Detailed Numerical and Experimental Investigation of Lamb Wave Mode Conversion for Transcranial Ultrasound Delivery

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Background, Motivation and Objective

Transcranial focused ultrasound (tFUS) is gaining attention for treatment of tumors, drug delivery to the brain and neuromodulation. Conventionally, tFUS method utilizes normal incidence wave transmission. Oblique incidence transmission through Lamb wave mode conversion has been recently suggested to improve ultrasound transmission [1] and transmission improvements were evaluated at a single point. This work investigates whole wavefront transmission through the inhomogeneous skull geometry which is critical for determining the transmission coefficient, focusing capability, thermal impact and transducer array design.

Statement of Contribution/Methods

Detailed geometry of a human skull fragment from temporal region was obtained using micro-computed tomography. k-Wave toolbox was utilized for accurate numerical study of wave propagation and thermal diffusion based on bioheat transfer equation [2]. Simulations were performed for different incidence angles to explore mode conversion effects. Acoustic wavefront measurements were conducted on the degassed sample in a water tank and a custom data acquisition and scanning system. Angular dependence of transmission coefficient at 1MHz is calculated by integrating the spatial pressure distribution over the entire beam and normalizing it with the no-skull condition on the same plane.

Results/Discussion

It is found that transmission coefficient varies significantly with incidence angle for a 4mm thick section of the skull fragment. At specific angles (around 54°) transmission was around 3dB better than normal incidence with less wavefront degradation (Fig. 1a), in agreement with the acoustic simulations which predicted similar beam profile and 3dB reduction in peak pressure in the skull (Fig. 1b, c). More importantly, the thermal simulations showed that the maximum temperature rise in the skull was significantly lower for mode converted beam (4°C vs 45°C) (Fig. 1d, e). The results indicate that this approach has significant potential for tFUS, but significant optimization effort is required.

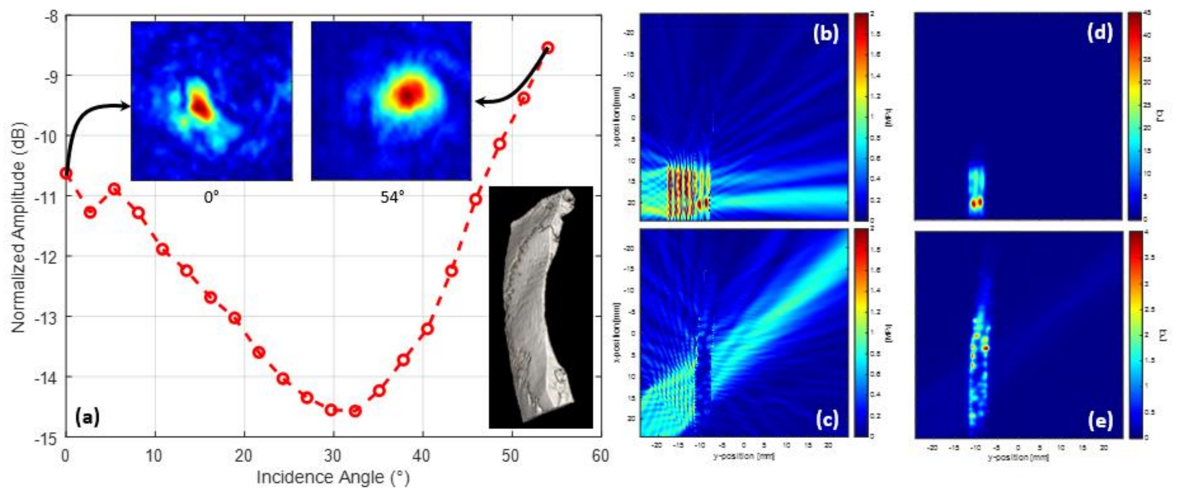

Fig. 1. (a) Normalized through skull transmission coefficient plot. Acoustic pressure field normal incidence(b) and oblique incidence(c). Temperature rise distribution normal incidence(range: 0-45ºC) and oblique incidence(range: 0-4ºC)

[1] Firouzi, Kamyar, Pejman Ghanouni, and Butrus T. Khuri-Yakub. "Efficient transcranial ultrasound delivery via excitation of lamb waves: Concept and preliminary results." In 2017 IEEE International Ultrasonics Symposium (IUS), pp. 1-4. IEEE, 2017.
[2] Treeby, Bradley E., and Teedah Saratoon. "The contribution of shear wave absorption to ultrasound heating in bones: Coupled elastic and thermal modeling." In 2015 IEEE International Ultrasonics Symposium (IUS), pp. 1-4. IEEE, 2015.