Evaluation of Realtime Temperature Monitoring of human liver based on patients undergoing a Radiofrequency Ablation

A. Kickhefel[1], H. Rempp[2], J. Roland[3], and F. Schick[2]

[1]Ernst-Moritz-Arndt University, Greifswald, Germany, [2]Eberhard-Karls University, Tuebingen, Germany, [3]Siemens, Erlangen, Germany

Introduction

Minimally invasive therapies such as radiofrequency ablation (RFA) are rapidly becoming a significant aspect of the multi-disciplinary treatment of liver tumors. The use of multiple RF electrodes, the heat sink effects produced by nearby vessels, and the susceptibility artifacts of RF electrodes makes intra-procedure estimation of the therapeutic zone difficult without real-time thermometry (1). The proton resonance frequency method (PRF) has a gained acceptance for the guidance of thermal ablation procedures (2). MR thermometry in combination with RFA remains difficult due to the challenge of inter- and intra-scan respiratory motion artifacts (3,4). The aim of this study was to examine real-time temperature monitoring of the liver using a 2D Gradient Echo sequence (GRE) in free breathing patients during RFA for inoperable hepatic tumors. To evaluate the results of the relative temperature measurement, a comparison was drawn between the necrosis seen 24 hours after the intervention and the region with temperatures greater than 57°C demonstrated at the end of the RFA.

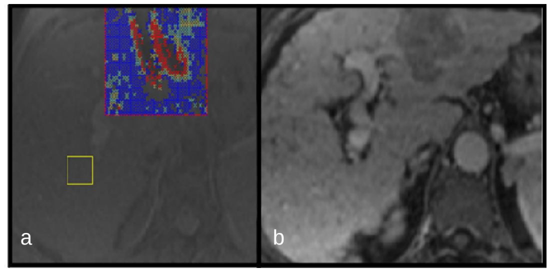

Figure 1: (a) Real-time visualization of relative temperature areas during RFA of human liver using 2D GRE; (b) Resulting necrosis demonstrated with 24 hour follow up imaging (post contrast 3D GRE).

Methods

Four patients with primary and metastatic hepatic tumors underwent RFA with real-time visualization of relative temperature changes (T-map) on a 1.5 Tesla scanner (MAGNETOM Espree, Siemens, Erlangen). RF ablations were performed using an impedance-controlled RF generator (CC; Valleylab, Boulder, CO, USA) operating at a frequency of 480 kHz in combination with the placement of two bipolar internally water-cooled RF-probes. During the procedure, RF application was performed out of the magnet bore, and intra-procedure temperature monitoring was performed inside of the bore in an in-and-out fashion. Three slices of the 2D Gradient Echo sequence (GRE) for temperature visualization were positioned along the plane spanned by the RF electrodes. Imaging parameters were: TR / TE = 174 / 18ms, resolution 128 x 96, FOV variable 280-320mm, fat saturation, 3 slices interleaved, bandwidth 880 Hz/Px, slice thickness 4mm. Temperatures were calculated on the basis of the Proton-Resonance-Frequency (PRF) method (2) considering a B0 drift correction. Contrast enhanced (Gadovist; Bayer-Schering, Berlin) images of the liver were acquired 24 hours after treatment in order to demonstrate tumor necrosis (3D-GRE with TR / TE = 5 / 2.38ms, resolution: 256 x 176, FOV variable 280-320, fat saturation). After acquisition, slices with comparable positions and angulations to the temperature mapped images acquired during the prior RFA were placed into 3D data volume of the follow up MR images. For every slice, T-map and post-contrast images were compared using MATLAB (Mathworks, Natick, MA, USA, version 6.0, Imaging Processing Toolbox). Data evaluation consisted of image registration and segmentation of the temperature and the post-treatment images. The registration between 2D-GRE and 3D GRE was verified by a segmentation of the entire liver (on one slice). The segmentation of the temperature region >57°C and the areas of necrosis on post-contrast images was performed automatically using a region-growing algorithm (4). Figure 2 demonstrates an example of an overlay of segmented structures (temperature region above 57°C and necrosis). We defined three different areas for evaluation: OT (overestimation of necrosis by T-Map), IR (accurate estimation of necrosis by T-Map) and UT (underestimation of necrosis by T-Map). To assess the under- and overestimated regions by T-Map in relation to the necrotic zone demonstrated on post-contrast MRI, the ratio of the UT and of the OT to the total area of necrosis (UT+IR) calculated (Table 1).

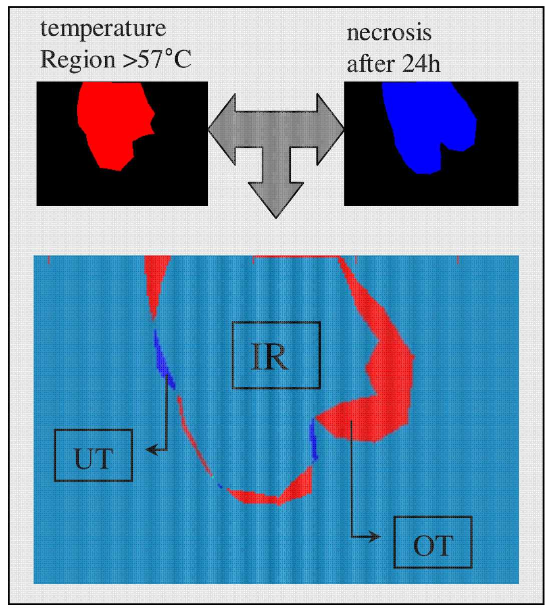

Figure 2: Overview of the T-Map evaluation procedure. The overlay of the T-Map areas with temperatures > 57°C and the area of true necrosis is separated into regions overestimated by the T-Map (OT), regions underestimated by the T-Map (UT) and regions accurately estimated (intersecting) by the T-Map (IR).

Results and discussion

The average registration error of registration was 5% as determined by the segmentation of the entire liver in one slice. Table 1 summarizes the values of the under- and overestimation areas by the T-Map in ratio to the areas of necrosis. The mean overestimation of the necrosis by the T-Map was 25.2%, (range 14.1% to 31.4%) with a standard deviation of 8%. The mean underestimation by the T-Map was 6.5% (range 1.5%-11.6%). Since the PRF method calculates temperatures based on phase differences comparisons to a non heated reference image inter- and intra-scan respiratory artifacts can lead to an under- or overestimation of the temperature, and thus the necrotic zone. This is made worse by the fact that during an intervention patient breathing becomes even more irregular. As well, the artifacts from the RF electrode can cause further mis-estimation of the area of necrosis by the temperature visualization process. To improve real-time temperature visualization during thermal ablation procedures with freely breathing patients, motion artifacts must be further reduced.

	width x highof necrosis [mm]	Active length of RF-probe [mm]	Applied energy [kJ]	Type of Lesion	UT / (UT+IR) [%]	OT / (UT+IR) [%]
Patient A	29 x 21	40	132	Colorectal Carcinoma	2.2	31.4
Patient B	21 x 18	40	170	Colorectal Carcinoma	10.8	30.9
Patient C	18 x 13	30	120	Hepatocellular Carcinoma	1.5	24.4
Patient D	25 x 15	30	150	Hepatocellular Carcinoma	11.6	14.1
mean	**23 x 17**	**35**	**143**	-	**6.5**	**25.2**

Table 1: **Characterization of tumor necrosis by temperature mapping.**
UT / (UT+IR) is the percentage of the true necrotic area that is underestimated on the T-Map. OT / (UT+IR) is the percentage of the true necrotic area that is overestimated on the T-Map

Conclusion

The comparison of tumor areas with temperatures > 57°C by T-Map, and areas of tumor necrosis defined by post-contrast MR imaging after 24 hours after RFA demonstrated that nearly the entire area of tumor necrosis at 24 hours is predicted by the elevated temperature zone. In fact, this study demonstrated an overestimation of the necrotic zone by the real-time temperature visualization. This translates to an average overestimation of ~ 5mm, with a large variation in error between patients. Temperature measurement during RFA is possible at this point needs to become more reliable. One of the most significant sources of error is the inter- and intra-scan respiratory motion artifacts. These artifacts could be improved by applying slice-by-slice respiratory triggering and by improving the in-and-out workflow of MR-guided RF ablation. Nevertheless, real-time temperature mapping can allow an operator to assess treatment success within moving organs during thermal therapy, and to alter the procedure accordingly, during a single ablation session.

References:

(1) Vigen KK et al. JMRI 2006; 23:578–584. (2)McDannold N. Int J Hyperthermia 2005; 21:533–546. (3)Rieke V et al. MRM 2004; 51:1223–1231. (4)de Senneville BD et al. J WSCG 2003; 11: 1213-6972. (5)Dirk-Jan Kroon; http://www.mathworks.com/matlabcentral/fileexchange/19084