Self-referenced Temperature Imaging based on Complex Image Estimation and Target Tracking Slab

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INTRODUCTION To overcome the effect of respiratory motion in liver temperature imaging, a novel temperature imaging technique called "Referenceless PRF thermometry" (1) or "Self-referenced method" (2, 3), in which a region of interest (ROI) covering the heated area is set and the phase distribution in the ROI without thermal change is estimated from that in a doughnut-like surrounding region. The estimated reference phase image is then deduced from the original phase image, and hence the temperature change distribution in the ROI is obtained. Since this technique does not required any "external" reference taken before temperature change, it reduces the effect of inter scan organ motion during heating process. There are, however, several significant problems to be solved to raise this technique on a practical stage. First, the phase estimation becomes problematic when the phase field has "wrapping" in the heated region or in the surrounding area. Second, the image has to be taken at the slice right on the position of heating. Third, phase distortion induced by the susceptibility discontinuity between the tissue and the needle or optical fiber used in interstitial heating can be a crucial source of estimation error. In this paper, a new "self-referenced" method using not the phase image but the complex image taken by a "target tracking slab" technique is proposed to solve these problems.

MATERIALS AND METHODS The normalized real or imaginary field is smooth and continuous in its spatial distribution without wrapping. The two dimensional distribution of the complex image can be approximated by a complex polynomial function of spatial coordinates as $S(x, y) = \Sigma\Sigma a_{m,n} x^m y^n$, where $S(x, y)$ is the complex signal at a spatial position (x, y), $a_{m,n}$ is the complex coefficients with orders of m and n along x and y direction, M and N are the optimal orders of polynomial function for the approximation. The coefficients were optimized by using a linear least mean square method. The phase difference in the ROI between the original images and the estimated images are obtained along the algorism shown in Figure 1. To assess the error of the phase estimation in the self-reference method, experiments with 3 healthy human volunteers were made assuming that temperature in a volunteer liver is constant. A 0.5-Tesla open MR system (Signa SPi, GE Medical Systems, Milwaukee, WI, USA) sliced axial planes in the upper abdomen of the volunteer using SPGR with TR/TE, 32/12 ms; flip angle, 30°; slice thickness, 5 mm; field of view (FOV), 400 ×400 mm^2; and spatial matrix, 256 ×128. Simple breath hold was used to avoid the respiratory motion during the scanning time (4 s). A circular ROI of a radius of 20 voxels was set in the liver. A coaxial, "doughnut-like" region of the outer and inner radii of 30 and 21 voxels, respectively, surrounding the ROI was used to fit the complex signal distribution and to extrapolate the signal experiments were performed on 5 animals (approximately 20 kg in weight) under general anesthesia were placed in the gantry of the MRI. The respiratory motion of the animal was monitored by the optical displacement detection system and manually controlled. An interstitial microwave needle of the heating device (Microtaze AZM-520, Azwell Inc., Osaka, Japan) was subcutaneously inserted into the liver of each animal. The organ was heated with the microwave power of 10 to 60 W. Complex images in the liver were acquired during heating with the identical imaging conditions stated above except for TR, 23 ms, TE, 10 ms, FOV, 260 × 260 mm.. To seize the region with the largest temperature change while minimizing the effect of susceptibility artifact induced by the needle, the heat center the needle was detected and the temperature scanning was performed in porcine liver samples at the plane right on the heat center and perpendicular to the needle tip. To mark the needle tip in the MR image, a thin copper wire of 0.1-mm diameter was winded to form serially connected very small aperture (1.2 mm in diameter) coils on a sheath covering the needle stem. A stabilized direct current (~ 10 mA) was fed to the coils to make localized field changes along the needle. An "in-plane" thick slice slab including the needle was taken with a conventional optical navigation system (Flash Point 5000, BIG Inc., Boulder, CO, USA) using the following imaging parameters; SPGR, TR/TE, 32/12 ms; flip angle, 30°; slice thickness, 10 mm; FOV, 200 ×200 mm^2; and spatial matrix, 256 ×128. The dark spots along the needle were then detected in the image, and hence the heat center was determined as a fixed-distance (15 mm from the marker at the most tip-side) point on the extrapolated line connecting the spots. A slab moving to be orthogonal to the heating tip and hence tracking the heated position of the sample was sliced for temperature mapping.

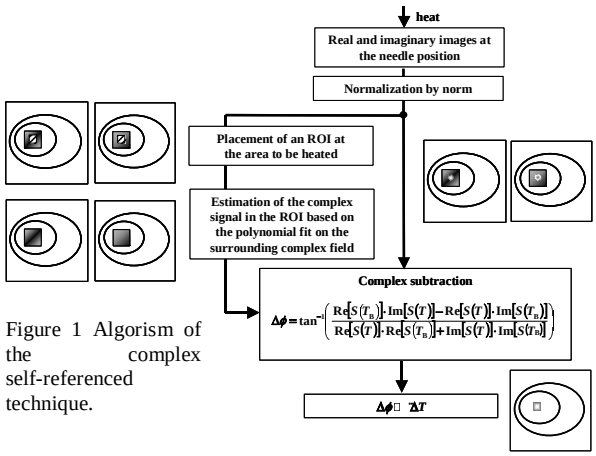

Figure 1 Algorism of the complex self-referenced technique.

RESULTS AND DISCUSSIONS The errors with the complex fit technique in the zero temperature estimation were 5 ~ 8 °C. These values were less than 10% of the error in the conventional external reference technique and were 15 % of the error in the phase field fit approach, whose accuracy was significantly spoiled by the phase wrap existed in the region. The complex and phase fitting strategies yielded similar results when no phase wrap existed. The error in complex fitting became slightly (2 ~ 3 %) smaller when the complex-coefficient polynomial function was used with the orders independently optimized for x and y directions. Figure 2 shows the examples of the in-plane image including the needle stem and the temperature elevation image in the plane orthogonal to the heating tip in the liver sample in vitro. The results in figure 2 demonstrated that the complex fitting technique was sufficient for mapping temperature change. The active needle tracking technique produced a slice at the heat center of the needle with minimum susceptibility artifact, which reduced the erroneous temperature read in the complex fitting technique. These results demonstrated that the proposed techniques are effective to make the self-referenced temperature imaging technique as a practical tool for liver thermal treatments with localized heating.

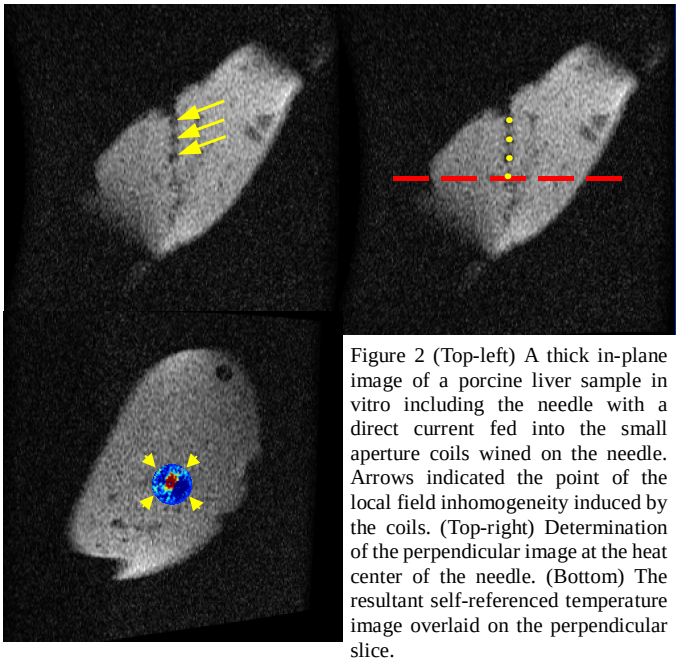

Figure 2 (Top-left) A thick in-plane image of a porcine liver sample in vitro including the needle with a direct current fed into the small aperture coils wined on the needle. Arrows indicated the point of the local field inhomogeneity induced by the coils. (Top-right) Determination of the perpendicular image at the heat center of the needle. (Bottom) The resultant self-referenced temperature image overlaid on the perpendicular slice.

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REFERENCES (1)Rieke V, Vigen KK, Sommer G et al., Proc 12th ISMRM meeting, Toronto, p. 75 (2003). (2)Kuroda K, Patent, #Toku-Gan-2003-273651, Japan (2003). (3)Kuroda K, Harada D, Kokuryo D et al., Japanese Journal of Magnetic Resonance in Medicine, 23 Suppl, p. 177 (2003).