Vessel-Mimicking Mask for Improved Unfolding in SENSE-Accelerated CE-MRA

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Introduction: The intentional exclusion of pixels known to have zero magnetization, a process called "masking," has been shown to reduce the noise amplification of the SENSE unfolding process, preserving signal-to-noise ratio (SNR) [1]. Masking prevents the measured aliased signal from being incorrectly assigned to SENSE-unfolded pixels with known zero signal, thus preserving the measured signal for those pixels with non-zero signal. Masking is particularly beneficial for 3D imaging with application of 2D SENSE [2] since the zero-signal pixels are aliased in two-dimensions, greatly increasing the potential for unfolding errors compared to 1D SENSE.

For conventional masking, the air outside the object under study, which is known to have zero signal, is excluded by segmenting the SENSE calibration image. In this case, the fraction of the masked 3D FOV that has non-zero signal is generally 60% or higher. The rationale for the current work is the recognition that in contrast-enhanced MR angiography (CE-MRA) the final 3D image of interest is often the difference between a pre- and post-contrast 3D image, and the resultant enhanced vascular tree will fill less of the 3D FOV with non-zero signal. Indeed, the ideal difference result is an image in which the only non-zero signal is contained within the vascular system. Depending on the specific vascular region studied, the fraction of the 3D FOV containing vessels is small, on the order of 10% or less. Thus, the purpose of this work is to investigate the feasibility of improving the performance of 2D SENSE in 3D CE-MRA by masking all non-vascular voxels prior to performing the SENSE unfolding of a difference angiogram.

Methods: Conventional masking is generally implemented by processing the coil sensitivity maps. These are unaliased images of the FOV under study, generally acquired prior to the SENSE-accelerated scan. Various threshold algorithms can be applied to determine the outer edge of the object, with pixels beyond the edge taken to be air and masked out for the subsequent SENSE unfolding. For the vascular masking case studied here, the process is not as straightforward, and a multi-step process has been developed. First, a contrast-enhanced difference volume is reconstructed using a conventional masking technique. Second, a vessel-mimicking mask is created from the volume created in the first step. Third, a contrast-enhanced difference volume is reconstructed using the vessel mask. The vessel-mimicking mask is created with a slice-by-slice classification technique based on normalized signal strength within the slice, distance from previously classified voxels, and slope of the normalized distance vs. normalized signal line. After classification, the vessel mask is closed and dilated with a 5x5x5 px^3 structuring element.

Six thigh 3D CE-MRA studies acquired with R=8-10 ($R_y x R_z$=[4-5]x2) 2D SENSE were reconstructed with the proposed vascular masking method and analyzed with respect to maximum-intensity projection (MIP) contrast-to-noise ratio (CNR) [3] and mean g-factor. MIP CNR measurements were performed by selecting ROIs within a vessel and in background noise nearby. Mean g-factor was measured over all included voxels. Results were compared using reconstructions with the conventional mask in which only the air outside the object was excluded. To further aid in the analysis of MIP CNR, a hybrid volume was created by unfolding with the conventional mask and then applying the vessel mask.

Results: Full FOV and targeted MIPs generated using the three methods are shown in Figure 1. Figures 1a-b were formed using conventional masking. Figures 1e-f were formed with the new vascular masking technique and illustrate finer vessel detail (arrows). Figures 1c-d were formed with the hybrid technique in which the projection path length in the axial plane is shorter than in (a-b) and thus the noise in the MIP is lower. The vascular masking technique results (e-f) are superior to the hybrid results, demonstrating that the improvement vs. (a-b) is not solely due to a shorter projection path length in the MIP. Averaged results of CNR for the six different studies for four major vessels are shown in Figure 2, showing ~30% improvement with vascular masking. On average, g-factors decreased from 1.75 to 1.20 when the vessel mask was used during unfolding. It should be noted that very restrictive masks can lead to artifacts in the final image [4]. Therefore, this method is most suitable in volumes where the difference volume approaches the ideal case.

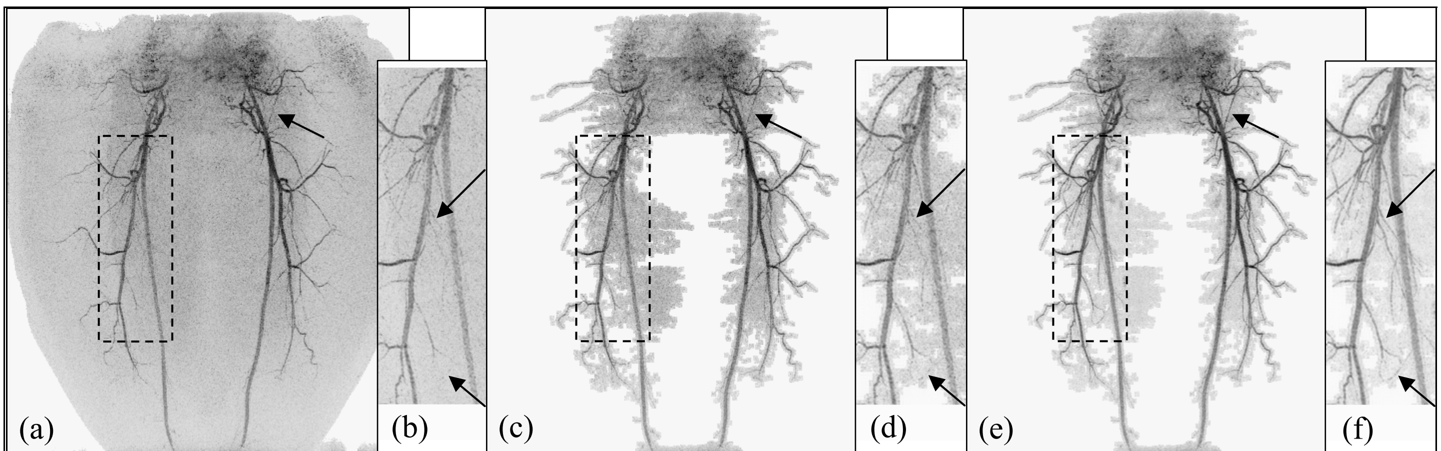

Figure 1: Full FOV and targeted MIPs of R=10 2D SENSE-accelerated 3D CE-MRA thigh angiograms reconstructed with the conventional masking technique (a-d) and the new masking technique (e-f). (c-d) show the hybrid volume described in the text. Note the reduced background noise and superior vessel conspicuity in the image reconstructed with the new masking technique (arrows).

Conclusion: Vessel-mimicking masking in 2D SENSE-accelerated CE-MRA unfolding enhances the visibility of small vessels, reduces mean g-factor, and provides improvement in MIP CNR. By masking out sections of the subtracted image that are background noise, more of the measured signal is preserved for pixels with non-zero vascular signal.

References:
1. Pruessmann, et al., Magn Reson Med, 42:952-62 (1999)
2. Weiger, et al., Magma, 14:10-9 (2002)
3. Brown, et al., Magn Reson Med, 23:130-7 (1992)
4. Larkman, et al., Physics in medicine and biology, 52:R15-55 (2007)

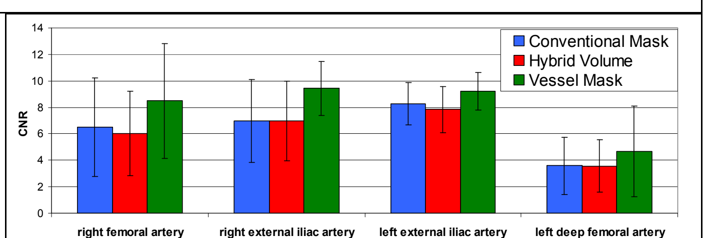

Figure 2: Mean MIP CNR over all included thigh studies (n=6). The CNR is on average ~30% higher using vessel-mimicking masking (green bar) vs. conventional masking (blue and red bars) for 2D SENSE unfolding.