time elapsed during a group of multiple k-space frames (0.83s apart for two adjacent frames). Selectively assigning k-lines from different frames in region **A** according to a user defined pattern and temporal order will form a new "simulated" k-space of region **A** with a temporal footprint equals the product of temporal resolution and number of frames. Three common k-space sampling approaches of these were shown in **Fig.1**: centric (**1b**), linear (**1c**), and random (**1d**). All utilizes five frames and thus a temporal footprint of 4.15 s. For **1c**, from top to bottom, the simulated new region **A** is from frames 1 to 5, respectively, where 1 stands for current frame.

Results. Signal to noise ratio (SNR) for the acquired DCE data is about 30. When the 8-channel k-space data were individually resampled with different region **A** pattern and reconstructed with the standard square-sum approach, no significant difference was seen for the three resampling approaches shown in **Fig.1**, even for a temporal footprint of 14.1 s. This is most likely due to SNR limit. Thus, time course data from the images were numerically smoothed pixel by pixel and each resulted image (original) were then inverse Fourier transformed to get its corresponding k-space data. This effectively boosts SNR to about 500 and also removes any k-space updating order from actual data acquisition. K-space resampling of region **A** always starts with a portion of current frame and then to portions of corresponding later frames defined by the updating pattern (centric, linear, random, etc). For remaining figures, portion of region **A** [PA = (diameter of **A**) / (edge length of k-space)] is fixed at 0.25 Full **B** region k-space data were always obtained from current frame (k-space data of **B** region were obtained no later than those of **A**) unless otherwise indicated.



Myometrium represents one of the fastest CR enhancing tissues in the body except blood. **Fig. 2a** plots a myometrium ROI (shown in **Fig. 3a,** yellow) time-course for the original smoothed image (magenta), and those from the reconstructed images of the centric (blue), linear (red), and random (black) approaches. The temporal footprint is 7.47 s (9 frames). Time course from images reconstructed from the 9 frame k-space averaged data is shown in green. The time-courses largely differ only by a time shift mostly defined by when the central k-space line was sampled. Time-shifting every signal intensity curve accordingly to when the central line k-space sampling occurred indeed removes most of the difference between sampling strategies. This is observed in **Fig. 2b**.

Fig. 3a shows a post-CR DCE image after the numerically smoothing. **Fig. 3b** shows the difference image from that of the centric (temporal footprint 14.1 s, or 17 frames) and the smoothed one (original). Grey scale used for **3b** – **3d** is about 30X more sensitive than that of **3a**. **Figs. 3c** and **3d** display the **3b** equivalent for linear and random approaches, respectively. Except blood flow introduced difference (filled bright dots), most other non-structural patterns are most likely due to k-line "discontinuity" at **A**/**B** boundaries. Using **3b** as an example, all k-space data in region **B** occurred no later than those from **A**. Due to CR introduced signal increase, there will be a small sudden change in some simulated k-lines at the **A**/**B** boundary. This change is likely towards the same direction for **3b** and thus a pattern similar to a low pass filter is seen. A well defined "ring" feature seen in **3c** and **3d** almost matching that of myometrium is due to time difference from center k-space lines. The yellow ROI in **3a** was duplicated in the remaining panels for reference purpose.



Discussion. Our results indicate that for most DCE data where typical SNR < 30, image or time-course difference introduced due to region **A** updating pattern is expected to be buried under noise except for conditions of rapidly changing signal intensity time courses and very long k-space temporal footprint. Center k-space lines define most contrast and thus carry most temporal information for the fast-enhancing time courses. When timing of center k-line can be well defined, time course difference from sampling pattern can be greatly reduced. Minimizing k-space "discontinuity" either occurred at **A/B** boundary or within region **A** (due to 3D acquisition strategy) will help in keeping data acquisition consistent. Phase and amplitude correction can be employed to further correct k-space "discontinuity". For a fully sampled region **A**, no difference is expected for time-invariant signals (DCE baseline images, etc).

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Reference: **1**. Laub, Kroeker, *Magnetom Flash* 3 : 93 (2006). **2**. Song, Laine, Chen, Rusinek, Bokacheva, Lim, Laub, Kroeker, Lee, *Magn Reson Med.* **61**: 1242-1248 (2009).