Rapid Fat Suppression by Spectral Partial Inversion Recovery and Spatial-Spectral Excitation (SPIR-SSE)

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Introduction

The generation of fat suppressed MR images with high spatial and temporal resolution is very important for many clinical applications, especially for contrast-enhanced studies. For example, in contrast-enhanced dynamic studies of the breast, fat suppression, high temporal and spatial resolution is critical for benign/malignant lesion differentiation. Two popular fast fat suppression techniques are fat presaturation using spectral partial inversion recovery (SPIR), and spatial-spectral excitation (SSE) for water-selective imaging (1). SPIR is technically easier for clinical implementation. The spectrally selective SPIR prepulse is adjusted to excite the lipid resonance, which is followed by a spoiling gradient leaving water spins available for imaging. This will generally increase TR by 10~20 ms in FFE (or FLASH) pulse sequences. Shorter TR can be achieved using spatial-spectral excitation instead, which obviates the time-consuming spectral fat pre-saturation RF pulses. However, its spectral-selective capability is highly dependent on the order of the binomial RF pulses. A higher order binomial excitation is more spectrally selective and gives better fat suppression, but will increase both TR and TE significantly. A 1-3-3-1 excitation pulse train may take 12 ms, thus limiting the shortest achievable TR and TE. A lower order binomial excitation RF pulse train (e.g., 1-1) is much shorter, but fat suppression result will be less effective. A more efficient fat suppression technique utilizes turbo field echo (TFE, or turboFLASH), wherein one SPIR pulse is followed by multiple excitations, and several phase encoding echoes are acquired. This decreases shortest achievable TR and scan duration, as the number of SPIR pulses is decreased. However, echo train length (ETL) and shot duration is limited since the T_1 relaxation of fat is short (about 280 ms) and images are otherwise readily contaminated by fat signal. Shot duration must usually be less than half of fat T_1 to avoid severe artifacts, such as ghosting and blurring. In this article, a novel hybrid fat suppression technique, Spectral Partial Inversion Recovery and Spatial Spectral Excitation (SPIR-SSE), is described that circumvents this problem. This technique combines SPIR for fat presaturation, with a short, low order (e. g., 1-1) binomial SSE for sustained fat suppression, thus long ETL is achievable without the introduction of severe artifacts.

Methods

SPIR-SSE fat suppression was implemented on a 1.5 T Philips Intera MR scanner. A 4-channel dedicated breast coil was employed. The basic time scheme of this SPIR-SSE TFE sequence was similar to a traditional 3D RF spoiled TFE (or turbo-FLASH), and is shown in Fig. 1. A 106º, 15 ms fat-selective SPIR pulse followed with a spoiling gradient to perform fat presaturation precedes the gradient echo train. Water-selective 1-1 binomial SSE RF pulse trains, each with a length of 3.5 ms, were used to achieve sustained fat suppression and short TR and TE. The phase encodings are arranged in a low-high (centric) order to achieve better fat saturation for central k-space data. The sequence was tested on a 51-year-old healthy volunteer with the following, TR/TE/FA=12.0/6.0/40° and NSA=1. 50 axial images were obtained on the right breast, and the measured slice-thickness was 4 mm with 2 mm overlap. The FOV was 20 cm and matrix size was 256 × 256, leading to an in-plane resolution of 0.78 × 0.78 mm^2. The readout bandwidth was 38.3 kHz. Volume shimming was applied on the breast of interest. For comparison, fat suppression using traditional fat saturated FFE with SPIR (TR/TE/FA= 32.0/4.7/40°), spatial-spectral water selective FFE (TR/TE/FA=17/8.3/40°) using 1-3-3-1 binomial RF excitation, and fat pre-saturated with SPIR TFE (9.5/4.7/40°) were also tested with the other parameters fixed. In all circumstances, shortest TRs and TEs were employed to decrease scan duration, and to obtain more T_1 weighting.

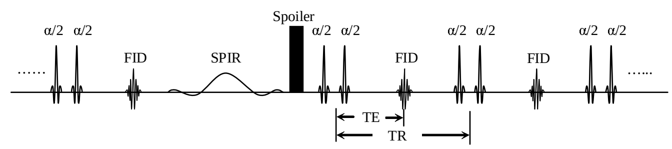

Fig. 1: SPIR-SSE (1-1) TFE sequence, which combines fat-selective presaturation with sustained 1-1 binomial RF for water excitation.

Results

Fig. 2 shows three identical slices measured with different fat suppression techniques. Images obtained with SSE (1-3-3-1) FFE suffered from strong residual fat signal and severe partial-volume effect as shown in Fig. 2a. SPIR FFE (Fig. 2b) had better performance for fat suppression compared with SSE FFE. Superior fat suppression and clearer parenchymal detail was obtained with SPIR-SSE TFE with ETL=64 (Fig. 2c) over the two traditional approaches even though the scan duration was much shorter. Fig. 3 shows images at the same position as in Fig. 2, but obtained by combining 3D TFE with three different fat suppression strategies. It is shown that SPIR-SSE TFE has much better fat suppression efficacy even when a very long ETL=256 is used (Fig. 3a), compared with short-ETL TFE with only SPIR fat presaturation and no sustained 1-1 water-selective excitation (Figs. 3b, c).

Discussion

In TFE sequences, combining fat presaturation with sustained fat suppression is demonstrated to be a more effective approach to fat suppression. By acquiring k-space profiles with a centric order, the lipid signal of central profiles is suppressed twice (by both SPIR and SSE). This is desirable, since the fat suppression in central k-space is of greater importance than that of peripheral region. Short, low order 1-1 binomial RF pulses, generally believed to offer poor spectral selective capability, are shown to be suitable for efficient sustained fat suppression. These pulses tip most of the water spins, but only a small ratio of lipid spins, to the transverse plane, even when lipid spins have almost reached thermal equilibrium along the longitudinal direction. This greatly limits the artifacts that might otherwise be introduced by fat signal when a long ETL is used.

It has been shown in the results that a SPIR-SSE TFE sequence with a reasonably long ETL outperforms SPIR TFE for fat suppression. More importantly, SPIR-SSE TFE outperforms SPIR FFE and SSE FFE sequences as shown in Fig. 2. This is likely due to the fact that, for both SSE FFE and SPIR FFE, since TR used is much shorter than lipid T_1, lipid spins will have reached a steady state in transverse plane when the central k-space profiles are acquired. This leads to a high fat signal background on the resultant images. The long ETL used in SPIR-SSE TFE, however, ensures lipid magnetization returns to the longitudinal direction before the administration of a following SPIR. The water-selective RF pulses further limit the lipid signal when centric k-space data are acquired soon after SPIR fat-presaturation. Furthermore, the long ETL used in SPIR-FFE TFE sequences also makes the high spatial-frequency profiles be acquired during rarely-interrupted steady-state, leading to high quality fine spatial structure (less blurring). Lastly, a long ETL also decreases the number of SPIR pulses that have to be administered, which reduced scan duration and SAR.

The strategy of combining fat-presaturation with sustained water-selective excitation can be employed on any short TR sequences for improved rapid fat suppression. For balanced steady-state free precession (b-SSFP), however, RF amplitude or phase cycling (2, 3) for sustained fat suppression is preferable to obtain shortest achievable TR instead of employing 1-1 binomial RF pulses. This method can be combined with the magnetization preparation technique described by Scheffler et al. (4) for fat presaturation.

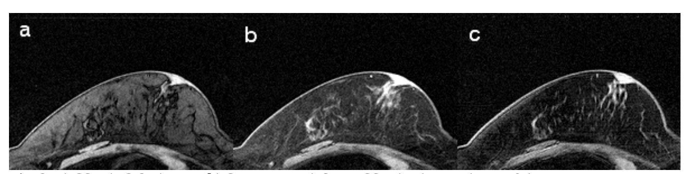

Fig. 2: a) SSE (1-3-3-1) FFE, b) SPIR FFE, c) SPIR-SSE (1-1) TFE (ETL=64).

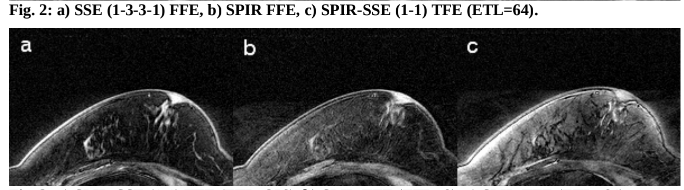

Fig. 3: a) SPIR-SSE (1-1) TFE (ETL=256), b) SPIR TFE (ETL=8), c) SPIR TFE (ETL=64).

References

1. Meyer CH et al, MRM 1990; 15: 287-304.
2. Hardy CJ et al, ISMRM, Honolulu; 2002:p 473.
3. Overall WR et al, MRM 2003; 50: 550-559.
4. Scheffler K et al, MRM 2001; 45: 1075-1080.