Imaging the Neonatal Brain with 3-D MP-RAGE: Optimization of K-space Weighting During the Approach to Steady State

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Introduction

Three-dimensional (3-D) MRI has shown great potential for studying the impact of both prematurity[1] and pathology[2] on brain development. Therefore, it is important to optimize such techniques for imaging of neonatal brain tissue. Previously, studies have been carried out to optimize contrast between gray matter (GM) and white matter (WM) for signals at the center of k-space with a centre-out acquisition of the 3-D magnetization-prepared rapid gradient-echo (MP-RAGE)[3] sequence.[4] We extend this investigation to optimize the k-space weighting associated with imaging while the signal approaches steady state.

Gradient echo imaging during the approach to steady state (for example, 3-D MP-RAGE) relies on efficient spoiling of residual transverse magnetization between RF-pulses. Previous phantom experiments (T2 = 110 ms) have shown that RF-spoiling, with the RF-phase difference increment (ϕ_{spoil}) set to the standard value (ϕ_{spoil} = 117º) is an effective method of reducing image artifacts associated with residual transverse magnetization.[5] In the same report, numerical simulations demonstrated that RF-spoiling should be successful for T2 < 200 ms. The potential for further improvement in performance with ϕ_{spoil} = 84º was also demonstrated numerically.[5] In the previous work[5], the RF spoiling technique included an extension of the readout gradient sufficient to produce dephasing of 360º across a voxel.

For neonatal brain tissues, in particular white matter (WM), T2 has been reported to be between 200 ms and almost 400 ms depending on the gestational age and pathology of the infant being studied.[6,7] Thus, the efficacy of spoiling methods in eliminating residual transverse magnetization in the neonatal brain must be experimentally investigated. Applied to neonatal brain imaging using 3-D MP-RAGE, the objectives of this work were: (i) To compare experimentally the performance of RF-spoiling using the conventional ϕ_{spoil} of 117º with 84º (ii) To determine if further performance improvement can be obtained by increasing the amount of dephasing produced by the extended readout gradient.

Methods

Phantom Studies: Experiments were performed using a distilled water solution phantom ([$MnCl_2$ ~ 5mg/L]) with relaxation times representative of neonatal brain tissue at 3.0 T (T1 ~ 2000 ms and T2 ~ 280 ms). The MR signal was acquired during the approach to steady state using the MP-RAGE sequence with the phase encoding gradients turned off in two directions. Data was acquired under three conditions (i) ϕ_{spoil} = 117º and $\phi_{dephase}$ = 360º, where $\phi_{dephase}$ is the amount of dephasing across a voxel at the end of the readout gradient extension (ii) ϕ_{spoil} = 84º and $\phi_{dephase}$ = 360º, and (iii) ϕ_{spoil} = 84º and $\phi_{dephase}$ = 9 × 360º. The acquired signals were Fourier transformed along the readout direction and the centre profile was selected for analysis. 3-D images of the phantom were acquired using T1-weighted MP-RAGE with ϕ_{spoil} = 84º with both $\phi_{dephase}$ = 360º and $\phi_{dephase}$ = 9 × 360º. Other sequence parameters included a centre-out acquisition with an inter-segment repeat time (TRseg) of 5200ms, TI =2250 ms, TR = 13 ms, TE = 5 ms, BW = 33.3 kHz, flip angle = 10 degrees, matrix size = 120 × 120 × 75, and FOV = 160 × 160 × 100 mm giving an isotropic resolution of 1.3 mm.

Neonatal Studies: Using the optimized parameters, including ϕ_{spoil} = 84º and $\phi_{dephase}$ = 9 × 360º, a 3-D image was acquired from a term neonate who had been referred by a neonatologist because of suspected neurological injury.

Results

Phantom experiments demonstrated that with ϕ_{spoil} = 84º the signal amplitude decays to steady state more smoothly than for ϕ_{spoil} = 117º (Figure 1). Increasing the gradient dephasing ($\phi_{dephase}$ = 9 × 360º) lead to further smoothing of the decay (Figure 1). In addition, the phase of the signal obtained with ϕ_{spoil} = 84º shows reduced variation compared to that obtained with ϕ_{spoil} = 117º (Figure 2). Increased gradient dephasing reduced the high-frequency phase variations, but lead to an initial slow monotonic change in the phase. The elimination of artifacts in phantom images acquired with increased gradient dephasing was also demonstrated (Figure 3). Finally, a sample 3-D image obtained from a term infant using the increased gradient dephasing and ϕ_{spoil} = 84º is illustrated in Figure 4.

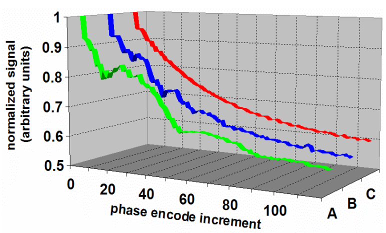

Figure 1: Signal amplitude evolution for **A** (green) ϕ_{spoil} = 117º; **B** (blue) ϕ_{spoil} = 84°; **C** (red) ϕ_{spoil} = 84º and $\phi_{dephase}$ = 9 × 360º

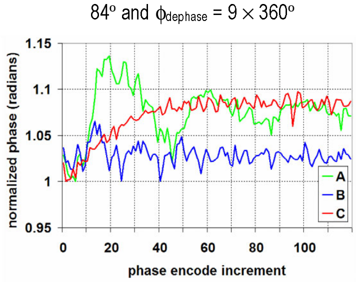

Figure 2: Phase evolution for **A** (green) ϕ_{spoil} = 117º; **B** (blue) ϕ_{spoil} = 84°; **C** (red) ϕ_{spoil} = 84º and $\phi_{dephase}$ = 9 × 360º

Conclusion

For imaging neonates using 3D MP-RAGE, RF-spoiling is an effective spoiling technique, despite the very long relaxation times encountered. In particular, high quality images can be obtained using ϕ_{spoil} = 84° and strong gradient dephasing.

References

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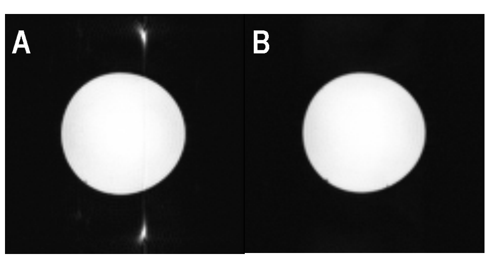

Figure 3: 3-D images for **A** ϕ_{spoil} = 84°; **B** ϕ_{spoil} = 84º and $\phi_{dephase}$ = 9 × 360º

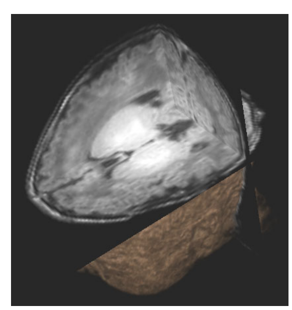

Figure 4: 3-D image of neonatal brain acquired with ϕ_{spoil} = 84º and $\phi_{dephase}$ = 9 × 360º