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► **To cite this version:**

Andrew Drainville, David Moore, John Snell, Sylvain Chatillon, Cyril Lafon, et al.. Influence of bone properties on transcranial propagation. 2020 7th International Symposium on Focused Ultrasound, Nov 2020, Virtual meeting, United States. , 2020. cea-04418211

**HAL Id: cea-04418211**

**<https://cea.hal.science/cea-04418211>**

Submitted on 25 Jan 2024

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## Influence of bone properties on transcranial propagation

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### **Background:**

For transcranial focused ultrasound therapeutic, such as treatment of essential tremor via local thermal ablation of a small volume in the thalamus, acoustic energy is focused through the skull using a phased-array transducer. Per-element phase delay is derived using individual patient's skull CT to compensate for skull heterogeneity in geometry and acoustical properties, but MRI thermometry is still required for precise targeting and localization of the focal spot. An accurate simulation system would help to improve the refocusing of the beam in the targeted zones.

Through a parametric study, we investigated how variations of the acoustic properties of the skull, due to uncertainties of their estimates, may translates into errors in spatial positioning and focal gain at the treatment spot.

**Materials and Methods:** The parametric study examined the influence of density, speed of sound, attenuation, and fluid vs elastic models of the skull. The simulation method employed the CIVA Healthcare simulation platform – a software platform which uses dynamic ray tracing method to model linear acoustic propagation through the skull.

The transducer was modeled on an ExAblate Neuro 650 kHz (Insightec) clinical system

To perform the parametric study, various published relationships between skull density from CT and acoustic velocity and attenuation were used. The influence of the variation in acoustic properties between these different models was quantified by its impact on spatial positioning and acoustic intensity at the treatment spot.

Simulations were performed at the maximum and minimum predicted acoustic velocities for a given density value between 1600 and 2400kg per cubic metre. The phase delay profile was calculated from the average of the maximum and minimum speed of sound values. These values as a function of density are shown in Figure 1. The quality of focalization was quantified based on the maximum acoustic field amplitude, and its corresponding location.

**Results:** The results of the parametric simulation study indicate that the uncertainty in the acoustic properties of the skull determined from CT scans translate into significant errors in focalization quality for clinical applications. The disagreement among proposed relationships between density and acoustic velocity produces errors in the acoustic field up to 25%, as shown

in Figure 2. Errors in spatial positioning were found to be less than 0.5mm for all values of density and velocity, as shown in Figure 3.

The uncertainty on skull attenuation is found to have less effect on the quality of focalization, with a 20% error in skull attenuation producing no more than a 10% change in maximum acoustic amplitude, and no more than a 0.2mm change in spatial position.

Consistent with the findings of previous publications, the results support the conclusion that shear waves can be ignored without significant impacts on the maximum amplitude or spatial positioning.

**Conclusions:** The result of the parametric study quantifies the sensitivity of focal intensity and position to uncertainty in acoustic properties of the human skull used for numerical simulations for transcranial applications. These findings illustrate the importance of accurately determining the relationship between density and acoustic velocity in ray-tracing models of transcranial ultrasound.

**Take away:** Parametric simulation studies were used to quantify the sensitivity of transcranial focalization to uncertainties in estimated skull acoustic properties. Errors in speed of sound and density can translate into significant errors in focalization, whereas attenuation has less impact.

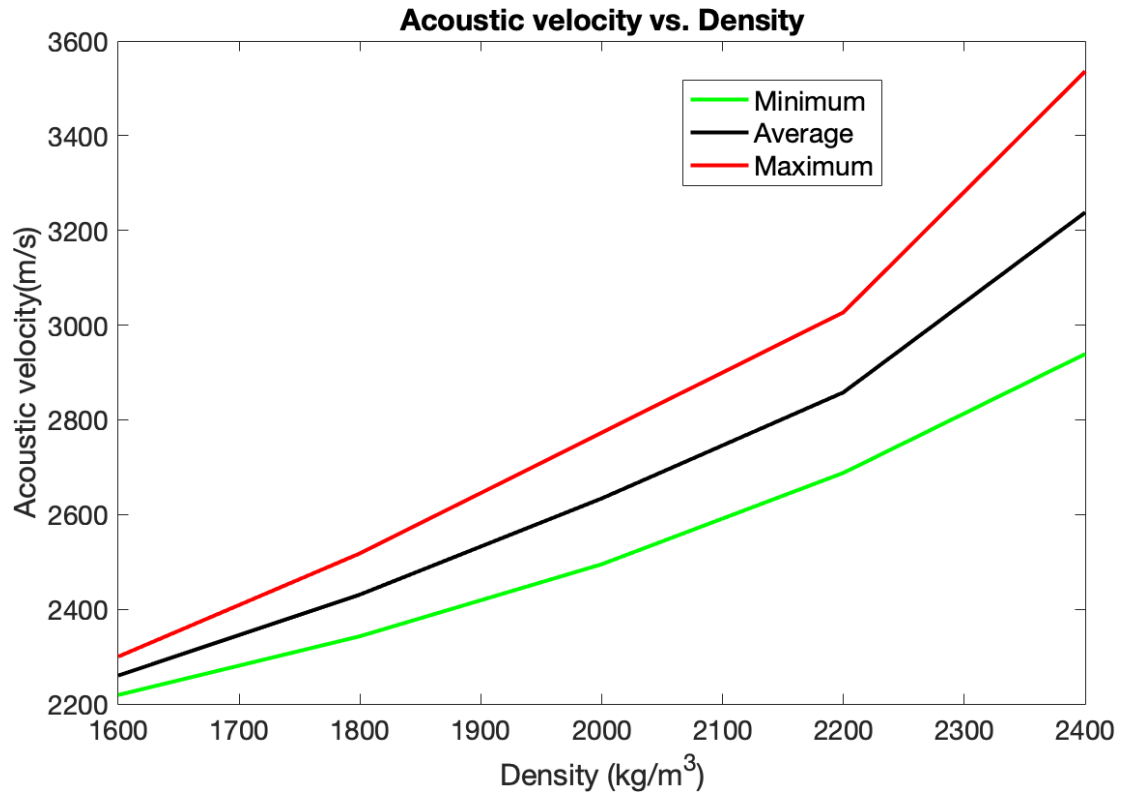


Figure 1: Range of predicted acoustic velocity as a function of density across all proposed models. Simulations were performed at all 3 velocity values in density intervals of 200kg per cubic metre, with the phase delay profile calculated based on the average acoustic velocity.

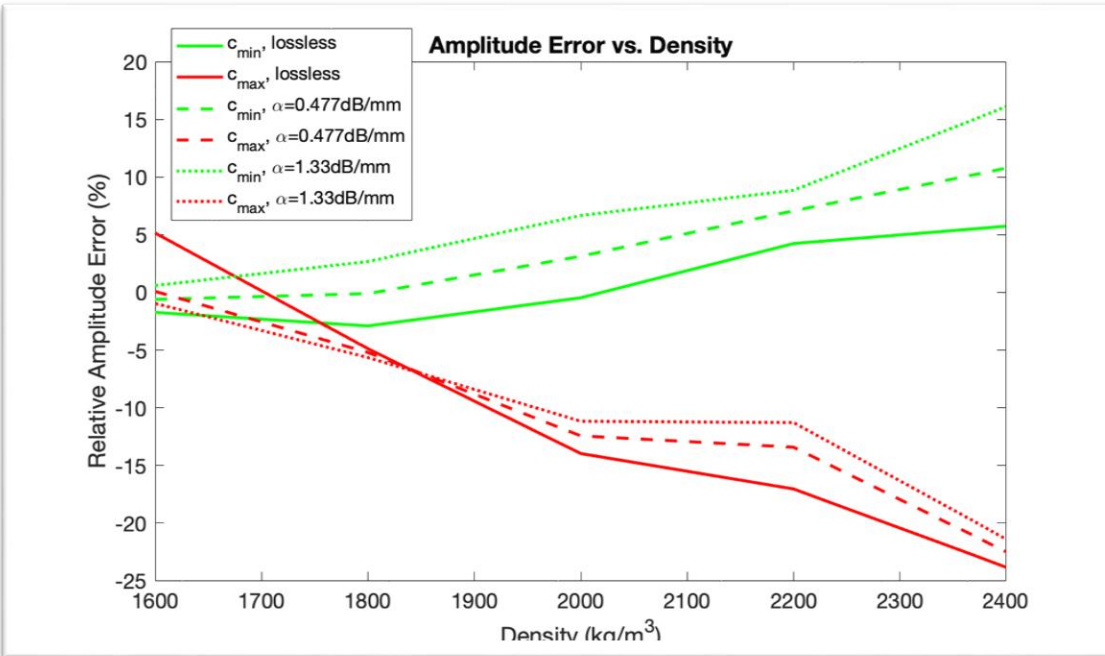


Figure 2: Amplitude error vs density, with three different values of attenuation: 0, 0.48 and 1.33 dB/mm, where the latter two values are average and maximum attenuative values for the skull. Amplitude error is calculated with reference to results from simulations performed with skull acoustic velocity equal to the average speed given Figure 1, which was used to determine the phase delay profile.

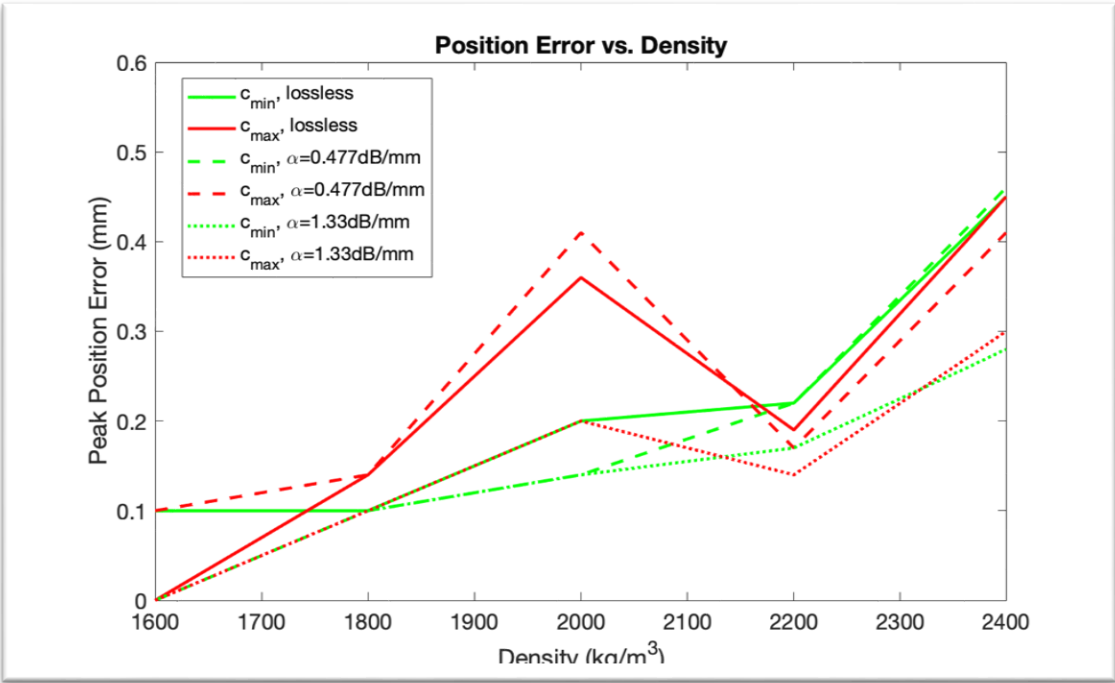


Figure 3: Peak position error vs density for various density values, with three different values of attenuation: 0, 0.48 and 1.33 dB/mm, where the latter two values are average and maximum attenuative values for the skull.