Simultaneous Ultrasound/MRI Motion Monitoring in the Abdomen

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Objective
Ultrasound and MRI are complementary imaging modalities. US imaging provides high temporal resolution and direct visualization of acoustic obstacles, while MRI provides excellent tissue contrast and a confirmed method for near real time thermometry. Overall, the expected added value of combining these two modalities would consist of more complete description of the investigated anatomy [1,2], a more accurate targeting, efficient motion tracking, and reliable immediate assessment of the therapeutic results. The aim of the present work is to set-up an integrated environment for simultaneously ultrasound and MR image acquisition, satisfying clinical standards, and to evaluate the feasibility of performing hybrid imaging. A study on healthy volunteers is presented here with simultaneous 4DMRI/dynamic 2D ultrasound.

Materials and Methods
An MR-compatible Acuson prototype ultrasound imager (Antares, Siemens Medical Solutions, Mountain View, CA, USA) was used with a non-magnetic CH4-1 phased array transducer (BW from 1.8 to 4.0 MHz, multi-focal operating mode). The investigational device is equipped with packages for abdominal imaging (real time image reconstruction and display), colour Doppler mode and tissue harmonic imaging.

The ultrasound transducer can be used inside the magnet bore at 1.5T and 3T without a susceptibility-artefact penalty if a minimum distance of 4 cm is allowed from the skin. The US head was rigidly attached at the isocenter of a customised holder, manufactured with stereo-lithography (resin) and coated with a thin aluminum layer (common ground to Faraday cage). The transmission line of the US probe (7m long) was also entirely shielded. The holder was filled with degassed water and the distal end was closed by a non-shielded, acoustically transparent membrane. A second compartment was employed to provide both acoustic coupling to the skin and motion decoupling from the patient. This compartment, delimited by a compliant membrane, contained standard echographic gel (see Figure 1).

The US transducer holder was positioned approximately at the isocenter of the magnet (Magnetom Trio a Tim system, Siemens AG, Erlangen, Germany), fixed on an MR-compatible orbital ring that guarantees that the probe maintains a fixed position (i.e. rigid reference frame) despite acoustic coupling with the body of the breathing patient.

Figure 1 a, b) Ultrasound transducer (EM shielded) and holder fixed on the orbital ring. The gel compartment which provides acoustic coupling and motion decoupling is also visible.

The position of the US head’s holder was visualized with a high resolution T1 3D gradient-echo (VIBE) acquisition [3,4] (1x1x1mm³ voxel size TE/TR/TA/FA/BW =2.99ms/6.88ms/1.36min/10°/300Hz/Px).

4DMRI [5] and dynamic 2D ultrasound images were simultaneously acquired on healthy volunteers under free breathing during 450 sec. The respiratory 4D organ motion of
the liver during free breathing was captured as previously described in ref. [5]. The volume of interest in this acquisition protocol is covered by sagittal 2D slices, further called data slices. The key concept of this 4DMRI method is to additionally acquire a dedicated so-called navigator slice at a fixed anatomical position between each acquired data slice pair, resulting in an interleaved sequence of data-, navigator-, data-slices. To generate 3D volumes out of these 2D data slices, retrospective stacking of data slices showing the liver at a similar breathing state is performed. The temporal correspondence of data frames is determined by comparing the embracing navigator frames (that always depict the same anatomical location) acquired immediately before and after the respective data frames in the interleaved sequence. The frame similarity of the navigator slices is determined by template matching, tracking and comparing the position of 4 regions of interest in the navigator frame.

Data slices at 30 different locations with slice thickness of 5mm were acquired during 7 minutes based on a balanced EPI kernel TE/TR/FA/BW = 1.28ms/2.86ms/42°/1500Hz/Px. Each slice had 88x128 voxels and an in-plane resolution of 2.66 mm*2.66 mm. The resulting acquisition time was 185 ms per frame, yielding a temporal resolution of roughly 3 Hz.

Real time US monitoring was performed simultaneously (f=2.2MHz) and images were exported on-the-fly from the US scanner to an external PC (26 frames per second, 640 x 480 pixels per exported images, resolution =0.6 mm²).

Results
During simultaneous US/MRI acquisition we did not detect any mutual RF interferences. The unshielded distal tip of the US head’s holder was easily detectable in the MRI images, without any susceptibility-related nor b1-type artifacts (Figure 2 a-c).

An example of US image concurrent with 3D T1w VIBE MRI acquisition is shown in Figure 2d. The liver vascularization and the acoustic coupling gel are clearly visible.

![Simultaneous US/MRI imaging](image)

**Figure 2.** Simultaneous US/MRI imaging. a)-c) VIBE T1w 3D MRI images showing the position of the US transducer and its holder; b) the expected imaging plane of the ultrasound scanner, d) US image of the liver acquired during the MRI sequence.
The 4DMRI sequence permitted the dynamic reconstruction of the intra-abdominal motion. A typical artifact of this balanced-EPI type sequence in the presence of field inhomogeneities was observed in the MRI images as dark band in the liver (Figure 3 a-b). An appropriate shim over the liver should be able to reduce it or to shift it in a marginal zone (an example of an image with no-detectable artifacts is shown in Figure 3c).

Figure 3 a) and b) Transparent pseudo-3D image from 4DMRI reconstruction at two different respiration phases, acquired simultaneously with the US imaging. The artifact (the dark band through the liver) is due to the lung-liver interface, c) same type of reconstructed MR image with no visible artifact for a different volunteer, d-e) US images at two different respiration phases.

Conclusion
Interference-free simultaneous acquisition of US and MR images is achievable and our technical set-up is appropriate for clinical use. The quality of the US images will be further improved with a wider-angle head-holder/shield. The potential field of application to interventional MRI is significant, including motion tracking and locking during HIFU, catheter tracking, tracking of local drug delivery from sonosensitive particles.

References