Improved Venous Suppression with SENSE in Elliptical Centric Contrast-Enhanced MR Angiography

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Introduction: Venous suppression in 3D contrast-enhanced MR angiography (CE-MRA) remains critical in obtaining high quality angiograms. The elliptical-centric (EC) view order [1] exploits the relationship between low spatial frequencies and image contrast by sampling center k-space during peak contrast in the arteries of interest. By properly initiating the EC acquisition, venous return is solely encoded by high spatial frequencies and venous signals are thus intrinsically attenuated. Previous work [2] related the k-space radius of an EC trajectory to field-of-view (FOV) and showed that the k-space radius corresponding to venous return k_{venous} is inversely proportional to FOV along the phase encoding axes. Therefore, venous enhancement can be limited by minimizing the phase FOVs in a properly triggered EC acquisition.

Sensitivity encoding (SENSE) [3] is a parallel-imaging method that provides scan time reduction or spatial resolution improvement over standard acquisitions. When applied to enhance spatial resolution, SENSE reduces the phase FOVs by an acceleration factor *R*. Consequently, k-space is traversed faster and farther using SENSE, thus sampling higher spatial frequencies. Since the SENSE algorithm inherently requires a factor *R* reduction in FOV, we hypothesized that it not only improves resolution, but further suppresses venous signal in CE-MRA when combined with a properly initiated EC acquisition.

Methods: Figure 1 plots k_{venous} as a function of venous return time post EC sequence initiation using the parameters stated below. In general, as this radius increases the reconstructed venous signal is reduced. The solid line represents the growth of k_{venous} for an EC trajectory with full FOV (*Ry*=*Rz*=1). The dashed line plots k_{venous} for a similar acquisition with SENSE in Y (*Ry*=2). It is evident that when SENSE and EC are applied together, the center of k-space is traversed more rapidly and k_{venous} expands faster than in a similar non-SENSE EC scan. Consequently, k-space is more sparsely sampled with SENSE and EC than with EC alone, and leads to a greater k-space coverage in the same scan time. A flow phantom was designed to test our hypothesis. Four parallel tubes were placed in the center of a GE 1.5T Signa scanner. A water source linked to an electronic contrast injector provided continuous flow and controlled quantities of contrast agent. Two surface coils were placed along the Y axis. A resolution phantom was placed between the tubes. Flow initially enters and exits the imaging FOV through two of the inner tubes (arteries). After a time delay, flow returns to the imaging FOV via the remaining two outer tubes (veins). Gadolinium boluses were used to measure the arterial and venous contrast arrival times of the setup (Figure 2). Six scans were acquired with varying start times of the EC acquisition window (*Tstart*) after contrast injection. For each scan, a non-SENSE and SENSE acquisition were obtained. Coronal slices (X-S/I, Y-L/R, Z-A/P) were acquired using a 3D spoiled gradient echo with TR/TE=8.5/1.6ms, FOVy=30cm, Δz=1.6mm, 256x128x16, scan time = 18 seconds. For SENSE acquisitions, *Ry*=2 was applied, while all other parameters remained the same.

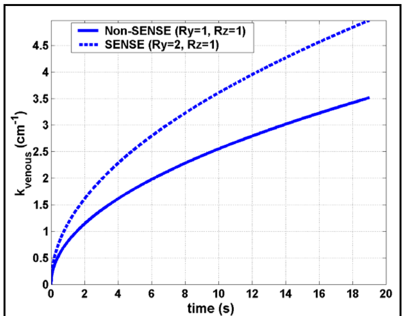

Figure 1: (a) k_{venous} as a function of venous return time for EC trajectory.

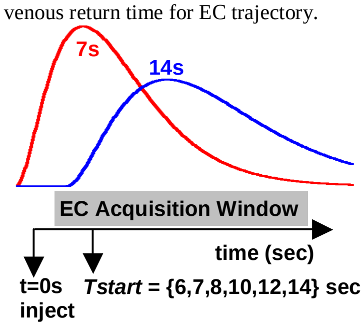

Figure 2: Arterial and venous arrival times of the phantom setup from gadolinium test bolus measurements.

Results: Figure 3 shows MIP images from the phantom experiment for *Tstart*=10s, depicting peak arterial phase in tubes 2 and 3 (white arrowheads). Improvement in spatial resolution is evident in the SENSE image (3b), with the first and second rows of resolution bars (enlarged insets) better resolved vs. those in the non-SENSE image (3a). Veins (tubes 1 and 4) show contrast enhancement in the non-SENSE image. On the contrary, the SENSE image depicts significant venous suppression, especially in tube 4 (dashed box). Figure 4 summarizes venous enhancement (% arterial) as a function of *Tstart* from 6 to 14 seconds. Mean and standard deviations were collected from ROIs throughout vessels 1 and 4. For properly triggered EC scans with *Tstart* values between 6 and 10 seconds, SENSE significantly suppressed venous signal in comparison to corresponding non-SENSE scans (p<0.001). For *Tstart* values beyond 10 seconds, SENSE was unsuccessful at limiting venous enhancement principally because the scan was being initiated at the onset of the venous phase.

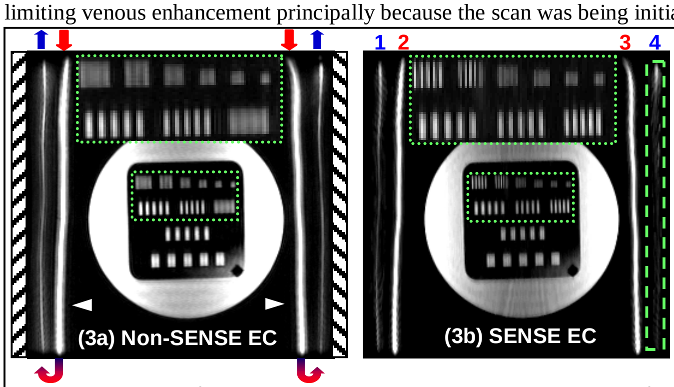

Figure 3: MIP images for *Tstart* =10s. Red and blue arrows denote directional flow of arteries and veins, respectively. Hashed boxes in (a) represent coil placements.

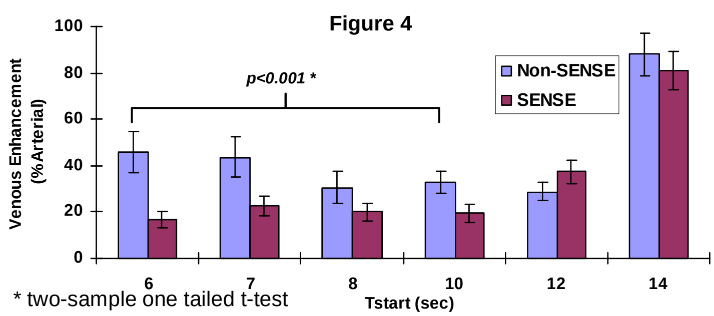

Figure 4: Venous enhancement of non-SENSE and SENSE scans with EC. Superior venous suppression with SENSE is evident for *Tstart* up to 10 seconds.

Conclusion: Preliminary experimental results have shown that SENSE when used in conjunction with a properly triggered EC acquisition can significantly reduce venous signal and improve spatial resolution in CE-MRA when compared to full-FOV, non-SENSE EC acquisitions of the same duration. Since the EC temporal view-order is based on the Euclidean distance of each view to k-space origin, tailoring the phase FOVs and applying SENSE can greatly suppress venous enhancement in CE-MRA. Clinical application of this technique to renal, carotid, and intracranial CE-MRA should be readily feasible.

References: [1] Wilman, et al. Radiol.1997; 205:137-146; [2] Fain and Riederer, MRM 2001; 45:1134-1141; [3] Preussmann, et al. MRM 1999; 45:952-962.