Magnetization-Prepared Shells for Efficient T1-Weighted Brain Imaging

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Introduction The magnetization-prepared rapid gradient-echo (MP-RAGE) [1] and related pulse sequences like IR-SPGR are widely used for high-resolution T1-weighted volumetric brain MRI. They provide a high contrast-to-noise ratio (CNR) between white matter (WM) and gray matter (GM). To maximize contrast, it is desirable to select a k-space acquisition order that can sample the center of k-space compactly around the peak contrast difference between WM and GM during the inversion recovery curve [2]. The shells trajectory [3] is a non-Cartesian 3D trajectory with higher acquisition efficiency compared to its Cartesian counterpart. It samples data on a series of spherical shells with their common concentric point located at the center of k-space. The highly centric nature of the trajectory provides the flexibility required to synchronize the acquisition of the center of k-space to the maximum contrast on the inversion recovery curve. The aim of this work is to explore the feasibility of combining magnetization preparation (MP) with the 3D non-Cartesian shells trajectory.

Theory and Methods The shells trajectory was implemented with a spoiled gradient-echo sequence. Helical spiral interleaves are used the fully sample the surface of each shells. The number of interleaved spirals is determined by the Nyquist criterion, off-resonance effects, and gradient hardware limits. Due to limits on slew rate and gradient amplitude, additional spiral interleaves were required to sample data on the “polar ice caps” of the shells [3].
To adapt the shells acquisition to MP, selected interleaves from shells of various radii were grouped together to form the data acquisition train within a preparation-acquisition-recovery (P-A-R) cycle (Fig. 1). An adiabatic 180° RF pulse is used the invert the magnetization. A recovery section completes the cycle to allow the magnetization to recover back towards its equilibrium value.
A 3D MP shells imaging protocol that closely matches the 3T MP-RAGE protocol in for the ADNI study [4] was generated. The imaging parameters are sequence time = 7.6ms, readout time = 4 ms, imaging matrix = 240^3, image resolution = 1 mm^3, readout bandwidth = ±64 kHz, flip angle = 8°, inversion time (TI) = 900ms, and recovery time = 660ms. Each P-A-R cycle is TR = 2300 ms long, and consists of a train of 175 interleaves acquired with RF spoiling. Two dummy repetitions were played at the beginning of the sampling of each shell. A recessed acquisition [2] order for the shells is used to improve the acquisition efficiency, i.e., some interleaves are acquired before the inversion time.
Each PAR cycle begins with interleaves from shells with the largest radii, and then the radii of the shells are progressively decreased. TI is the time interval between the inversion pulse and the acquisition of the sampled shell with the minimum radius. After TI, interleaves from progressively larger shells are sampled. In total, 100 PAR cycles were used, which yields 3:52 acquisition time for the MP shells acquisition. Without MP, and its associated delay times, the shells scan time is 2:13.
The signal intensity and contrast behavior of GM and WM was simulated and shown in Fig. 1. T1 times for GM and WM were chosen to be 1400 ms and 800 ms, respectively, at 3.0T with a relative proton density of 0.75 and 0.65.
A healthy volunteer was scanned under an IRB-approved protocol on a GE Signa 3.0T Excite system running 14.0 M4 software and using an 8-channel phased array head coil. Acquisitions were obtained with and without MP.

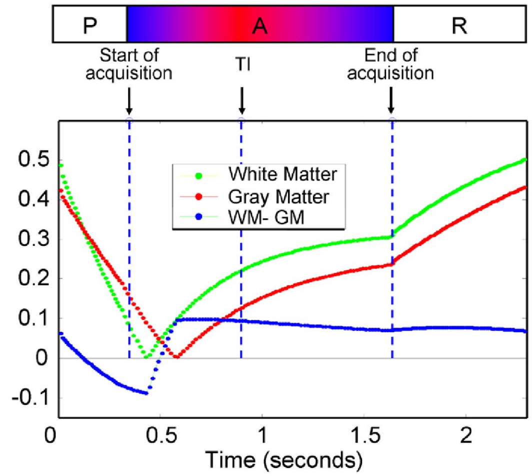

Fig. 1 Simulated signal intensity change for gray matter and white matter and their difference in a P-A-R cycle, as in [2]. The TI time indicates the interval between the 180° RF pulse and the acquisition of the center of k-space, i.e., the acquisition of the smallest-radius shell. The acquisition order of the shells is illustrated by color coding in the acquisition segment. Blue indicates shells with larger radius and red represents the shell with smaller radius.

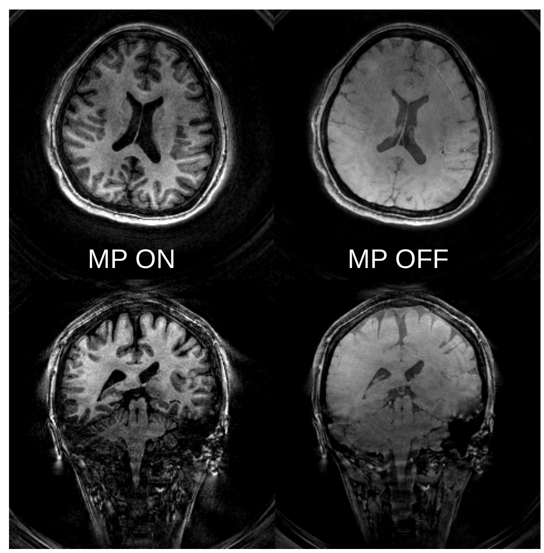

Fig. 2 Axial and coronal reformatted images of a healthy volunteer. With MP, the GM/WM contrast is substantially improved.

Results The scan time and spatial resolution comparison with an MP-RAGE clinical protocol is listed in Table 1. Axial and coronal reformatted slices are shown in Fig. 2. With MP, the shells acquisition can effectively capture the contrast difference between the white matter and the gray matter. Compared to a Cartesian MP-RAGE counterpart, the scan time is reduced for the shells acquisition with slightly reduced voxel size. Although it is easier to implement parallel imaging methods with Cartesian sampling, they do incur an SNR penalty.

Conclusion and Discussion The advantages offered by the shells trajectory make it well-suited for combination with an MP module. We have demonstrated that the magnetization prepared shells trajectory can capture the peak contrast difference efficiently.
Due to relative long readout time and high field magnetic field, off-resonant effects caused by fat signal are noticeable. Fat suppression technique like a spectrally-selective inversion pulse might be helpful to remove the artifacts and improve the image quality. Removal of residual artifacts remains area of study for this work.

Table 1: Acquisition time and spatial resolution

	Acquisition time	Spatial Resolution
SHELLS	2:13	1×1×1 mm3
MP-SHELLS	3:52	1×1×1 mm3
MP-RAGE	9:14	1×1×1.2 mm3

References

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