Cartesian Acquisition with Projection-Reconstruction-Like Sampling (CAPR): An Optimum Sequence for Time-Resolved CE-MRA

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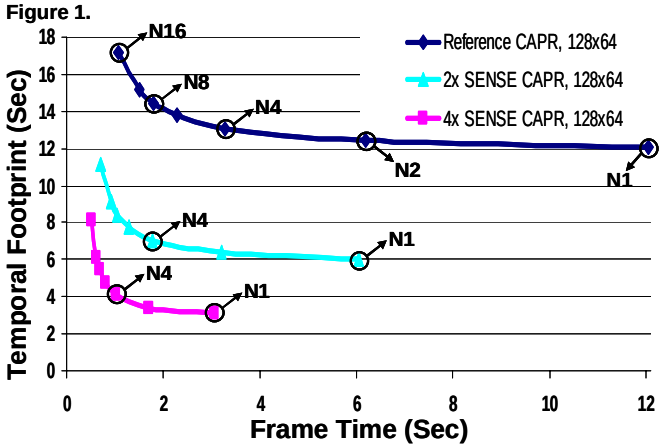
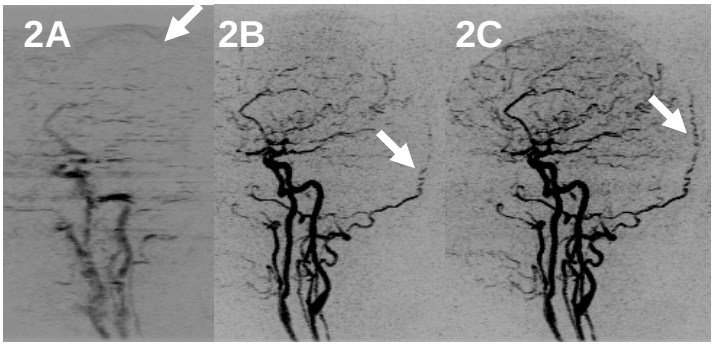
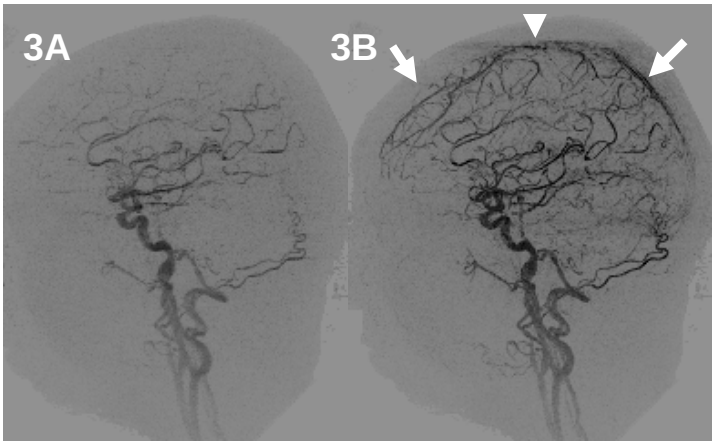
Introduction: A variety of methods have been proposed for 3D time-resolved contrast-enhanced MRA. Many of these are based on view sharing [1], in which the k-space center is updated more frequently than peripheral k-space. Although such methods can generate a time series in which the image contrast changes, the temporal fidelity of these methods in portraying a dynamic phenomenon is not always obvious. More recently, these have been coupled with acceleration techniques for providing reduced acquisition times [2,3]. In addition, many such techniques reach practical limitations as: the acceleration along a single direction becomes poorly conditioned, the autocalibration size becomes burdensome, or heavy use of view sharing results in temporal averaging. The purpose of this work is to describe the incorporation of 2D SENSE acceleration into a view-shared acquisition, yielding a time-resolved sequence which has a high level of: consistency, centricity, temporal fidelity, and SNR robustness. We apply this to high resolution time-resolved imaging of the intracranial vasculature.

Methods: ***Description of Sequence***. This work is an enhancement of a Cartesian acquisition with PR-like sampling (CAPR) discussed previously [4] in which the k_Y-k_Z phase encoding plane is apportioned into a central, fully-sampled zone and an annular region comprised of multiple sets of vanes with unsampled intervening sectors. Acquisition is done by sampling the central zone followed by one set of vanes, repeat sampling of the central zone, a second set of vanes, etc. The image reconstruction rate matches the sampling rate of the central zone. An individual image is reconstructed from one sampling of the central zone and subsequent sampling of a complete set of vanes. Data in the unsampled regions are estimated by 2D homodyne reconstruction. ***Temporal Footprint vs. Frame Time.*** The temporal footprint can be defined as the time over which any data used for image formation are acquired. When view sharing is performed by sub-dividing the vanes into an increased number of sets, designated N1, N2, ..., the frame time is smaller than the footprint, a relationship shown in Figure 1. As the degree of view sharing is increased the temporal footprint increases while the frame time decreases, corresponding to leftward motion along any curve in the figure. ***2D SENSE***. 2D SENSE acceleration can be incorporated into the CAPR acquisition decreasing both the footprint and the frame time, creating distinct curves in Fig. 1; each curve moves closer to the origin as the SENSE acceleration is increased. In this work a factor as high as 5.33 (2.67 x 2) was used. ***Experimental Studies***. The CAPR sequence was studied *in vivo* with two specific hypotheses. The first hypothesis (H1) was that for two view-shared sequences having equal frame rate and equal spatial resolution, the sequence with smaller temporal footprint will exhibit better arterial venous separation and higher temporal fidelity. Elliptical centric ordering was used and both sequences had an image update time of just over 1 sec. This hypothesis was tested in five volunteers imaged twice with no less than two days between the imaging sessions, once with a 16 sec temporal footprint sequence and once with a 5.3-fold SENSE accelerated 3 sec temporal footprint sequence. The second hypothesis (H2) was that high quality intracranial arterial phases clear of venous contamination can be obtained with temporal footprints as short as 12 seconds and image update times of 1-3 seconds using 5.3-fold 2D SENSE. This was evaluated in six volunteers.

Figure 1.







Results: Testing of H1 showed that the short temporal footprint sequence was markedly superior ($P < 0.05$) for arterial to venous separation as well as for ringing and ghosting image artifact ($P < 0.05$). An early arterial frame from the 16 second temporal footprint sequence is shown Figure 2A and the venous contamination is marked by the arrow. The angiogram is of poor quality due to the extended temporal footpint. The same arterial frame for the 3 second temporal footprint is shown in 2B and the next arterial frame in 2C. Both sequences had acquired spatial resolution of 1x2x2 mm^3. As a consequence of its consistency, the portrayal of a uniformly moving object by the CAPR sequence is uniform. This is highlighted anecdotally by the arrows in Fig. 2 (B-C) showing progressive filling of the right occipital artery. Figure 3A shows a 1 mm^3 isotropic arterial frame of the 12 second sequence. The absence of venous contamination demonstrates H2. Finally, the necessity of centric encoding is shown in Fig. 3. The same high spatial frequency vanes were used in both A and B. Only a later central region, within the same temporal footprint as A, was used in the reconstruction of B, resulting in undesirable venous contamination shown by the arrows.

Conclusions: The CAPR sequence combines the desirable characteristics of: (i) consistency – the distribution of phase encoding views is identical for all time frames; (ii) centricity – centric view ordering is employed for all time frames, allowing arterial phase images devoid of venous enhancement; (iii) temporal fidelity – provided by the short temporal footprint; (iv) high SNR – 2D SENSE acceleration factors exceeding 5 can routinely be used while retaining diagnostic quality. This combination of features has to date not been shown for any time-resolved sequence. The result is that whole brain images of the arterial and venous vasculature can be attained with 1 mm isotropic resolution with a high temporal fidelity heretofore not demonstrated with existing MRA techniques.

[1] Korosec FR, et al. MRM, 1996. [2] Frydrychowicz A, et al. MAGMA, 2006. [3] Cashen TA, et al. AJNR, 2006. [4] Haider CR, et al. 15th ISMRM, 2007, #3117.