Patient study of realtime Magnetic Resonance Temperature Monitoring on moving organ simultaneous to Laserinduced Thermal Therapy (LITT)

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Introduction

Magnetic Resonance Imaging (MRI) is a standard technique for the diagnosis, localization, and post-treatment follow up of primary or metastatic liver cancers. Minimally invasive therapies such as laser-induced thermal therapy (LITT) have become a key component of a multidisciplinary approach to cancer therapy. The use of multiple laser applicators, the heat sink effect of vessels, and variable tissue perfusion complicates these thermal therapies, and ideally ablation procedures should include real-time temperature visualization to guide therapy. The proton resonance frequency method (PRF) has become established for the guidance of various thermotherapy procedures (1). The implementation of simultaneous MRI thermometry and LITT is especially challenging in the liver due to inter- and intra-scan respiratory motion artifacts (2,3). The purpose of this study is to demonstrate, using temperature monitoring, the feasibility of real-time estimation of the necrotic zone created during LITT of liver tumors. To evaluate the accuracy of temperature measurement, a comparison was made between areas on the MR temperature map which measured greater than 55°C and the areas of necrosis seen on post-gadolinium MRI 24 hours after the LITT.

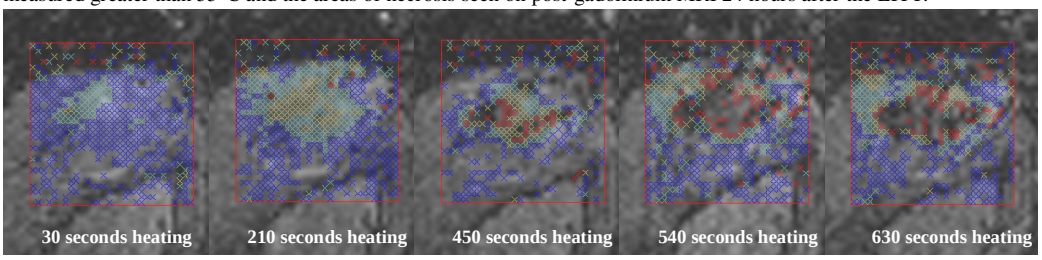

Figure 1: Example of in-vivo, real-time temperature measurement at various times during LITT of the liver. The temporal resolution for an acquisition of 3 slices is 3.2 seconds. (color-coding: blue < 55°C, light blue: 55-70°C, yellow: 70-85°C, red: 85-100°C).

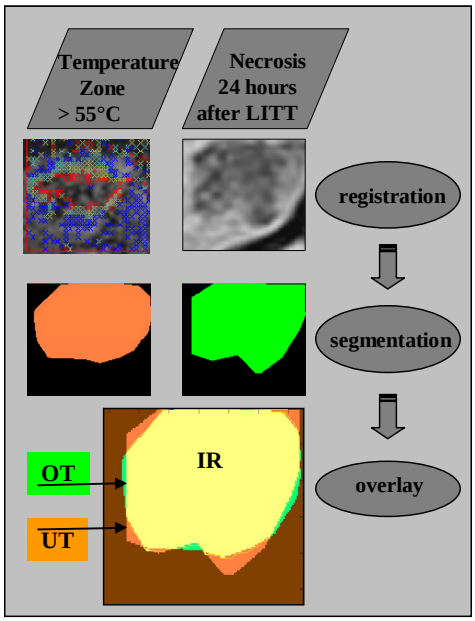

Figure 2: Overview of the T-Map evaluation procedure. The overlay of the T-Map areas with temperatures > 55°C and the area of true necrosis is separated into regions overestimated by the T-Map (OT), regions underestimated by the T-Map (UT) and regions accurately estimated (intersecting) by the T-Map (IR).

Methods

Four patients with liver tumors underwent LITT with simultaneous real time visualization of relative temperature changes (T-Map) on a 1.5 Tesla scanner (MAGNETOM Avanto, Siemens, Erlangen) (Figure 1). Depending on the tumor size either one or two laser applicators (Monocath; MeoMedical, Munich, 30mm active length) were placed into the liver (Table 1). The power of the Nd:YAG-laser (1064nm) was applied uniformly (increasing from 5 to max. 14 Watt) over 20 minutes.

Three parallel slices of 2D Gradient Echo sequence (2D GRE) for temperature visualization were positioned along the plane spanned by the laser applicators. Imaging parameters were: TR / TE = 500 / 12ms, flip angle 65°, resolution 128 x 97, FOV 320mm, fat saturation, bandwidth 260 Hz/Px, slice thickness 2.5mm, distance factor 200%, GRAPPA acceleration factor 2. Image acquisition was triggered to one slice using a triggering belt. The T-Map was calculated on the basis of the proton resonance frequency (PRF) method considering a B0 drift correction (1). For the purposes of this study, regions with a temperature greater than 55°C were defined as the "necrotic zone".

Correlative contrast enhanced (Gadovist; Bayer-Schering, Berlin) images of the liver were acquired 24 hours after treatment using the same slice position and angulations of the temperature mapping images acquired during LITT treatment (2D FLASH (Fast low angle shot) with TR / TE = 115 / 5ms, 30 slices, flip angle 70°, slice thickness 2.5mm). The necrotic zone was defined as the area of non-enhancing tumor 24 hours post therapy.

For each slice, T-Map and control images were compared using MATLAB (Mathworks, Natick, MA, USA, version 6.0, Imaging Processing Toolbox). The data evaluation consisted of registration of the 3 magnitude images from the temperature mapping sequence into the 3D volume of the follow-up images followed by segmentation of the temperature images and the corresponding post-contrast images. This registration between 2D-GRE and 2D FLASH was verified by a segmentation of the whole liver in one slice. The segmentation of the temperature region above 55°C and the necrosis from the follow-up was performed automatically by a region-growing algorithm (4). Figure 2 demonstrates the overlaid segmented structures (temperature region > 55°C and post contrast areas of necrosis). The overlay is divided into 3 different areas for evaluation: OT (overestimation of necrosis by T-Map), IR (intersecting region) 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 ratios of the UT and the OT to the entire necrosis (UT+IR) was calculated.

Results and discussion

The average registration error as calculated by whole liver segmentation was 5%. Table 1 summarizes the values of the areas of under- and overestimation of the T-Map relative to the areas of actual necrosis for each slice separately and for all patients. The average overestimation of the necrosis on the T-Map is 12.5%, the average underestimation is 9.8%. Temperature measurements of the liver are affected by inter- and intra-scan respiratory motion artifacts, due to PRF method, where temperatures are calculated from phase differences to a non heated reference image. This is made worse during an intervention, during which the patients' breathing often becomes irregular, thereby reducing the temperature precision drastically. Nevertheless, the separate triggering for each slice and the low temporal resolution of about 1 second per slice allows for a reasonable real-time estimation of a coagulation zone (i.e. necrotic zone) during LITT. To improve real-time temperature visualization during a thermal therapy with free breathing patients further techniques must be developed to reduce the remaining motion artifacts.

	UT/(UT+IR) [%]	OT/(UT+IR) [%]	width x height x length of necrosis [mm]	Number of applicators	Applied energy [kJ]	Type of lesion
Patient 1: Slice 1 / 2 / 3	18.3 / 2.3 / 15.1	17.8 / 20.4 / 17.1	31x18x20	1	18.4	colorectal metastasis
Patient 2: Slice 1 / 2 / 3	4.9 / 8.5 / 7.0	6.5 /11.2 /14.8	45x31x28	2	37.8	colorectal metastasis
Patient 3: Slice 1 / 2 / 3	16.5 / 16.6 / 7.3	13.5 / 2.7 / 14.0	48x22x46	2	44.1	multifocal HCC
Patient 4: Slice 1 / 2 / 3	7.6 / 6.6 / 7.5	2.8 / 10.4 / 19.5	55x40x38	2	43.4	colorectal metastasis
mean	**9.8**	**12.5**				

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 between the necrosis seen in follow-up post-contrast MR 24 hours after LITT and the region of temperatures greater than 55°C (2D GRE) seen at the end of the LITT procedure demonstrates a strong correlation with over/underestimation of the necrotic area of 10% / 12% respectively. This study demonstrates that, using MR temperature mapping, an adequate estimation of tumor necrosis can be achieved during LITT treatment. This should allow the operator to monitor the treatment in real-time during the thermal ablation procedure and to alter treatment according to the developing treatment conditions namely the development of necrosis during the thermal therapy. Although deviations due to motion were reduced by breathing triggering and fast imaging, further steps have to be developed to minimize artifacts due to inter- and intra-scan respiratory motion artifacts.

References:

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