Leading Edge Fidelity in View-Shared Time-Resolved 3D MRA

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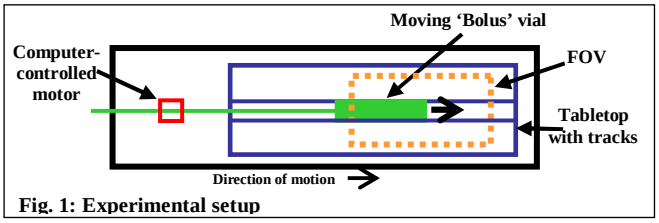

Fig. 1: Experimental setup

Introduction. As the frame rates for 3D time-resolved imaging have increased, there has been growing interest in defining the accuracy with which an image series portrays a dynamic process. Specifically, for contrast-enhanced MRA it is desirable to accurately portray the leading edge of an advancing contrast bolus. Artifactual signal enhancement in a vessel occurring in advance of actual contrast arrival can misrepresent the underlying contrast bolus dynamics. When this occurs in veins it can confound visualization of nearby arteries. Accurate depiction of the leading edge is important for delineation of vascular abnormalities having rapid flow, such as arteriovenous malformations and fistulas. Previous work [1] has shown for 3DFT acquisitions that view orders centric in both the k_Y and k_Z directions provide improved edge sharpness compared to those which are not, and that for a given acquisition method incorporation of parallel imaging provides improved edge sharpness. The purpose of this work is to show how the "anticipation" artifact occurring in advance of the contrast bolus leading edge can be minimized with appropriate ordering of phase encoding views. This is demonstrated experimentally in phantoms and with *in vivo* CE-MRA.

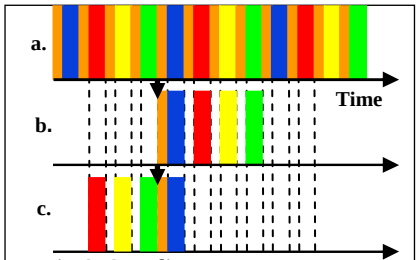

Fig. 2: Sampling pattern

Methods: ***Experimental Setup***: Phantom studies were performed using diluted gadolinium-filled vials (400 mm long, 22 mm inner diameter) that were moved along tabletop tracks by a computer-controlled motor, which provided precise control and reproducibility of motion (Fig. 1). ***View Orders***: The view order studied was Cartesian Acquisition with Projection-Reconstruction like sampling (CAPR) [2], which uses a modified elliptical centric view order and partial Fourier acquisition across the 2D k_Y-k_Z phase encoding plane. The sampling pattern consists of a central circular region in k_Y-k_Z space which is sampled every image update. The annular region beyond this is divided into four groups of vanes, one of which is updated every new time frame; the other three are maintained. ***Reconstruction Method***: When some phase encode views or k-space points are sampled more frequently than others, there is a choice as to which sampling of a redundantly sampled view should be incorporated into the reconstruction. We define the "reconstruction delay" as the number of central samplings acquired after the k-space center used for a given reconstruction. Fig. 2a shows the sampling pattern over time for the CAPR acquisition. Here the orange blocks represent the central k-space region and the other colored blocks represent the four vane sets of outer k-space. Figs. 2b,c show the selection of views used to reconstruct corresponding time frames using the same orange k-space center for Delay 3 and Delay 0 respectively. A Delay 3 (b) reconstruction uses the earliest acquired center for a given full peripheral k-space sampling. A Delay 0 (c) reconstruction uses the most recently acquired center for a given full peripheral k-space sampling. ***Experiments Performed***: Experiments were run at 3.0T [GE Signa] with a 3D GRE sequence with TR/TE = 6.3/2.8 ms, flip angle 30°, BW = ± 62.5 kHz, FOV 40 cm (S/I frequency) x 32 cm (R/L phase) x 13.2 cm (A/P slice), sampling matrix 400 (S/I) x 320 (R/L) x 132 (A/P), 1 mm isotropic resolution. Phantom studies used a bolus velocity of 16 mm/s, similar to that encountered in CE-MRA of the calves. *In vivo* CE-MRA of the calves was done with standard 20 ml contrast dose. All studies were acquired using CAPR and reconstructed with Delays of 0 through 3.

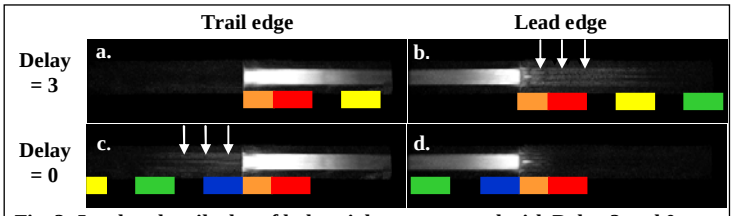

Fig. 3: Lead and trail edge of bolus vial reconstructed with Delay 3 and 0.

Results: Fig. 3 shows images of the leading and trailing edges of the bolus vial for a CAPR acquisition reconstructed with Delay 3 and Delay 0. The k-space sampling pattern over time is matched to longitudinal position and displayed on the images by the colored blocks, the color scheme matching that of Fig. 2. With Delay 3 (a,b) all four vane sets are acquired after the k-space center, while for Delay 0 (c,d) three of the four vane sets are acquired prior to the center. In the Delay 3 reconstruction, the sampling of high spatial frequencies with continued advancement of the contrast bolus leads to extended opacity or anticipation artifact beyond the leading edge (b, arrows). With Delay 0 reconstruction, there is diminished anticipation artifact but an analogous artifact at the trailing edge which we call "persistence" artifact (c, arrow). Thus, there is a tradeoff between anticipation and persistence artifact in choosing reconstruction Delay. Since only the leading edge of the contrast bolus is physiologically relevant in CE-MRA, Delay 0 reconstruction is superior. Fig. 4 shows results from an *in vivo* study acquired using CAPR with 2D SENSE (R = 8) and reconstructed with Delay 3 (a,b) and Delay 0 (c,d). To study the depiction of the contrast bolus leading edge and the character of signal when it first appears in a given vascular segment, the Delay 0 and Delay 3 frames shown were reconstructed using the same four sections of the peripheral k-space, in which the temporal footprints are aligned in time. Different samplings of central k-space were used. The continuity and crispness of the vessels when signal is first apparent in a given vascular segment is greatly improved for Delay 0 reconstruction (c,d). The signal in the Delay 3 reconstruction is solely due to the sampling of high spatial frequencies. Thus, continued sampling of high spatial frequencies beyond the sampling of central k-space generates anticipation artifact, discontinuous appearing vessels, and uncertainty in the true extent of contrast bolus travel at a given time. Although not shown here, reconstruction using even a later central k-space with Delay -1 led to degradation in spatial resolution in the plane transverse to bolus motion.

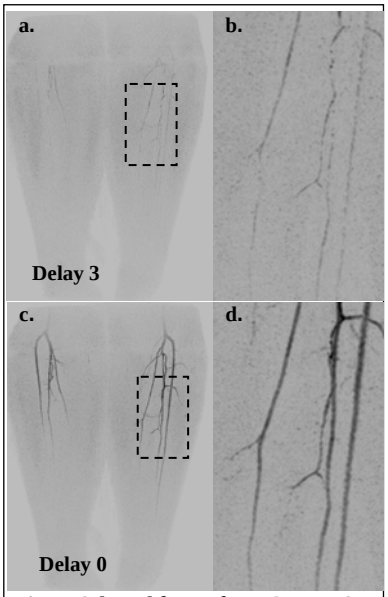

Fig. 4: Selected frame from CE-MRA calf study reconstructed with Delay 3 and 0.

Conclusions: Reconstructing time-resolved data sets using predominantly high spatial frequency data acquired before the central k-space region for that update allows for decreased anticipation artifact and crisper images, as borne out *in vivo*. This allows for more accurate depiction of the contrast bolus leading edge, higher fidelity representation of contrast bolus dynamics, and more accurate time-of-arrival estimation.

References: [1] Mostardi PM, 2008 ISMRM #3611; [2] Haider CR, MRM 60:749(2008)