The Application of Acceleration Techniques for High Spatial and High Temporal Resolution Extra- and Intracranial Contrast-Enhanced MRA

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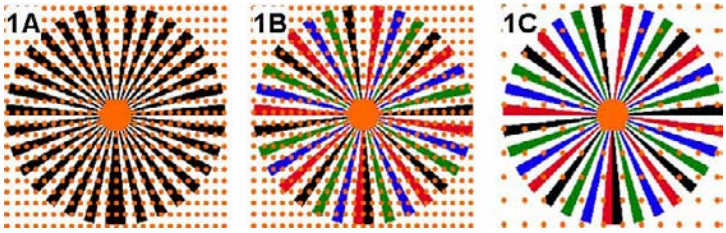
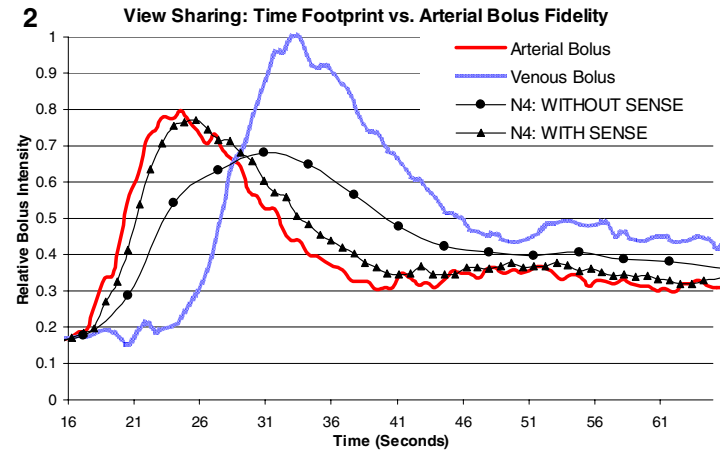
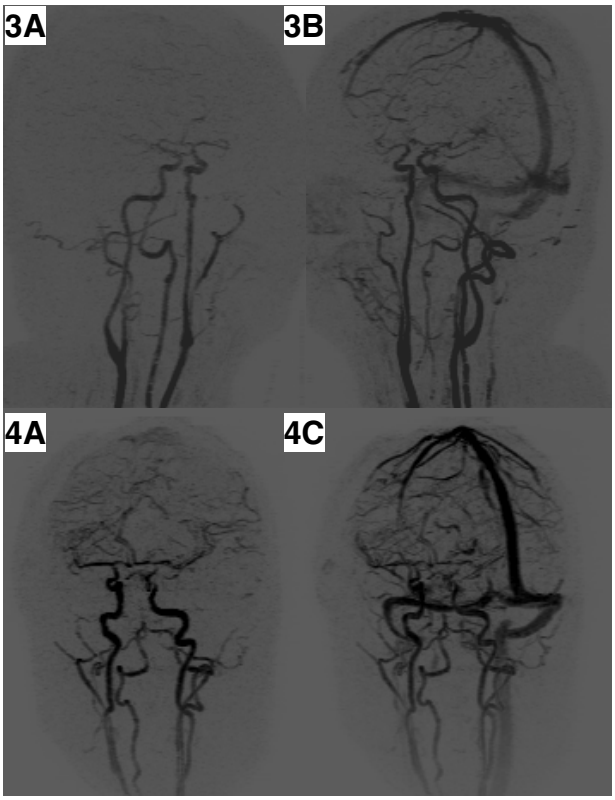
Introduction Functional imaging of contrast bolus dynamics, in additional to morphological imaging, plays a key role in the diagnosis of vascular diseases. This has been highlighted by the many recent technical advances in time-resolved imaging [1-3]. However, a performance limitation of any time-resolved technique is the tradeoff between spatial resolution and the image update rate (IUR). To improve the IUR, view-sharing (VS) has been frequently used. However, increased acceleration from VS results in an extension in the time over which data used to reconstruct a given frame are taken [4]. As an alternative, the application of 2D partial Fourier (PF) and 2D parallel imaging, SENSE, techniques [5], can offset this and effectively provide a net reduction in the acquisition time required per frame. The central result is a reduction in the temporal blurring and improved representation of the dynamic phenomenon being imaged, i.e. the temporal resolution is improved. In this work, we hypothesize that the synergistic combination of VS, 2D PF, and 2D SENSE can be exploited to achieve both high temporal and spatial resolution. Numerical and experimental results are demonstrated in time-resolved intracranial contrast-enhanced 3D MR angiography (CE-MRA).



Methods ***Pulse Sequence.*** Fig. 1A schematically shows the k-space sampling in the k_Y-k_Z (phase-slice) encoding plane of a modified reverse elliptical centric acquisition that employs 2D PF [6]. While the central region (orange) is fully sampled, the outer annulus of vanes (black) is asymmetrically sampled across the k_Y and k_Z axes. Non-sampled vanes (white) are compensated by homodyne reconstruction. The points in the overlaid orange grid which intersect the black pattern represent the full echoes along the frequency encoding direction that are acquired. Next consider in Fig. 1B conversion to a time-resolved sequence by dividing the outer annulus into four (N4) groups. The eight red vanes are acquired first, followed by the orange central region. At this point, a reconstruction is performed. Next, the eight blue vanes are sampled, followed by re-sampling of the orange central region. Subsequently, another reconstruction is performed. The cycle continues for the green and black vanes and then repeats starting again with the red vanes. The orange central region is freshly sampled prior to each reconstruction point. Finally, Fig. 1C schematically shows the sampling if R = 4 2D SENSE is additionally applied within the k_Y-k_Z plane. This increases the sampling distance in each direction, improves the IUR, and reduces the overall acquisition time.



Phantom Simulation and In Vivo Studies. To assess the fidelity with which the sampling patterns portrayed enhancing blood vessels, a numerical phantom was designed which contained an artery and vein, each 1.5 cm in diameter, running along the readout direction. The assumed signal within each vessel was based on enhancement patterns measured independently at high temporal resolution, as shown in Fig. 2 as the solid curves. The assumed bolus within the artery was then sampled using the assumed sampling patterns and time ordering of Figs. 1B-C, the peak signal within the vessel reconstructed, and the result compared with the original arterial signal. The 2D SENSE-PF-VS sequence was also evaluated in time-resolved studies of the intracranial vasculature in 22 volunteers at 1.5T and 3T field strengths (GE Medical Systems, Excite) using various combinations of VS and SENSE accelerations. Typical scan parameters include a 3D fast spoiled gradient echo sequence with a repetition time/echo time of 3.8/2.0 msec, flip angle 30°, FOV = 25 cm, BW = ±62.5 kHz, sampling matrix 256 (S/I frequency) × 48-78 (A/P phase) × 32-74 (R/L slice). 2D SENSE accelerations ranged from 4× to 5.3× with reconstructed voxel sizes between 1 and 8 mm^3. Image update rates were between 0.64 and 1.75 sec. For each study, 19 ml of Gadolinium contrast agent (Multihance) was injected at 3 ml/sec followed by 25 ml of saline at 2 ml/sec. All image reconstructions were performed on a 16 processor Mercury reconstruction system in real-time.



Results Note in Fig. 2 that for the same spatial resolution the SENSE acquisition provides marked improvement in the fidelity of portraying the arterial bolus vs. the non-SENSE case. Specifically, the temporal behavior more closely tracks the arterial enhancement, and there is negligible blunting of the peak signal. This is because the time window over which data are acquired is much shorter for the 2D SENSE case (3.2 vs. 7 seconds). Sample *in vivo* results at 1.5T (Fig. 3) using R = 5.3x 2D SENSE show excellent enhancement and spatial resolution of the carotid arteries bilaterally and no venous filling. Results in a different subject at 3.0T (Fig. 4) clearly distinguish the intracranial arterial phase (A) from the early venous phase (B) reconstructed four timeframes (3.2 sec) later.

Conclusion Incorporation of R=5.3x 2D SENSE and 2D partial Fourier techniques into time-resolved acquisition allows whole brain imaging with 1mm x 2 mm x 2mm resolution, 0.8 sec frames rate, and 3.2 sec acquisition time.

References [1] Korosec FR, MRM, 1996. [2] van Vaals JJ, JMRI, 1993. [3] Mistretta CA, MRM, 2006. [4] Riederer SJ, MRM, 1988. [5] Haider CR, 14th ISMRM, 2006. [6] Madhuranthakam AJ, MRM, 2006.