A Novel Technique in Therapeutic Ultrasound: Histotripsy and Aberration Correction

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INTRODUCTION

When a focused ultrasound beam propagates through heterogeneous media, sound travels at different speeds in different materials, and an aberration effect is observed which shifts and distorts the focus. In addition, the ultrasound pressure at the focus is reduced which has repercussions for histotripsy treatments. In therapeutic ultrasound, a water bath is typically used to couple ultrasound propagation from the transducer to the skin. Due to the difference in speed of sound between water and the skin, an aberration effect is induced, particularly for the large aperture, low f-number transducer arrays used in histotripsy, where the array elements at the outer rim sends sound waves through a very different water/tissue pathway compared to the inner transducer elements. This work investigates the focal position shift and pressure loss induced by the aberration from the water coupling bath in therapeutic ultrasound using a large aperture, low f-number transducer.

AIM

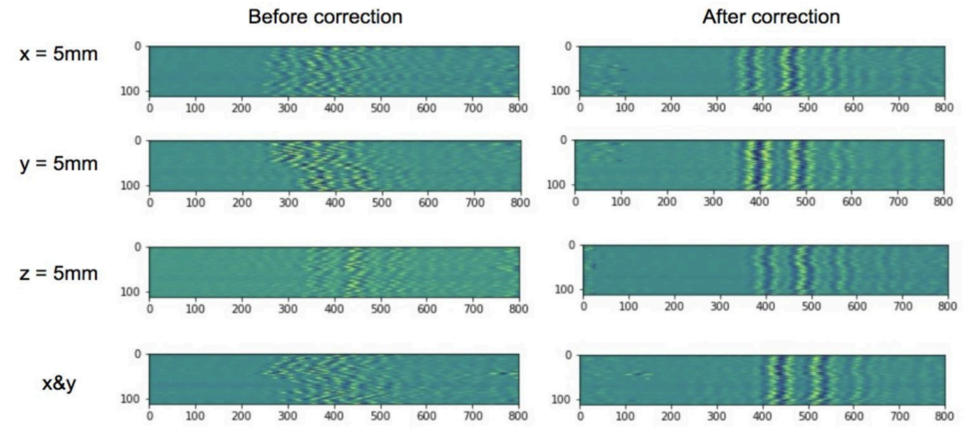
When ultrasound propagates through different layers of tissue, the focus on the transducer is distorted. The aim of this study is to quantify the aberration effect on a low f-number histotripsy transducer array and improve the efficiency of histotripsy treatments using both computational and experimental studies.

METHOD

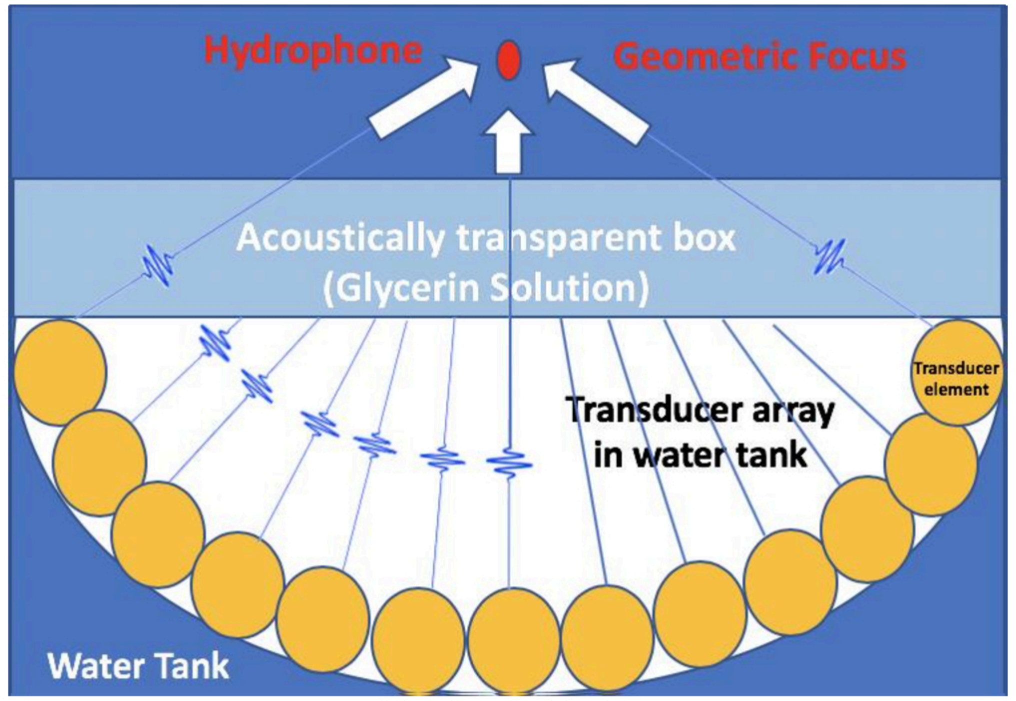
A simulation of a 500-kHz, 112-element array (f-number = 0.55) was used for the experiment. Glycerin solution containing 84.5% water and 15.5% glycerin yields the speed of sound in the skin/muscle (1560m/s) and was used to mimic soft tissue. A calibrated needle hydrophone was used to measure the pressure output. Glycerin solution contained in a cuboidal, acoustically transparent box was placed between the transducer and the hydrophone in a water tank, to mimic the situation of water-tissue coupling. The thickness of the glycerin box was varied in 25.4 mm increments from 0 mm to 50.8 mm to mimic different tissue path lengths. This experimental setup matched the computational conditions. The focal pressure and focal position were measured by experiments and compared to the simulation.

RESULTS

K-wave simulations show that a focal shift of 4 mm and 6 mm for the glycerin box thickness of 25.4 mm and 50.8 mm, respectively. This focal position shift was due to (1) difference in the speed of sound between water and skin/muscle, and (2) the path-length: ultrasound pulses from the outer elements of the array propagated through a much longer distance in the media compared to the ultrasound path of the inner elements. The experiments yielded similar results, 4 mm and 6 mm for the glycerin box thickness of 25.4 mm and 50.8 mm, respectively, validating the k-wave simulation. The focal pressure loss was minimal, 4.6% for both glycerin box thickness of 25.4 mm and 50.8 mm. K-wave simulations quantifying the aberration effect within the heterogeneous tissue are shown in the table. The table shows the K-waves estimates for the focal pressure and the focal shift in the matched fluid (glycerin solution) before and after the phase correction.



The figure shows pressure field maps from the transducer used to gather the experimental data at different distances from the geometric focus. The pressure that is regained as a result of aberration correction can be visualized. The distance scales of the axes are in arbitrary units.



The experimental setup is shown in the figure. The transducer contains 112, 500 kHz elements with transmit and receive capabilities. A polycarbonate box was fabricated with acoustically transparent film to hold a glycerin solution for which the speed of sound is closely matched with that of the human skin. The hydrophone to measure pressure is placed at the geometric focus during the experimental validation.

Simulated Relative Focal Pressure and Shift from the Geometric Focus

Scenario	**Normalized Focal Pressure** Median (Range)	**Pre Axial Shift** Median (Range) **(mm)**
Uncorrected	1.0	2.8 (2.4-3.8)
Matched Fluid	1.03 (0.952-1.04)	0.950 (0.950-0.950)
Phase Corrected (Ideal*)	1.30 (1.29-1.35)	0 (0.0-0.0)

CONCLUSIONS

These results show that the water coupling resulted in substantial focal shift due to the aberration effect using the low f-number histotripsy transducers. There was good agreement in ultrasound focal shifts between the experiment and the k-wave simulations. To correct the focal shift, the coupling medium may be changed from water to a solution that matches the speed of sound in tissue. The next step will focus on investigating the aberration effects through multi-layer heterogeneous tissue.

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