

# Magnetization-Prepared Shells With Integrated Radial and Spirals

Y. Shu<sup>1</sup>, and M. A. Bernstein<sup>1</sup>

<sup>1</sup>Department of Radiology, Mayo Clinic, Rochester, MN, United States

**Introduction** 3D magnetization-prepared fast gradient echo MR sequences, such as MP-RAGE [1], have been widely used for 3D brain volumetric imaging due to high spatial resolution and good contrast between white matter and gray matter. However, these techniques usually require long acquisition time, which increases the probability of motion and decreases clinical throughput. There have been several other methods combined with MP-RAGE to reduce the scan time or enhance the contrast-to-noise ratio, such as parallel imaging [2], centric acquisition order [3], and non-Cartesian trajectories [4, 5]. Combining MP-RAGE with the spherical shells trajectory [5] was demonstrated to effectively capture the peak contrast difference between the white matter (WM) and gray matter (GM). The traditional shells trajectory is composed of concentric spherical shells covered by interleaved helical spirals and additional spirals to cover the "polar icecaps". The polar icecap sampling can be inefficient and can cause phase discontinuities between interleaves. An improved version of shells, SWIRLS [6] covers shells from pole-to-pole with a single continuous shot combining radial lines and helical spirals. SWIRLS offer more flexibility when it is advantageous to group interleaves on specific shells. This work explores the feasibility of applying the improved SWIRLS trajectory with the MP-RAGE technique.

**Methods** The SWIRLS trajectory was implemented on a 3T scanner (GE Signa, v14.0, Milwaukee, WI). The hardware limits for the gradient amplitude and the slew rate are 40 mT/m and 150 T/m/s respectively. The trajectory used 13600 interleaves and 110 shells. The numbers of interleaves for each shell is determined by the Nyquist sampling criteria. To facilitate grouping interleaves, every 10 shells are grouped together to share the same number of interleaves. For example, shells with radius  $0.5\Delta k$  to  $9.5\Delta k$  (shells 1-10) all use 10 interleaves to cover the spherical shell surfaces. The SWIRLS interleaves were designed for the outermost shell (radius  $9.5\Delta k$ ) in this group and scaled down accordingly for shells with radius  $0.5\Delta k$  to  $8.5\Delta k$ . To adapt the trajectory for MP-RAGE application, a preparation-acquisition-recovery (P-A-R) cycle was used in each TR. The entire set of k-space sampling was composed of 100 P-A-R groups of 136 interleaves. To yield the desired k-space weighting, selected interleaves from shells with various radii were grouped together. The ordering within each P-A-R was designed to sample shells with the smallest radius as close as possible to the nominal inversion time. For example, for the first P-A-R cycle, shells [101, 81, 61, 41, 21, 1, 11, 31, 51, 71, and 91] were sampled. The number of interleaves sampled for each shells were 37, 26, 17, 10, 5, 2, 1, 3, 7, 13, 21 and 31 respectively, for a total of 136 interleaves. Sampling of shell 1 falls on the nominal T1 time. When this group of shells was fully sampled, the indexes for next group of shells were 102, 82, 62, 42, 22, 2, 12, 32, 52, 72 and 92, and so on.

For imaging experiment, a 3T MP-RAGE protocol that was used for the ADNI study [7] as adapted for the MP-SWIRLS study. The scan parameters were: TI = 900 ms, TD = 660ms, TR = 2020 ms, FOV = 24 cm, imaging matrix =  $110^3$ , flip angle =  $8^\circ$ , imaging bandwidth = 62.5 kHz. For each interleave, the readout length was 512 data points and each SWIRLS interleave repetition was 7.6 ms. The total acquisition time was 3 minutes and 24 seconds. For the non-MP-RAGE application, the scan time was reduced to 1 minutes and 45 seconds without the preparation and recovery stage.

The signal intensity and contrast different for both the WM and the GM (for each P-A-R cycle were simulated and plotted in Fig. 1.

The volunteer experiment was acquired with the GE 3T scanner and an 8 channel phased array head coil with IRB approved protocol. For comparison, two image data sets were obtained, one with MP enabled.

**Results** From Fig. 1, it can be observed that the peak contrast difference between the WM and GM were synchronized with the acquisition of the center most shells in k-space. Also the k-space weighting for the signal intensities of both GM and WM was distributed isotropically in all three dimensions for the SWIRLS trajectory.

Axial and coronal reformats of the head images are shown in Fig. 2. Generally good image quality and high spatial resolution were achieved. Strong T1-weighted contrast can be seen in the MP-SWIRLS acquisition. Comparing to its Cartesian counterpart MP-RAGE acquisition, the MP-SWIRLS can achieve the same spatial resolution with nearly half of the scan time, although some off-resonance related artifacts are present. Note that fat saturation was not used in this feasibility experiment.

**Conclusion and Discussion** We have demonstrated the initial feasibility of combining the SWIRLS trajectory with the MP-RAGE application. The SWIRLS trajectory uses one continuous shot to cover the surface of a spherical shell from pole-to-pole, which offers more flexibility for MP design than the traditional shells trajectory. It retains the previously described advantages of shells trajectory that optimize the contrast between WM and GM with reduced scan time. Future work includes fine tuning of the acquisition parameters, reduction artifacts due to off-resonance effects.

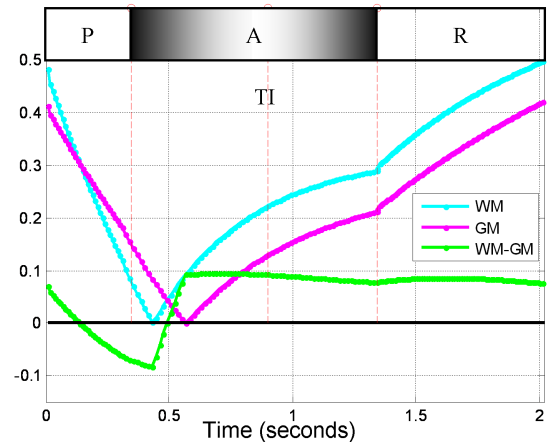
## References

- [1] Mugler JP, 3rd, et al. Magn Reson Med 1990; 15: 152-157.
- [2] Tan ET, et al. ISMRM 2008 No. 2095.
- [3] Lin C, et al. Magn Reson Med 2008; 59: 434-439.
- [4] Wu HH, et al. Magn Reson Med 2008;59:102-112.

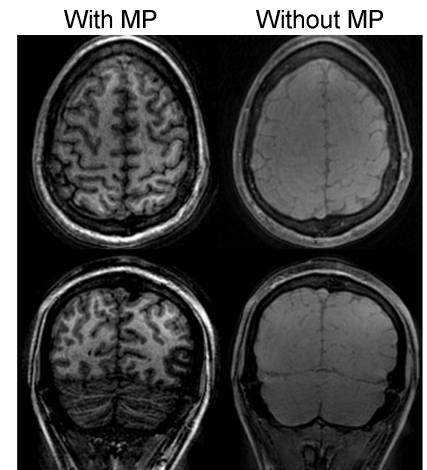
- [5] Shu Y, et al. ISMRM 2008 No. 3078

- [6] Shu Y, et al. ISMRM 2009 No. 764.

- [7] Jack CR, Jr., et al. J Magn Reson Imaging 2008;27:685-691.



**Fig. 1:** The normalized signal intensities and difference between GM and WM at 3T during one P-A-R cycle. The different shading illustrates sampling at different parts in k-space, with white representing central k-space and black representing peripheral k-space respectively.



**Fig. 2:** Axial and coronal reformatted head images acquired with and without MP using the SWIRLS trajectory.