Ultrasound/MR hybrid imaging: truly simultaneous motion monitoring in the abdomen and image co-registration

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Introduction. The combination of ultrasound (US) and MR imaging results in a hybrid modality that offers a complementary description of the investigated anatomy [1] and increases control and assessment in image guided therapies. US imaging provides high temporal resolution and direct visualization of acoustic obstacles, while MRI offers excellent tissue contrast and a confirmed method for near real time thermometry. The value of combining these methods is more accurate targeting, efficient motion tracking and reliable, immediate assessment of the therapeutic results. The aim of this work is to set up an integrated environment for simultaneous acquisition of US and MR images with clinical standards, to evaluate the feasibility of this hybrid imaging and to assess the precision of image co-registration in the abdomen.

Materials and Methods. Ultrasound imaging simultaneous to MRI was achieved using a clinical ultrasound scanner (Antares, Siemens Medical Solutions, Mountain View, USA) modified to be MR compatible, equipped with SW packages for abdominal imaging (real time image reconstruction and display), B-mode, low energy pulse train, colour Doppler and tissue harmonic imaging. The non-magnetic CH4-1 US phased-array transducer (256 element, BW from 1.8 to 4.0 MHz, multi-focal option) was used inside the magnetic bore at 1.5T Espree and 3T Trio (Siemens AG, Erlangen, Germany) without inducing a susceptibility-artefact if a minimum distance of 4cm from the skin was respected. The transducer was embedded in a gel-filled bag that provided both acoustic coupling to the skin and decoupling of respiratory motion, and was rigidly attached inside a customised holder coated with a copper layer. The holder was attached to a MR-compatible orbital ring (Fig 1). The transmission line of the US probe (7m long) was also entirely shielded. The EM shielding structures were electrically grounded to the Faraday cage. A study was performed on four healthy volunteers (with written consent agreement). The coupling gel in front of the US head was visualized with a high resolution T1-3D gradient-echo (VIBE) acquisition [2] ($1x1x1mm^3$ voxel, TE/TR/TA/FA/BW =2.99ms/6.88ms/1.36min/10°/300Hz/Px, breath hold 32s) and permitted 3D registration of the holder (Fig 2**a**). 4D MRI [3] and dynamic 2D ultrasound images were simultaneously acquired on volunteers under free breathing during 10min. Morphological image slices at 40 different locations with slice thickness of 4mm were measured during 10min using a trueFISP (bSSFP) sequence (TE/TR/TA/FA/BW = 1.28ms/2.86ms/ 185ms/65°/1000Hz/Px). Image matrix was 88x128 with in-plane resolution of (2.66x2.66) mm. The resultant acquisition time was 185ms/frame, yielding a temporal resolution of about 3Hz for image and navigator. Real-time US 2^{nd}-harmonic imaging was simultaneously performed (Fo=2.2MHz, 20frames/s) and US images were exported on-the-fly to an external PC (640x480 pixels/image). In order to enhance meaningful features US images were processed by computing the magnitude of the images gradient. The US applicator was semi-automatically extracted and under the assumption that the US plane is located centrally in the applicator object the US plane was defined. The scaling of the images was guaranteed using US images calibration information and the alignment of the two image modalities performed.

Results. No significant RF mutual interferences were detected during simultaneous US/MRI acquisition, only some minor spikes in the K-space of the bSSFP acquisition at 1.5T (Espree) were found above the noise level. In the VIBE T1w 3D MRI images (breath hold) the unshielded distal tip of the US head's holder was easily detectable (Figure 2 **a**,**c**,**d**) *via* the embedded coupling gel. A section of the 3D MR data set (Figure 2c) is presented along the US imaging plane (Figure 2b). The liver margins and vascularization, and the diaphragm were clearly identified in the US images and served as landmarks for image co-registration, an example is presented in Figure 2**d**. The 4D MRI sequence permitted the dynamic reconstruction of the intra-abdominal motion and the calculation of high temporal resolution motion field vectors. The motion vectors are calculated using 3D non-rigid image registration between the volumes and extracted for the US imaging plane. In Figure 3**c** the motion vectors for one respiratory cycle of a free breathing volunteer are plotted on top of the corresponding US plane.

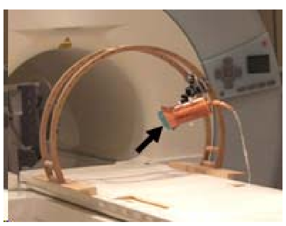

Figure 1. US transducer (EM shielded) embedded in the gel-filled bag and its holder fixed to the orbital ring

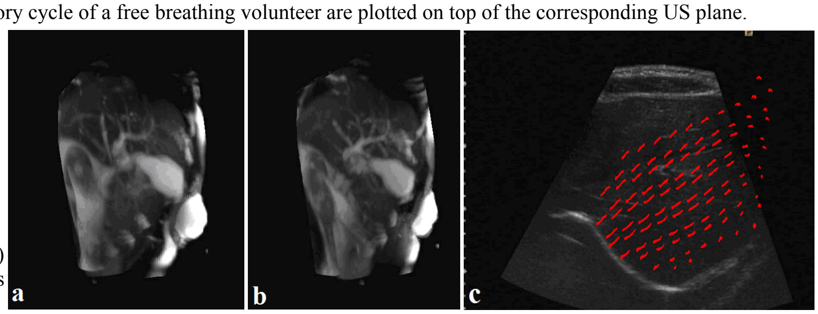

Figure 3. **a,b)** Maximum intensity projection (MIP) from the 4DMRI reconstruction of the abdominal motion of two breathing cycles, at 2 different respiration phases acquired simultaneously with the US; **c)** US imaging plane and corresponding MR-derived motion field vectors for one respiratory cycle.

Figure 2 a) VIBE T1w 3D MRI images (orthogonal planes shown) and the registered US transducer's holder; **b**) 2nd harmonic US image of the liver; **c**) 2D section of the 3D MR data set along the US imaging plane; **d**) fused MR and color-coded edge-detection US images.

Discussions. Truly simultaneous US and MR acquisition is achievable using clinical instruments, delivering hybrid images of standard quality. The US imaging plane could be registered to 3D or 4D MRI data using a priori information on the transducer's holder shape, exploiting marker-points in the images and eventually the dynamic information of respiratory cycles. Distortion of MR images was noticed to affect the apparent position of the US holder (Fig 2**d**, upper side) thus non-rigid registration was necessary. The potential field of application of this hybrid method to interventional MRI is broad, including: motion tracking and focus locking on target during hybrid-US-MR-guided HIFU ablation, simultaneous temperature and cavitation monitoring during HIFU, simultaneous monitoring of sono-sensitive carriers breakage and MR contrast agent uptake in local drug delivery, US Doppler calibration of MR flow measurement. **References:** [1] Tang AM et al, IEEE Trans Med Imaging. 2008, [2] Rofsky N M et al,Radiology 1999, [3] Siebenthal M et al, PMB, 2007