Development of a hybrid MR-US system for the assessment of cardiac function during free breathing

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Introduction: Cardiac MRI scans are often performed during free breathing since the scan time exceeds the patient's breathhold capability. Typically, information about the respiratory position is determined with navigators and used to either accept or reject MR data (respiratory gating [1-2]). However, navigators require an interruption of data acquisition and are therefore played out once per cardiac cycle which can lead to breathing related artifacts particularly in Cine imaging. As an alternative, ultrasound (US) imaging was recently proposed [3-6] allowing a higher update rate of the respiratory information, avoiding signal voids and interruptions of data acquisition. Therefore, the update rate of the respiratory position can be significantly improved compared to the standard navigator technique. The aim in this work was to establish a hybrid MR-US system for cardiac Cine imaging using an update of the respiratory position on each cardiac time frame and to compare this method with the conventional approach with one update per cardiac cycle.

Methods: All measurements were performed on a 1.5T system (Sonata, Siemens, Germany) using a respiratory gated Cine gradient echo pulse sequence. The US system (Model T15-SonoPlan, mediri) consists of a beam former (Echo Blaster 128) and a computational unit with a touch screen. It was integrated into the MR scanner environment by adjusting the hardware (e.g. RF-shielding) and software (sequence implementation) accordingly. The US system was placed into the MR scanner room next to the patient table. Thus, US imaging and positioning of the transducer was possible without the need to leave and re-enter the MR scanner room. To eliminate background noise, induced by RF-interferences between the US system and the MR scanner, RF-shielding according to the principles of a Faraday cage was established (Fig. 1). Three different Cine measurements were performed in a short axis view of a healthy volunteer during free breathing: 1) MR navigator gating with one respiratory update per cardiac cycle (Fig. 2a). 2) US gating with one respiratory update per cardiac cycle (Fig. 2b). 3) US gating with a respiratory update per cardiac frame (Fig. 2c). An additional breathhold scan was performed for comparison. MR and US imaging parameters are summarized in tables 1 and 2.

voxel size [mm]	1.33x1.77x10
matrix	256x192
temp. resolution [ms]	37.6
TE/TR [ms]	1.7/4.7
flip angle/(°)	15
bandwidth [Hz/pixel]	349
# of k-space lines per phase per heartbeat	8

Table.1: MR-Scan parameters.

scanning depth	power	gain	frequency
18 cm	50%	100%	4 MHz

Table 2: Ultrasound parameters for real time B-mode imaging.

In order to optimize the efficacy of the data acceptance rate, respiratory gating with two different gating algorithms were implemented and tested by simulations: 1) gating window width adjusted to a predefined percentage value of the respiratory amplitude (p_{amp}); 2) gating window width adjusted to a predefined acceptance rate (p_{loc}) (hence, the duration of the measurement). Both gating algorithms use relative values for calculating the size of the gating window since navigator and US gated images were to be compared and navigator data and US data are in two distinct coordinate systems.

A structure next to the heart, representing the respiratory displacement of the heart, was tracked by the US system. In order to investigate the impact of the integrated US system on the signal intensity an SNR analysis based on a ROI in the liver and outside the object was performed.

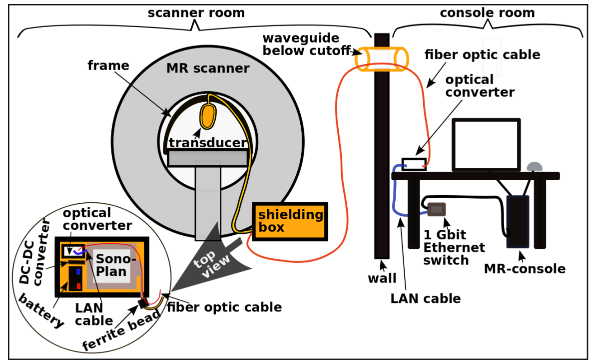

Fig.1: Final setup of the hybrid MR-US system (power cables are not shown for clarity). Entire US system shielded with copper.

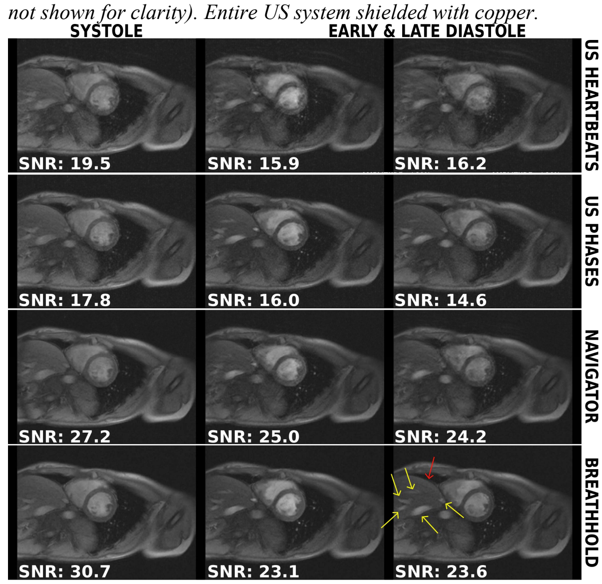

Fig.3: Systole and diastole short axis images were acquired using ultrasound gating, navigator gating and breathhold. The gating window was dynamically adjusted to p_{amp} = +/-20%. Liver vessels and the border of the liver are highlighted (yellow and red arrows, respectively).

Results: Representative short axis slices for one systole and two diastole time frames are shown in Fig. 3. Both gating methods using one respiratory update per heartbeat (US and navigator) demonstrate an increased artifact behavior from systole to late diastole. Clearly improved artifact behavior can be observed for US gating with one respiratory update per cardiac phase and shows similar image quality compared to breathhold images which can be observed by anatomical structures such as the liver vessels (Fig. 3 yellow arrows), the border of the liver (Fig. 3 red arrow) and parts of the right ventricle of the heart. When US gating with one respiratory update per cardiac phase with p_{loc} = 40% or 50% was used, ghosting artifacts showed up in the short axis slice; however, no artifacts can be observed when p_{amp} = +/-20% or +/-30% was used instead. When the US system was used during MR image acquisition a decrease of SNR between 36% and 42% was observed.

Discussion: The US system was successfully integrated into the MR scanner setup for real-time respiratory gating. Since the US system and the MR scanner work independently from each other, the respiratory pattern could be sampled at a higher temporal rate in Cine imaging compared to the conventional navigator gating. Using an update rate of the respiratory position per cardiac phase clearly improved the MR image quality with respect to motion artifacts especially in late diastole. Apart from a decreased SNR, the image quality was comparable with the breathhold scan. In order to account for drifts and changes in the respiratory pattern which might happen especially during longer measurements, the gating window width was adjusted to p_{amp} or p_{loc} , respectively. The motion compensation of the latter tends to be less effective compared to gating onto the respiratory amplitude. However, further volunteer measurements have to be performed to allow for a statistical analysis.

The update rate of the US system (43+/-11 ms) was slightly lower than the temporal resolution of the MR measurements (37.6 ms) and was mainly limited by the acquisition time of the real time B-mode images. However, the averaged update rate agrees well with a typical temporal resolution used in cardiac MR imaging exams. The elaborate RF-shielding of the US system still yield in a slight noise enhancement in the MR images; nevertheless, the image quality with respect to anatomical structures was fully maintained. The issue of RF-shielding might be solved with the new US system being currently developed. The increase of the update rate of the respiratory position might allow for an adaption of the imaged slice with its changing position due to breathing. Thus, allowing a 100% data efficiency while tracking on the heart itself.

Acknowledgements: Deutsche Forschungsgemeinschaft (DFG), Grant # MA 2383/5-1, Bundesministerium für Bildung und Forschung (BMBF), Grant # 01EQ0605.

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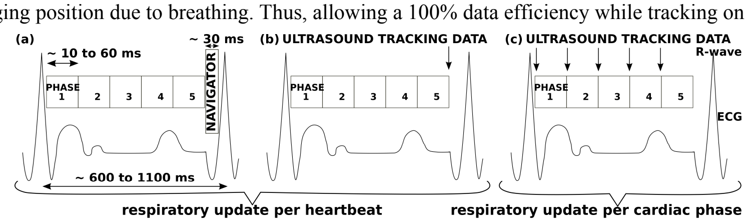

Fig.2: Respiratory data are requested either ***(a)-(b)*** *per heartbeat (navigator / US) or* ***(c)*** *per cardiac phase (US).*