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The role of compressional pressure in formation of dense bubble clouds in histotripsy

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Background, Motivation and Objective

The onset of tissue fractionation by histotripsy pulses has been shown to coincide with initiation of a dense cavitating bubble cloud. Histotripsy pulses are short (<20 cycles) and highly non-linear, with high peak rarefractional pressures (>10MPa) and compressional pressures (>30MPa). How a histotripsy pulse forms a dense cloud in tissue is not clearly understood. Using high-speed imaging, we studied bubble cloud formation induced by a histotripsy pulse and the role of the positive pressure phase in cloud formation.

Statement of Contribution/Methods

Bubble clouds were generated in a gelatin tissue phantom using histotripsy pulses. A focused, 1-MHz transducer (aperture = 10 cm, f# = 0.9) was used to apply single 15-cycle pulses with peak negative/positive pressures of 19/70 MPa. Shadowgraphic images of pulse propagation and bubble cloud formation were recorded with a high-speed camera at 0.1-10 million fps. To assess the importance of the compression phases of the pulse in forming bubble clouds, an 80-um thickness steel foil was placed between the transducer and focus to reflect the high frequency components found in the positive shock. As a result, the transmitted positive pressure was reduced by 48%, while peak negative pressure remained unchanged.

Results

High speed images show that in the first 3-5 cycles of the ultrasound pulse, a sparse field of single cavitation bubbles with maximum radii of 50 – 120 um was formed within 5 mm of the focal region. During subsequent cycles, a dense cavitation cloud erupted from one of the single bubbles at the focus, and grew in length opposite the direction of ultrasound propagation until all 15 cycles passed the focus. After the pulse ended, the cloud ceased growth and collapsed. Images suggest that the cavitation cloud started to form directly after incidence of the shock front on the single bubble. When the positive pressure at the focus was reduced, single bubbles still formed, but a bubble cloud was never observed.

Discussion and Conclusions

Bubble clouds nucleate from the location of a single cavitation bubble. After single bubbles are generated, a high compression component of the ultrasound cycle is necessary to induce cavitation clouds. Based on these results, we hypothesize that the backscattered shock from a single cavitation bubble is inverted, resulting in extremely high rarefractional pressure, which is responsible cloud formation.

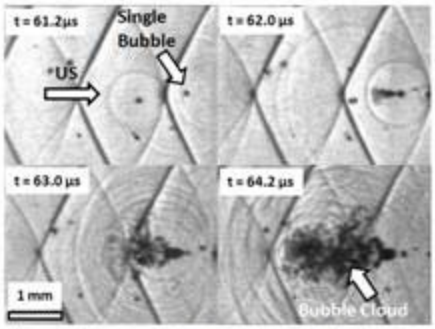

Fig. 1 – Bubble cloud forming from single bubble during 3 cycles of a histotripsy pulse