Hybrid US/MR System for Real-Time Compensation of Breathing Motion Artifacts in Cardiovascular MRI at 3 Tesla

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Introduction: Breathing artifacts in ECG synchronized cardiac CINE acquisitions remain a major source of degraded image quality in clinical applications. Due to restrictions regarding temporal and/or spatial resolution using breath-holding acquisitions, image acquisition during free breathing is desirable for a number of applications [1]. Several methods for motion compensation or synchronization have been proposed for free-breathing acquisitions. Commonly used MR navigator gating techniques in combination with adaptive phase encoding line reordering schemes [2], however, suffer from disadvantages including steady-state interruption, signal saturation and low scan efficiencies. Slice following methods have been proposed, often however restricted by the uncertain correlation between heart and diaphragm motion [3]. As an alternative, external respiratory motion tracking devices offer several advantages, since information on breathing patterns can be acquired simultaneously with the MR acquisition and integrated into the imaging procedure in real-time. As shown previously, MR compatible ultrasound can be used simultaneously with MR data acquisition to directly monitor the motion of the diaphragm or heart in real time [4]. To date, the potential of ultrasound imaging for motion tracking has not been fully exploited due to hardware and software integration issues. We present a straightforward integration of an ultrasound system in a 3 Tesla MR environment including a short latency real-time feedback implementation for prospective compensation of breathing motion in cardiovascular MRI. Results of ultrasound gated gradient echo acquisitions of a motion phantom as well as in-vivo time resolved cardiac imaging demonstrate the feasibility of the hybrid imaging technique.

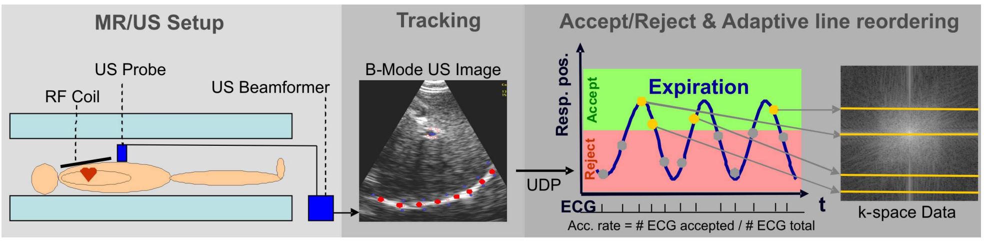

Fig.1: US/MR Setup incl. data processing for gated acquisitions. Breathing motion is tracked; decisions are made for each ECG cycle, end-expiratory positions are favored for central k-space phase encoding steps.

Methods: A portable USB-connected ultrasound system (*mediri GmbH*) was hardware shielded by a copper RF cage and aluminium foil. The probe was fixed on a frame mounted on the scanner bed. The right hemi-diaphragm was scanned by ultrasound during free breathing. Moving object coordinate tracking on the B-Mode images was performed using an algorithm based on conditional density propagation [5]. Data were transferred in real-time via UDP to the MR sequence [6]. An Accept/Reject Algorithm (ARA) in combination with an adaptive phase encoding line reordering algorithm was used in a Cartesian RF spoiled ECG synchronized k-space segmented (CINE) gradient echo sequence [2]. A single decision per heartbeat was made whether to accept or repeat the cycle (Fig.1). All measurements were performed on a 3T system (*TimTrio, Siemens Medical Solutions, Germany*). For comparison, MR navigator gating consisted of a simple crossed-pair navigator placed on the right hemi-diaphragm, executed at the end of each ECG cycle. Single slices of an MR compatible ultrasound motion phantom as well as a short axis cardiac slice were acquired (1.4x1.4x8mm^3**,** GRAPPA (x2), TR/TE=3,7/1.33ms, 40 time frames, 6 k-space lines per phase). Image features and statistical noise behavior were analyzed using *MatLab (The Mathworks, USA)* and *ImageJ (NIH, USA)*.

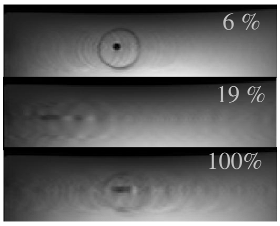

Fig.2: US gated motion phantom images for diff. acceptance rates. The moving sphere appears immobile when gating.

	Off	MR	US
mean	13.02	7.23	7.2
std	6.96	2.53	2.49

Table1: Quantification of motion induced background noise in-vivo (averaged over all time points in identical artifact-affected ROIs).

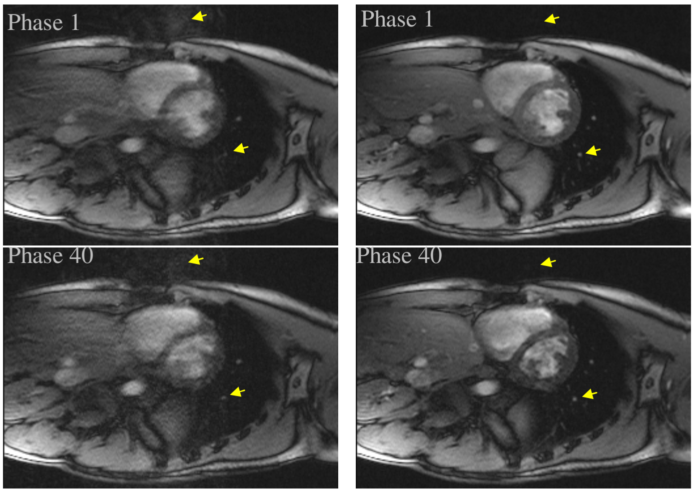

Fig.3: Free breathing short axis cardiac acquisitions without (left) and with (right) US gating (acceptance rate: 27%).

Results: 2D MR acquisitions of a motion phantom using ultrasound gating were acquired and demonstrated the feasibility of a real-time feedback ultrasound-MR system with minimal data latency. Refreshing rates of 8TR (ca. 40Hz) were achieved by using standard ultrasound B-Mode imaging. Motion artifacts were clearly reduced by diminishing the ARA acceptance window (Fig.2), i.e. by freezing the phantom motion. Compared to ungated acquisitions, in-vivo US gated acquisitions considerably improved blurring and ghosting (arrows Fig.3) due to subject respiration throughout the ECG cycle. Results were comparable to standard MR navigator gated acquisitions; reflected in similar motion artifact reduction (Table 1) and edge sharpness (Fig.4) for similar acceptance rates. Advantages compared to MR navigators included retained magnetization steady-state, higher ECG triggering accuracy (no RF interferences with electrodes by the navigator pulses) and absence of navigator-induced signal saturation effects.

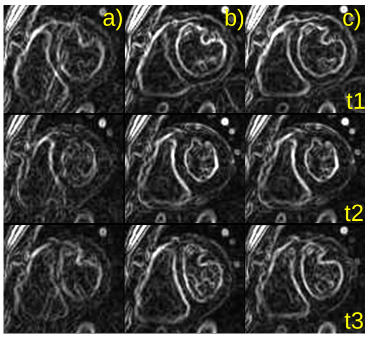

Fig.4: *Sobel*-Filter based edge detection on non-gated (a), US-gated (b) and MR-gated (c) acquisitions for three different ECG time-points (t1,t2,t3).

Discussion: The feasibility of a hybrid Ultrasound/MR system at 3T including a real-time ultrasound feedback system was demonstrated. Phantom experiments and first in-vivo applications using ultrasound gating for ECG triggered CINE MRI were performed. Short axis slices showed promising results; correcting for breathing motion artifacts, without further artifacts arising from the ultrasound device. Advantages compared to MR navigators include no steady-state interruption, no signal saturation and the possibility to directly track the heart movement. Future work will include latency-corrected heart motion tracking, isolating respiration-induced from heart beating motion. A combination with a prospective slice following method including translation, rotation and scaling parameters from the tracking algorithm may further improve image quality and/or acceptance rates. Moreover, a replacement of the electrode ECG-recording by direct ultrasound imaging of the cardiac motion will be considered.

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References: [1] Jung B, et al. Magn Reson Med 2006;55 **[2]** Markl M, et al. J Magn Reson Imaging 2007;25 **[3]** Nehrke K, et al.: Radiology 2001;220 **[4]** Günther M, et al. Magn Reson Med 2004;52 **[5]** Isard M, et al. Int J Computer Vision 1998;29 **[6]** Zaitsev M, et al. Neuroimage 2006;31