

Method for High Spatial Resolution of Proximal Stations in 3D Time-Resolved Fluoroscopically-Triggered Bolus Chase MRA

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Introduction: Bolus chase 3D contrast-enhanced MRA of the peripheral vasculature requires both rapid k-space sampling and precise timing of table motion to achieve high spatial resolution throughout an extended field-of-view while avoiding venous contamination at the lower extremities. Bolus chase methods typically guide table motion based on an estimate of the time for the contrast bolus to reach the most distal station, which is usually determined using a separate test injection of contrast. A potentially more accurate approach is to use MR fluoroscopy to trigger table motion in real time [1]. MR fluoroscopy has traditionally used low resolution 2D images with frame times as short as 1.0 sec to provide precise triggering [2]. However, given the time constraints in bolus chase MRA, it is desirable that the fluoroscopic images themselves be used for diagnostic purposes. This requires generation of 3D images with both high (1.0 mm isotropic) spatial resolution and short frame times. However, achieving frame times even as short as 2.5 sec is challenging. To date this has only been achieved using a high degree of view sharing with an extended temporal footprint of 20 sec or more, which is often longer than the time available to image a proximal station. As a result, there is often loss in lateral sharpness of vessels due to incomplete sampling of the k_y - k_z phase encoding plane. In this work a modified CAPR-based fluoroscopic acquisition is described which maintains the 2.5 sec frame time while significantly reducing the temporal footprint, thereby improving the lateral sharpness of vessels in proximal stations by allowing more rapid sampling of the phase encoding plane. In vivo calf arteriograms from calf-foot studies demonstrate the high quality that can be obtained using the technique while rapidly generating time frames within a limited acquisition time window.

Methods: The CAPR time-resolved acquisition strategy [3] allows flexible tradeoff of spatial and temporal resolution by adjustment of the sampling pattern in the k_y - k_z phase encoding plane. Single-station CE-MRA CAPR studies of the calves have used a view share factor of $N=4$ (N_4) with a large center region [4]. In combination with 8x 2D SENSE and 1.8x 2D homodyne, these exams yield 1.0 mm isotropic resolution, a 5.0 sec frame time, and a 17.7 sec temporal footprint. In comparison, arteriograms with the same spatial resolution can be imaged with a shorter 2.5 sec frame time by doubling the view share factor to N_8 and halving the center size, but these alterations come at the cost of an increased temporal footprint of almost 20 sec and potential homodyne errors [1]. We call this the reference N_8 CAPR acquisition.

In this work, simulations and phantom experiments were used to assess the spatial and temporal effects of altering the CAPR center size and view share factor for imaging of the calves. The center size, shown as the orange regions in Figs. 1A-B, can be reduced to decrease the scan time. If the time reduction is utilized to shorten the temporal footprint, then the k_y - k_z phase encoding plane can be sampled more rapidly. Such a center reduction has both favorable and unfavorable consequences: (i) less time is required to image vessels sharply while maintaining a short frame time; (ii) less lowpass signal power sampled per frame will increase temporal blur and reduce the signal of individual frames; and (iii) a small center can preclude accurate homodyne reconstruction. In this work, a small center size was selected such that, compared to an acquisition with zero center samples, only 250 ms was added to the frame time while providing sufficient lowpass signal power unique to each frame to limit temporal blur.

In vivo calf CE-MRA exams were used to compare the reference N_8 CAPR acquisition having 188 center views (Fig. 1A; 2.41 sec frame time; 18.2 sec temporal footprint) to a new N_5 CAPR acquisition with 44 center views (Fig. 1B; 2.46 sec frame time; 12.1 sec temporal footprint). Eight healthy volunteers were imaged using an IRB-approved protocol, the first four with N_8 CAPR and the second four with N_5 CAPR. The studies were part of a two-station calf-foot bolus chase protocol. Only the calf station was considered for this study. Exams were done on a 3.0T GE Signa imaging system with a fast coronal GRE sequence. Typical calf station scan parameters were: FOV = 35 x 31.2 x 13.2 cm³; sampling matrix = 400 x 312 x 132 (0.88 x 1.0 x 1.0 mm³); TR/TE = 5.7/2.6 ms; 8x (4x2) 2D SENSE; and contrast injection of 20 mL Multihance followed by 20 mL saline at 3 mL/sec. The N_8 and N_5 CAPR acquisitions were reconstructed using 2D homodyne and zero filling, respectively.

Results: Targeted maximum intensity projections (MIPs) of calf arteriograms for two volunteers are shown in Figures 2A and 2B using the N_8 and N_5 CAPR acquisitions, respectively. After five frames with contrast, all of k -space had been sampled using the N_5 acquisition compared to only 5/8 of k -space with the N_8 acquisition. The improved sharpness of the fifth N_5 CAPR frame (B5) is evident versus that for N_8 CAPR (A5). This was confirmed by line profile analysis. The other volunteer results are similar.

Conclusion: We have demonstrated how 3D images of the calves can be generated which simultaneously have: (i) spatial resolution finer than 1.0 mm isotropic; (ii) a frame time of 2.5 sec; and (iii) a temporal footprint of only 12.1 sec. We believe the acquisition technique can form the basis of real-time multi-station exams having unprecedented spatial and temporal resolution as well as precision in triggering table motion to track the advancing contrast bolus in real time.

References: [1] Johnson CP, et al. MRM (2010) 64:629-637. [2] Riederer SJ, et al. Radiology (2000) 215:584-593. [3] Haider CR, et al. MRM (2008) 60:749-760. [4] Haider CR, et al. Radiology (2009) 253:831-843.

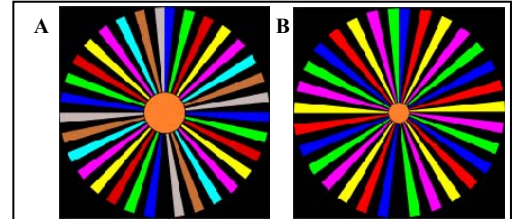


Figure 1: Plots in k_y - k_z space of CAPR sampling patterns used in this work with view share factors of (A) $N=8$ and (B) $N=5$. The N_5 pattern has a small center to reduce the temporal footprint.

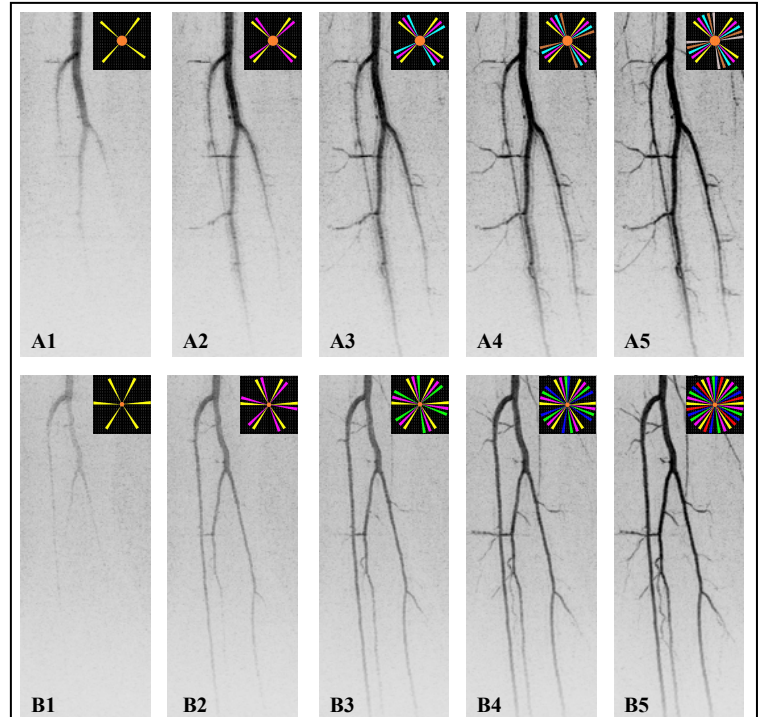


Figure 2: Targeted calf MIPs comparing five consecutive frames of two volunteers acquired with (A) N_8 and (B) N_5 CAPR. Both acquisitions have the same ~2.5 sec frame time and lateral spatial resolution. The N_5 acquisition has a shorter temporal footprint (12.1 vs. 18.2 sec) allowing more rapid sampling of the phase encoding plane, as indicated by the inset CAPR patterns illustrating the extent of view sharing after contrast arrival and manifest by the improved vessel sharpness seen shortly after contrast arrival.