Continuous Monitoring of Radiofrequency Ablation using MR-based Fast Conductivity Imaging Method

Woo Chul Jeong[1], Saurav ZK Sajib[1], Ji Eun Kim[1], Hyung Joong Kim[1], Oh In Kwon[2], and Eung Je Woo[1]
[1]*Kyung Hee University, Yongin, Gyeonggi, Korea,* [2]*Konkuk University, Seoul, Korea*

Target audience

This study might be helpful to the researchers who are interested in the practical applications of electromagnetic tissue property mapping such as image-guided thermal interventional treatments.

Purpose

The purpose of this study is to show the potentials of fast MREIT conductivity imaging as a non-invasive continuous monitoring of RF ablation through *ex vivo* bovine muscle tissue imaging experiments.

Methods

Bovine muscle tissue was used for imaging experiments. For RF ablation, we used the RF 2000 generator (RadioTherapeutics, CA, USA) and a pair of non-magnetic pure silver wire electrodes. We positioned the ablation electrodes in the tissue so that their tips were positioned at the imaging slice. To directly measure tissue temperature, we inserted a temperature sensor into the tissue between the tips of the ablation electrodes at the imaging slice. We attached two pairs of carbon-hydrogel electrodes (HUREV Co. Ltd, Korea) in the middle surface of the tissue for conductivity imaging. Imaging object was positioned inside a 3T MRI scanner with 8-channel RF head coil. We used a passive notch filter with its center frequency of 128.6 MHz to remove the RF generator signals around the Larmor frequency. We turned the RF generator on for 20 minutes.

Using a constant current source, we injected 10 mA currents along the horizontal and vertical directions through two pairsof surface electrodes. We acquired artifact-free MR images during and after RF ablation for 30.72 minutes using the ICNE-MGRE pulse sequence.[1] Imaging parameters were as follows: TR/TE=40/2.2 msec, echo spacing = 2.2 msec, number of echoes = 8, FOV = 160 × 160 mm^2, matrix size = 64 × 64, number of slices = 1, slice thickness = 10 mm, bandwidth = 550 Hz, and NSA = 1. After imaging experiment, we collected 180 image data sets at 10.24 seconds intervals for the total data acquisition time of 30.72 minutes. From each image data set, we extracted the induced magnetic flux densities B_z^1 and B_z^2 subject to the horizontal and vertical injection currents, respectively. We reconstructed conductivity images from the measured B_z^1 and B_z^2. For the quantitative analysis of time-course conductivity images, we applied a relative conductivity contrast ratio (rCCR) defined in reference 2.

Results and Discussion

Figure 1 shows the spatiotemporal profile maps of the reconstructed conductivity from 180 image data sets at 10.24 seconds intervals. Fig. 1(a) is MR magnitude image of the slice including the tips of the ablation electrodes. We chose two regions-of-interest (ROI) marked as R_V and R_H. The R_V was a vertical region passing through the middle of two ablation electrodes. The R_H was a horizontal region passing through the horizontal line connecting two ablation electrodes. Fig. 1(b) and (c) illustrate how reconstructed conductivity values changed within R_V and R_H during and after RF ablation. For the better understanding, we plotted the RF output power and the directly measured tissue temperature from the ablated lesion (Fig. 1d).

Figure 2 shows the quantitative analysis of reconstructed conductivity images in the ablated lesion. Fig. 2a represents the plot of the rCCR versus the tissue temperature. The six different stages marked as I to VI are defined in Fig. 2b. After reaching 60°C, there occurred a steep increase in tissue conductivity values with relatively little temperature increase. After RF ablation, tissue conductivity values in the lesion decreased as with temperature but values were different from those before ablation due to permanent structural changes of tissue by RF ablation.

Conclusion

We could monitor temperature and also structural changes in tissue during RF ablation by producing spatiotemporal maps of tissue conductivity using a fast MREIT conductivity imaging method.

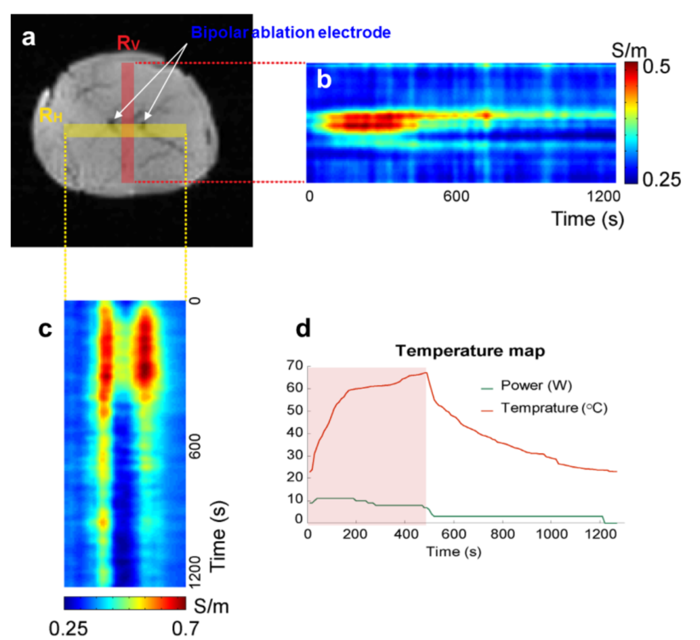
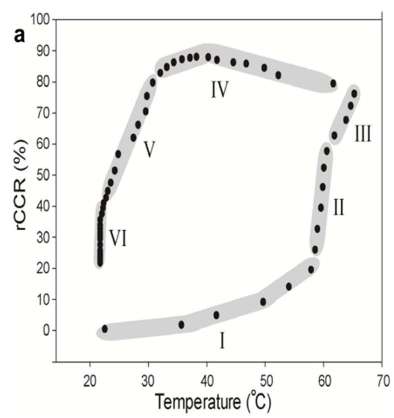


Fig. 1. Spatiotemporal profile maps of the reconstructed conductivity in bovine muscle tissue obtained from 180 image data sets at 10.24 seconds intervals during and after RF ablation.



b

Stage	Duration (s)	Description
I	0–163.84	RF generator was on and its power increased to 11 W. Temperature increased from 23.1 to 59.2 °C. rCCR increased with temperature.
II	174.08–348.16	RF generator was on and its power decreased from 11 to 8 W. Temperature was maintained at about 60 °C. rCCR increased due to structural tissue changes.
III	358.40–471.04	RF generator was on and its power was maintained at 8 W. Temperature gradually increased to 66.6 °C. rCCR increased with temperature.
IV	481.28–808.96	RF generator was on and its power decreased to 3 W. Temperature rapidly decreased to 35.7 °C. rCCR was maintained at about 87.8% due to structural changes.
V	819.20–1208.32	RF generator was maintained at 3 W. Temperature gradually decreased to 23.7 °C. rCCR decreased with temperature.
VI	1218.56–1843.20	RF generator was off. Temperature remained at 23.1 °C. rCCR slowly decreased to values different from those before ablation.

Fig. 2. Quantitative analysis of reconstructed conductivity images. (a) Plot of rCCR versus tissue temperature and (b) six different stage considering the relation among RF power, tissue temperature, and measured conductivity value.

References

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