Simultaneous multi-slice imaging with chemical shift separation

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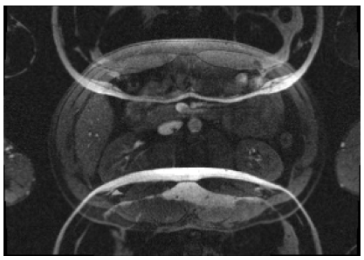
Purpose: Simultaneous multi-slice (SMS) imaging [1] is becoming a prominent imaging acceleration technique. SMS is often combined with the CAIPIRINHA principle [2] to reduce the impact of slice aliasing. Multiband/SMS acquisition has hitherto been focused on acceleration in the spatial domain. Here we show a pulse sequence and reconstruction method that acquires signals from multiple species in multiple slices simultaneously and subsequently separates them into individual images.

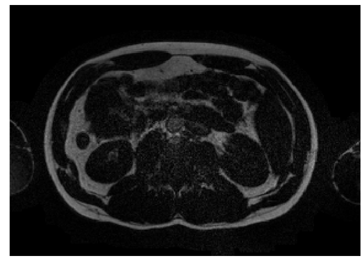
Methods: Experiments were performed on a 1.5T Achieva scanner (Philips, Best, NL). The scanner software was modified to allow alternation of multiple excitation waveforms in subsequent phase encoding intervals. RF pulses were designed using a numerical multi-shift algorithm as introduced in [3], which was modified to allow spectral control based on the binomial composite pulses principle [4]. In a first experiment, we design two RF pulses to excite a single slice, where the first pulse excites water and fat in phase and the second excites them out of phase. The two pulses are alternated for odd and even phase encoding lines to induce a fat-specific shift of FOV/2 in the image domain. In a second experiment, we create four RF pulses that selectively excite the water and the fat in two slices simultaneously. Together, the pulses are designed to result in a FOV/4 shift for all species in the second slice and, concurrently, a FOV/2 shift of the fat in both slices. For both cases abdominal imaging was carried out on a healthy volunteer using a 16 channel coil array, using a gradient echo sequence with α/TE/TR = 20°/5ms/14ms, FOV 40x40cm, voxel size 2x2x5mm^3. Image reconstruction was performed in Matlab (The MathWorks, Natick, USA) using the ReconFrame toolbox (Gyrotools, Zurich, CH).

Results and discussion: In our first experiment, RF pulse alternation yields a fat image offset from the water image by FOV/2. Water and fat images fold over (a) (SoS reconstruction), which is resolved using in-plane SENSE reconstruction (b), where the coil sensitivities have been modified as proposed in [5].



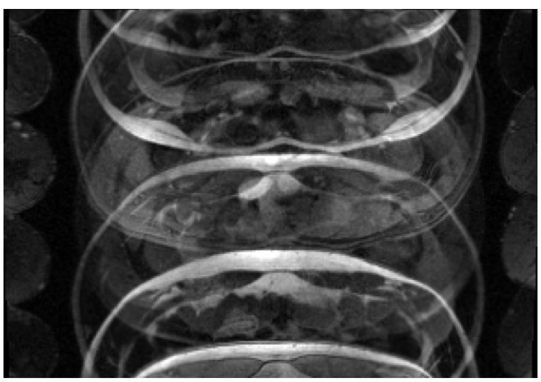
(a) result for single slice experiment before fold-over is resolved.

(b) water image

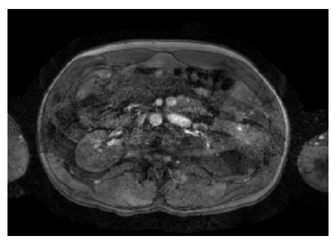


(c) fat image

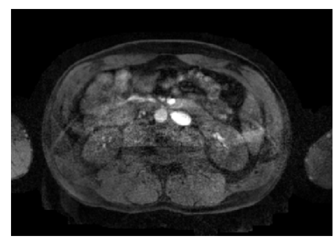
In the second experiment, the employed pulses result in correctly shifted fat and water images for the two slices and here, too, the spatial fold-over artefacts are resolved using combination of in-plane and through-plane SENSE.



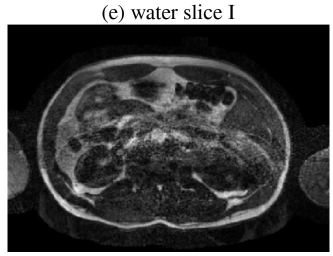
(d) result for dual slice experiment before fold-over is resolved



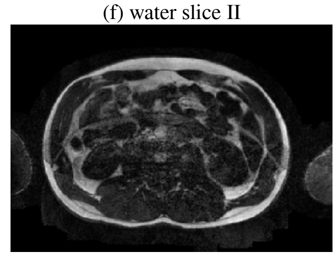
(e) water slice I



(f) water slice II



(g) fat slice I



(h) fat slice II

Spectral-spatial selective excitation as used here is susceptible to B0 inhomogeneity as well as B1+ inhomogeneity effects that may become apparent at higher field strengths (3T and above). This is also visible in images (g) and (h), where the arms seem wrongly composed of fat entirely. The RF pulse design technique used here can take the B0 and B1+ field deviations into account however [3]. Further improvements may henceforth come from RF pulses that enforce more strict control over the spectral part of the excitation.

Conclusion: The proposed technique yields chemical-shift separated images in multiple slices from a single measurement and is in principle applicable to other sequences than the simple gradient echo used here (e.g. balanced SSFP). This technique is not limited to water and fat but can be used in principle to separate arbitrary chemical species or spin population precessing at distinguishable frequencies.

References: [1] Larkman et al. J Magn Reson Imaging 2001 13:131-317; [2] Breuer et al. Magn Reson Med 2005 53(3):684-91; [3] Sbrizzi et al. Magn Reson Med. 2011 66(3):879-85; [4] Hore J Magn Reson 1983; 54:539-542; [5]] Breuer et al. Magn Reson Med. 2006 Mar;55(3):549-56