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Self-gating Reconstructions of Motion and Perfusion for Free-breathing T1-weighted DCE-MRI of the Thorax Using 3D Stack-of-stars GRE Imaging

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INTRODUCTION: Dynamic imaging of the lung and abdomen requires a trade-off between spatial resolution, temporal resolution, and total acquisition time. Only 2D sequences are fast enough to capture both breathing motion and fast perfusion processes. However, multi-slice 2D sampling usually suffers from inter-slice inconsistencies. For 3D imaging, it is common practice to acquire the data using one or multiple breath-holds. If patients are uncooperative or unable to suspend respiration, a navigator may be used to trigger the acquisition during free breathing, which significantly prolongs the scan time. Due to its robustness against motion, the clinical use of free-breathing 3D radial spoiled gradient echo (VIBE) imaging for abdominal applications has recently gained interest [1,2,3]. It has also been shown that self-gating techniques enable the reconstruction of different respiratory phases [4] and compensation of respiratory motion in dynamic contrast-enhanced MRI (DCE-MRI) [5]. Typically, however, separate acquisitions are required to capture the respiratory movement *and* dynamic perfusion. In the present work, we show that a retrospective self-gating technique can be employed to extract all information from a single continuous free-breathing scan acquired with a stack-of-stars 3D VIBE sequence. This technique can be used to compute different sliding-window reconstructions that show a complete 'virtual' respiratory cycle with high spatial resolution, or, alternatively, a time series of the contrast-enhancement at a specified level of inspiration and with high temporal resolution.

MATERIALS AND METHODS: The intrinsic self-gating signal (SGS) used here is obtained from the central k-space samples acquired with every radial spoke. A Gaussian weighting is applied both in space and time to reduce noise and angle-dependent fluctuations. To detect the extrema in the SGS that correspond to maximal inspiration and expiration, first, the average breathing rate is estimated by finding the dominant frequency between 0.1 and 2 Hz in the Fourier transform of the SGS. For each expected respiratory extremum, the position and type (minimum / maximum) are then determined by locally fitting a quadratic polynomial. A relative position is assigned to every radial readout according to the relative position within a respiratory cycle: ranging from -1, denoting full exhalation, to +1, for full inhalation. For image reconstruction, only two parameters can be adjusted, keeping user interaction simple and intuitive: the width of the sliding window in seconds, which trades off between temporal resolution and spatial resolution, and the desired gating tolerance. This second parameter determines the gating efficiency, i.e. the fraction of the data used for the reconstruction.
There are three interesting parameter combinations: (1) Low temporal resolution and low gating efficiency produce high-resolution images without motion artifacts. By computing these images at different levels of inspiration, a movie of the full respiratory cycle can be obtained. (2) When intermediate values are chosen both for the resolution and for the efficiency, the perfusion can be visualized for any given level of inspiration and without respiratory motion. (3) If high temporal resolution and high gating efficiency are selected, the reconstruction shows motion blurring e.g. at the liver dome but is optimal to visualize fast perfusion processes. This last combination corresponds to a conventional sliding-window reconstruction.
The three types of retrospective reconstructions were performed for a clinical dataset obtained using a 3D stack-of-stars GRE sequence with golden angle reordering and coronal slab orientation. The scan was performed on a 1.5 T MR System (MAGNETOM Avanto, Siemens Healthcare, Erlangen, Germany) with a combination of neck, body, and spine coil arrays, and after intravenous administration of 14.7 ml of Gd-DTPA (Magnevist). Written informed prior consent was obtained prior to the study. The following protocol parameters were used: FOV 50x50x5 cm (256x256 matrix, 10 slices), 7 repetitions with 2004 radial spokes each, total acquisition time 280 s (temporal resolution of 17.1 ms per stack of spokes), TR/TE 3.22/1.11 ms, FA 10°, BW 1028 Hz/pixel. For the visualization of the respiratory motion (1), a sliding window with a width of 40 s was placed at approximately t=50 s. The gating tolerance was set to +/- 5 %, and images were computed for 25 different levels of respiration. For the dynamic images with frozen respiration (2), the window width was set to 13 s, and the tolerance to +/- 15 %. The window was shifted in increments of approximately 2 s. Finally, for the regular sliding window reconstruction (3), the window was restricted to 5 s, accepting all data.

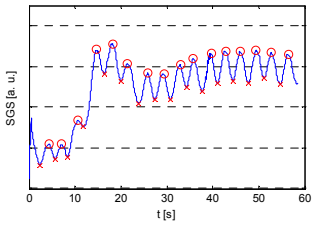

Fig. 1: Self-gating signal.

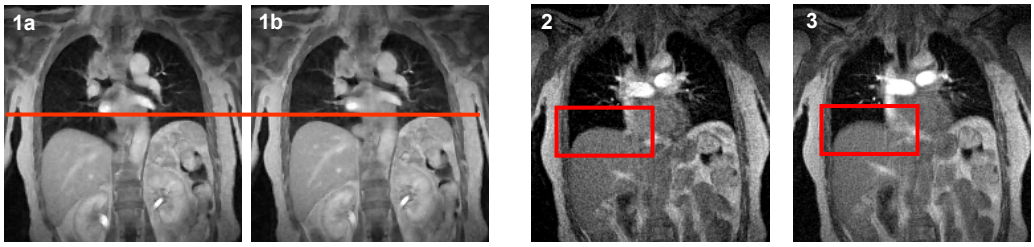

Fig. 2: Reconstructions with high spatial resolution at maximal inspiration and expiration (1a,1b). Dynamic image at end-inspiration (2). Dynamic sliding-window reconstruction (3).

RESULTS AND DISCUSSION: The extracted self-gating signal for the first two repetitions is shown in Fig. 1 where circles and crosses indicate the detected maxima and minima. The arrival of the contrast agent bolus at t=10 s is clearly visible. Figures 2.1a) and 2.1b) show the states of full inspiration and expiration, respectively. In these images, the perfusion dynamics are lost by temporal averaging, but motion artifacts and noise are low. The red line highlights the displacement of the liver, due to respiratory motion. Fig. 2.2 shows the second type of reconstruction at the point where the contrast agent bolus just passes the pulmonary arteries and the gating was set to end-inspiration. The regular sliding-window reconstruction, shown in Fig. 2.3, is more blurred from motion, as clearly visible at the upper edge of the liver (red box). Unlike in the type (2) reconstruction, where the position of liver and heart remain mostly constant throughout time, the average respiratory phase is still visible in the conventional sliding-window reconstructions and leads to distracting changes between time frames. Nevertheless, this setting would be preferable to obtain the highest temporal resolution.

CONCLUSION: We showed that retrospective self-gating combined with different sliding-window reconstructions enables visualization of both the respiratory cycle *and* the contrast dynamics from a single continuous free-breathing acquisition. Since the technique does not require breath holding nor critical timing with respect to the contrast arrival, it is well suited for patients that are unable to suspend respiration during the acquisitions. Future work includes the use of advanced reconstruction techniques to reduce the remaining undersampling artifacts and noise.

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