Investigation of fallacies in focused ultrasound transducer acoustic modeling

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TITLE: INVESTIGATION OF FALLACIES IN FOCUSED ULTRASOUND TRANSDUCER ACOUSTIC MODELING

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OBJECTIVES: When simulating therapeutic applications of focused ultrasound (FUS), the transducer is typically modelled by constructing the transducer surface geometry and imposing a pressure boundary condition (e.g., when employing an acoustic pressure wave solver) or a velocity boundary condition (e.g., in combination with an elastic wave solver). However, during experimental validation of transcranial FUS modeling, dramatic deviations between simulated and measured pressure distributions (focus location, focus shape, side-foci) that were shown to originate from transducer modeling were observed. Here we report the results of a systematic study performed to identify and investigate the impact of factors to be considered to obtain realistic models of acoustic exposure by FUS.

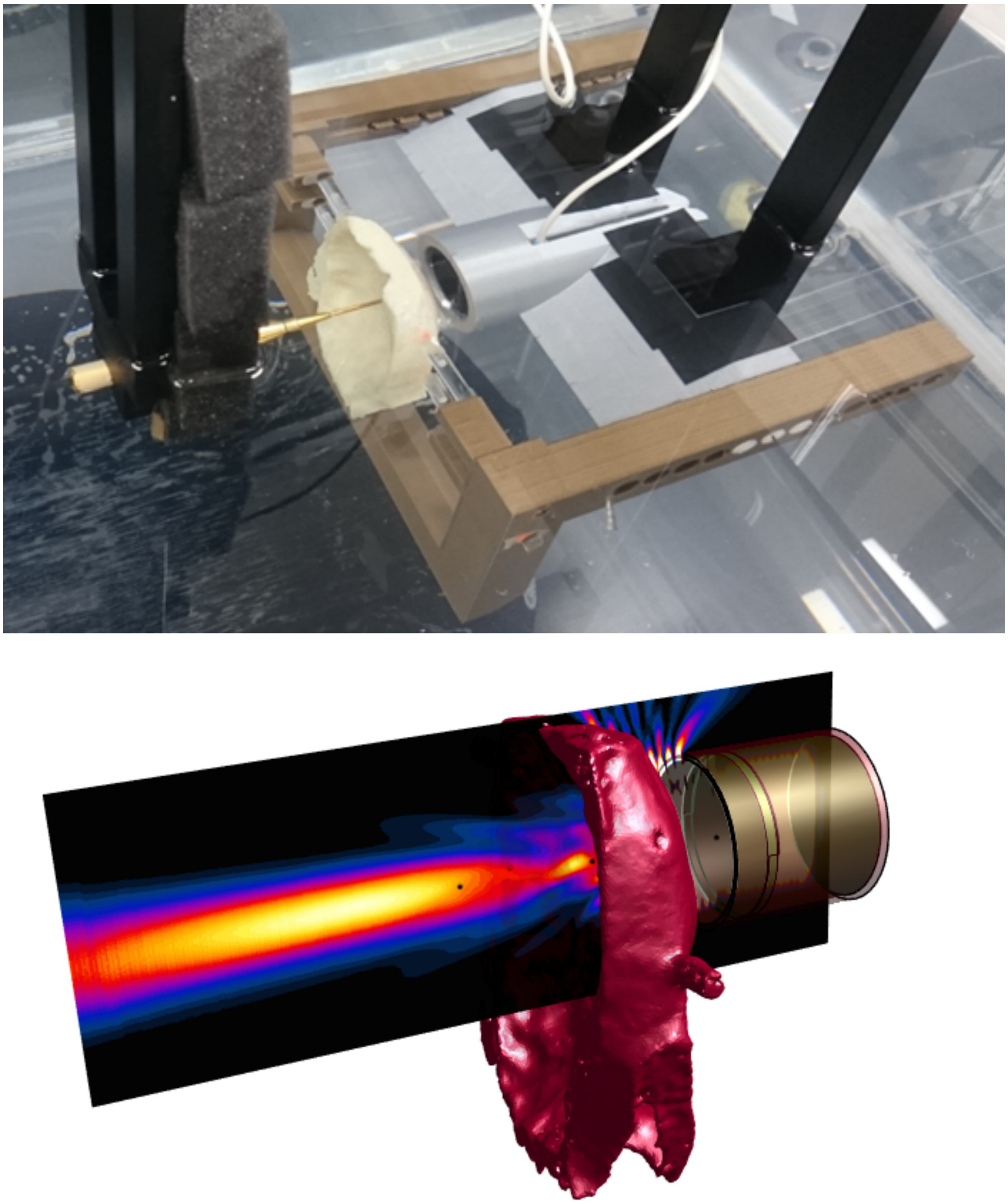
METHODS: Acoustic pressure fields generated by curved single-element focused transducers (0.5 MHz) in the presence and absence of skull obstacles (pig, sheep, and lamb; characterized by computed tomography (CT) and precisely positioned) were measured with a 3D-scannable, calibrated hydrophone and compared to acoustic simulations of corresponding setup models. The source was initially modeled as a pressure boundary condition imposed on the transducer surface, which was shaped according to the manufacturer specifications. Subsequently, the model was adapted to reflect the actually measured transducer geometry, which was found to deviate significantly from the specifications. Instead of assuming that the pressure wave originates from the transducer surface, we modeled the internal structure of the transducer, which features a planar piezoelectric disk below a shaped matching material. Uncertainties about the internal transducer geometry (primarily the depth of piezo-disk) and material properties (speed-of-sound, attenuation, density of the matching material) were considered, and an aperture function was introduced and varied to account for the mechanical impact of the transducer wall or for mechanical vibration modes.

RESULTS: The sensitivity of the pressure field to the above factors was investigated and, after careful model adaptation, good agreement between the simulated and measured fields was obtained in the absence of skulls. Focus location, shape, and the overall pressure distribution were also in agreement. Particularly, the depth of the piezo element and the matching material speed-of-sound were found to strongly affect the pressure distribution, while attenuation primarily impacts the overall intensity. The aperture function influences the occurrence and exact shape of secondary foci.

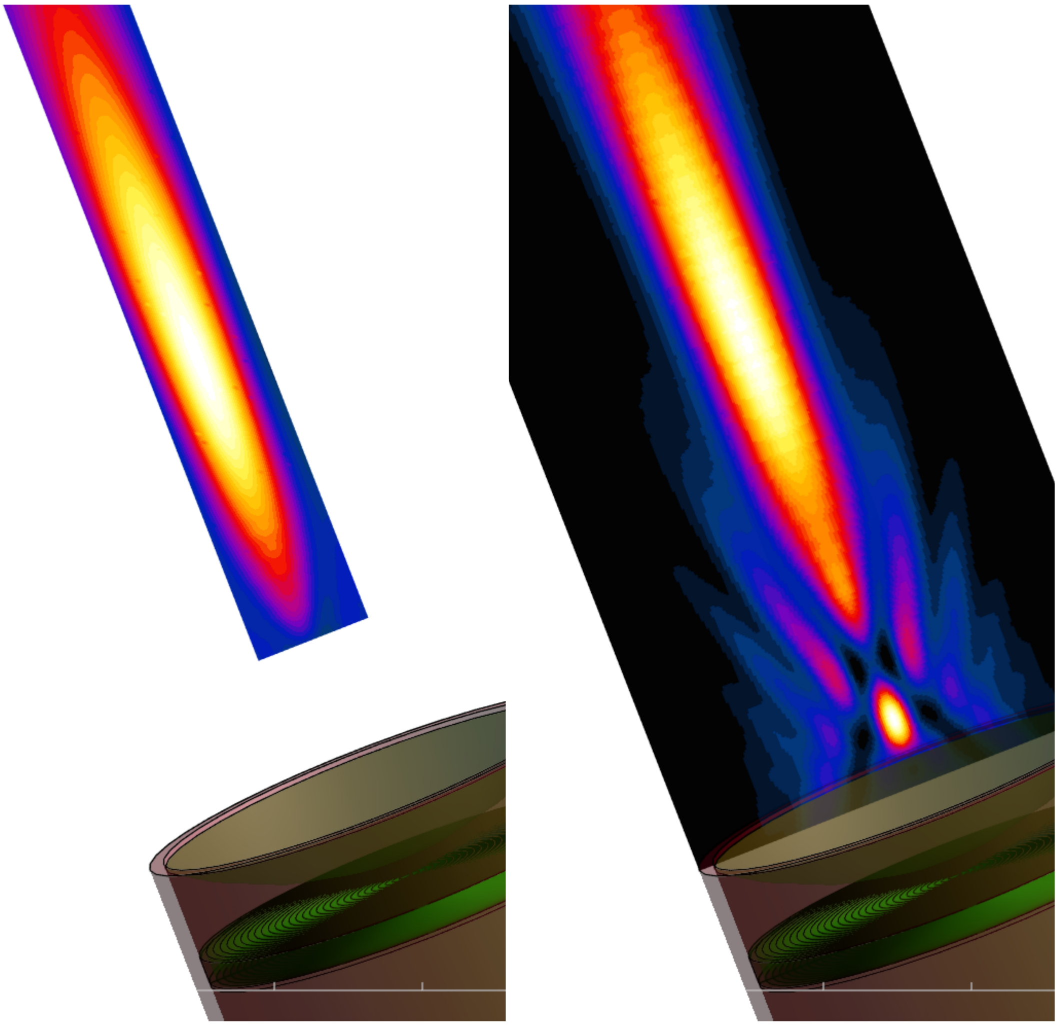
Significant deviations are still observed in the presence of skulls and current work focuses on establishing whether the deviations originate from transducer modeling or from the approach employed to map CT data to acoustic property distributions. Literature reveals large uncertainty about the relationship between CT Hounsfield units and acoustic properties, which is further exacerbated by the lack of transferability between different CT scanners (and even more when going to MicroCT).

The lack of equivalence between pressure and velocity boundary conditions should also be taken into consideration.

CONCLUSIONS: Careful transducer modeling and experimental validation is crucial for reliable simulation of FUS fields, and the current approaches commonly used are found to be unsuitable for extended, curved, or complex transducers. An optimal, but highly demanding and typically infeasible, approach would include complete mechanical modeling of the transducer with its housing and fixation. However, a compromise combining 1) improved acoustic modeling of the transducer and its internal structure with 2) aperture functions to account for the missing mechanical modeling can be acceptable. Comprehensive uncertainty assessment should typically be performed along with computational modeling.



Measurement setup and computational model



Illustrative measured and simulated pressure fields

IMAGE CAPTION: Measurement setup and computational model Illustrative measured and simulated pressure fields
AWARDS: Student Award Competition|Student Travel Awards