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Authors

Ozhinsky, Eugene
Kohi, Maureen
Ghanouni, Pejman
et al.

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T2-Based Temperature Monitoring in Abdominal Fat during HIFU Treatment of Patients with Uterine Fibroids

Eugene Ozhinsky[1, a)], Maureen Kohi[1], Pejman Ghanouni[2], and Viola Rieke[1]

[1]*Department of Radiology and Biomedical Imaging University of California, San Francisco, 185 Berry Street, Suite 350, Box 0946, San Francisco CA 94107*
[2]*Department of Radiology, Stanford University, 1201 Welch Road, Stanford, CA 94305-5488*

[a)]Corresponding author: eugene.ozhinsky@ucsf.edu

Abstract. In this study, we have implemented T2-based monitoring of near-field heating in patients undergoing HIFU ablation of uterine fibroids using Insightec ExAblate system. In certain areas, near-field heating can reach 18°C and the tissue may experience sustained heating of more than 10°C for the period of 2 hours or more. This indicates a cumulative thermal dose that may cause necrosis. Our results show the feasibility and importance of measuring near-field heating in subcutaneous fat.

INTRODUCTION

High intensity focused ultrasound (HIFU) is a non-invasive technique that ablates tissue using an external transducer by focusing the ultrasound beam from outside the patient into a small focal spot and raising its temperature beyond the lethal level. One of the most common applications of HIFU is ablation of uterine fibroids (UF).

Near-field heating is a serious problem in UF treatments that may cause burns and necrosis of healthy tissue. Proton Resonance Frequency (PRF) shift thermometry is commonly used to monitor the heating during treatment. While effective in water-based tissues PRF thermometry cannot detect a temperature change in abdominal fat. Previously, Baron et al. [1] described the use of T2 mapping to measure near-field heating and demonstrated its application in a Philips Sonalleve HIFU system.

The goal of this study was to investigate near-field heating in patients treated with the InSightec ExAblate fibroid system. Accurate measurement of near-field heating in adipose tissue could lead to shorter treatments by eliminating unnecessary cooling time between sonications while preventing injury in healthy tissues.

METHODS

Heating & Cooling in Healthy Volunteers

T2 mapping for temperature measurement has been tested in two healthy volunteers. Fiber optic probes (Luxtron, LumaSense Technologies, Santa Clara, CA) were attached to the skin of the abdomen (fig. 1) and back (fig. 2) of the volunteers. Cooling and heating was performed by placing commercially available thermal pads onto the skin.

T2 maps were acquired with a 3T MRI scanner (GE Healthcare, Waukesha, WI) using a double echo Fast Spin Echo sequence with water suppression (TR=1500ms, TE=35/181 ms, 15 sec acquisition time). Maps of temperature change were generated from Gaussian-filtered T2 maps (filter size: 10x10 px., st. dev.: 5 px.), assuming a T2 change of 5.17 ms per °C [1].

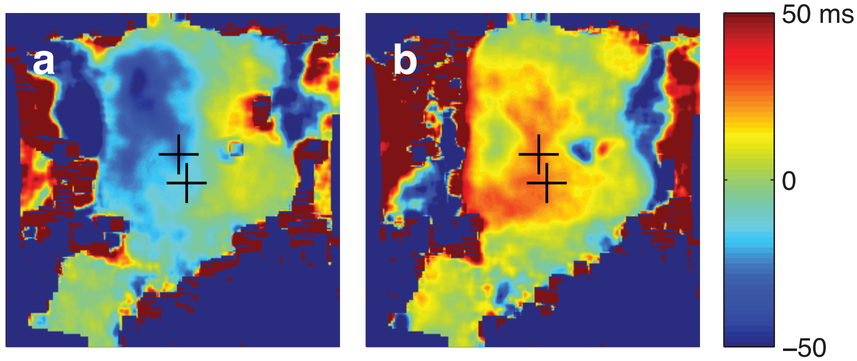

FIGURE 1. Coronal maps of T2 difference from baseline of abdominal fat layer (volunteer 1) after cooling (a) and heating (b).

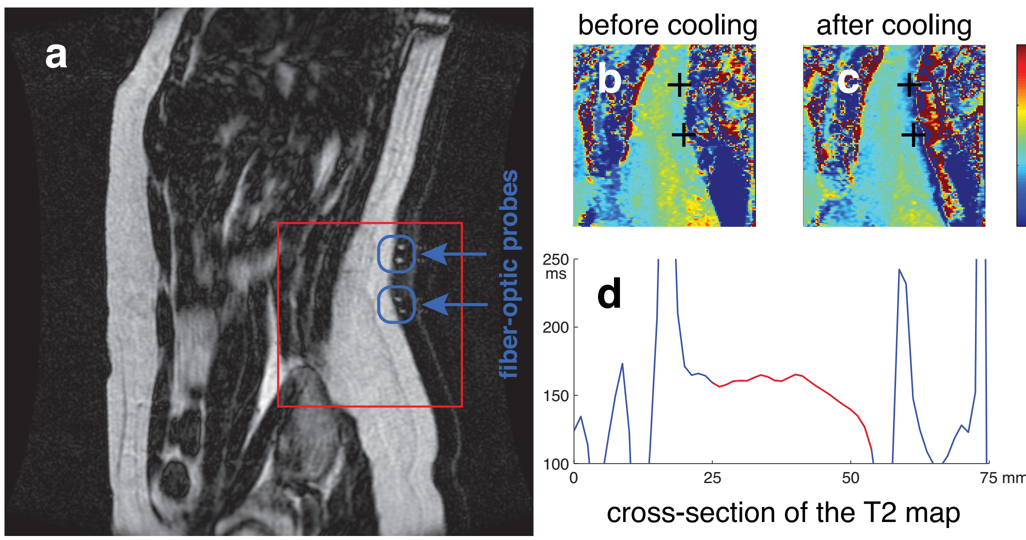

FIGURE 2. (a) Sagittal T2-mapping slice (volunteer 2) with the locations of the fiber optic probes; (b,c) sagittal T2 maps before and after cooling of the area, outlined in red in the figure on the left. Locations of fiber optic probes marked with crosses; (d) cross-section of the T2 map at the level of the superior probe at the end of the cooling period. The fat layer is highlighted in red. The T2 maps show decreased T2 values, but only in the outer layer of fat near the skin.

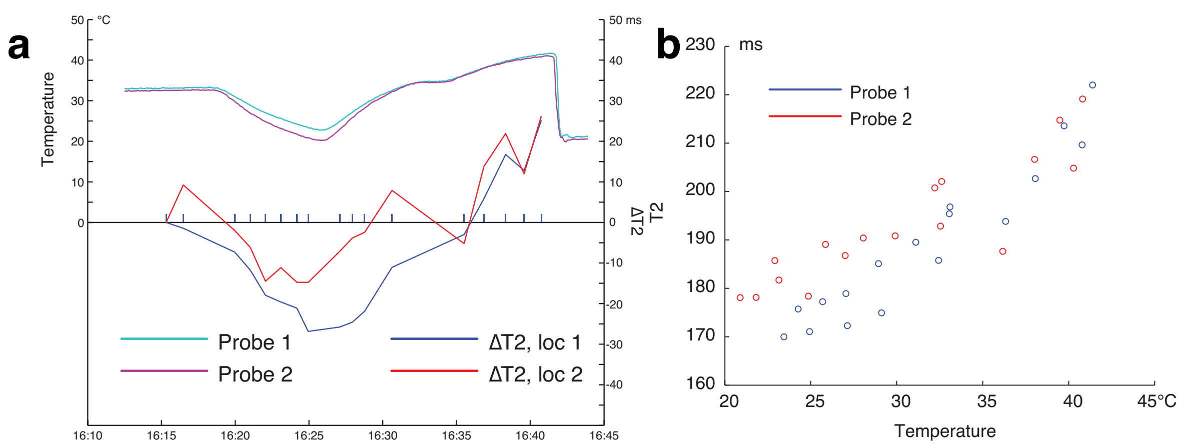

FIGURE 3. (a) Temperature, recorded by the probes and the corresponding change in T2 for volunteer 1 during cooling and heating. (b) relationship between temperature and T2 at the locations of the probes. The temperature change in the middle of the fat layer, where T2 maps were acquired was likely smaller than on the surface due thermal isolating properties of the fat layer.

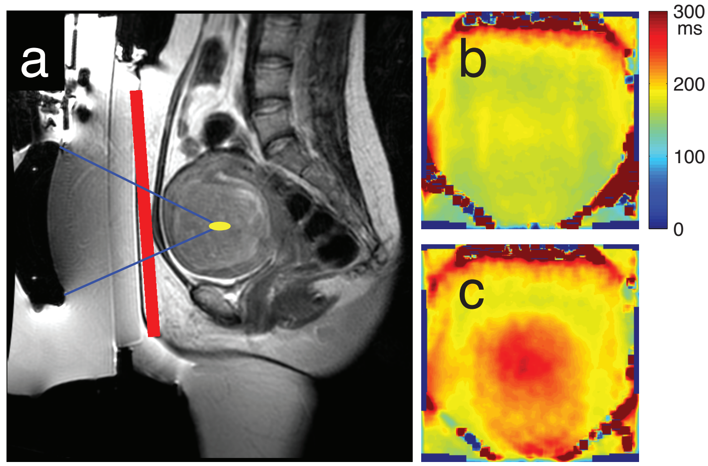

FIGURE 4. (a) Placement of the T2 mapping slice during HIFU treatment of a patient with uterine fibroid; (b) baseline fat T2 map; (c) T2 map during the treatment.

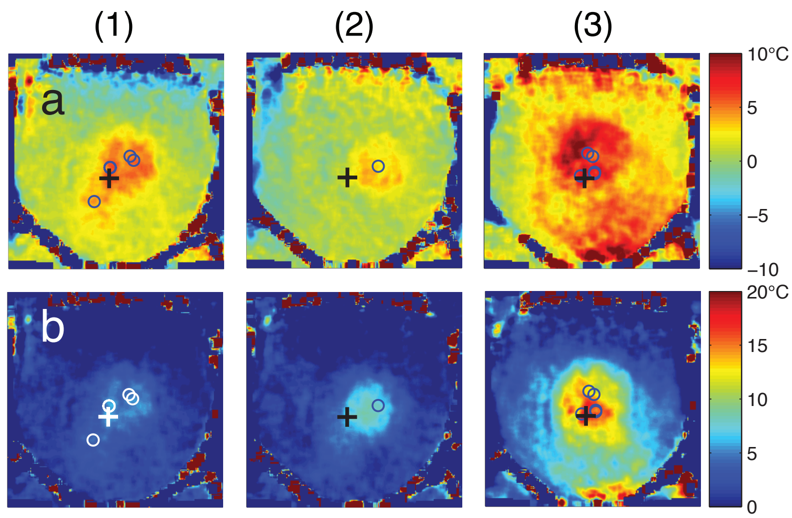

FIGURE 5. (a) Temperature change between subsequent measurements and (b) from baseline. Intersections of the beam axes and the slice are shown as circles, location of the measurement in fig. 6 as "+"

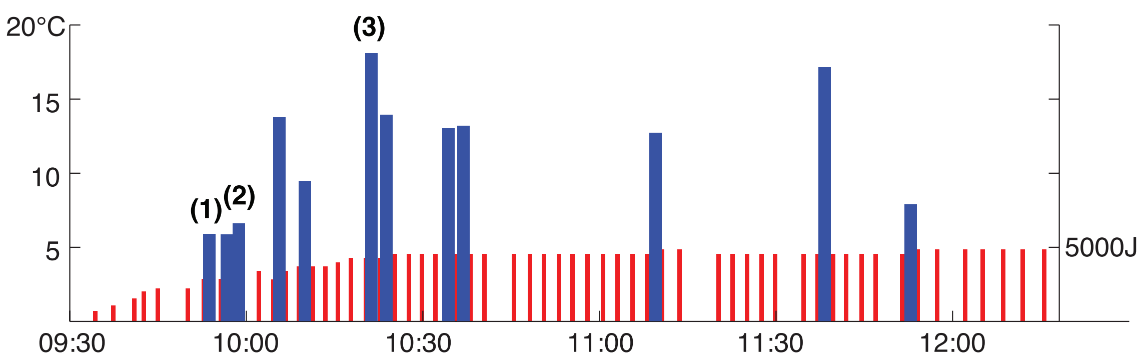

FIGURE 6. Measured temperature change from baseline (blue bars) for the location marked with a cross in fig. 5 and energy of sonications (red bars) over the course of the treatment.

HIFU Treatment of Patients with Uterine Fibroids

Fat temperature mapping was performed during seven UF treatments using the ExAblate 2100 system (InSightec, Israel) with sonication energy up to 5700 J and duration of 20 s per sonication (70 – 98 sonications total). T2-maps of abdominal fat were acquired between sonications (14 and 13 images per patient, single coronal oblique slice, fig. 4) using the double echo Fast Spin Echo sequence with water suppression (TR=1500ms, TE=35/181 ms, 15 sec acquisition time).

To reduce noise, Gaussian filter was applied to reconstructed T2 maps in Matlab. Maps of temperature change between subsequent T2 maps (fig. 5a) and since baseline (fig. 5b) were generated using calibration data, described by Baron et al. [1] Intersections of the beam axes and the T2 map slice were calculated and overlaid on the generated temperature maps.

RESULTS

Healthy Volunteers

Fat temperature mapping has been tested in two healthy volunteers. Figure 1 shows coronal maps of the T2 difference from baseline of the abdominal fat layer in one volunteer after cooling (a) and heating (b). T2 values decreased while cooling of the tissue and increased during the heating.

Figure 2 shows the propagation of the temperature change through the fat layer. The sagittal T2-maps in figure 2 before cooling of the area (b) and after cooling (c) show the decreased T2 values, but only in the outer layer of fat near the skin. The cross-section (d) shows the steep decrease of T2 values in the pixels of the fat area near the skin, due to low thermal conductivity of fatty tissues.

Figure 3a shows the temperatures, measured by the two fiber optic probes, overlaid with the calculated T2 change values in the locations, closest to the probes. Qualitative comparison in subcutaneous fat showed excellent correspondence between T2-maps and fiber optic measurements. Quantitative comparison was not possible in-vivo without the ability to embed the fiber optic sensors in the tissue.

Patients with Uterine Fibroids

The technique was used to acquire thermometry data during treatment of seven patients with uterine fibroids so far. Figure 4 shows the placement of the imaging slice and examples of the T2 maps at baseline and during treatment. We observed a measurable change in T2 of fat tissue in the path of the ultrasound beam.

Examples of the maps of T2 change between sonications (a) and from baseline (b) could be seen in figure 5. The areas of the increased temperature after clusters of sonications matched the intersection of the US beam with the slice (fig. 5a).

Figure 6 shows the timeline of the treatment with individual sonications as red bars and T2 measurements at the location shown in fig. 5 as red bars. We observed temperature increase up to 18°C and sustained heating of more than 10°C for the duration of the treatment.

DISCUSSION

Our preliminary results demonstrate the feasibility of monitoring near-field heating in fatty tissues using T2 mapping. In certain areas, near-field heating can reach 18°C and the tissue may experience sustained heating of more than 10°C for the period of 2 hours or more. This indicates a cumulative thermal dose that may cause necrosis [2,3].

The limitations of the current study include relying on previously reported calibration data [1] and lack of absolute temperature measurement. Measurement of baseline temperature is necessary to accurately quantify the temperature reached during the treatment. The volunteer experiments suggest that external cooling does not significantly affect the temperature within the fat layer. More frequent measurements will allow to better quantify the cumulative thermal dose and the rate of cooling after the sonication.

In conclusion, our data show the feasibility and importance of measurement of near-field heating in subcutaneous fat. More accurate measurement of fat temperature is crucial for achieving shorter treatments and minimizing adverse effects.

ACKNOWLEDGMENTS

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