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# Simulation of transcranial focused ultrasound propagation for prediction of thermal lesions and patient selection

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**Title:**

Simulation of Transcranial Focused Ultrasound Propagation for Prediction of Thermal Lesions and Patient Selection

**Indication:**

Brain technical

**Mechanism of Action:**

Thermal ablation

**Take Home Message / Precipis:**

The CIVA simulation package can predict transcranial heating of tissue mimicking materials, and a parametric study revealed that the transcranial are most affected by the skull geometry and shear wave propagation, while internal reflections can be neglected.

**Background:**

Focused ultrasound has long been recognized as a therapeutic tool with potential to treat disorders throughout the brain. However, precise planning software is still required for patient selection and for assessing the feasibility of treating novel anatomical targets.

Numerical models are essential tools for calculating the phase corrections needed to account for the presence of the skull, but can be prohibitively expensive in required computational resources. These models require precise knowledge of the geometry and material properties of individual patients' skulls. Studies indicate that estimates of skull properties from CT-derived HU measurements may not account for all variability in the speed of sound within human skulls. Patient classification for eligibility for transcranial ultrasound treatments is currently based on a ratio of cortical to trabecular thickness, but to date no clear justification of this metric has been provided in terms of the physics of ultrasound propagation.

The CIVA Healthcare software provides a user-friendly simulation platform with a ray-tracing modelling method that has been shown to be an efficient, accurate, and computationally inexpensive method of modelling transcranial focused ultrasound.

This work quantifies the significance of parametric variation of homogeneous skull properties, and the effects of mode conversion and internal reflection within a layered model of the skull, on transcranial focalization quality using an acoustic source based on the InSightec ExAblate Neuro clinical system - a hemispherical 1024-element system operating at a 670kHz. A numerical BHTE solver is implemented to predict temperature changes based on simulated acoustic fields, and results are validated by comparison to MRI thermometry measurements.

**Materials and Methods:**

Using an acoustic source based on the InSightec ExAblate Neuro system, a parametric simulation study was performed to examine the effect of uncertainty and variation of homogeneous skull properties (density, speed of sound, attenuation) on transcranial focalization quality.

To investigate the role of bone micro-architecture, simulations were performed in which the skull was modelled as a layered material composed of cortical and trabecular layers, and the impact of internal reflection and mode conversion was quantified for varying degrees of skull heterogeneity. Focalization quality was quantified based on the maximum acoustic amplitude obtained near the focus, its corresponding distance from the intended focal point, and the focal volume.

Finally, a numerical BHTE solver was coupled to the acoustic solver in order to model the temperature changes in tissue mimicking phantoms within human skulls. Simulation results were validated with comparison to experimental MRI thermometry.

**Results:**

The parametric simulation study provided quantification of the effect of changes and uncertainties of acoustic properties on two homogeneous skull models on transcranial focalization quality, as shown in Figure 1. The effects of mode conversion in a layered model of the skull was examined, with results shown in Figure 2 indicating that shear wave mode conversion within the skull had a significant effect on the focal quality. The effects of internal reflection were found to be negligible. Neither internal reflection nor mode conversion were found to account for degraded focal quality for skull models with high volume of trabecular bone. A comparison of the results obtained from the BHTE numerical model found strong agreement with experimental measured temperature rise measured using MR thermometry, as shown in Figure 3.

**Conclusions:**

This work provides quantification of the role of skull property uncertainty on transcranial focal quality within a ray-tracing model of ultrasound propagation. The effects of internal reflection and mode conversion within a layered model of the skull were not sufficient to explain degraded focal quality for skulls models with low ratio of cortical to trabecular thickness. The use of a coupled numerical BHTE solver was found to produce temperature estimates that were in good agreement with experimental measures of experimental temperature rise.

**Acknowledgment/Funding Sources:**

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**Image/Figure 1:**

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**Caption 1:**

Figure 1: Effect of velocity uncertainty on the maximum acoustic amplitude (left), focal position error (center), and focal volume (right) for two different homogeneous skull models. Dashed line indicates speed of sound used for phase profile calculation.

**Image/Figure 2:****View File -**

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**Caption 2:**

Figure 2: Effect of shear mode conversion on maximum acoustic amplitude (left), focal position error (center), and focal volume (right) for heterogeneous model of the skull with varying levels of trabecular bone.

**Image/Figure 3:****View File -**

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**Caption 3:**

Figure 3: Experimental and modelled temperature rise within a tissue mimicking material within the skull.

**Presenting Author Biography:**

Robert Andrew Drainville was born in Thunder Bay, Canada. He received his Honours Bachelor of Science in physics and his Ph.D degree in Biotechnology from Lakehead University for his work in finite difference time domain modelling of viscoelastic wave propagation. His research experience includes work on numerical modelling of transcranial ultrasound, acoustic cavitation, and experimental and theoretical fibre optics. He joined LabTAU INSERM 1032 in Lyon, France as a postdoctoral researcher in March 2020, where his current research focuses on numerical modelling of transcranial ultrasound and medical device design.

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