Continuous Fat Suppression during Respiratory Triggering

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Introduction: Respiratory triggering is a technique that reduces motion artifacts by synchronizing the measurement with the breathing cycle of the patient and by placing the data acquisition period into the relatively quiet end expiration phase [1]. The trigger algorithm usually generates one trigger per respiratory cycle. After the trigger the imaging sequence acquires data from a predefined number of slices and then stops data acquisition unless the next trigger is generated during the next breathing cycle of the patient. The effective repetition time (TR) is therefore determined by the breathing cycle, which is typically between 3 and 6 seconds. Respiratory triggering is hence used in conjunction with 'long TR' sequences such as T2w turbo spin echo (T2-TSE) or diffusion weighted spin-echo EPI (DW-SEEPI). To suppress bright fat signal in T2-TSE or to avoid fat ghosts in DW-SEEPI a spectral selective, spatial non-selective saturation or inversion can be used. Due to the relative long echo train duration (50-200ms) and the relative short TR of fat (T1 ~ 260 ms for 1.5T) the fat suppression pulse is repeated prior to the excitation of every slice. The TR of the fat suppression module is therefore significantly shorter than the TR of the imaging sequence. In a respiratory triggered acquisition the steady state of the fat signal is interrupted during inspiration while the sequence waits on the next trigger and therefore passes through a transcendent state at the beginning of each acquisition period (Fig. 1). This leads to a significant inferior fat suppression of the slices acquired at the beginning of the acquisition period compared to the fat suppression of the slices acquired later. We tried to solve this problem by a fat selective steady state prep pulse at the beginning of each acquisition period [2, 3]. However, this did not solve the problem completely. In this work it is shown that the steady state of fat signal can be sustained by continuing the sequence of fat suppression modules between triggers.

Methods: Fig. 1 is a schematic plot of our previous respiratory triggered sequence which derives the physiological signal needed for triggering with a navigator.
At the beginning and between the acquisition periods the navigator module is repeated with constant time interval TR_{SCOUT}. The result of each navigator module is one physiological data point which is the input to the trigger algorithm. As soon as the trigger condition is fulfilled the navigator sequence stops and gives control to the imaging sequence. In the example shown in Fig. 1 the imaging sequence acquires data from three different slices S1…S3 (e.g. one echo train per slice). Before each of the three acquisition modules a spatial non-selective fat suppression module "FS" is executed. After this acquisition period the navigator sequence sets on again until the trigger condition is fulfilled again during the next breathing cycle. The effective TR of the spatial selective acquisition modules is therefore determined by the breathing cycle. The TR of the fat suppression TR_{FAT} modules during the acquisition period is determined by the accumulated duration of one FS module and one acquisition module. The time between the last FS module of one acquisition period and the first FS module of the next acquisition period is significantly longer. This disturbs the steady state of the fat spins and is the likely reason for the insufficient fat suppression of the early slices. Fig.2 is a schematic plot of the modified respiratory triggered sequence. Here FS modules are repeated with constant time interval TR_{FAT} during the entire run-time of the sequence. Hence the steady state of fat spins is not interrupted between acquisition periods and similar fat suppression of all acquired slices is expected. The spatial non-selective FS module now also affects the navigator signal, in general. Therefore the time interval between the navigator and the preceding FS module must be constant. Otherwise a difference between an actual navigator signal and the reference, which is due the different fat suppression, may be interpreted as physiological motion. The time between successive navigators TR_{SCOUT} is therefore not an independent parameter but is equal to TR_{FAT}. Note that Fig.1 and Fig.2 are not drawn to scale. The actual number of acquisition modules is usually much higher than 3 and also the number of navigator modules between respiratory cycles is significantly higher than drawn. Single-shot DW-SEEPI images were acquired with both navigator techniques in a healthy female volunteer using a 3T MAGNETOM Verio scanner. Figure 3 shows images from the slices acquired at the beginning of the breathing cycles. The label S1…S9 increases with the temporal acquisition order (and also with the spatial position in feet-head direction). Each trace weighted b=50 s/mm^2 image was acquired during three successive respiratory cycles. Even labeled slices were acquired after the completion of the odd labeled slices. In the upper row of Fig. 3 the sequence of Fig. 1 was used. Not shown in Fig. 1 is a spectral selective steady state prep pulse at the beginning of each acquisition period which was used to drive fat spins towards steady state. The lower row shows the results with the new sequence of Fig. 2.
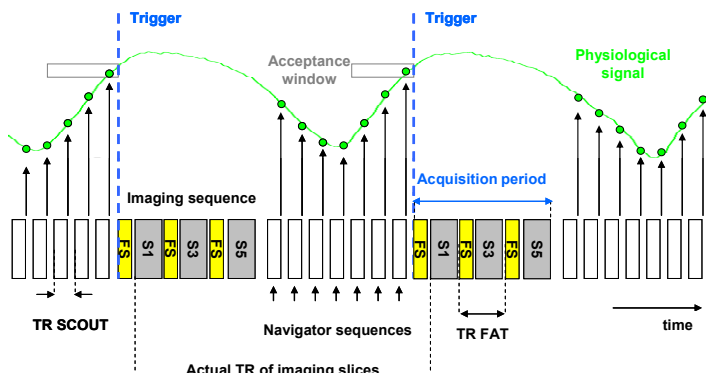

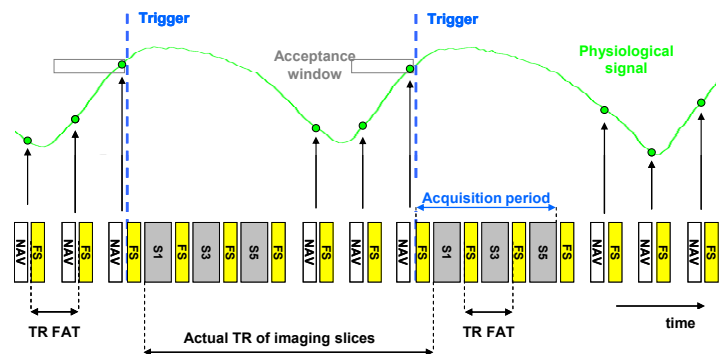Figure 1: Previous respiratory triggered sequence.

Figure 2: Respiratory triggered sequence with continuous fat suppression.

Results and discussion: The images acquired at the beginning of the acquisition period using the previous technique show residual fat ghosts. The ghost intensity decreases in acquisition order. The fat suppression of the images acquired with the new technique is independent of the temporal acquisition position. One disadvantage of the new technique is the higher SAR exposure of the patient due to the increased number of FS modules. In the previous technique the temporal resolution of the physiological signal is limited by the duration of the navigator. The temporal resolution of the new technique is limited by the accumulated duration of one fat suppression module and one acquisition module. This limits the new technique to sequences where this time is below 200 milliseconds. T2-TSE and SEEPI sequences usually fulfill this condition. Please note that this restriction does not exist if an external device such as a respiratory belt or cushion is used to derive the respiratory signal.

References:
[1] Lewis et al. Radiology 160:803–810 (1986)
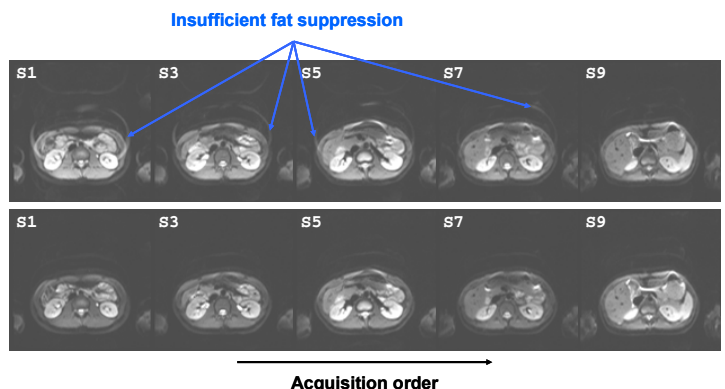[2] R.F. Busse et. al. MRM 45: 653-661 (2001)
[3] Patent No.: US 7,609,059

Figure 3: Single shot DW-SEEPI images acquired with the sequence of Fig.1 (upper row) and the sequence of Fig.2 (lower row). In the upper row the interruption of the fat steady state during inspiration leads to insufficient fat suppression of those slices acquired at the beginning of the acquisition periods. With the new technique the quality of fat suppression is independent of the temporal acquisition position.