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The Brain's Attenuation Coefficient as a Potential Estimator of Temperature Elevation during Intracranial High Intensity Focused Ultrasound Procedures

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Abstract : Noninvasive image-guided intracranial treatments using high intensity focused ultrasound (HIFU) are on the course of translation into clinical applications. They include, among others, tumor ablation, hyperthermia, and blood-brain-barrier (BBB) penetration. Since many of these procedures are associated with local temperature elevation, thermal monitoring is essential. MRI constitutes an imaging method with high spatial resolution and thermal mapping capacity. It is the currently leading modality for temperature guidance, commonly under the name MRgHIFU (magnetic-resonance guided HIFU). Nevertheless, MRI is a very expensive non-portable modality which jeopardizes its accessibility. Ultrasonic thermal monitoring, on the other hand, could provide a modular, cost-effective alternative with higher temporal resolution and accessibility. In order to assess the feasibility of ultrasonic brain thermal monitoring, this study investigated the usage of brain tissue attenuation coefficient (AC) temporal changes as potential estimators of thermal changes. Newton's law of cooling describes a temporal exponential decay behavior for the temperature of a heated object immersed in a relatively cold surrounding. Similarly, in the case of cerebral HIFU treatments, the temperature in the region of interest, i.e., focal zone, is suggested to follow the same law. Thus, it was hypothesized that the AC of the irradiated tissue may follow a temporal exponential behavior during cool down regime. Three ex-vivo bovine brain tissue specimens were inserted into plastic containers along with four thermocouple probes in each sample. The containers were placed inside a specially built ultrasonic tomograph and scanned at room temperature. The corresponding pixel-averaged AC was acquired for each specimen and used as a reference. Subsequently, the containers were placed in a beaker containing hot water and gradually heated to about 45^{o}C. They were then repeatedly rescanned during cool down using ultrasonic through-transmission raster trajectory until reaching about 30^{o}C. From the obtained images, the normalized AC and its temporal derivative as a function of temperature and time were registered. The results have demonstrated high correlation ($R^2 > 0.92$) between both the brain AC and its temporal derivative to temperature. This indicates the validity of the hypothesis and the possibility of obtaining brain tissue temperature estimation from the temporal AC thermal changes. It is important to note that each brain yielded different AC values and slopes. This implies that a calibration step is required for each specimen. Thus, for a practical acoustic monitoring of the brain, two steps are suggested. The first step consists of simply measuring the AC at normal body temperature. The second step entails measuring the AC after small temperature elevation. In face of the urging need for a more accessible thermal monitoring technique for brain treatments, the proposed methodology enables a cost-effective high temporal resolution acoustical temperature estimation during HIFU treatments.

Keywords : attenuation coefficient, brain, HIFU, image-guidance, temperature
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