Spatial and Temporal Characteristics of Soft Tissue Heating in MR-HIFU Treatment of Bone Metastasis

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Purpose An emerging application of MR guided high intensity focused ultrasound (HIFU or FUS) is the ablation of nerves affected by painful tumor metastasis located in bone. The goal of these treatments is to achieve sufficiently high temperatures to cause necrosis of the nerves in the surrounding periosteum, thereby relieving the pain associated with tumor growth. Due to its relatively high acoustic absorption coefficient and low heat capacity, bone heats more easily than the surrounding soft tissue. However, the relatively low thermal conductivity and perfusion of bone causes it to radiate much of that heat into the surrounding soft tissue [1]. The purpose of this work was to investigate the radiating properties of bone on the adjacent soft tissue; specifically we investigated when the temperature rise is the highest with respect to the end of the sonication and whether the rate of cooling in soft tissue is dependent on proximity to bone. Finally, we considered how these spatiotemporal effects impact temperature and dose estimation.

Methods Temperature images from the treatment of a patient with metastatic tumor in the bone were analyzed. During the treatment, 14 cooling phases were acquired after the ultrasound was turned off to provide information about the temporal characteristics of the temperature. Thermometry data were acquired in five slices every 4.2 seconds - continuously throughout each sonication.

The images were analyzed by choosing regions of interest at varying distances from the bone. Temperature was estimated with the baseline subtraction method [2]. Average temperatures in these regions were tracked over time and smoothed by a moving average filter with a span of 5. To estimate the delay between the end of the ultrasound pulse and the peak temperature rise the temperature data was up-sampled by a factor of 10. Decay rates were determined by fitting the decaying portion of the temperature curves to an exponential of the form $e^{\tau t}$.

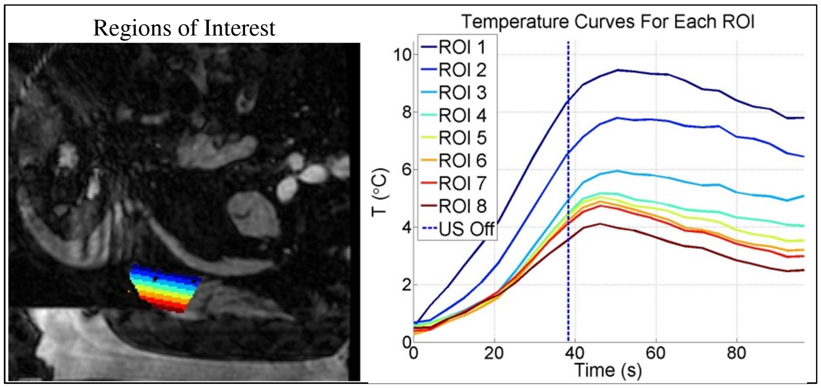

Figure 1: a) Regions of interest. b) Temperature curves for the regions of interest shown in a.

Results Temperature curves for the regions of interest shown in Figure 1a are plotted in Figure 1b. The curves demonstrate a delay between the end of the ultrasound and the peak measured temperature. This delay is plotted as a function of distance from the bone in Figure 2. The delay decreases with increasing distance from the bone. This can be understood by considering that the primary heating of the soft tissue near the bone is due to radiation from the bone, leading to a delay between the ultrasound heating of the bone and the radiation of that heat into the soft tissue. Away from the bone, the primary source of heating is direct absorption of the ultrasound.

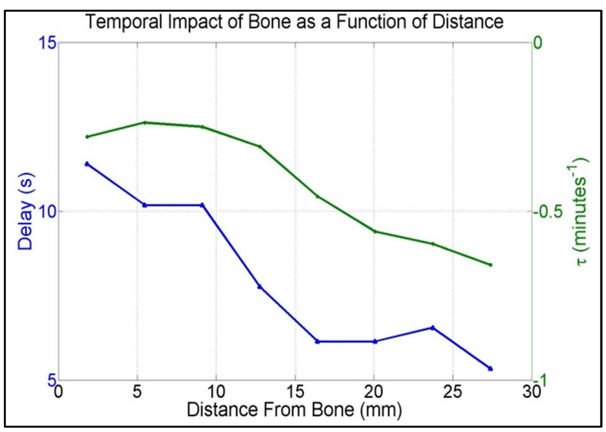

Figure 2: The number of images after the sonication at which the maximum temperature is reached as a function of distance from the bone. The decay rate, τ, is also plotted verse distance. Distance is measured from the center of the region of interest to the edge of the bone.

The rate at which the soft tissue cools is also affected by its proximity to bone. Figure 2 shows that the decay rate, τ, becomes increasingly negative – meaning that temperature decays more rapidly – with increasing distance from the bone. This slower cooling rate for tissue near bone has implications for thermometry techniques and dose calculations. The slower cooling of tissue near bones imposes a longer cooling time between sonications and the acquisition of subsequent baseline images. Dose calculations must also be adjusted. For the values of τ shown in Figure 2 a region close to the bone that is heated to 10 ºC above body temperature acquires approximately 7 additional equivalent minutes at 43 ºC and 148 additional equivalent minutes for a 15 ºC temperature rise.

Conclusion Temperature radiation from bone affects the temporal and spatial characteristics of temperature in soft tissue. These effects must be accounted for to achieve accurate temperature monitoring and dose estimation.

References

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