Optimization of Magnetization-Prepared Rapid Gradient-Echo (MP-RAGE) Sequence for Neonatal Brain MRI

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INTRODUCTION: Three-dimensional T1-weighted sequences such as MP-RAGE are extremely valuable to evaluate neonatal and infant brain injury/development. Yet, the lack of complete myelination and smaller head size results in comparatively lower quality images as compared to adult brains. Signal and contrast to noise ratios for neonatal scans can be enhanced through simulation work. MP-RAGE parameter optimizations for adults have been previously investigated [1-3]. As compared to adult brains, neonates exhibit reversed white matter- gray matter (WM-GM) contrast on T_1w scans. Additionally, this relative contrast difference is considerably less in neonates than in adults (the maximum theoretical contrast for neonates is approximately 1/3 of that for adult [4]), which makes sequence optimization for neonates more challenging. Williams et al. [4] published optimized MP-RAGE sequence parameters for neonates [4]. While the image quality was enhanced, its clinical applicability appears limited due to the elongated scan time (~9 minutes). In this paper, we consider WM-GM contrast efficiency (contrast per square root of total scan time) as an objective function to optimize neonatal MP-RAGE parameters under optimal k-space sampling by means of computer simulation. The results are validated using *in vivo* imaging.

METHODS: Effects of the major imaging parameters on GM-WM contrast efficiency were simulated using Bloch's equation based on the values of T_1, T_2, and proton density of the WM, GM and CSF of neonatal brain, which at 3.0 T are 2840/2170/3700 ms, 266/138/2000 ms, and 0.94/0.90/1.0, respectively. *In vivo experiment:* This study is part of an ongoing study of brain development and neurodevelopmental outcomes for very preterm infants with term controls. It was approved by the Institutional Review Board of Nationwide Children's Hospital, and written informed consent was obtained before MRI acquisition. Ten healthy full-term infants were scanned within two weeks of birth on a 3T Siemens skyra scanner that was equipped with a 32-channel head coil. All subjects were scanned during natural sleep after being fed, swaddled, and restrained using a Med-Vac vacuum fixation device (CFI Medical, Fenton, MI)**.** MRI noise was minimized using Insta-Puffy Silicone Earplugs (E.A.R. Inc, Boulder, CO). Based on the computer simulation above, we set our optimized MP-RAGE imaging parameters to be: repetition time (TR) = 2130 ms, effective inversion recovery time (TI_{eff}) = 1610 ms, and flip angle (FA) = 13°. Total scan time was 3min, 32s. We compared the images acquired using our optimized parameters with those recommended in ref. [4], which were: TR = 7000 ms, TI_{eff} = 2250 ms, FA = 10°. Total scan time was 9min, 8s.

RESULTS: According to the simulated results shown in Fig. 1, the theoretical optimal temporal position of the read-out RF pulse could be in the range of 10 to 40 for various TIs by considering the tradeoff between GM-WM contrast and CSF signal intensity efficiencies in K space. Limited by the scanner's constraint, the 30th read-out RF pulse was chosen to fill the K space center. Simulated results in Fig. 3 demonstrate that the maximum CNR efficiencies were achieved at a FA of 13°. For the in vivo studies, 8 of the 10 Williams protocol scans were corrupted by motion, likely due to the prolonged scan time. Fig. 4 qualitatively shows that the images acquired using our optimized parameters exhibited much stronger signal intensity than acquired using the parameters proposed in [4] for the two infants with non-motion corrupted results, while exhibiting similar contrast between WM and GM. Quantitative analysis indicated that WM-GM CNR efficiency of images acquired with our optimal parameters was more than 20% higher than those acquired using parameters recommended by Williams et al. [4]; similarly, our mean SNR efficiency was increased by around 150%.

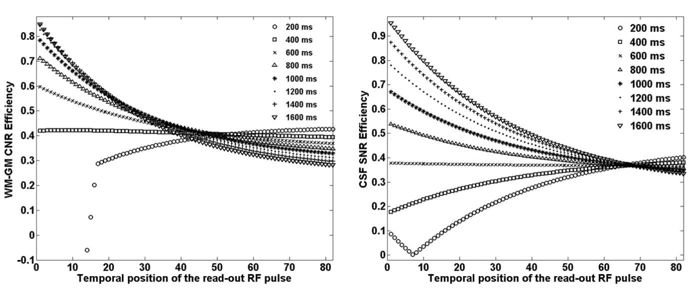

Fig.1. Left: simulated GM-WM contrast-to-noise ratio (CNR) efficiency for different temporal positions of the read-out RF pulse at different TIs; right: Simulated CSF signal-to-noise ratio (SNR) efficiency.

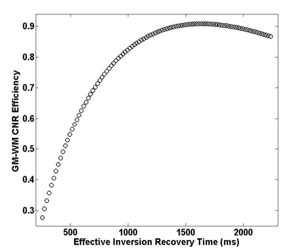

Fig. 2. Simulated GM-WM CNR efficiency as a function of TI.

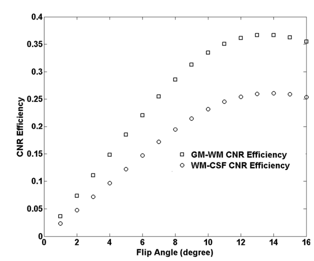

Fig.3. Simulated GM-WM and WM-CSF CNR efficiencies as functions of flip angle.

CONCLUSIONS

In this study, we presented and validated an optimized MP-RAGE protocol with optimal k-space sampling for neonates. This work emphasizes the importance of the enhancement of contrast efficiency rather than contrast alone in neonates to account for the tradeoff between image quality and total scan time. Our optimized MP-RAGE protocol can be applied to improve brain injury detection for several populations of neonates/infants, including term neonates with asphyxia, preterm infants with encephalopathy of prematurity, and for research applications to enhance brain tissue segmentation.

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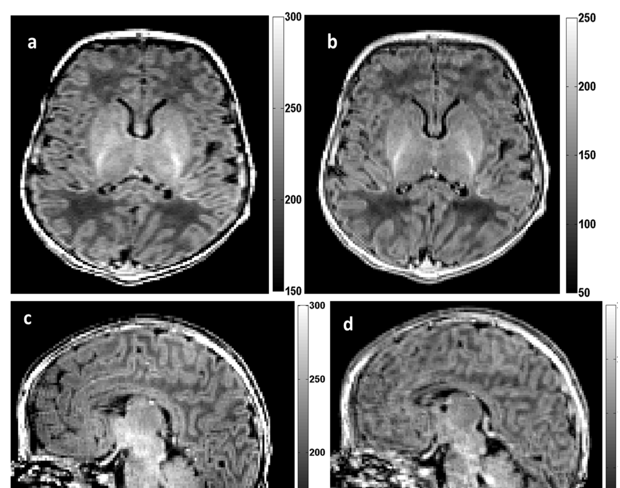

Fig. 4 In vivo brain images from a full-term infant acquired with different MP-RAGE parameters: our optimized parameters (a and c) and recommended parameters from Williams et al. [4] (b and d).