Controlled Experimental Study Depicting Moving Objects in View-Shared Time-Resolved 3D MRA

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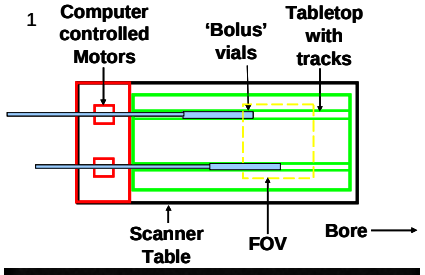
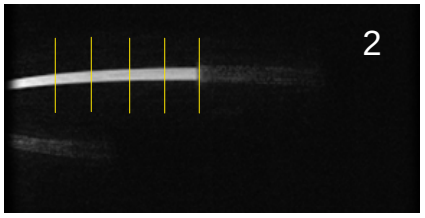
Introduction: A variety of methods have been used for time-resolved contrast-enhanced MRA (CE-MRA), many involving view sharing [1,2,3]. When central k-space is updated more frequently than non-central k-space, the net image frame rate is higher than the intrinsic image acquisition time. However, it is not always clear to what extent the resultant image time series truly represents the dynamic behavior of the object of interest. Although simulations can be used to estimate various aspects of performance [4], an experimental study can allow more realistic characterization. The purpose of this work was to develop and use a computer-controlled motion phantom for study of the fidelity with which 3D time-resolved sequences can portray dynamic phenomena. This allowed determination not only of such properties as ghosting, blurring, and undesired vascular enhancement, but also the fidelity of portraying a rapid influx of contrast into a vessel as well as the smooth passage of contrast across an extended field of view. These studies helped to identify desirable characteristics of a pulse sequence used for time-resolved studies.

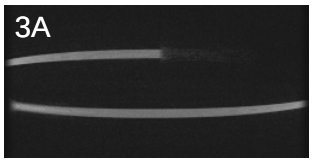
Methods: ***Experimental Setup***: Studies were performed using diluted gadolinium-filled vials (400 mm long, 22 mm inner diameter) that were moved along tabletop tracks by a computer-controlled motor (Figure 1). The vials were connected to rods that were driven using a stepper motor, which provided precise control and reproducibility of motion. A computer program designates a start position for the rods and a travel velocity. For each experiment, the motion of the vials was manually triggered with the initiation of the pulse sequence.

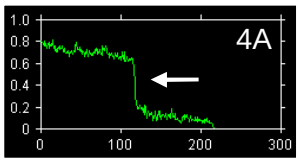
Pulse Sequences: Three pulse sequences were implemented, each of which samples a k-space center R1 and an outer region R2, which is divided into N groups. For each image update, R1 is sampled as well as one group of R2. Cartesian sampling is used in all sequences. Sequence 1 is Cartesian projection reconstruction (CAPR) [3] which uses a modified elliptical centric view order and partial Fourier acquisition across the 2D k_Y-k_Z phase encoding plane. R1 is a center ellipse and R2 is the outer region divided into N groups of vanes that are asymmetrically sampled. Sequence 2 (S2) is centric in the k_Y-k_Z phase encoding plane. R1 is a center ellipse and R2 is divided into concentric circles of equal area about the center. Sequence 3 (S3) is centric in k_Y only. R1 is a rectangle sampled sequentially and R2 is composed of N groups of two rectangles on either side of the origin that consecutively increase in distance from the center. When comparing sequences N varied between them as the image update time was held constant.

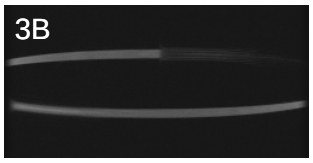
Experiments Performed: Experiments were typically run at 1.5T (GE Medical Systems) with scan parameters: 3D fast spoiled gradient echo sequence with TR/TE = 7.8/2.5 msec, flip angle 30°, FOV = 40 cm, BW = ± 62.5 kHz, sampling matrix 256 (S/I frequency) x 128 (A/P phase) x 64 (R/L slice). To assess the ability of a target acquisition sequence to depict linear motion and portray the leading edge of a contrast bolus, each sequence was used to acquire continuous images as the vials in the above design were moved through one FOV (40 cm). To test whether the CAPR sequence accurately portrays continuous linear motion, it was used to acquire images with the phantom speeds of 1.8mm/sec, 2.8mm/sec, and 3.8mm/sec. The image sequences were analyzed to find the bolus leading edge at each frame, defined as where signal intensity first reaches 75% of the maximum signal in that frame (Figure 2). The location of the leading edge was plotted against time to compare actual phantom speed to the captured speed. CAPR was then compared with other view sharing methods S2 and S3 in motion phantom experiments at a speed of 3.8mm/sec (Figure 3). Leading edge position analysis was performed as above, and the sharpness of the leading edge was compared by taking a line profile along the central axis of the bolus vial (Figure 4). To explore the effects of increased temporal resolution with parallel imaging we compared CAPR (N=4) without SENSE and with a 2D SENSE acceleration of 5.3 at a bolus speed of 16mm/s.

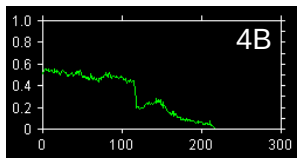


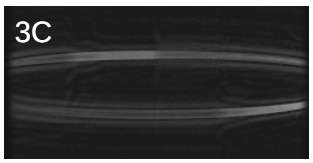


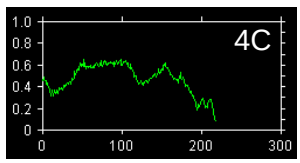




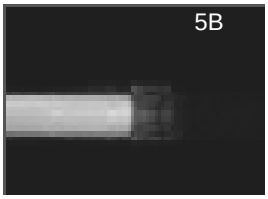








Results: In all of the figures the vials are moving left to right. Figure 2 shows one frame from a CAPR acquisition with vertical lines depicting the location of the leading edge at all previous frames up to the present. The equal spacing means that CAPR accurately portrayed linear motion. S2 also accurately portrayed the bolus travel but S3 showed nonuniform spacing between edges. These results indicate that linear depiction of motion is dependent on the consistency of the sequence in sampling the center of k-space for all timeframes. Figure 3 shows one frame from each of three different view orders: CAPR (A), S2 (B) and S3 (C). The lower vial can be considered to be an artery and the upper vial the corresponding vein. The CAPR sequence shows the least amount of leading edge artifact and 'venous' signal enhancement, indicating that it provides venous suppression due to its inherent centricity. Figure 4 shows line profiles along the central axis of the bolus. The sharpness of the bolus leading edge is excellent for CAPR (A, arrow) but is progressively degraded for S2(B) and S(3), corresponding to the increasing temporal footprints of these sequences. The greater extent of the leading edge artifact is due to the longer time period over which high frequency data are acquired as the bolus continues to advance throughout the sampling period. CAPR also shows increased signal compared to the other sequences due to its centricity and consistent coverage of k-space. Figure 5 shows results obtained using bolus motion at 16 mm/s without (A) and with (B) SENSE and depicts enlargement of the leading edge of the bolus. Increased bolus speeds lead to increased blurring artifact due to the long image update time relative to the speed of motion. When SENSE is applied there is decreased blurring and a sharper leading edge due to reduction in image update time and footprint while maintaining k-space coverage.



Conclusions: A computer-controlled phantom can be used to carefully characterize the experimental performance of pulse sequences used for time-resolved 3D CE-MRA. Consistency of view ordering within each reconstruction frame causes uniformly moving objects to appear as such (Fig. 2). Centricity in both k_Y and k_Z provides the desirable features of sharp and focused portrayal of the leading edge of a contrast bolus (Fig. 4A) and diminished intensity of late-enhancing vessels such as veins (Fig. 3A). These properties are intrinsic to the CAPR sequence. 2D SENSE acceleration provides improved performance (Fig. 5).

References: [1] Korosec FR, MRM 36:345(1996) [2] Fink C, IR 40:40(2005) [3] Haider CR, 2007 ISMRM #3117. [4] Huang Y, MRM 58:316(2007)