Spectral Profiles of Sonothrombolysis Bubble Radiation

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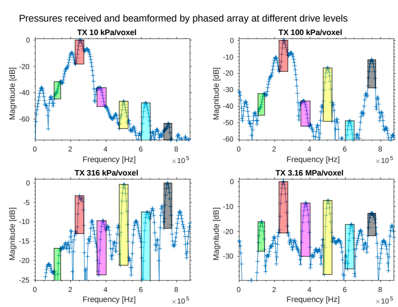
Background. Clinical applications of controlled, ultrasound-induced bubble cavitation, such as cardiac sonothrombolysis, are becoming more of a reality by the day. The dynamics of cavitating bubbles have been studied in laboratory settings, but during a therapeutic procedure information regarding the type and intensity of cavitation activity in the coronary arteries is desirable in real time for patient-specific balancing of efficacy against safety. A system for acoustic detection of cavitation would lend itself quite well to that purpose, at little added expense compared to transmit-only ultrasound devices. In order to assess the feasibility of such a system, we sought to identify characteristic profiles of sound reradiated by bubbles driven by different acoustic fields.

Methods. The Rayleigh–Plesset and Gilmore models were implemented in software and used to predict the sound that would be reradiated by bubbles. Bubbles were driven by a simulated phased array transducer, and the sound received afterward by the array was beamformed and spectrally analyzed.

Results. The transmitted pressure amplitude (drive) was ramped up from 1 kPa to 10 MPa per transducing voxel of the phased array, inducing pressures of roughly 60% that much at the bubble. Three distinctive spectral morphologies could be identified: (i) below the atmospheric pressure, the spectral energy was predominantly at the insonation frequency (fundamental), indicating linear oscillations; (ii) as the drive approached the atmosphere, integer harmonic components became very strong, with the second harmonic eventually overtaking the fundamental; and (iii) about an order of magnitude above the atmosphere, the 1/2 subharmonic and associated ultraharmonics often appeared rather strongly, a characteristic of high-energy cavitation. Furthermore, as the driving pressure was raised, the broadband spectral power increased remarkably.



Sounds of a 3-μm-radius Gilmore bubble driven at 250 kHz with various amplitudes.

Conclusion. Our findings are in general agreement with qualitative descriptions from the literature, and may help guide the development of a real-time cavitation reporting system for controlled, safe sonothrombolysis interventions.