Complementary Use of SPAIR and STIR for robust fat suppression in single-slab 3D TSE

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Introduction Single-Slab 3D Turbo Spin Echo sequence with variable flip angles (aka SPACE) [1] has been widely used for the isotropic, high resolution imaging of a large volume. The fat suppression techniques, which are compatible with SPACE, include: Short T1/tau Inversion Recovery (STIR), Spectral Selection Attenuated Inversion Recovery (SPAIR), and DIXON [2]; DIXON is a promising technique, but needs to acquire multiple echoes for water-fat signal separation, which will substantially increase the echo spacing in SPACE, and then obviously degrade its performance. Compared to STIR, SPAIR provides better contrast, but may suffer from nonuniform fat suppression in B0 inhomogeneous region. However, due to the configuration of powerful shimming gradients in modern MR scanner, SPAIR is able to work well in large portion of the selected FOV, and may fail only in the outer regions. In this work, a new concept is presented, to Complementarily Use SPAIR in the homogeneous regions and short T1 selected inversion Recovery in the inhomogeneous regions (abbr. CUSTER) for uniform fat suppression in a single acquisition in SPACE (illustrated in Fig1), in order to preserve good contrast in the main region of the FOV and achieve uniform fat suppression in whole FOV.

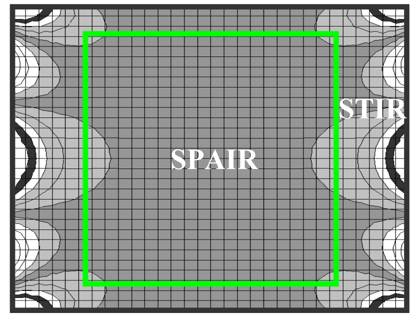

Fig1. A typical B0 filed map. The target is to apply SPAIR inside the green box, and STIR in the outer regions, which is automatically determined by the B0 inhomogeneity.

Methods As shown in Fig2 a), a spectral selected inversion recovery pulse is performed before the image data acquisition. The effective pass band BW_{IR} of the IR pulse is designed to be much wider than the frequency difference induced by chemical shift. Compared to the frequency of the water signal in the homogeneous region, the center frequency of the IR pulse is offset by $-BW_{IR}*0.5 - f_{tol}$. f_{tol} is a tolerance to ensure the main water signal won't be affected by the IR pulse, which is empirically about 30% of the chemical shift. Because the strength of the B0 field will generally decrease in the off-center regions, the entire fat-water spectrum will be shifted accordingly into the pass band of the IR pulse, which goes into the procedure of STIR fat suppression if a suitable inversion time TI is selected. Fortunately in single-slab SPACE, there is only one echo train in each TR, a TI value, which is about 150ms ~170ms, can meet the need of both SPAIR and STIR. Long TR ensures the water signal won't be attenuated in frequent inversion. There is a narrow transition band of the IR pulse from the procedure of SPAIR to STIR. Inside the transition band, signal will be rotated into the transversal plane and spoiled by the following gradient, therefore some dark bands can be found in the image (Fig4. a). The missed signal can be acquired by a complementary acquisition (see Fig3), where new IR pulse and excitation pulse are designed to exactly cover the right transition band of the IR pulse in the Fig2 a). Since the excitation pulse has a long duration, a dual-echo spacing method [3] is employed to shorten echo spacing. Finally, data from the main acquisition and the complementary acquisition are combined to reconstruct the complete images with uniform fat suppression.

Results Both phantom and volunteer experiments were performed on a 3T MR scanner (MAGNETOM Verio, Siemens, Erlangen). In Fig4 and Fig5, the pass band of the IR pulse #1 in the main acquisition is 1.4 kHz, and its transition band is about 228Hz. The FOV in the readout direction is up to 450mm. SPAIR failed to suppress the fat signal at the edge of the FOV, but CUSTER achieved uniform fat suppression inside the entire FOV. Because the k-space was fully sampled in the complementary acquisition, the acquisition time of CUSTER is double of that in standard SPAIR method.

Discussion Due to the intrinsic sparse distribution of the signal nulled by the transition band of the IR pulse, it is possible to dramatically reduce the acquisition time of the complementary acquisition by using acceleration techniques, such as compressed sensing etc, which is the key step to reap the benefit of the CUSTER method.

References [1] Mugler, ISMRM 2003, p203;
[2] Dixon WT, Radiology, 1984, 153: 189-194;
[3] Mugler, ISMRM 2004, p695;

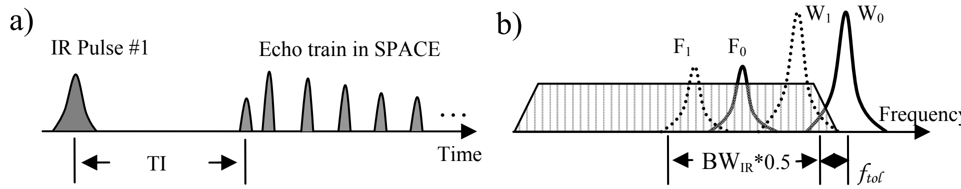

Fig2. a) The diagram for the CUSTER method, which is similar to SPAIR, except that a long TI is required here. b) The frequency selection of the IR pulse. W_0-F_0 is the spectrum of the water and fat signal in B0 homogeneous region. W_1-F_1 is the shifted spectrum of the signal due to the decrease of the B0 field in the outer regions.

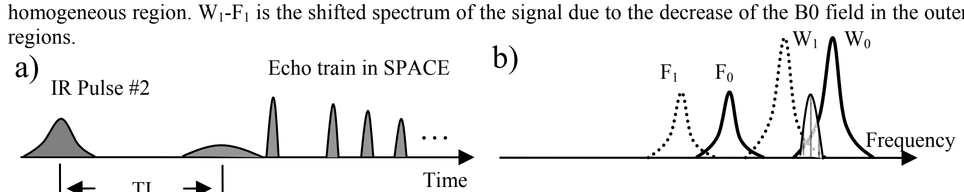

Fig3. a) The diagram for sampling the signal in the transition band of the IR pulse #1. As shown in b), both IR pulse #2 and excitation pulse own narrow bandwidth, and are intended to exactly cover the right transition band of IR pulse #1 (shaded region). The signal is non-selectively excited, but selectively refocused in case of slab-selective acquisition. A dual-echo spacing technique is used to remove the influence of the excitation pulse to the echo spacing, in which the first echo spacing is much longer than the following echo spacings.

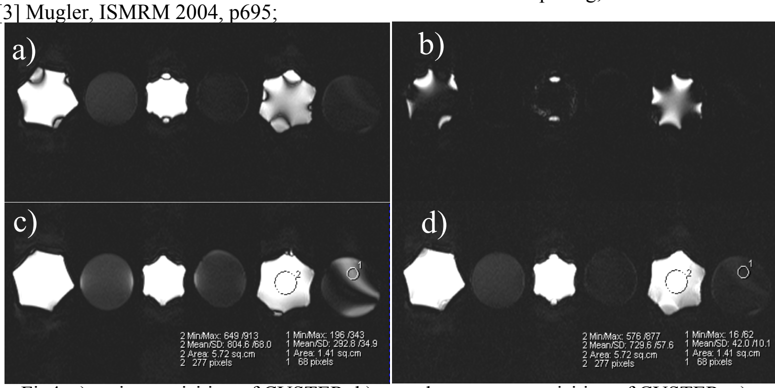

Fig4. a) main acquisition of CUSTER. b) complementary acquisition of CUSTER. c) standard SPAIR. d) combined image of CUSTER. Compared to SPAIR, the fat signal over a large FOV (450 mm in this experiment) was uniformly suppressed in CUSTER.

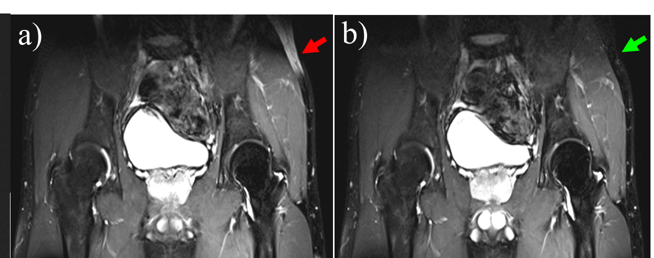

Fig5.a) PD weighted hip image, with standard SPAIR fat suppression; b) PD weighted hip image, with CUSTER fat suppression. Due to the B0 inhomogeneity, the standard SPAIR failed to suppress the fat signal at the edge of the FOV (red arrow), but CUSTER obtained the uniform fat suppression. Inside the center FOV, CUSTER has essentially the same contrast as in the standard SPAIR method, which is superior to that by using pure STIR fat suppression.