Accuracy Assessment of Transcranial Power Cavitation Imaging for BBB Opening

Alec J. Batts[1] and Elisa E. Konofagou[1,2] Department of [1]Biomedical Engineering, [2]Radiology, Columbia University, New York, New York, USA

Background, Motivation and Objective

Blood-brain barrier (BBB) opening with focused ultrasound (FUS) is a noninvasive technique for delivering therapeutics to the brain parenchyma. While FUS-mediated therapy is largely monitored by MR-guidance in the clinic, ultrasound-guidance poses the additional benefit of monitoring cavitation activity during treatment. However, due to phase aberration and signal attenuation after transcranial ultrasound transmission, reliable ultrasound-based monitoring is a challenge. Our group has previously demonstrated the feasibility and efficacy of employing a cavitation mapping technique called power cavitation imaging (PCI) with a linear array to target and monitor FUS-mediated BBB opening. The objective of this study is to evaluate the accuracy of transcranial PCI in mapping cavitation events to their points of origin.

Statement of Contribution/Methods

A P4-1 (ATL, Philips) phased array transducer operated by a Verasonics research system at a frequency of 1.5 MHz was placed in a degassed water bath at an axial distance of 3-5 mm to evaluate propagation through 4.65-mm and 2.25-mm thick fragments of human and non-human primate (NHP) skulls, respectively. A 254-µm diameter flow channel containing polydisperse, lipid-shelled microbubbles simulating a cerebral vessel was imaged transcranially. An initial B-mode acquisition of the tube without skull interference established ground-truth coordinates of the channel before PCI. 500 sets of focused transmit/receive sequences acquired delay and sum (DAS)-beamformed RF data at a rate of 1000 Hz at the set rate of 0.5 Hz. The singular value decomposition (SVD) clutter-filtered mean intensity of 12-20 sets of cavitation maps formed the final 2D PCI. The focal shifts resulting from P4-1 transcranial transmits through both skull fragments were modeled in 2D using the k-Wave MATLAB toolbox with a grid resolution of 8 points/wavelength. Density, sound speed, and absorption maps of the skull fragments were derived from CT scans.

Results/Discussion

In vitro skull experiments revealed shifts in the apparent location of the flow channel from the initial B-mode acquisition of 1.2 mm in the axial dimension and 0.3 mm and 0.6 mm in the lateral dimensions for the human skull (Fig. 1A) and NHP skull (Fig. 1D), respectively. Simulation results predicted shifts of 2.25 mm and 0.50 mm in the axial dimension and 0.75 mm and 0.125 mm in the lateral dimension for the human skull (Fig. 1B-C) and NHP skull (Fig. 1E-F), respectively. Both simulations and *in vitro* experiments revealed an axial acoustic lens effect that could be imaged by PCI with an accuracy of 3.56% and 1.69% through the human and NHP skulls, respectively.

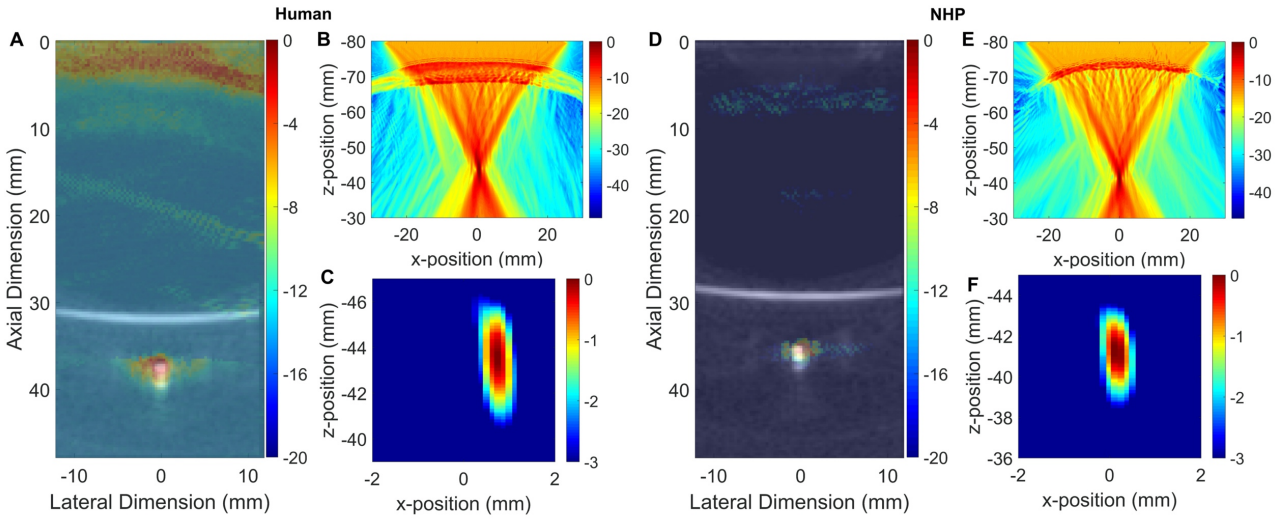

Figure 1: Power cavitation images demonstrating axial and lateral focal shifts from B-mode overlay in human skull (A) and NHP skull (D). Simulated pressure field in human skull (B) with -3 dB focal area (C). Simulated pressure field in NHP skull (E) with -3 dB focal area (F). The simulated center of the focus in free-field is located at (0 mm,-40.75 mm).