Real-time Ultrasound Imaging in MRI scanner for Guidance of Cardiac MR

D. A. Feinberg[1,2], A. Bongers[3], S. Ramanna[1], and M. Guenther[1,3]

[1]Advanced MRI Technologies, Sebastopol, CA, United States, [2]Redwood Regional Medical Group, Sebastopol, CA, United States, [3]Mediri GmbH, Heidelberg, Germany

Introduction: One potential guidance system is to use real-time ultrasound imaging (US) to prospectively measure and correct for respiratory motion while performing cardiac MR imaging. US guidance of MR scanning would require 2D or 3D US scanning to be performed without producing noise in the MR image and with a feedback loop to modify the MR pulse sequence during cardiac scanning.

Methods: The setup uses an ultrasound scanner (Echo Blaster 128, Telemed), which has a programmable software interface and is light weight and compact. The ultrasound unit can be placed in close proximity to the scanner. It is connected to a PC outside of the scanner room through a 5 yard long USB cable which passes through a waveguide filter in the RF shielding. A single PC was used to run both the US scanner and the tracking software. The MRI scanner (Siemens, Sonata 1.5T) was adapted with an US transducer mounting system, Fig.1, of rigid fiberglass and aluminum brackets to hold the ultrasound on the patient. The rigidity of the mounting system and the adjustable articulated arm holds the ultrasound at a constant position, with measured orientation of the ultrasound probe registered with respect to the coordinates of the MR system

The electronic shielding was optimized for the ultrasound scanner and tracking computer to minimize noise in the MR images. The PC placed in the MR control room is connected to the ultrasound device through a 5 yard long USB cable which passes through a waveguide filter in the RF shielding. Shielding was achieved with aluminum foil and copper covering of the transducer and other US components. All system components including the ultrasound unit device, transducer and cables are grounded to the magnet screen room. The US interface uses Microsoft DirectX technology which is COM (Component Object Model) based. We also use MFC (Microsoft Foundation Class) was used to implement the necessary graphic user interface. The tracking algorithm is based on the CONDENSATION algorithm (1) and was optimized for low signal-to-noise ultrasound images. The speed of the US image is between 10ms and 50ms, depending on the number of image lines (FOV). The execution of the tracking algorithm was less than 1 ms and transfer to the MR control computer is 4ms. A cardiac MR pulse sequence (SSFP, "trueFISP") was modified with real-time update capabilities of the sequence's rotational coordinate matrix. The current slice position and orientation is read from a set of variables, update as soon as new positional data from the US system is available.

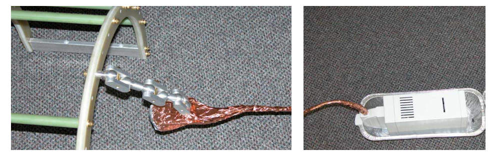

Fig.1 (right) MR patient table mounting frame, articular arm, shielded US transducer, (left) US unit.

Results: Imaging was performed in 3 normal volunteers. The cardiac images were free of noise from the US system once the interference from the ultrasound transducer was eliminated by Faraday shielding with copper and aluminum foil and by maximizing ground coupling to the screen room floor. Motion phantom studies (not shown here) were used during system set-up to demonstrate noise free images and see that all system components were operating in proper feedback prior to in vivo studies. The right diaphragm was tracked with US during normal breathing and during intentional rapid breathing. Tracking of the structures within US was robust. A representative coronal SSFP image of the heart acquired during US guidance, Fig. 2, was combined with cardiacECG gating. In some studies, chordae tendinae attached to papillary muscle in left ventricle were better seen with US guidance which updated the heart position during the SSFP sequence reducing blurring. The cine MR movies of the heart obtained with and without US guidance demonstrated a shift of coordinate system between the stationary body and the moving heart and the heart appeared nearly motionless during the US tracking while the body appears to move. M-mode type MR image display, utilizing a single line oriented vertical through the heart is plotted during the cine acquisition. Fig 3 shows different combinations of US guidance for respiratory gating, ECG cardiac gating and breath-holding. During US guidance activated there is a sinusoidal motion of the upper chest wall identified at the top of the M-mode strip while at the heart-diaphragm interface there is markedly reduced motion.

Discussion and Conclusion: Some residual motion of the heart is present during cine-movie images and identifiable on the M-mode data, attributed to lack of calibration and indirect correlation of the displacement of the diaphragm and heart which could likely be further improved by calibrating relative displacements of heart and diaphragm. In contrast, the US guidance was highly effective in eliminating motion displacement in liver and right kidney as expected due to their highly correlated position with the motion of the right hemi-diaphragm. Adaptation of a system to track transducer displacements could be used instead of fixing the transducer position. The removal of the PC from the scanner room, while not a source of noise, has a practical advantage of permitting real-time graphic overlay display of the tracked regions on the dynamic ultrasound images.

One advantage of US guidance compared to MR navigator techniques is the US guidance is performed simultaneous with the running of the pulse sequence so the heart's position within the slice is continuously being updated within a SSFP sequence to maintain steady state magnetization. Beyond this initial *in vivo* cardiac study, the US guidance system could be used to directly track on the heart wall or pericardium. US guided MR imaging of heart could be useful for coronary MRA studies in combination with navigator echoes. The tracking of liver and kidney indicates potential use for imaging other body organs including breast where the US guidance with real time MRI may be useful for therapeutic biopsy within the MR scanner. In conclusion, these results are the first demonstration of a functioning US guidance system for cardiac MRI.

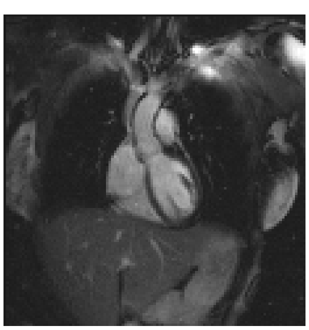

Fig. 2 cine-cardiac MRI with US guidance.

Acknowledgments*:* Funded by National Center for Research Resources, NIH Grant R43RR17474.

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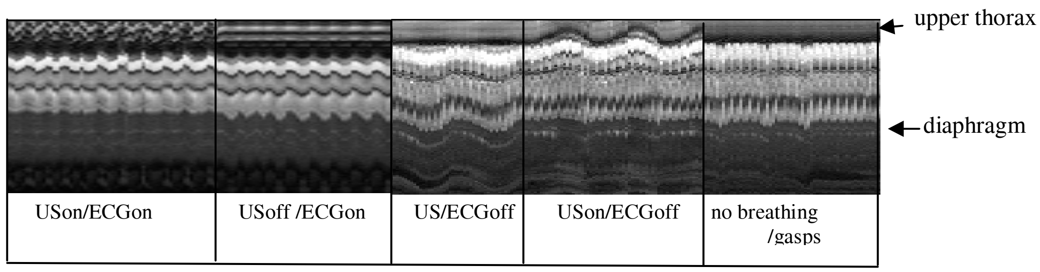

Fig.3 Comparison of different cine heart studies with US tracking and ECG gating.