

Clinical demonstration of transient cavitation induced errors on PRFS MR thermometry during RF ablation in liver, using simultaneous US/MR imaging

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Introduction. Hybrid systems combine the strengths of two imaging modalities offering new opportunities for diagnostic imaging or therapeutic monitoring. Simultaneous US/MR acquisition represents an appropriate tool to investigate RFA-induced thermal cavitation's effects, particularly the subsequent magnetic susceptibility-mediated errors in concurrent PRFS MR-thermometry (MRT) [1]. A clinical study of RF ablation of hepatocellular carcinoma (HCC) nodules in liver using simultaneous MR and US guidance on 2 patients is presented here.

Materials and Methods. The prospective study was approved by the institutional ethics review board. For the RF ablations, a bipolar internally cooled electrode (CelonProSurge MR compatible, Celon AG, Berlin, Germany) and a RF generator (Celon Power, Celon AG, Teltow, Germany) working at 475 kHz were used. Prescribed RF power was 30W during 20 minutes. Simultaneous US and MR imaging was achieved using a clinical ultrasound scanner (Antares, Siemens Medical Solutions, Mountain View, USA) equipped with packages for abdominal imaging. MR compatible non-magnetic CH4-1 phased-array transducer ($F=1.33$ - 4MHz) was used for US imaging. A customized holder with an electromagnetic shield was realized, allowing an optimal window for the US beam [2]. The US device was embedded in a gel-filled bag and fixed inside the shield, then attached on an MR compatible orbital ring using an articulated handle (Figure 1), which offered 4 freedom degrees (3 rotations + 1 translation). General anaesthesia was induced and the patient was placed feet first on the MR table (MAGNETOM Espree 1.5T, Siemens Healthcare, Erlangen, Germany) in a supine position. The MR signal was received by a spine matrix coil and a 19 cm diameter loop surface coil, with the US holder positioned inside. The procedure was performed in a sterile fashion regarding the needle insertion. The orientation of the RF electrode was oblique to the B_0 field. Multi-planar reconstructions of the 3D acquisitions (T1w VIBE) were used for planning the RF needle trajectory from the entry point to the target, avoiding critical structures. Guidance of the needle placement was achieved using a interactive real-time balanced steady-state free precession (bSSFP) interleaved radial sequence that was specially designed for the purpose of MR-guided interventions (BEAT_IRTTT, Siemens Corporate Research, USA) with the following parameters: radial views: 64, sliding window width: 5, TR: 4.3ms, TE: 2.2ms, flip angle: 70°, bandwidth: 558 Hz/pixel, matrix: 128x128, voxel size: 3x3x5mm³, update rate: 275ms [3]. The progression of the RF electrode was followed in near real time on a MR compatible monitor placed in the MR room and the images acquired in axial and sagittal oblique perpendicular planes were readjusted accordingly. The trajectory of the RF electrode trajectory was also visible in US images (Figure 2.f, 2nd harmonic mode). MR thermometry (MRT) was performed using a segmented GRE-EPI, respiratory triggered acquisition (TR/TE = 50/20ms, Flip Angle=25°, BW=1KHz/pixel, voxel size 2.3 x 2.3 x 6 mm³, three reciprocally orthogonal imaging slices: one slice orthogonal to the RF electrode approximately at the anode/cathode gap and two slices covering longitudinally the RF electrode). Time referenced MRT maps were visualized in real time on an external computer. At the end of the RF application, electrode track coagulation was systematically performed.

Results. US/MR simultaneous monitoring was free from mutual interferences. One example of dual acquisition is presented in Figure 2, illustrating two different time point: early stage of RF ablation (first row) and 30s after the ablation end-point (second row). US images (b and d frames, contrast agent visualization mode) are clearly indicating the presence of gas bubbles (see red arrow) created during the RF heating nearby the RF electrode. Concurrently to bubble visualization, butterfly-like dipolar major distortion of the MRT maps (a and c frames, sagittal-oblique plane) can be observed in this figure. Three phenomena were detected synchronously: 1) appearance of the "white cavitation" bubbles, 2) dipolar distortion of the MR temperature maps and 3) size expansion of the magnitude artifact around the needle tip. False negative changes in temperature were detected on MR thermal maps along the B_0 field direction. After the end-point of RF heating, the MR temperature maps slowly recovered the symmetrical shape around the RF electrode while the gas bubbles reabsorbed. This effect is clearly visible in the temperature vs. time curves (frame e) in 2 independent pixels situated equidistant from the RF needle but along orthogonal directions, demonstrating a relative apparent offset of 20°C to 30°C.

Conclusions. This clinical study demonstrates that RF ablation is technically feasible with US/MR simultaneous monitoring. The interactive targeting mode enables effective and sufficiently rapid electrode placement in clinical practice. The disruptive changes in the local bulk-susceptibility of tissue heated by RFA were monitored and correlated with the induced thermal cavitation around the active part of the RF electrode, the position of this RF electrode being confirmed by the US monitoring. The physical cause of systematic errors between PRFS thermal dose maps and anatomic lesions obtained after MRgRFA reported earlier [3] was formally identified here under clinical conditions.

References: [1] Viallon *et al*, Med Phys, 2009 ; [2] Petrusca *et al*, ISMRM, 2011; [3] Terraz *et al*, Eur Radiol, 2010.

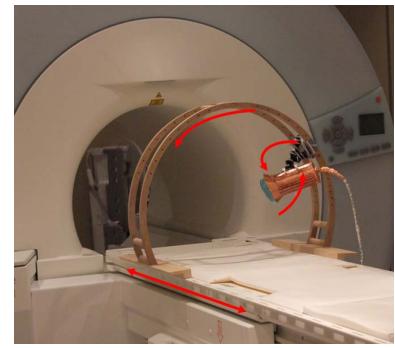


Fig1. US device embedded in the gel-filled bag and fixed inside the EM shielded holder attached on a MR compatible orbital ring.

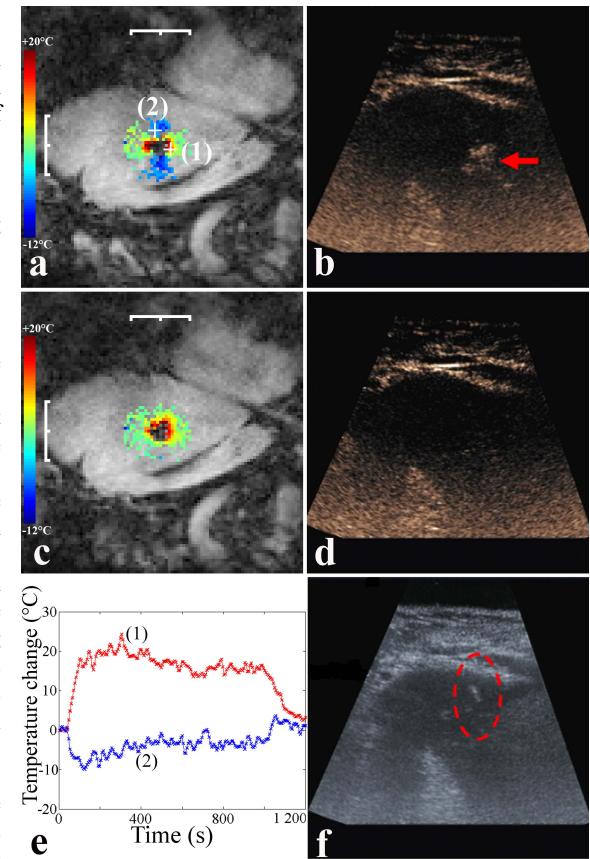


Fig2. US/MR simultaneous monitoring of an RF ablation. MRT (a,c) and US (b,d) images are showed during the RF ablation (a,b) and 30s after the end-point (c,d). The PRFS temperature vs. time evolution during the RF ablation in 2 different pixels (see + symbols) equidistant from the electrode are shown in frame (e). The reference US image before RF heating visualizing the electrode position is shown in frame (f).