Three Dimensional MR Guided Temperature Imaging Feedback System for Microwave Liver Ablations in an Open MRI

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Introduction

The merit of magnetic resonance imaging (MRI) for guiding the thermal ablation is its ability to restrict the energy deposition to the target tissue by demonstrating the transient temperature elevation in the surrounding normal tissue and to signal the irreversible phase transition within the target. The practical drawback of MR guided thermal ablation procedure is the quantitative temperature feedback due to organ motion through the treated volume. Adequate monitoring of temperature and thermal changes in the tissue is necessary for safe and accurate controlled energy deposition and effective thermal therapy. This has long been an unresolved problem of MR guided thermal ablation. Of the MR techniques for temperature imaging, MRI thermometry based on the temperature sensitivity of the conventional proton resonant frequency (PRF) has been shown to be the most promising for thermal ablation procedures because of its ability to quantify temperature changes, and independence of tissue type. However, the disadvantage of this technique lies in its sensitivity to motion artifacts and frequency drifts induced by system instabilities. Since it relies on the voxel-by-voxel subtraction of the phase to obtain the temperature-induced phase change, factors producing phase change can be the source of temperature misreading due to organ motion. A few techniques to compensate for those motion effects in temperature imaging have been proposed (1-3). To overcome the limitations of conventional temperature imaging methods, we have developed an effective and interactively controllable quasi-real time three-dimensional (3D) temperature imaging feedback system using self-reference method based on complex field fitting technique for guiding and assisting the microwave liver ablation procedures in an open MRI with on-line monitoring of respiratory profile. The 3D method uses the sequential acquisition of three orthogonal/arbitrary planes to seize the volume distribution of both temperature and thermal dose inside the target region. The self-referenced method does not require neither the separate image taken before the treatment nor the subtraction of the "external" reference image from the current image.

Materials and Methods

To evaluate the ability of the newly developed feedback control system as well as temperature imaging method, preliminary experiments using in vivo porcine liver were performed in a 0.5T open GE MR scanner. A microwave coagulator (Microtaze AZM-520, Azwell, Osaka, Japan), operating at 2.45 GHz, was used as a heating device with a generator located outside the shielding room. Microwave-induced thermal ablative lesions were created in the liver of each animal using an MR compatible 18G Teflon-coated needle type electrode (250 mm long, 1.6 mm in diameter). The needle type electrode was connected to microwave heating device that was partitioned by the shielding wall from the magnet to avoid electro-magnetic interactions with the MR scanner. Before starting microwave heating, first, PC based interactive image plane control window was used to guide microwave needle type electrode placement into the targeted region. To determine the exact needle tip location in the MR image, a thin copper wire of 0.1 mm in diameter was winded to form four serially connected very small aperture coils on a sheath covering the needle. Second, a set of MR complex images in three orthogonal planes were acquired at the position of microwave needle tip using the quasi-real time sequential acquisition of three orthogonal planes by fast spoiled gradient-echo sequence (3pFSPGR) with the following parameters: TR 23 ms, TE 12 ms, flip angle 30 degree, bandwidth 15.6 kHz, slice thickness 5 mm, field of view 260×260 mm^2, and spatial matrix 256×128. After setting the feedback control parameters using the temperature imaging software, microwave energy (60W) was applied for approximately two minutes. The images were retrieved from the MRI workstation within nine seconds for the three orthogonal planes at each time point, and the computation time for on-line analysis took an additional 1-2 seconds. As each time point was collected, the MR temperature imaging was updated to guide the process. All images were displayed on the dual head monitors outside the shielding room as well as two RF-shielded 17' LCD display monitors inside the MR operation room. The respiratory motion by using an optical displacement detection system (AZ-733, Anzai Medical Co., Tokyo, Japan), was again stopped almost at the same liver position to continue collecting temperature images for further processes by quantitative measurements of the abdomen wall with on-line visualization of the respiratory profile within 10 to 15 seconds. This process was continuously repeated until the previously determined target volume was ablated completely.

Results and Discussion

The dedicated user interface of the temperature imaging feedback during the imaging of thermal heating was shown in Figure 1. Figure 2 shows temperature and thermal dose images overlaid on updated magnitude images of a single time frame for each plane during the heating of the liver. The position, size and rough estimation of the temperature elevation in the tissue are clearly visualized with self-referenced method. Also, we have used the sequential acquisition of three orthogonal planes for real time temperature imaging. With this pulse sequence, the image planes does not have to be orthogonal to each other and can be chosen arbitrarily based on location, shape, size and orientation of the target volume in the anatomical region. The ability of controlling temperature monitoring from the determined scan planes ensures the thermal heating more accurately to the previously determined target volume and prevents the surrounding normal tissue damage.

The results demonstrated the efficacy of the 3D MR-derived thermometry to detect the local temperature elevations at the needle tip in vivo liver. The proposed system through knowledge of the 3D distribution of both temperature and thermal dose with on-line monitoring of respiratory profile may allow clinicians to control MR-guided microwave liver ablation procedure accurately.

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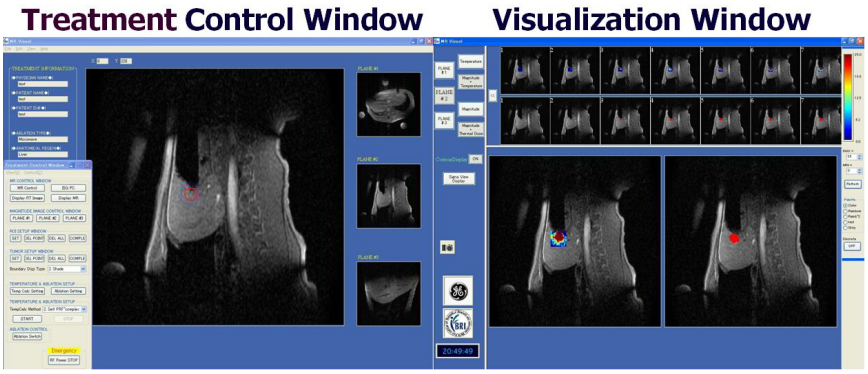

Figure 1. The user interface of PC-based temperature imaging software.

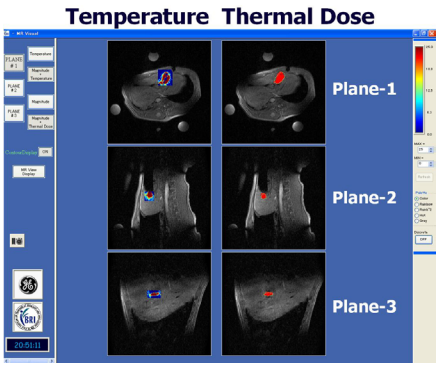

Figure 2. Temperature and thermal dose maps overlaid on updated magnitude images of a single time frame for each plane.