High resolution intracranial time-of-flight (TOF) MRA at 7T using autocalibrating parallel imaging

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Introduction- Higher resolution intracranial 3D TOF MRA studies are desirable for detecting subtle pathology of the intracranial circulation. This is especially true in the case of atherosclerosis of distal arterial branches, cerebral vasculitis, and small intracranial aneurysms. Increased SNR and better background suppression (due to the longer T1 relaxation times of background brain tissues) at 7T yield enhanced vessel CNR, and thus enable higher spatial resolution angiography [1-4]. However, at very high field strengths, the extended scan time needed for sequential phase encoding of the larger matrix needed for higher possible resolution is not clinically feasible. Parallel imaging techniques can accelerate high resolution acquisitions, at the expense of SNR, but SNR may be regained at higher resolutions if the effects of partial voluming and/or intravoxel dephasing are reduced. In this study, we developed a customized auto-calibrating parallel imaging technique and applied it to 7T TOF MRA, achieving very high resolution MRA studies of normal volunteers and vascular disease patients within a reasonable scan time.

Materials and Methods- *MRI Hardware-* MRA was performed using a research 7T system (GE Healthcare, Waukesha, WI) with custom insert transmitter and eight-channel phased array receiver coils (Nova Medical, Wilmington, MA). *Acquisition parameters-* The TR (30ms), flip angle (25°), slab size, and slice thickness were taken from an initial 7T study [4], where these parameters were empirically optimized for the multiple overlapping thin slab acquisition (MOTSA) technique [5]. For each exam, four 1.8-cm slabs were acquired, each consisting of 38 x 0.5-mm slices, including six overlapping slices per slab. The in-plane matrix size was expanded to 512x384 from 384x224, over the same field-of-view of 22cm. The voxel size was thus reduced to 0.146mm^3 from 0.335mm^3. The readout bandwidth was increased to ±62.5kHz from ±32kHz to achieve a similar TE (2.6ms, including flow compensation along slab and read directions) and bandwidth per pixel along the larger frequency encoding dimension (332 points vs. 248 points, using 65% fractional echo readout), in order to limit the susceptibility-induced signal dropouts observed previously in the internal carotids [4], as well as artifacts due to blood flow. A fully encoded scan would have required 22min, 7 sec. Instead, data was undersampled with variable density along the in-plane phase encoding direction, with outer reduction factor (ORF) = 2 around a central block sampled at Nyquist rate, containing 12 acquired auto-calibrating signal (ACS) lines. The total scan time was thus reduced to 12min, 45s, which is slightly less than the prior study. *Reconstruction details-* Images were reconstructed first using standard GRAPPA reconstruction [6], and subsequently using an expanded GRAPPA-based reconstruction kernel including additional terms incorporating products of first-order spatial harmonics along the frequency encoding direction, thus employing a form of the multi-column multi-line interpolation (MCMLI) technique proposed by Wang et al [7]. Six to twelve GRAPPA blocks were used to reconstruct the data, with kernel coefficients determined by least squares fitting among several central acquired lines among all coils. The reconstruction software was coded in Matlab (The MathWorks, Natick, MA). For display purposes, data was zero-filled in all dimensions (to 1024x768x268), and the sum-of-squares image was filter corrected to remove surface coil sensitivity variation [8]. *Human studies-* The described MRA protocol was applied to seven normal adult volunteers and two patients with known vascular disease. MRA slabs were prescribed on standard three-plane localizers and positioned axially, extending from the petrous internal carotids towards the vertex.

Results- While the standard GRAPPA reconstruction was generally successful, it resulted in significant residual aliasing artifacts in certain imaged regions, whereas the expanded GRAPPA-based reconstruction reduced this to a negligible level throughout the imaging volume. A reconstruction kernel size of eight blocks gave the best results for both techniques. Figure 1 compares two typical reconstructions in side-by-side axial targeted maximum intensity projections (MIP's) through the same imaging volume in one volunteer. The described protocol with the customized auto-calibrating reconstruction produced MR angiograms that were largely free from artifacts for all volunteers and patients. As expected, artifacts due to pulsatile blood flow were limited and comparable to those in the initial study [4]. In the first patient, 7T TOF MRA correctly identified a fenestrated right MCA (middle cerebral artery) in a patient with history of internal carotid artery (ICA) dissection and possible fibromuscular dysplasia (FMD). The full axial MIP alongside an oblique MIP showing the fenestration is given in Figure 2. In the second patient, MRA showed near total signal dropout of left-sided circulation beyond the first segment of the MCA, consistent with signal saturation due to slow flow through a critically stenosed left ICA.

Discussion- Autocalibrating parallel imaging enables the acquisition of very high resolution intracranial MRA studies in a clinically feasible scan time at 7T. Good results are obtained despite an expected 60% SNR loss associated with the new higher resolution protocol (after estimating all effects), indicating that resolution dependent effects may be reduced. GRAPPA-based parallel imaging techniques are better suited than SENSE for maximum resolution scans, which demand a tight FOV, since they are not vulnerable to reconstruction artifacts resulting from small amounts of phase wrap in the full FOV [9]. In previous experience, standard GRAPPA successfully reconstructs 3T TOF MRA studies with only negligible residual aliasing artifact. Considering the unique geometry of the non-overlapping receiver coil used at 7T, we believe the additional terms were necessary to better model the greater coil sensitivity variation orthogonal to the phase encoding direction.

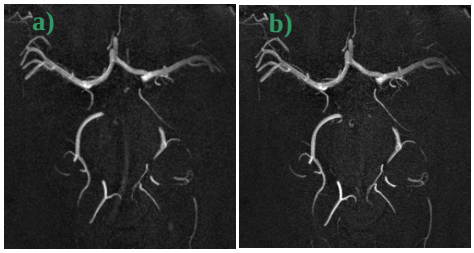
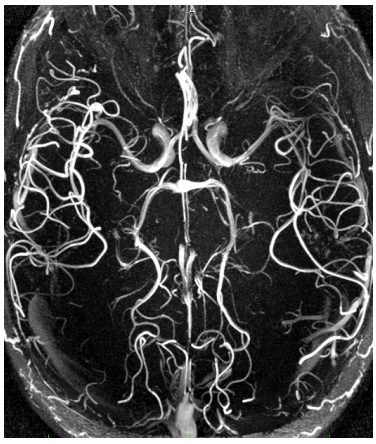


Fig 1 (top) - Axial MIPs (8mm) through the same imaging region, showing data reconstructed using standard GRAPPA (a), with increased artifact, and the customized autocalibrating reconstruction (b)



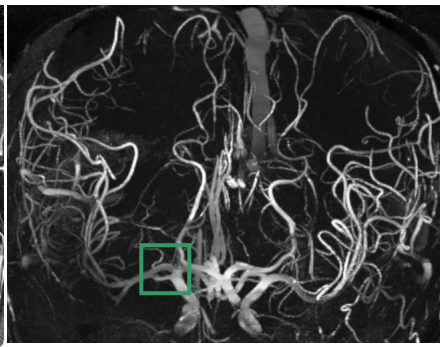


Fig 2 – Full axial MIP (left) and oblique frontal MIP (right) of image data from FMD patient, showing fenestrated right MCA (green)

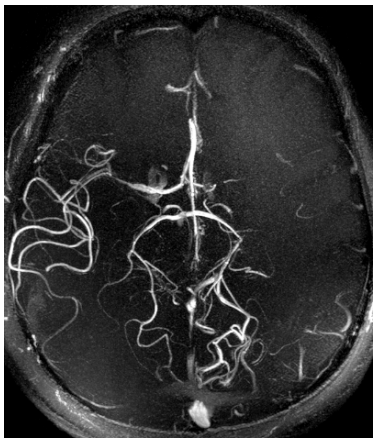


Fig 3. (bottom) - Full axial MIP through images acquired from patient with near complete occlusion of left ICA

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