Real time volumetric temperature imaging of High Intensity Focused Ultrasound thermal ablation on the liver

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Introduction

Recent studies [1,2] have reported encouraging results for High Intensity Focused Ultrasound (HIFU) treatment of large liver tumor metastases. However, complete tumor necrosis was obtained in half of the treated patients and no quantitative real time monitoring of the temperature distribution was proposed. The development of Magnetic Resonance guided HIFU opens perspectives for precise monitoring of the noninvasive treatment of tumors with HIFU. Thermometry in the liver remains difficult because of the presence of motion. Moreover, the important blood flow in the liver constitutes one of the main sources of therapeutic failure since it evacuates the heat outside the targeted region. As a consequence, the required local acoustic energy deposition is high, increasing the risk of inducing thermal lesions outside the targeted area (eg skin). Therefore, optimal MRI thermometry requires both an important volumetric coverage to analyze the thermal effects at the targeted location and in the surrounding tissues [3] and a high temporal resolution to efficiently monitor the local temperature evolution in order to evaluate the displacement of the target and to precisely calculate the thermal dose. Recent developements in dedicated image processing algorithms for motion compensation [4] show promise for MR thermometry in abdominal organs, taking into account organ position in the sonication strategy. The objectives of the study were to demonstrate the possibility to perform rapid and volumetric temperature monitoring of HIFU ablations in the liver and surrounding tissues (skin) and to evaluate the precision of the thermometry with the help of an image based motion compensation technique.

Materials and methods

MRgHIFU was performed in the liver of pigs (N=5) in vivo under general anaesthesia with a MR compatible Philips HIFU platform prototype, integrated in the 1.5T Achieva-Intera MRI, including a 256 elements HIFU transducer. Eight HIFU sonications were performed in the liver, varying the sonication power (80 to 300W) and duration (10 to 27 sec). MR thermometry was performed before, during and after HIFU sonications with the Proton Resonant Frequency shift method. Rapid and volumetric MRI images (2.2x2.7 mm², 6 mm slice thickness) were acquired with a multislice single shot EPI sequence (TE/TR=34/80 ms, flip angle=30°, FOV=210x300, matrix=96x112). Four slices were acquired in the saggital plane (3 slices on the liver and 1 slice on the skin) and one in the coronal plane (slice crossing the skin and the liver). This imaging volume was acquired continuously at a frequency of 2.5Hz. Images acquired before sonication were stored in an atlas of reference and used to compensate for the influence of motion artifacts on temperature maps acquired during sonication [5]. Temperature images were calculated and displayed in real time and the thermal dose maps were computed online using the Sapareto equation [6]. At the end of the experiment, the animals were sacrificed for macroscopic and microscopic examinations of the liver and the skin.

Results

No technical failure was observed and each HIFU sonication could be identified on temperature images. The maximal temperature rise was 30° C for a sonication performed at 300W during 15 sec. The lethal thermal dose was obtained in 4/8 sonications and a value of energy deposition higher than 2.7 kJ was required for reaching the lethal threshold of 240 equivalent minutes at 43°C. Figure 1 shows a HIFU ablation performed on the pig liver with motion compensation. A local temperature increase can be observed on each slice, with the hottest spot centered in the liver. The standard deviation prior to heating in the sonicated area was 0.9°C in the liver and 2.5°C on the skin. Temperature increase was sufficient to reach the lethal thermal dose value in the liver but not in the skin. Histological analysis confirmed the presence of lesions in the liver and the absence of skin alterations.

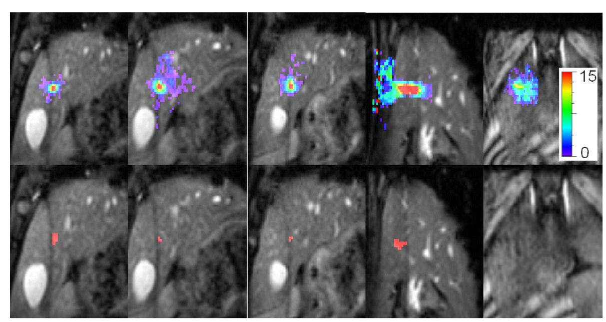

Figure 1 : Temperature (top row) and thermal doses (bottom row) images of the liver and skin during HIFU. The scale of temperature increase is indicated on the right. The pixels in which the lethal thermal dose was reached are coloured in red. From left to right : 3 coronal slices and one sagittal slice centered on the target point, and 1 slice located on the skin.

Discussion

This study demonstrates the possibility to precisely measure local temperature changes with rapid and volumetric MRI thermometry during HIFU ablation, in the liver and in surrounding tissues, with an excellent spatial and temporal resolution, despite the presence of motion. This precise volumetric and rapid monitoring should improve patient safety and help in increasing the efficacy of non invasive HIFU procedure. Moreover, this method opens perspectives for the development of sophisticated temperature control algorithms for optimized HIFU therapy on mobile organs.

References

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