Improving the temperature accuracy of referenceless MR thermometry in the presense of susceptibility artifact

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Introduction Magnetic resonance thermometry (MRT) based on proton resonance frequency shift (PRFS) can be used to monitor temperature change during MR guided thermotherapy. The conventional PRFS method based on phase change over a reference is sensitive to motion. Referenceless MRT [1], where the baseline phase is obtained by fitting the phase map to a polynomial model, has been proposed to address this problem. However, susceptibility induced phase changes due to tissue interface or interventional devices can affect model fitting and result in large temperature error. The hybrid method of referenceless and multi-baseline [2] was proposed to address this problem. However, the baseline atlas must be updated whenever susceptibility distribution changes during ablation. We proposed here a way to improve the robustness of referenceless MRT against susceptibility changes by excluding the regions with large susceptibility artifact from being used for polynomial fitting. Such regions are automatically identified from the local field map extracted by the projection onto dipole fields (PDF) method [3] using the same phase image. The performance of the approach in improving temperature accuracy of referenceless MRT was evaluated using phantom and *ex-vivo* heating experiments.

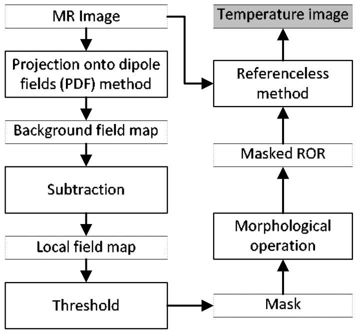

Figure 1: Flow chart of the algorithm

Theory The B_0 field inhomogeneity caused by imperfect shimming or magnetic susceptibility sources outside varies slowly spatially. This property is exploited in the referenceless method to estimate the baseline of heated region from the unheated region (region of reference, ROR) using polynomial model [1]. The local magnetic field inhomogeneity originating from susceptibility change is combined with the background phase, introducing large error to the polynomial when ROR is used to model B_0 field inhomogeneity. According to [3], susceptibility induced local field can be separated from the background B_0 field using the projection onto dipole fields (PDF) algorithm. Large absolute values in local field map means that the susceptibility induced change would significantly influence the phase map due to B_0 field inhomogeneity. Such areas should be masked out and excluded in the ROR during polynomial fitting. Fig.1 explains the algorithm of this approach used for MRT.

Materials and Methods Experiment was first performed in an agar phantom with a titanium needle inserted vertical to the B_0 in a 3T system (TIM Trio, Germany) at room temperature without heating. 3D GRE sequence was used for imaging: TR/TE=30/10ms, flip angle=15°, slices=30, voxel size=1mm isotropic, matrix size=128×128. *Ex-vivo* HIFU ablation on the *ex-vivo* bovine liver was conducted on the same scanner. The liver was heated by an MR compatible HIFU system. A titanium needle was placed vertical to B_0 around the HIFU focus. 3D GRE-EPI sequence was used for imaging: TR/TE=19/8.6ms, flip angle=15°, slice=24, voxel size=2mm isotropic, matrix size=160×160. The bovine liver was heated for 40 seconds. In both experiments, temperature maps were calculated by both the original referenceless method and our method for comparison. Temperature accuracies of both methods were evaluated using the root of mean square (RMS) and standard deviation (SD) of error to the reference subtraction method.

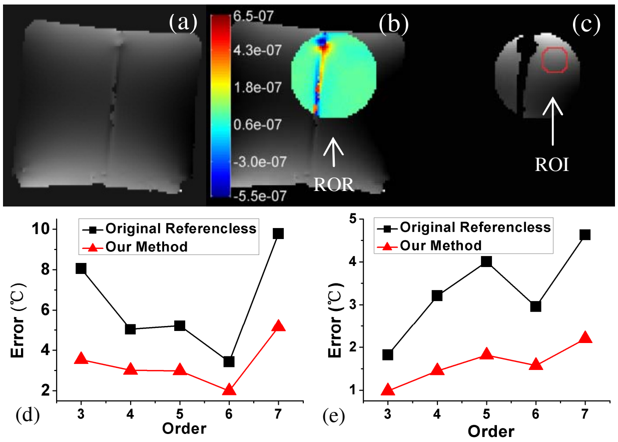

Fig.2: Agar phantom with titanium needle. (a) phase image, (b) local field in ROR extracted by PDF algorithm, (c) ROR after excluding regions with large susceptibility artifact, (d)-(e) RMS and SD of error of the original referenceless and our method to reference method.

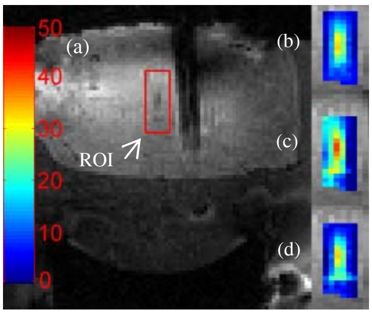

Fig.3: Ex-vivo liver with titanium needle. (a) Magnitude image with ROI. (b-d) temperature maps by reference, original referenceless and our method.

Results In phantom experiment the RMSE and SD decrease significantly for all polynomial orders (Fig.2). Fig.3 shows the results from the *ex-vivo* bovine liver heating experiment. Temperature distribution around the HIFU focus calculated by reference subtraction method, original referenceless method and our method were compared. The original referenceless method overestimated the temperature around the focal point due to the erroneous polynomial fitting (Fig.3c). Fig.4 shows the temperature change over time at the HIFU focal point by the three methods. Temperatures obtained from our method were very close to the reference method throughout the ablation while the original referenceless method overestimated the temperature (compared to the reference method) due to the polynomial fitting error originating from the susceptibility artifact. Table 1 shows the RMS and SD of error of the original referenceless method and our method compared to the reference method using the best polynomial order over the entire ROI from the ex-vivo liver ablation experiment.

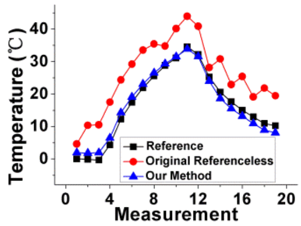

Fig.4: temperature change in focus of HIFU by three methods

Table 1: error of the original referenceless and our method to reference method.

	RMSE(℃)	SD(℃)
Referenceless	11.34	9.82
Our method	2.91	2.45

Discussion Effect of susceptibility on MRT can be eliminated using the multiple baseline method. When the susceptibility distribution changes irregularly, such as the motion of RF electrode and biopsy needle during intervention, accurate real time temperature monitoring is impossible as the baseline atlas should be acquired again after the tissue cools down. Our method improves the baseline estimation of referenceless method by excluding the regions with large susceptibility artifacts automatically from ROR for polynomial fitting, and does not require extra image acquisition. The PDF algorithm applied in our method requires a 3D or multi-slice 2D dataset. Such imaging method would favor MR thermometry with larger coverage.

Conclusion A method to minimize the effect of large susceptibility artifact in ROR on temperature accuracy of referenceless MRT was proposed. Phantom and *ex-vivo* bovine liver studies showed that this method can estimate the baseline temperature image with an error of less than 3°C even when the ROR is corrupted by large susceptibility artifact.

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Reference [1] Rieke V, et al MRM 51: 1223-1231. [2] Grissom W, et al Med Phys 37: 5014-5026. [3] Liu Tian, et al NMR in Biomedicine 24, 1129-1136.