Whole-Brain 3D Contrast-Enhanced MR Venography with Robust 4 to 8-Fold 2D-SENSE and Sub-mm Spatial Resolution in Approximately 60 Seconds

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INTRODUCTION 3D contrast-enhanced MR venography (CE-MRV) requires sub-millimeter spatial resolution for accurate visualization of the intracranial venous system. Typically, over 120 sagittal slices of 1.0-1.4 mm partition thickness are acquired, with an average in-plane isotropic resolution of 0.8 mm **[1]**. Since the acquisition volume typically encompasses the subject's entire brain, a large sampling matrix is needed to provide coverage at the desired spatial resolution. With a TR of 5-6 ms, a 3D CE-MRV acquisition can take 4-6 minutes. To reduce this, asymmetric readout (partial echo) or phase encoding (partial NEX) has been applied **[2]**. In this work, we hypothesize that 2D-Sensitivity Encoding (SENSE) **[3]** can significantly decrease the duration of a CE-MRV acquisition. 3D CE-MRV represents an ideal candidate for the application of 2D-SENSE, since the full extent of the brain along the anterior/posterior and right/left directions is excited. While the upper limit of SENSE acceleration (R) is bounded by the number of coil elements (N_{COILS}) used during a scan, typical R values are much smaller than N_{COILS} as a consequence of unfavorable coil geometries and SNR. In this work, an eight-element head coil was used. We demonstrate 4×, 5×, 6.4×, and even 8× ($R = N_{COILS}$) accelerations ranging in scan time between 47 and 90 seconds at the 1.5T field in 14 volunteers.

METHODS All volunteer studies were approved by our institution's review board. Examinations were performed on a GE 1.5T Excite 11.0 scanner with a standard GE eight-element head coil (~25 cm coverage). Initial experiments with a brain-mimicking homogenous phantom yielded reasonable maximum SENSE *g*-factors of 1.7, 2.4, 2.7, and 3.0 for 4×, 5×, 6.4×, and 8× accelerations, respectively. A 3D fast spoiled gradient echo sequence was used to acquire sagittal slices with the following parameters: TR/TE = 6/2 ms, flip angle = 30°, full echo, FOV = 25 cm, BW = ±62.5 kHz, sampling matrix 320×320, 1.0-1.4 mm partitions, 124-176 slices, and a truly-acquired voxel size of 0.8×0.8×1.0-1.4 mm. Axes definitions were S/I–readout (X), A/P–phase (Y), and R/L–slice (Z). Data collection followed the elliptical centric view-order. A non-accelerated acquisition with 124 1.4 mm slices required 4 minutes and 20 seconds to complete, while those with 176 1.0 mm slices needed 6 minutes and 20 seconds. In implementing 2D-SENSE, a 2× acceleration was apportioned to the Z-slice axis, while an additional 2×, 2.5×, 3.2×, and 4× speed-up was allotted to the Y-phase axis, resulting in the net 4×, 5×, 6.4×, and 8× scenarios, respectively. For each contrast-enhanced scan, 19 ml of Gd contrast was injected at 3 ml/s followed by 25 ml of saline at 2 ml/s. All SENSE-encoded data sets were reconstructed offline. Reconstructed images were reviewed by two experienced neuro-radiologists and were scored on a 5-point scale based on SNR and vessel conspicuity: (1) non-, (2) marginally-, (3) adequate-, (4) good-, and (5) excellent-diagnostic quality.

RESULTS Figure 1 shows sagittal and axial projections of 4× (a-b), 5× (c-d), 6.4× (e-f), and 8× (g-h) 2D-SENSE reconstructions. The 4× images were acquired with 1.4 mm slices in 90 seconds. The 5×, 6.4×, and 8× images were acquired with a 1.0 mm partitions, requiring 76, 60 and 47 seconds, respectively. In 4 studies, comparison of non-accelerated and 4× 2D-SENSE MRV results demonstrated better enhancement and depiction of small cerebral vessels with the 2D-SENSE technique. Overall, 4× images received an average score of 4.4 (n = 8), 5× results received an average score of 4 (n = 3), a sole 6.4× reconstruction received a 3, and two 8× results scored 1.5 and 3. All 4-5× images were regarded to have excellent SNR, while modest noise amplification was identified in the 6.4× and 8× results, particularly in the region of the skull base. This is mostly due to the high R factors relative to the number of coils (N_{COILS} = 8). In all 14 volunteers, robust 2D-SENSE reconstructed images exhibited no aliasing artifacts, good vessel enhancement with <1-mm resolution, and ample SNR for diagnosis of cerebral venous and dural sinus diseases.

CONCLUSION Whole-brain 3D CE-MRV using 2D-SENSE was successfully implemented with up to 8× acceleration. CE-MRV acquisitions previously requiring 4-6 minutes were completed in 47-90 seconds. Optimum results were obtained using R factors of 4 and 5, yielding venograms that were rated as good to excellent in diagnostic quality. Additional benefits of 2D-SENSE over non-accelerated CE-MRV include higher spatial resolution, improved depiction of smaller cerebral vessels due to a greater portion of the image acquisition being collected during first-pass of the contrast bolus, and inherently decreased artifact and blurring due to subject motion.

[1] Farb RI. Radiology 2003;226:203-209. **[2]** Mermuys KP. Radiology 2005; 234:901-908. **[3]** Weiger M. Magma 2002;14:10-19.

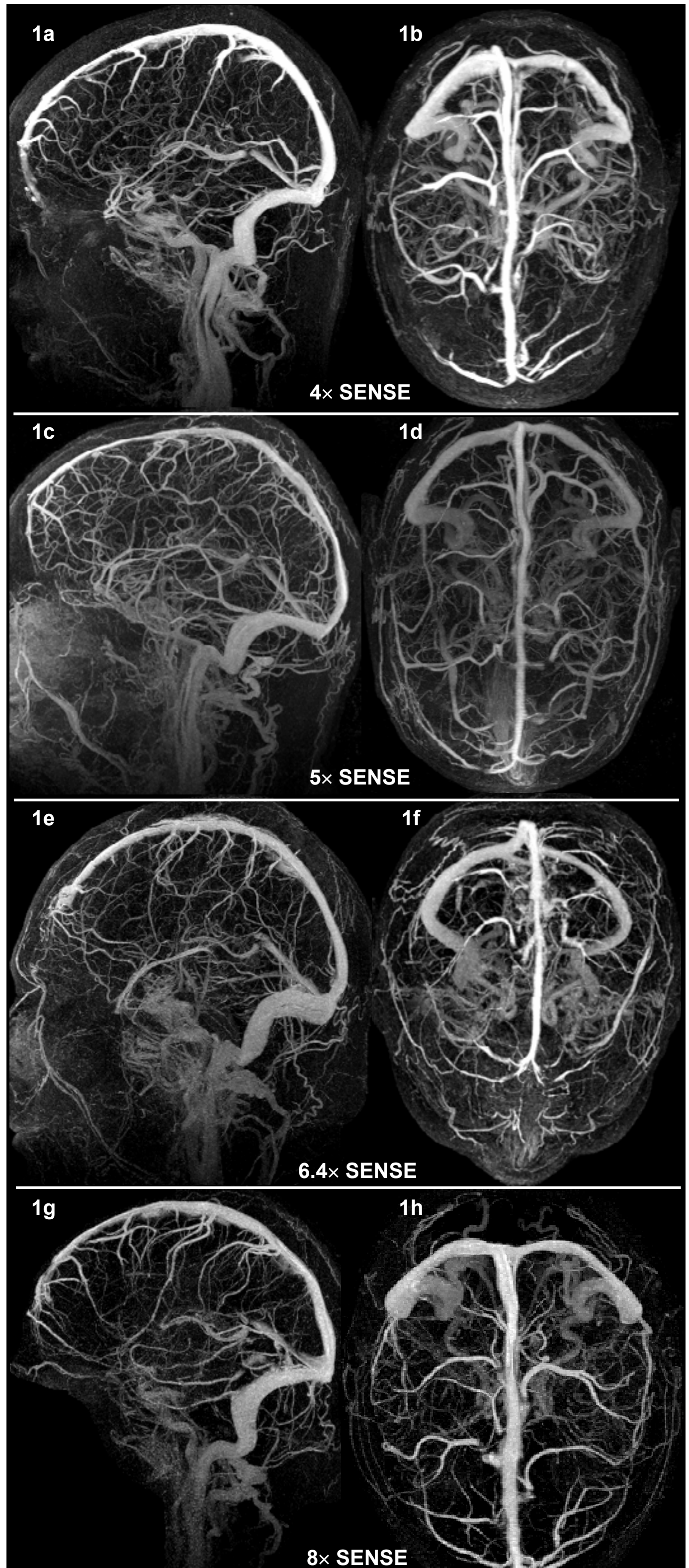

FIG. 1 – 2D-SENSE venograms acquired with 8-element head coil.