Fast separation of water, acetone, fat and silicone with a multiecho balanced SSFP sequence

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Introduction: Fast methods based on multiecho bSSFP have been proposed recently to map species with different chemical shifts into separate images [1,2], which in it's simplest form means fat/water separation. However, in advanced tumor diagnostic techniques like metabolite mapping it is desirable to be able to separate more than two species. We demonstrate the feasibility of separation of four species with multiecho bSSFP data on ^{1}H phantoms (water, acetone, fat, silicone) and the separation of three species (water, fat silicone) in vivo. The method is of potential use for fast CSI imaging of ^{13}C or ^{31}P.

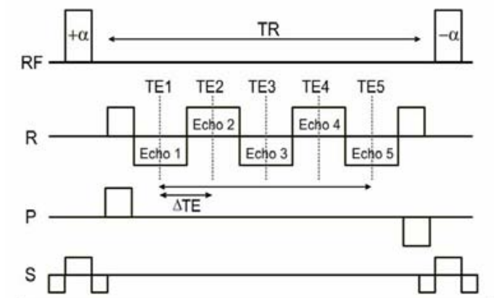

Figure 1: Balanced SSFP multiecho sequence, shown for 5 echoes during one TR interval.

Method: A 2D multiecho balanced SSFP sequence as exemplarily depicted in fig. 1 was implemented on a Sonata 1.5 T scanner (Siemens Medical Solutions, Erlangen, Germany, max. Amplitude 40 mT/m, max. slew rate 200 mT/m/s). For a each phase encoded line a number of N echoes was acquired to finally get N images at different echo times. This complex image data can be processed with the IDEAL algorithm [3,4] to display images in spectral domain at predetermined frequencies. The IDEAL algorithm takes field inhomgeneties into account, i.e. to separate M species M+1 echoes are needed at minimum. As the multiecho data were acquired with an EPI-like readout gradient with alternating polarity, a phase correction must be applied allowing correction of inconsistencies between the trains of odd and even numbered echoes, caused by delays in gradient switching and eddy currents [5]. To improve the performance of the IDEAL algorithm a fieldmap according to [6] was computed to start with the iteration. In contrast to the original IDEAL method [4] data was acquired with symmetric echoes, i.e. the echoes are symetrically ordered around the central echo at TR/2.

Results: Data of a phantom of water (chemical shift Δf=0 Hz), acetone (Δf=-120 Hz), fat (Δf=-234 Hz) and silcone (Δf=-322 Hz) was acquired with 5 echoes (fig. 2), TR=10.15 ms, TE=1.66/3.37/5.08/6.79/8.5 ms, α=40°, matrix size 128*128, FOV=340*340mm^2, voxel size 2.7*2.7*10 mm^3, BW/Px=630 Hz. Total acquisition time 6.4 s, including 500 preparing dummy cycles. The phantom consists of bottles filled with doped water, vegetable oil, acetone, and a silicone breast implant. Parameters for the in vivo dataset (fig. 3) were: 5 echoes, TR=8.5 ms, TE = 1.49/2.87/4.25/5.63/7.01 ms, matrix 128*128, FOV=340*340 mm^2, voxel size 2.7*2.7*10 mm^3, BW/Px=800Hz, α=50°. Total acquisition time 3.6 s (300 dummy cycles). The silicone phantom was placed on the abdominal wall of a volunteer to create an invivo situation with three ^{1}H species water (Δf=0 Hz), fat (Δf=215 Hz) silicone (Δf=310 Hz). The expected resonance frequency of each metabolite was determined with a STEAM sequence during the frequency adjustment after an automated shimming procedure. Thereby the chemical shift frequencies are determined which are needed as prior knowledge for the iterative reconstrution.

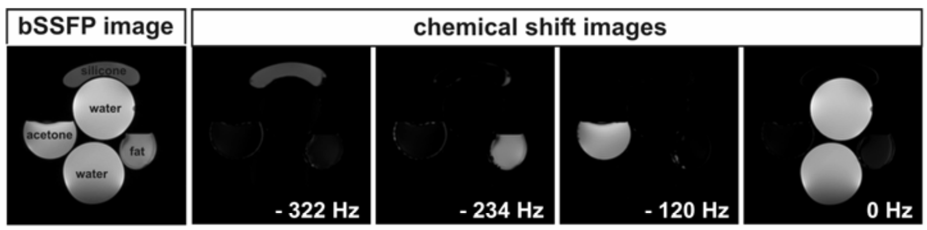

Figure 2: Phantom of water (0 Hz), acetone (-120 Hz), fat (-234 Hz) and silicone (-322 Hz) after iterative frequency reconstruction of bSSFP multiecho data (5 echoes). Balanced SSFP image on the left.

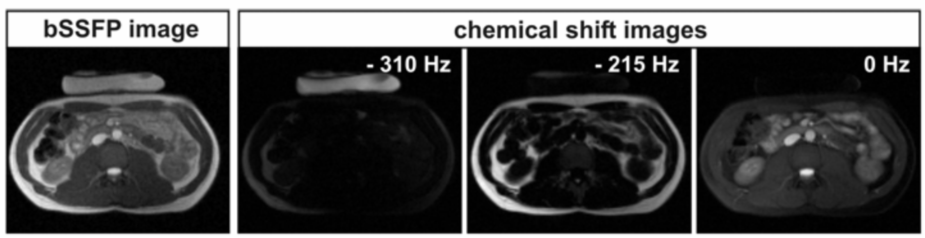

Figure 3: Separation in vivo of water (0 Hz), fat (-215 Hz) and silicone (-310 Hz) with multiecho bSSFP (5 echoes) and iterative frequency reconstruction. Balanced SSFP image on the left.

Conclusion: The feasibility of separation of up to four ^{1}H species of different chemical shift is demonstrated with a multiecho balanced SSFP sequence and IDEAL reconstruction. The method is useful for fast CSI with high spatial and moderate spetral resolution for situations where the expected chemical shifts are known. Higher frequency resolution would be possible with longer echo trains, however, TR can not be arbitrarily long due to the common banding artefact problems. The method is promising particularly for fast ^{13}C CSI imaging, because the larmor frequency of ^{13}C is about one fourth of ^{1}H, thus TR values of 20-30 ms are easily available for ^{13}C. Imaging speed especially becomes important for hyperpolarized ^{13}C with a decay rate of about T_1 ~ 1 min.

References: [1] Wieben, ISMRM 2005, Nr.2386 [2] Leupold, ISMRM 2005, Nr.102 [3] Reeder, MRM 51:35-45(2004) [4] Reeder, MRM 54:636-644(2005) [5] Reeder, JMRI 9:847-852(1999) [6] Yu, MRM 54:1032-1039(2005)