Highly Accelerated (>10x) Parallel Acquisition for 3D Time-Resolved CE-MRA of the Calves

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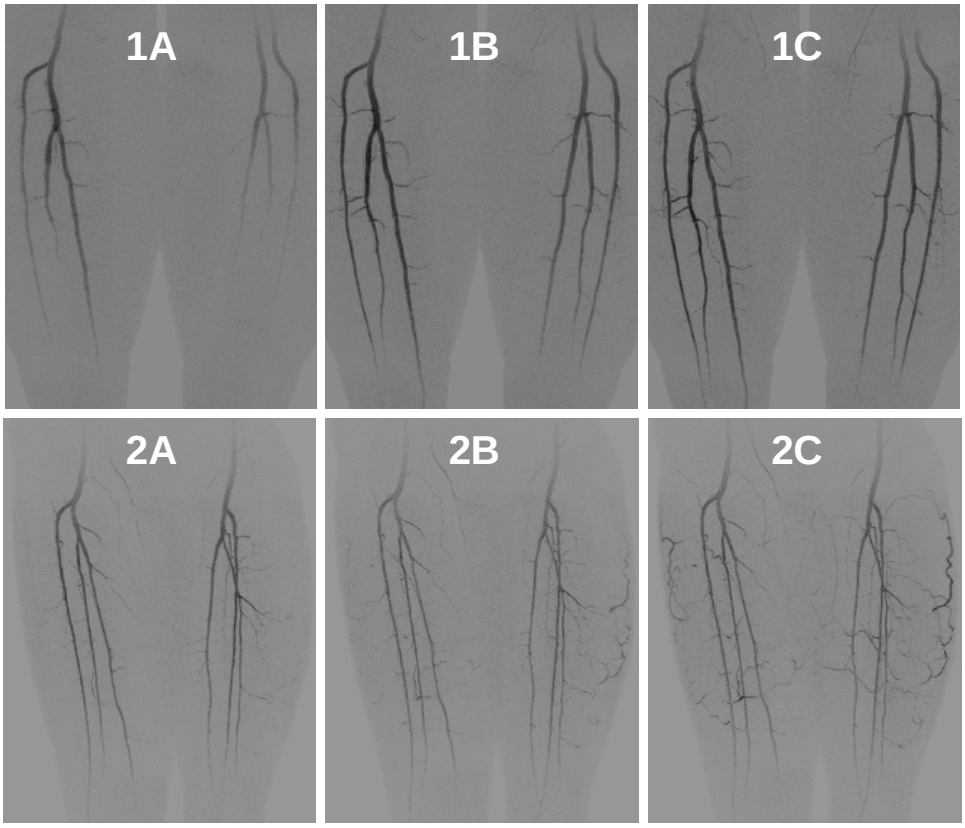
INTRODUCTION: Time-resolved imaging of the peripheral vasculature ideally allows accurate visualization of contrast dynamics. However, the high spatial resolution required to clearly portray the small vessels of the calves requires long acquisition times. Various methods using view sharing [1,2,3] provide image update times in the range of five to seven seconds, however, these methods still require data acquisition over an extended duration, typically well over one minute. Parallel imaging has also been used for peripheral MRA, but as in neurovascular applications the acceleration has generally been performed along only one direction, with acceleration factors limited to no higher than 3X to 4X [4,5,6]. The purpose of this work is to describe how 2D SENSE with 2D homodyne processing can be applied to peripheral MRA to provide an order of magnitude (>10X) reduction of acquisition time. When additionally incorporated with a Cartesian-based view sharing method, CAPR [7], the result is a method providing both high spatial and high temporal resolution. It is hypothesized in this work that a 2D SENSE-accelerated CAPR acquisition can provide a time series of diagnostic quality, 1 mm^3 isotropic spatial resolution images of the lower legs with 5 sec update times and 20 sec image acquisition times.

METHODS: Formation of a 1 mm^3 isotropic resolution image over the targeted field of view (40 S/I x 32 L/R x 13.2 A/P, all in cm) without any acceleration requires an acquisition time on the order of four minutes. The CAPR method: (i) incorporates 2D SENSE over the k_Y x k_Z phase encoding plane; (ii) allows an additional 1.6 – 1.9x undersampling via 2D homodyne (HD) reconstruction; and (iii) employs view sharing with an elliptical centric readout to provide image updates more frequently than the total acquisition time per image or "temporal footprint." This was adapted to CE-MRA of the calves by using 2D SENSE with an acceleration $R = R_Y \times R_Z = 3.67 \times 2 = 7.33$. This factor is just shy of the limit imposed by the eight elements of the receiver coil. A further 1.83 x reduction using HD yielded a net acceleration of 13.4 using k-space undersampling. View sharing caused a modest increase of the temporal footprint to 20 sec while allowing 5 sec image updates.

The CAPR sequence as described was used in CE-MRA studies of the lower legs of four volunteers using a fast GRE sequence, GE 3.0T (V14.0) scanner and a custom eight-channel leg array, with parameters: TR/TE = 5.85/2.7 ms, flip angle 30°, BW = ±62.5 KHz, coronal acquisition with FOV 40 (S/I) x 32 (L/R) x 13.2 (A/P) cm^3, and sampling matrix of 400x320x132 yielding 1 mm^3 acquired voxels. The receive coil consisted of eight identical elements, each 21.5 x 14.3 cm^2, placed circumferentially around the lower legs. This configuration provides both uniform coverage and optimal sensitivity profiles for SENSE reconstruction, however, the limited S/I coverage of this prototype caused signal dropout limited to the distal portions of the 40 cm S/I FOV. 7.3x 2D SENSE was used to reach the desired 5 second image update time and 20 second temporal footprint. A 1x2x2 mm^3 calibration scan was acquired prior to the injection of 20 mL of Multihance® contrast at 3 ml/sec + 20 ml saline at 3 ml/sec.



RESULTS: Figure 1 shows a time series of A/P maximum intensity projections for Volunteer 1 with 5 seconds between each image. Fig 1A shows an early arterial frame and the arterial phase continues to fill in for the next 10 seconds in frames (B) and (C). Even given the 20 second temporal footprint, no venous contamination is visible in these arterial frames.

The isotropic resolution can also be appreciated in a similar time series of 45° maximum intensity projections with 5 seconds per frame for Volunteer 4, Figure 2. Fig. 2A is the last clear arterial frame. This volunteer exhibited more rapid and pronounced superficial venous enhancement, but clear arterial frames were captured along with progressive venous enhancement visible in Fig 2B and C.

DISCUSSION: The high vessel conspicuity, sharpness of resolution, and absence of venous contamination during the arterial phase, as observed in all four volunteer studies, are taken as proof of the hypothesis. In spite of the fact that the net 2D SENSE – 2D HD acceleration factor is greater than 13, the resultant images are not seriously limited in SNR. This is a consequence of several factors. One is the improved robustness of 2D vs. 1D SENSE at a given acceleration. A second factor is the coil array used, which had elements placed circumferentially around the legs, thereby leading to distinct coil sensitivities and well-conditioned linear equations for the SENSE inversion. A manifestation of this was the low g-factors, with mean values less than 2. Finally, another factor is the intrinsic SNR robustness occurring when 2D SENSE is applied to elliptical centric CE-MRA [8]. The level of performance observed in this work suggests that even higher acceleration factors will still provide image quality which readily allows diagnosis.

In summary we have demonstrated the robust nature of highly accelerated (>10X) CE-MRA of the lower legs. 2D SENSE-accelerated CAPR provides time-resolved imaging with high, 1 mm^3 isotropic resolution which can readily distinguish arterial from venous phases with a temporal footprint no larger than 20 seconds.

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