Optimization of Magnetization Prepared Rapid Gradient Echo (MP-RAGE) at 7T

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Target audience: MR physicists and clinicians interested in 7T clinical imaging

Purpose: The purpose of this work was to optimize MP-RAGE imaging at 7T. Two regimes- a conventional cerebral spinal fluid nulled (CSFn) and a recently reported white-matter nulled (WMn) MP-RAGE for imaging cortical lesions[1] and thalamus[2] - were optimized for scan time, SNR and contrast efficiency. We hypothesized that long T_1s and high B_1 heterogeneity at 7T would result in different optima for WMn and CSFn MP-RAGE compared to 3T literature values. The effect of α and TR on image blurring was modeled and validated. A novel 2D-centric radial fanbeam (RFB) k-space segmentation scheme was used for reducing scan times. Finally, healthy human subjects and patients with multiple sclerosis (MS) were scanned at 7T to demonstrate novel lesion detectability.

Materials and methods: MP-RAGE signal was modeled in MATLAB, taking into account inversion pulse interval TS, sequence repetition time TR, excitation flip angle α, readouts per inversion N and bandwidth BW to maximize SNR and contrast efficiency. To understand blurring, differential PSF[3] (dPSF) was computed as the Fourier transform of the difference in signal recovery curves for WM and GM. This dPSF was computed for varying α and TR, for both regimes. We segmented 2D (k_y-k_z) k-space into M radial fanbeams, where M = 0.78*Ny*Nz/N with 0.78 accounting for the skipped corners. Within each fanbeam, N k-space points were ordered in increasing radial distance k_r (Fig 1a). This decoupled N_z the number of slices from N (in 1D-centric N = N_z) and also enabled the use of efficient 2D parallel imaging. After informed consent, 10 healthy subjects and 10 patients with multiple sclerosis were scanned on a 7T scanner (Discovery MR950, GE Healthcare) using a 32 channel receive array coil (Nova Medical). **Scan parameters**: **WMn**- TI 680ms, 180x180x200 matrix, 1 mm thick, 18 cm FOV, 4 flip, TS 6s, BW 12 kHz, TR 10ms, ARC parallel imaging 2.5 (1D-centric) or 1.5x1.5 (2D-RFB) **CSFn**- TI 1000ms, 224x224x200 matrix, 0.8 mm thick, 18 cm FOV, 7 flip, TS 3.7s, BW 15 kHz, TR 8ms, ARC parallel imaging 3 (1D-centric) or 1.7x1.6 (2D-RFB). Scan times were 8 min (centric) and 5 min (RFB) for WMn and 5 min (centric) and 3 min (RFB) respectively for CSFn.

Results: For the WMn regime, SNR and contrast efficiency were maximized at 6s TS; for the CSFn regime, a TS of 3-4s was a compromise between contrast and SNR. Other optimal parameters were N=240 and BW of 12/15kHz for WMn/CSFn. The dPSF was insensitive to TR for both regimes (data not shown); however, it was strongly sensitive to α for the WMn regime but not for the CSFn regime (Fig 1b-c). Based on this, a 4° flip angle was used for WMn to minimize blurring and a higher flip of 7° used for CSFn. At 7T, the ratio of actual to prescribed flip angles in the thalamus is 1.5-2X due to B_1 hetereogeneity. 2D-RFB scheme enabled a scan time reduction of 1.5X compared to 1D-centric due to skipped corners (22% reduction) and higher N (N 240 vs. N_z 200) while the use of 2D parallel imaging reduced residual aliasing and noise due to more optimal *g*-factors. Fig 2-3 show a comparison of 1D-centric vs. 2D-RFB for CSFn and WMn MP-RAGE. In both cases, the 2D-RFB achieved better image quality with shorter scan times. Fig 4 shows a section of a WMn MP-RAGE scan from a patient with MS clearly depicting additional thalamic lesions (white arrows) not detected in 3D magnetization-prepared FLAIR scans.

Conclusion: Optimized WMn and CSFn MP-RAGE sequences were developed and validated on human subjects for thalamic nuclear visualization and detection of thalamic MS lesions. The use of a novel 2D radial fanbeam segmentation helped reduce scan times by 1.5X. At 7T, a long TS of 6s for optimal SNR and a low flip of 4° for minimal blurring are used in the WMn regime but a 5-minute scan time was still achieved with our protocol, and the resulting images allowed for excellent visualization of subtle structures as well as pathology within the thalamus.

References: [1] Bluestein KT et al. *MRI* 2012 [2] Tourdias T et al. *Neuroimage* 2013 [3] Deichmann R. *Neuroimage* 2000
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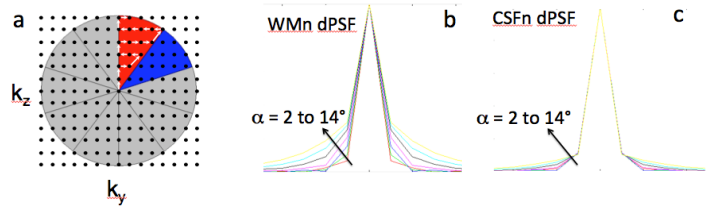

Fig 1. 2D Radial fanbeam k-space segmentation (a) Differential WM-GM PSF for α=2°-14° for WMn (b) and CSFn (c) showing the high sensitivity of the WMn regime to α

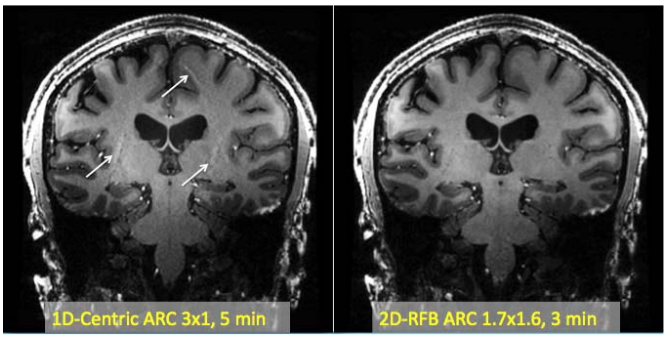

Fig 2. 1D-Centric CSFn (left) and 2D-RFB CSFn (right) MP-RAGE. Note the reduction in residual ghosting going from 1D to 2D ARC and improved SNR (right)

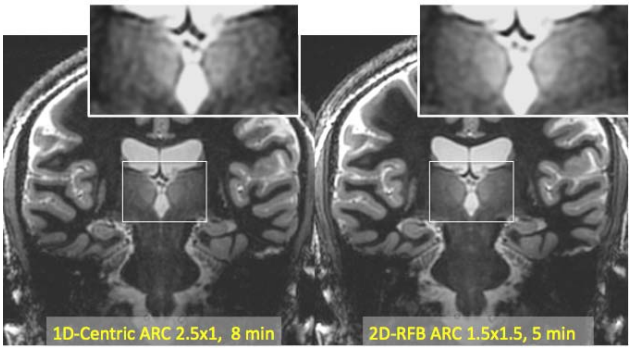

Fig 3. 1D-Centric (left) and 2D-RFB WMn (right) MP-RAGE with an inset zoom of the thalamus showing SNR and image quality improvement

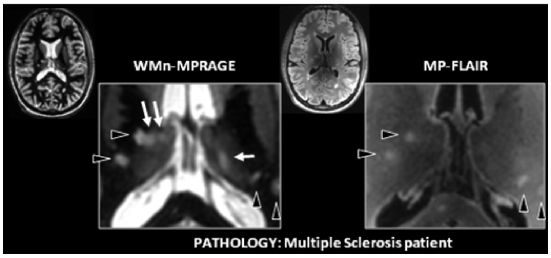

Fig 4. 2D-RFB WMn MPRAGE sequence (left) shows thalamic lesions (white arrows) not seen on conventional 3D MP-FLAIR