A new spectro-spatial RF pulse design for high-resolution isotropic diffusion imaging

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Introduction

Spectro-spatial RF pulses (SPSP RF pulses) for clinical 2D imaging have been widely used for B1-insensitive excitation with excellent lipid suppression compared to the conventional fat saturation methods [1,2]. However, these pulses require the sub-pulse length to be inversely proportional to the distance from spectral pass band to the spectral stop band. At 3T, this requirement is challenging due to the reduced sub-pulse width, and often results in compromise in the minimum slice thickness and poor slice excitation profile. In this work, we introduce a new spectral-spatial design scheme which allows very thin slice excitation with superior slice profile for single spin echo diffusion imaging.

Method

In SPSP RF pulse design, the maximum width of the sub-pulse for SPSP RF pulse is determined from the water-fat spectrum separation. For type I SPSP RF pulses [1], in order to have the true null located at the fat resonance frequency at 3T, the maximum allowed width of each sub-pulse is only 595 us. Given this maximum allowed pulse width, the pulse designer has to consider many factors such as the gradient hardware capability, peripheral nerve stimulation limit, system RF amplifier capability and specific absorption rate (SAR). After considering all design factors, in GE MR 750 scanner, the minimum slice thickness is found to be 2.9 mm, which is often not desired for isotropic diffusion imaging while the typical in-plane voxel size is 240mm/128 = 1.875 mm.

In this work, we utilized two SPSP RF pulses for 90 degree excitation and refocusing pulses rather than using a SPSP RF pulse only for the 90 degree excitation. This scheme allows one to choose the sub-pulse width to be greater than what the water-fat separation dictates in the conventional SPSP RF pulse design. The sub-pulse widths of 90 degree pulse and 180 degree pulse were determined to satisfy the following two conditions 1) the distance from spectral pass band to stop band of 90 degree pulse is smaller than the water - fat resonance frequency difference, while keeping FWHM of the spectral pass bandwidth is greater than 100Hz. 2) the 180 degree pulse does not invert the spectral component at fat resonance frequency. For 90 degree SPSP pulse, the sub-pulse width of 90 degree pulse was 1.67ms, number of sub-pulses was 7, time-bandwidth product of sub-pulse was 3,maximum b1 was 0.045G and the total pulse length was 11.7ms.For 180 degree SPSP pulse, the sub-pulse width was 1.25ms, number of sub-pulses was 4, time-bandwidth product of sub-pulse was 3, maximum b1 was 0.14G, and the total pulse length was 5ms. Given much longer sub-pulse width, the minimum slice thickness was 1.7mm.

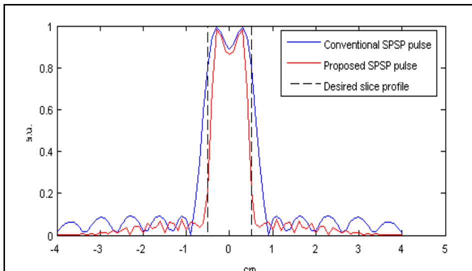

Figure1. The slice profile at 0Hz off-resonance frequency. The proposed pulse shows superior slice selectivity compared with the conventional design.

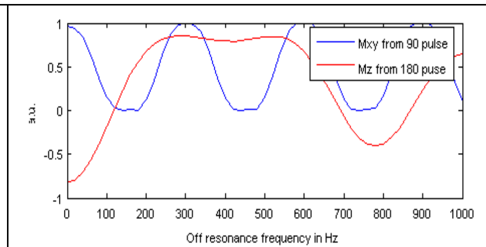

Figure 1. The combination of 90 degree excitation pulse and the inversion pulse enables efficient fat suppression while maintaining superior spatial selectivity. The fat component at -420 Hz will not experience inversion, and will be de-phased by crushers.

Experiment

With the new RF pulses, Bloch simulation was conducted using MATLAB (Mathworks, MA). Figure 1 shows the slice profile of the conventional SPSP RF pulse and the new SPSP RF pulse. Figure 2 shows the spectral profile of 90 degree excitation pulse and the refocusing pulse. Volunteer scan was also performed (FOV 24cm, 128x128 resolution, TE = 67.3ms, b=1000) using a GE 3T MR750 scanner (GE Healthcare, WI). Figure 3 shows that both the conventional SPSP RF pulse and the new proposed design provide excellent fat suppression with 5mm slice thickness. However, the conventional SPSP pulse allows minimum slice thickness of 3.2mm. We also acquired images with 1.7mm slice thickness using conventional fat saturation prep pulse and the proposed method. The conventional fat saturation method shows unsuppressed fat signal due to B1 inhomogeneity, while the proposed method showed excellent fat suppression.

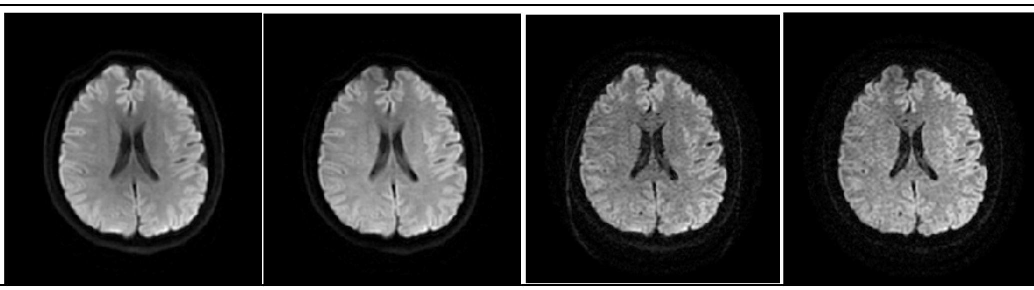

Figure 3. From the left, the conventional SPSP pulse with 5mm slice thickness, proposed SPSP pulses with 5mm slice thickness, the conventional fat sat pulse with 1.7mm slice thickness, the proposed SPSP pulses with 1.7mm slice thickness

Conclusion

In this work, we designed a new SPSP RF pulses for single spin echo diffusion weighted imaging. We demonstrated that the proposed method can result in similar image quality to the conventional SPSP RF pulse design for slices as thick as 5mm. We also showed that the proposed method provides superior slice profile with reduced slice thickness enabling high resolution isotropic diffusion imaging.

References

1. Meyer et.al. MRM 15:287-304 (1990)
2. Zur, MRM 43:410-420 (2000)