Intracranial Time-of-Flight MR Angiography at 7T with Comparison to 3T

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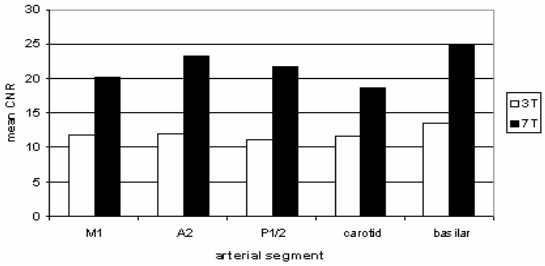
Introduction - Higher field strengths are particularly beneficial to time-of-flight (TOF) MRA techniques, which are clinically useful in the evaluation of small aneurysms, atherosclerosis, vasospasm, and inflammatory vasculitis. Both the increased SNR and the longer T1 relaxation times of background brain tissue at higher fields contribute to increased vessel contrast in intracranial TOF MRA. Improvements have previously been described in the transition from 1.5T to 3T[1-3], and 3T to 4.7T[4]. Recently a preliminary study showed intracranial TOF images at 7T[5], but without quantitative comparisons between field strengths or acquisition parameters, and without phased array coils. The goal of this study was to establish the feasibility of intracranial TOF MRA at 7T and investigate performance improvements over 3T.

Materials and Methods – ***MR Hardware***- Scanning was performed on a research GE 7T system, and a 3T GE Signa EXCITE system (GE Healthcare, Waukesha, WI). A custom transmitter insert coil equipped with an insertable eight-channel receiver array was used at 7T (Nova Medical, Wilmington, MA), while standard body coil transmit and the commercial eight-channel phased array coil (GE Healthcare) were used at 3T. ***Acquisition protocol-*** In an initial comparison study, five normal adult volunteers were scanned using identical acquisition parameters at both field strengths, taken from a standard clinical protocol for intracranial 3T TOF MRA at our institution (matrix 384x224x120, FOV=24cm x 16cm x 12cm, TR=20ms, flip=15°, TE=2.5ms, readout BW = 32kHz). The nominal spatial resolution was 0.63mm (frequency, anterior-posterior) x 0.80mm (phase, right-left) x 1.0mm (slice, superior-inferior). The acquisition was divided into five slabs of 24 1.0-mm thick partitions each (6 overlaps), employing the MOTSA (multiple overlapping thin slab acquisition) technique[6]. Scan time was 7min, 1sec. The slabs were prescribed axially on standard three-plane localizers, parallel to the intercommisural line, and spanned levels extending from the petrous internal carotids to the vertex. To minimize blood flow artifacts, a minimum phase RF pulse with fractional echo readout enabled the short echo time, and first order flow compensation was applied to the slab and readout gradient waveforms, at the cost of a slight increase in TE (1.9ms to 2.5ms). Following the initial study, a second series of experiments was performed in order to improve the acquisition protocol and more fully explore the capabilities of 7T. The TR, flip angle, slice and slab thicknesses were varied empirically at 7T, while maintaining the position of the leading edge of the graphic prescription to keep inflow effects constant. Three additional volunteers were scanned at both 7T and 3T using the resultant improved high resolution protocol (TR=30ms, flip=25°, 4 slabs with 38 slices x 0.5mm each). Some coverage near the vertex was sacrificed in order to limit the acquisition time to 13min, 1sec. ***Analysis Methods-*** To quantify the results, CNR measurements for major arterial segments were obtained directly from the source images. ROIs were manually drawn on each scan, within the anterior (M1, A2) and posterior circulation (P1/P2), as well as superior portions of the internal carotids and basilar arteries. For each scan, CNR was calculated by subtracting the average intensity value of the background tissue from the average value of each arterial segment and dividing by the average of noise regions outside the head (scaled by 0.8, a standard correction factor for magnitude images).

Results - TOF angiography at 7T resulted in improved vessel contrast throughout the intracranial vasculature in all five volunteers in the initial study. All individual vascular CNR comparisons showed improvements for 7T over 3T, ranging from 33% - 134% (figure 1). The average CNR increase among all measurements was 83%, with a median increase of 77%. Based on these results, it was determined that the increased CNR at 7T would allow doubling the spatial resolution to 0.5mm slice thickness. Also, varying the acquisition parameters showed that a somewhat longer TR and larger flip angle (30ms/25°) greatly improved the contrast throughout the vasculature at 7T and 3T. The CNR values achieved using the improved protocol were comparable to the values obtained in the initial study (3T mean=11.5, 7T mean=19.8), despite the expected 42% CNR loss due to the higher resolution (after accounting for the increased number of signal averages). Similar CNR increases between 3T and 7T were seen in the 0.5mm data as the 1mm data (average = +88%, median = +84%). Furthermore, CNR in the smaller peripheral vessels was actually increased dramatically throughout the head in the 0.5mm data at 7T. The axial and sagittal MIPs in figures 2 and 3 demonstrate the good contrast in the smaller peripheral vessels in the high resolution 7T data.

Fig. 1 – Mean CNR values grouped by arterial segment



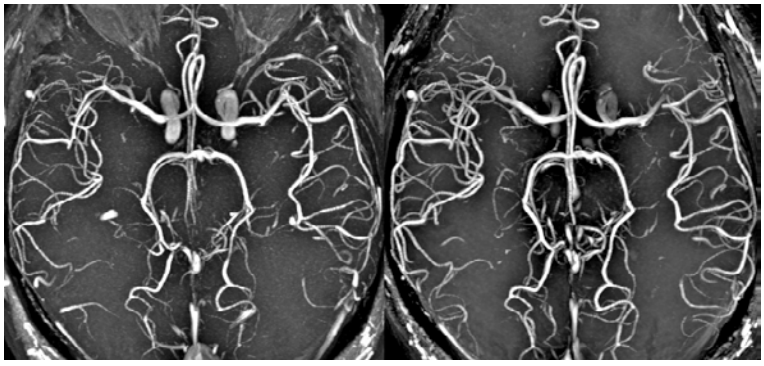


Fig. 2 – Axial MIP's at 3T (left) and 7T (right) (intensity corrected) →

Discussion - This study demonstrated not only the feasibility of 7T phased-array MRA but also its significant improvement over 3T both quantitatively and in the improved visualization of the tiny peripheral vessels. The contrast improvements seen with the improved parameters are probably the net result of multiple factors. The longer TR / larger flip angle combination result in reduced saturation of slower flowing blood versus stationary background tissues. These changes also alter the static T1 contrast between blood and background tissue. Finally, increasing the resolution does not necessarily reduce contrast in vessels with sub-voxel dimensions, since partial voluming and intravoxel dephasing are reduced. The new TR / flip angle combination is seen to be much more efficient than the original combination, despite a 50% increase in scan time due to the longer TR. A hypothetical rate-1.5 accelerated scan using the new TR / flip angle would be expected to produce about 42% more CNR than the original TR / flip (with the same imaging time, resolution, and coverage), ignoring reconstruction-related losses. There are several possible explanations for why the observed CNR increases between 3T and 7T are somewhat less than the ideal theoretical increases. First, the T1 of the blood pool is also longer at higher field and saturates with short TR sequences. Second, the smallest individual CNR increases (30%, 33%, 38%) occurred in the most inferior vessels, where both the reduced coil sensitivity of the smaller 7T coil and the increased susceptibility effects at 7T near the air-filled paranasal sinuses and petrous apices reduced the signal in some cases. Uncertainties in CNR measurements probably also arise due to the partial voluming of blood in voxels at vessel edges, and practical difficulties in duplicating graphic prescriptions and ROIs. Pulsatile blood flow through the more inhomogeneous B0 field at 7T could result in worsened ghosting and signal loss[7], but this effect did not appear to be particularly significant, presumably because the TE used was sufficiently short. A modest increase in ghosting along the phase encoding direction was seen in some of the data, but this could be explained by ordinary pulsatility effects magnified by the greater artifact-to-noise ratio at 7T.

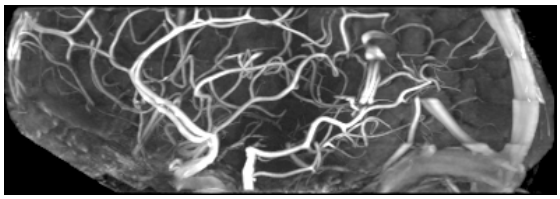


Fig. 3 – Sagittal targeted MIP through right half of intracranial vasculature at 7T

References- 1. Bernstein MA et al. MRM;46(5):955-62. (2001). 2. Gibbs GF et al. AJNR;25(1):84-7. (2004). 3. Al-Kwifi O et al. MRI;20(2):181-7. (2002). 4. Eissa A et al. Proc ISMRM;14:#1945. (2006). 5. Heverhagen J et al. Proc ISMRM;14:#814. 6. Parker DL et al. MRM;17(2):434-51. (1991). 7. Drangova M et al. MRM;35(1):26-30. (1996). *This research was supported by UC Discovery grants LSIT01-10107 and ITL-BIO04-10148, in conjunction with GE Healthcare.*