

Imaging Temperature Changes in Cortical Bone Using Ultrashort Echo-Time MRI

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Target Audience: MRI physicists and clinicians who are interested in monitoring temperature in cortical bone during thermal therapies.

Purpose: High-intensity focused ultrasound (HIFU) is a new, noninvasive technique to ablate bone tumors and palliate pain.¹ During HIFU treatment, MR thermometry is frequently employed to ensure proper heat deposition to the targeted tumor and to prevent unwanted damage to healthy tissues. However, conventional MR thermometry based on the proton resonance frequency (PRF) shift of water² is not suitable for monitoring temperature in cortical bone due to its short T_2^* relaxation time. Recently, it was shown that ultrashort echo-time (UTE) MRI can detect signal changes arising from temperature increases in bone.³ In this work, we demonstrate the ability of 3D UTE imaging to assess T_1 changes in cortical bone due to heating.

Methods: An *ex vivo* study was performed with a diaphysis segment of bovine femur on a Discovery MR 750w 3T scanner (GE Healthcare, Waukesha, WI) using an eight-channel phased-array wrist coil (Invivo, Gainesville, FL). A 7.7 MHz catheter-cooled interstitial ultrasound applicator with two-sectored cylindrical transducers⁴ was inserted into the fatty yellow bone marrow in the medullary cavity. Heating of cortical bone was conducted by delivering high intensity ultrasound energy with a 180° directional heating pattern towards the bone (12 W/cm² transducer surface intensity). Before heating began, 3D UTE imaging incorporating a non-selective hard pulse excitation and 3D radial acquisitions was conducted using a 11 ms TR, 76 μ s TE, 1 mm isotropic spatial resolution, 9 x 9 x 7.8 cm³ FOV, and RF spoiling. UTE images with two flip angles of 8° and 44° were acquired, each with 4.3 min scan time, to calculate T_1 using a variable flip angle scheme.⁵ To monitor transient temperature changes during heating, dynamic T_2 maps on yellow bone marrow were estimated by using a double-echo 2D fast spin-echo sequence. Scan parameters used were 35.6 ms and 185 ms TEs, 666 ms TR, echo train length of 40, 10 x 10 cm² FOV, 128 x 128 matrix size, 4 mm slice thickness, 10 slices, and 1.4 min/scan. Temperature was assumed to reach steady state at 10 min after heating began, and UTE imaging with the two flip angles were performed again.

Results: Figure 1 shows the maps of T_2 changes in bone marrow compared to baseline on one slice location. Since T_2 increases with temperature in fat,⁶ these maps demonstrate temperature increases over time due to ultrasound propagation. The maps of T_1 changes in the cortical bone due to heating are illustrated in Fig. 2 for two different locations. T_1 increase of up to 40 ms was measured, which was approximately a 20% increase from baseline. T_1 changes were more significant in the slice at the bottom (Fig. 2e), where temperature was higher in the adjacent bone marrow as indicated in the T_2 -change map.

Discussion: T_1 - and T_2 -based thermometry has gained increasing attention for temperature mapping in tissues where PRF-based thermometry is not suitable. Here, we demonstrated that UTE imaging can be used to detect T_1 changes in cortical bone due to temperature increases. Direct quantification of temperature changes in bone can provide more accurate monitoring of thermal dose than the extrapolation of temperature information in surrounding soft tissues. Actual temperature changes were not measured during our experiment, but we estimated a peak temperature increase of 37°C in the bone marrow with exploiting a T_2 -temperature coefficient of 5.16 ms/°C as previously measured.⁷ Future work includes quantification of T_1 and temperature dependence in cortical bone.

Conclusion: We have shown the feasibility of using UTE imaging to detect T_1 changes in cortical bone for temperature mapping. The direct quantification of bone temperature can improve the safety and efficacy of thermal ablation of bone tumors.

References

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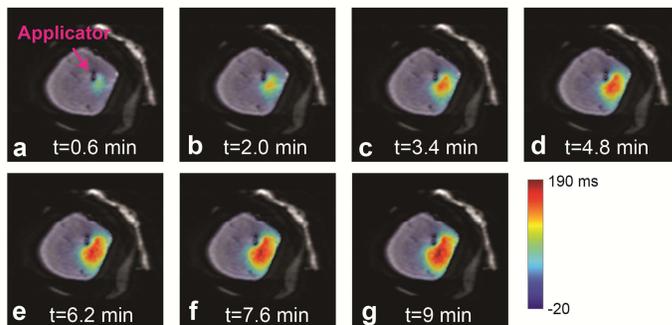


Figure 1. (a-g) Maps of T_2 changes in bone marrow during transient state, overlaid on the FSE images. Directional heating of cortical bone can be observed.

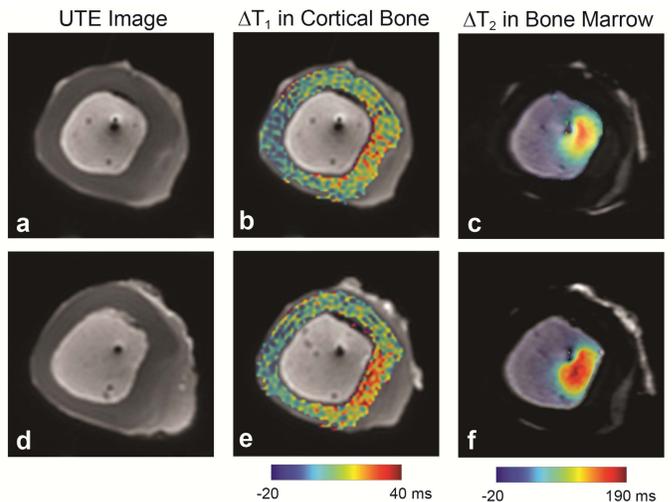


Figure 2. UTE images at baseline (a,d) and maps of T_1 changes (b,e) at two different locations. The T_2 -change maps in bone marrow (from the last temporal frame) at the matching locations are shown in (c,f). Increases in T_1 are observed in the cortical bone adjacent to the heated bone marrow.