A Validated Template for Computational Dose Modelling for Transcranial Focused Ultrasound Stimulation

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Title: A Validated Template for Computational Dose Modelling for Transcranial Focused Ultrasound Stimulation

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Abstract:

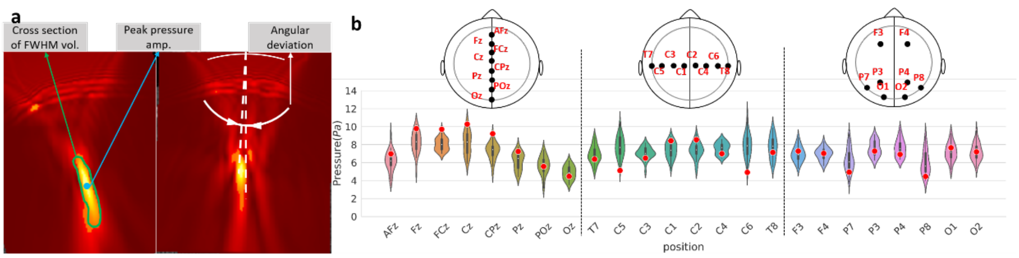
Background: Transcranial focused ultrasound stimulation (TUS) is emerging as a novel non-invasive method with far better spatial resolution than existing non-invasive brain stimulation methods and the unique ability to create small stimulation foci in deep brain areas. However, accurate focusing of the TUS acoustic waves through the intact human skull is problematic as the skull causes strong attenuation and reflection of the waves. As in-vivo acoustic wave measurements are not yet feasible, computer simulations are required to determine the spatial distribution and intensity of the acoustic wave after skull transmission.

Methods: Our work focuses on establishing accurate computer simulations of the TUS acoustic wave based on information of the skull morphology and its acoustic properties estimated from computed tomography (CT) images. As it is often challenging to obtain high-quality imaging data for individual participants, we are currently working on establishing a skull template that can be used to estimate the average effects of the skull on the TUS acoustic wave in the population. A reliable skull template can also provide valuable information as part of the study development process, including investigating different transducer alignment strategies, acoustic distortions, and safety metrics. The template was made from CT and magnetic resonance images (MRI) of the heads of thirty individuals of different ages (between 20-50 years old), gender, and ethnicity, using the ANTs [1] registration tool. Additionally, the individual scans were segmented using the CHARM [2] segmentation tool to create masks for skull, internal air cavities, and intracranial tissues. Then, by using the masks and the CT intensity information, a mapping to the acoustic properties was applied [3]. For the next step, the k-Wave [4] toolbox was employed for modeling the acoustic wave distribution for the template and each individual subject. For simulations, a 500 kHz ultrasonic transducer was modeled with a similar size to an existing commercial transducer. For positioning the transducer, 24 different positions based on the 10-20 standard EEG system were used.

Results: To show how well our template represents the population average, we compare different parameters to characterize the acoustic wave distribution and intensity and compare these parameters between the subjects and the template for all transducer positions. As shown in figure (a) these parameters include the amplitude of peak pressure, the volume of the focus area, and the angular deviation of the peak pressure location. In figure (b), the violin plot shows the peak pressure amplitude versus the transducer positions for 27 subjects and the template (shown with red dots). Among 27 subjects, the template results located within the interquartile range of violin plots for 12, 20, and 14 transducer positions out of 24 positions for peak pressure amplitude, FWHM volume, and angular deviation respectively. The results for all thirty subjects will be presented as part of our future work.

Discussion: As shown in figure (b), for some transducer positions, the template represents the average pressure very well, but is less accurate for others. The reason could be due to differences in skull morphology and composition between the template and subjects, which we will investigate further as part of our future work.

[1] Avants, Brian B., et al. Neuroimage 54.3 (2011): 2033-2044; [2] Puonti, Oula, et al. Neuroimage 219 (2020): 117044; [3] Montanaro H, et al. Journal of Neural Engineering. 2021 May 4;18(4):046041; [4] B. E. Treeby, et al. J. Biomed. Opt., vol. 15, no. 2, p. 021314, 2010.



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Conflicts of interest: none

Topic area: technical

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