Optimization of the Self-reference Thermometry using Isolated Regions for Complex Signal Estimation

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Introduction The purpose of this study is to minimize error contained in temperature change distribution obtained by the referenceless or self-reference thermometry technique[1, 2]. In our proposed method[2], temperature change distribution is estimated by calculating phase difference between the complex signal distribution in a region of interest (ROI) placed to cover a heated area and that extrapolated from the complex signal distribution in a region for estimation (RFE) surrounding the ROI using a complex polynomial model. Since this method does not use baseline subtraction, effects of inter-scan organ motion and magnetic flux distortion can be greatly reduced. However, error could be increased when changes in the complex signal due to heating or irregularity of the complex signal distribution are within the RFE. To solve these problems, in this paper, size, shape and the placement of the ROI and the RFE to minimize the effects of these factors are examined.

Methods Complex signal distributions in uterine fibroid treated with MR-guided focused ultrasound surgery (MRgFUS) device (ExAblate 2000, InSightec, Haifa, Israel) were acquired by a 1.5T MRI (Signa Excite 11, GE Medical Systems, Inc., Milwaukee, WI) with Fast Gradient Recalled Echo (FGRE) of the following conditions; TR/ TE, 25.2/12.5ms or 25.1/12.4ms; slice thickness, 5mm; field of view, 280×280 mm^2; spatial matrix, 256×128; flip angle, 30°; and read out band width, 11.4kHz. A circular ROI was located over the heated tissue region, and the complex-field based self-reference thermometry was then applied with the polynomial orders for x and y directions independently optimized [3]. Because uterine fibroid does not move with respiratory, temperature error was evaluated by comparing the estimated temperature with that obtained by the conventional baseline subtraction method. For RFE setting, three different types were devised; first, single, doughnut-like RFE surrounding a ROI ("doughnut-like"); second, multiple, equal-sized, isolated RFE's surrounding a ROI from four directions diagonally ("diagonal"); third, multiple, isolated RFE's with arbitrary shapes and locations ("arbitrary"). The radius of ROI and the area ratio between ROI and RFE were also optimized for all of the approaches.

Results Figure 1 shows the relationship between the radius of ROI and the average of temperature error calculated in 25 voxles near the heat center for 10 different sonication locations. In this chart, σ means the radius of the temperature field with temperature value of 1/e of the highest temperature at the center. The value was 3 voxels (3.27mm) in average. Figure 2 shows temperature error as a function of the area ratio of RFE against ROI in the case of "doughnut-like". The radius of the ROI was fixed at 9 voxels (3σ). Figure 3 compares the different types of the RFE settings at four sonication locations. Figure 4 demonstrates the temperature change images superimposed on a magnitude image at sonication location #4 appeared in Figure 3.

Discussions As is shown in Figure 1, the temperature error became stable at around 2.7°C when the radius of the ROI was larger than 2.5σ. The primary factor of the residual error was the temperature-induced phase change within the RFE. Based on this result, the radius of ROI was determined to be 2.5σ in the following examinations. The results in Figure 2 show that the error decreased with the area ratio, and was smaller than 3.0°C. The number of voxels in the RFE was 124 when the area ratio was 0.49, and the number of voxels was large enough to estimate all the polynomial coefficients (~ 49 terms) used in the estimation. Therefore, increase of the number of voxels in the RFE did not improve the estimation accuracy. Although the errors for the different RFE settings were similar for locations #1, #2 and #3, there was a significant difference between "doughnut-like" and the other strategies for location #4 as is shown in Figure 3. The reason was thought to be the irregular phase distribution near the boundary of the uterine fibroid was contained within the RFE when the RFE shape was a simple doughnut. Comparison of the images in Figure 4 (c), (d) and (e) tells that the RFE setting avoiding the organ boundary yielded better results according to the area of RFE located over the boundary. Note also that no marked increases of the errors were observed for these RFE settings in which the RFE's are isolated from the ROI. These results suggest that the influence of irregular phase distribution near the organ boundary can be effectively reduced by setting RFE's to have arbitrary sizes, shapes and locations, to avoid such irregular regions. This may lead to expanding the applicability of the complex, self-reference thermometry to the clinical situations where the operator wants to sonicate the target region located near the boundary of the organ as is often encountered in the FUS treatment.

References

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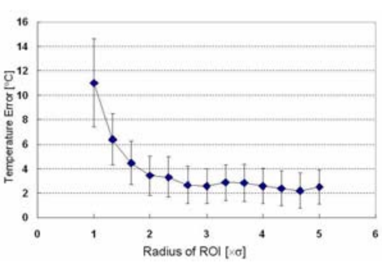

Figure 1. Relationship between the radius of ROI and the temperature estimation error near the sonication center. The values are the mean for the 10 different sonication locations. The error bars denote the ranges of the standard deviations.

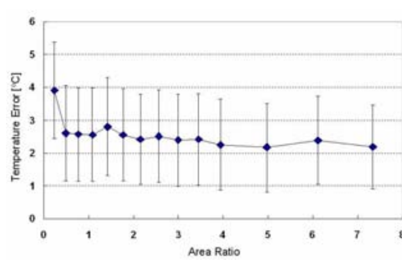

Figure 2. Temperature estimation error as a function of the area ratio between RFE and ROI. The mean and the standard deviations for the 10 sonication locations are shown.

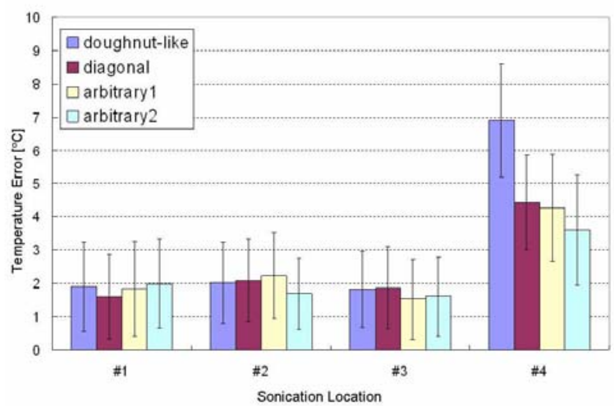

Figure 3. Comparison of the different types of RFE settings at four sonication locations. Location #1, #2 and #3 were at the middle of the uterine fibroid, while #4 was near the boundary.

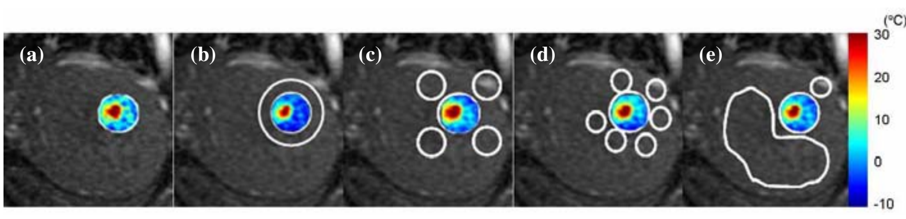

Figure 4. Temperature elevation distributions obtained by (a) the conventional baseline subtraction method, and (b), (c), (d) and (e) the self-reference method in uterine fibroid, superimposed on the magnitude images for sonication location #4 appeared in Figure 3. The RFE's settings were (b) "doughnut-like", (c) "diagonal", (d) "arbitrary1" and (e) "arbitrary2".