Simultaneous MR and Ultrasound Imaging: towards US-navigated MRI

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Synopsis: A new approach to cardiac and interventional imaging is proposed using fusion of two imaging technologies by simultaneously performing ultrasound (US) imaging within the magnet during MR imaging. Applications of simultaneous US/MRI acquisition include real time interventional imaging and 3D US navigation of MR imaging of the heart and other moving structures. Initial studies showed no interference in real-time cardiac US imaging from the magnetic and RF environment of the MR scanner during different pulse sequences. The degree of US interference in the MR image was minimal below 20dB of US transmitter gain using an unsheilded conventional US scanner.

Introduction: It appears physically possible to simultaneously perform ultrasound (US) imaging and MRI since ultrasound waves at the imaging level should not affect the magnetization in MRI, nor should the radiowaves and magnetic fields effect US. The potential fusion of these two imaging modalities may enable a very useful new medical imaging technology for both diagnostic radiology and interventional procedures. Integration of Doppler US signals or MR velocity phase shifts should be possible.

Another potential application of US/MRI is to use real-time spatial data acquired by an ultrasound (US) scanner to navigate MR data acquisition in cardiac imaging. The US images can be acquired with no time penalty during the MRI acquisition and on the same regions as the MR imaging without saturation or interference of signal. Another potential application is to combine temporal and morphologic information from US and MRI obtained in the same coordinate system to perform interventional procedures in the body. These proposed techniques would require 2D or 3D US scanning to be performed within the MRI scanner. Reliable and useful information from the US data can only be yielded if there is no interference between both imaging modalities.

Material and Methods: The principal structure of the US/MRI system is depicted in Fig. 1. The US-probe is attached to the MR-scanner to correlate both coordinate systems. During the MRI acquisition either one or two-dimensional US-data is digitized by an external computer, which analyzes the data to yield the required position information. This information can be updated at up to 100Hz and more, depending on the number of US-lines acquired per image. The external computer sends the navigational data to the scanner host computer via TCP/IP, where this information is used to update the slice orientation and position of the running MR-sequence.

Preliminary measurements were performed on a cardiovascular MR scanner (Sonata, Siemens) and a clinical US-scanner (SONOS 1500, Hewlett-Packard) to show the feasibility of the project and to estimate the time delay between acquisition of the navigational information and update of the MR pulse sequence. To evaluate the US/MRI interactions, simultaneous data acquisition was performed for different US-transmitter gains (0dB, 20dB, 30dB and 40dB) and different types of MR-sequences (FLASH, trueFISP, TSE). A standard PC (Pentium 4, 800 MHz) with a 20MHz digitizer board (NuDAQ PCI-9810) was used for data digitalization. For feature extraction of the US images an active contour algorithm was modified and optimized to work in real-time. For one-dimensional data sets a simple edge extraction with sliding window was used.

Results: No image degradation due to static or variable magnetic fields was seen in the US images in 3 normal volunteers. A low amount of interference in MR images is present at 20dB, whereas almost no MR imaging is possible at 40dB. A transmitter gain of 20dB was adequate for US cardiac imaging in this prototype system. Time delays in the US/MRI system were measured. The time to acquire one US-line essentially depends on the sound wave distance divided by the speed of sound, approximately 1540 m/s in human tissue. For depths of < 20 cm the response time per line is smaller than 300 us. The digitalization of the US data can be performed in real-time. Post-processing (FFT, demodulation) and feature extraction (edge detection for one-dimensional data sets) takes about 0.4 ms per line. Feature extraction of two-dimensional data sets took about 10 ms. Data transfer from stand-alone PC to MR scanner host via TCP/IP is less than 0.5 ms, depending on network load. Data Transfer from MR scanner host to MR scanner control unit takes 4 ms.

Discussion and Conclusion: Interference between both imaging modalities appears to be manageable, whereas the electronic noise of the US-scanner has to be decoupled effectively. There are several sources of US system noise, from the piezo-electrode of the probe and electronic noise introduced via the transducer cable. Optimization of the US scanner for the MRI environment by modifying the probe’s Faraday shielding and decoupling of noise to the transducer cable are two immediately obvious approaches. Preliminary system analysis of 2D US navigational information for MRI sequences allows position and orientation information to be updated in less than 20 ms, however, a real-time update rate of 200Hz should be possible for 1D positional information alone. In principle, multiple US probes, orthogonally oriented, can be used for 3D data. The US-navigation can be used with any type of MR sequence, since only the slice (or volume) position and orientation has to be updated during measurement.

In conclusion, these experiments demonstrate successful imaging of the human body by US and MRI at the same time and location without significant interference between the two respective signals.

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Fig. 1: Flow chart illustrating the use of cine US imaging combined with MR imaging.

Fig. 2: Interference in MRI caused by the US transmission, using a water phantom (20dB, 30dB, 40dB).

Fig. 3: Simultaneous measurement of MRI and real time US cardiac images in human volunteer (TSE 3, TE/12ms, TR/700ms, no gating).