Phase navigator for 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 physiological signal needed by the trigger algorithm can be derived from the motion of the abdominal wall with a pneumatic sensor or by measuring the diaphragm position with a navigator [2]. Novel short bore MR systems increase patient comfort and help to reduce claustrophobia significantly. However, in large patients it can be difficult to place the imaging volume and the navigator into the homogeneity volume of such a scanner. In FMRI navigator echoes are used to correct physiologically related phase errors [3]. In this work the signal for respiratory triggering is derived with a navigator that measures respiratory induced off-resonance effects.

Methods: In gradient echo imaging an off-resonance spin accumulates an extra phase that is proportional to the off-resonance and increases linearly in time. A respiratory induced global off-resonance can hence be derived from the phase difference of two successive echoes. The navigator pulse sequence used to measure the phase difference in this work is shown in Fig.1. The excitation volume of this sequence is an axial, 5 mm slice through the patient's abdomen. The readout direction was chosen along the left-right direction. Fig. 2 shows the processing of the data. The data of each individual echo is first Fourier transformed along the readout direction to yield two projections. Next a pixel-wise complex multiplication of the second projection times the conjugate of the first projection is performed. The phase of the resulting data set is correlated with the patient's breathing cycle. The combination of the different receiver channels, in the next step, can be performed by a simple complex addition since the phase contribution of an individual coil element was removed by the complex conjugate operation. The result of the channel combination is a one dimensional complex vector $p_n(q)$, where n is the navigator index and q the pixel index, which is associated with the spatial coordinate along the readout direction. The signal output is set equal to the weighted mean phase of a window, which is crudely located in the liver of the patient:

$$p_n = \sum_{q \in \text{window}} w_n(q)\ \mathrm{ATAN2}(\mathrm{Im}\{p_n(q)\}, \mathrm{Re}\{p_n(q)\}), \text{ where } w_n(q) = |p_n(q)|^2 \Big/ \sum_{\tilde{q} \in \text{window}} |p_n(\tilde{q})|^2 \qquad (1)$$

The assumption is that this signal is related to the respiratory induced off-resonance $\Delta B_0(t_n)$ in the vicinity of the window at the time t_n of the n-th navigator measurement, i.e.: $p_n = \gamma\ \Delta B_0(t_n)\ (TE_2 - TE_1)$ (2), where γ is the gyromagnetic ratio and TE_2, TE_1 are the echo times of second and first echo, respectively. From equation 2 it is clear that phase unwrapping before the calculation of the mean is not necessary since phase wraps can be avoided by making the echo time difference small enough.

The liver dome navigator of our previous navigator trigger approach was replaced by the phase navigator. The navigator is repeated at constant interval TR_{Scout} to generate a time series of physiological measurement points. This series is used as the input for the trigger algorithm. A trigger is generated when three trigger conditions are fulfilled: (*i*) the slope of the series indicates expiration; (*ii*) the latest signal point differs less than an acceptance window from the trigger threshold and (*iii*) a minimum time has passed since the last trigger event. The trigger stops the navigator sequence and the imaging sequence acquires a predefined block of imaging data (e.g. one echo train per slice in TSE). After this the navigator repetition restarts unless the trigger condition is fulfilled again during the next breathing cycle (Fig. 3). The trigger level is adjusted to the acquisition duration per trigger of the imaging sequence and to the individual breathing cycle of the patient after an initial learning phase. During the learning phase the navigator sequence is repeated without interruption of the imaging sequence. The learning phase lasts five respiratory cycles. The trigger algorithm is unchanged compared to our previous approach except that all empirical constants which were previously defined in mm are now defined as fractional values of the difference between the maximum and the minimum signal found during the learning phase. As before, the trigger level is readjusted during the measurement if the breathing cycle changes such that complete respiratory intervals are skipped.

T2-weighted turbo spin echo images and diffusion-weighted single shot EPI images were acquired with both navigator techniques in healthy volunteers using 1.5T Siemens MAGETOM Espree and 3T MAGNETOM Verio scanners.

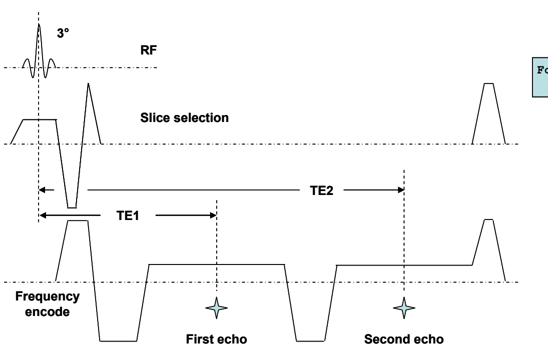

Figure 1: Sequence diagram.

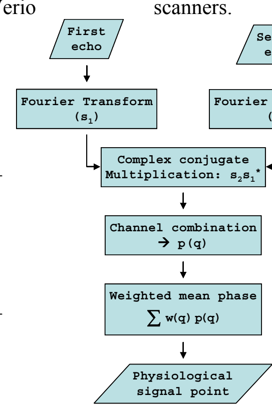

Figure 2: Data processing.

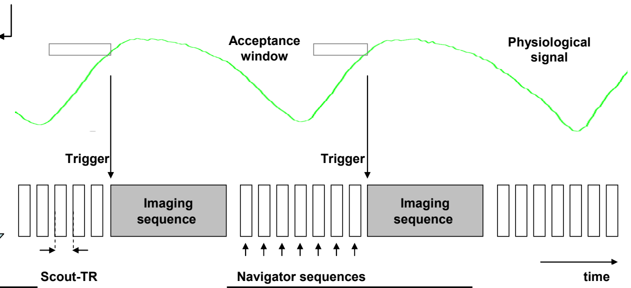

Figure 3: Timing diagram.

Results and discussion: In our experiments image quality with both navigator techniques was comparable. At the time of abstract submission the new technique has not yet been evaluated clinically. The phase navigator yields a robust respiratory signal for a wide range of navigator positions within the patient's abdomen and is therefore compatible with short bore systems. The phase navigator does not track tissue or object boundaries (like the diaphragm edge). Therefore it is not necessary that the operator positions the navigator. In most applications it can be set "automatically" by the system relative to the stack of imaging slices. Saturation of the imaging volume is avoided by a small flip angle (3°). Most navigator techniques derive the physiological signal by comparison of the actual navigator scan with an earlier reference scan (e.g. the very first navigator). An interfering signal (such as saturation stripes from the imaging slices), which is not present in the reference, can create a false output signal. Because the physiological signal of the phase navigator is derived from the comparison of the two echoes which are acquired within milliseconds the saturation stripes and the transcendent state after the imaging sequence do not distort the result. However, a single echo variant with reference comparison also worked.

References: [1] Lewis et al. Radiology 160:803–810 (1986); [2] Wang et al. Radiology 198: 55-60 (1996); [3] Hu et al. MRM 31:495-503 (1994)