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Title(English)	Characterization of liquid-filled thin tubes embedded in soft phantom through photoacoustically excited resonances
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Outline of the dissertation

Title: Characterization of liquid-filled thin tubes embedded in soft phantom through photoacoustically excited resonances

Photoacoustic imaging has been intensively researched for vascular medical applications in these two decades. In addition to the hemoglobin-based imaging, usage of contrast agent and functional imaging such as elasticity measurement tend to be hot topics. However, the lack of evaluation platform for contrast agent remains problems.

To provide a solution to the sensitivity measurement for photoacoustic contrast agent, this study first focused on the characterization of the geometrical dimension of a thin tube. An evaluation platform for the contrast agent was fabricated, which consisted with a liquid-filled tube of submillimeter in inner diameter embedded in a soft phantom. The acoustic resonances in the liquid-filled thin tubes were investigated through photoacoustic excitation. Then, a novel method was proposed to estimate the inner diameter of the tube being based on the theoretical studies. The principle of photoacoustic excitation and the acoustic modes in the tube were described. An infinite cylindrical model with the ideal stiff-boundary was used to simulate the thin tube. The acoustic field and corresponding resonance mode were studied and theoretically derived from the fundamental wave equation and the stiff boundary condition. A mathematical model of the photoacoustic generation was proposed, where the localized excitation by a light pulse was taken into consideration. Using the model, the waveform of the photoacoustic signal was predicted. The relationship between the excitation pulse width and the acoustic signal amplitude was clarified. A mathematical expression describing the relationship between these two variables in both time domain and frequency domain was presented. Furthermore, a selection of the optimal pulse width was discussed being based on the simulated results.

Second, a platform was designed for quantitative evaluation of photoacoustic sensitivity of liquid samples using a low power pulsed semiconductor laser and a MHz-range ultrasonic transducer to satisfy the demand of realistic evaluation. Sample liquid is confined in a thin glass capillary. The frequency dependence of the photoacoustic signal on the inner diameter of the capillaries was experimentally investigated. The influence of the pulse width was then discussed in association with the peak frequencies for many capillaries of different inner diameters. Furthermore, the influence of the pulse width on the amplitude of the generated photoacoustic signal was researched as well. To match the acoustic resonance of the target with the center frequency of the receiving transducer in a practical manner, several resonance modes were extracted and investigated. A series of experiments on the chosen resonance mode were conducted, and the relationship between the laser pulse width and the maximal amplitude of the resonance mode were experimentally studied. Finally, it was demonstrated that the concentration of samples had very limited influence on the frequencies and the optimal pulse width.

Third, the feasibility and the effectiveness of the newly developed platform were confirmed for several kinds of samples. The geometric configuration and the driving parameters for the laser were first optimized to 230 ns and 4.92 μs to maximize the signal-to-noise ratio in the generated ultrasonic signal. The performance of the platform was then quantitatively tested for several inks with different colors and Indocyanine green. The feasibility of the platform was verified by experimentally evaluating the relationship between the sample concentration and the photoacoustic signal level. The signal-to-noise ratio of the collected data was improved 2.5-fold by the resonance occurring in the glass capillary, and was superior to those obtained with the sample liquids confined in a soft tube, which induces little resonance.

Finally, a novel method to measure the inner diameter of soft tube was proposed being based on the acoustic resonance perspective other than usual imaging-based method. In-vitro experiments were conducted for red-ink-filled soft tubes with diameter of less than 1 mm embedded in a tissue-mimicking phantom. Percentage error of 4% was marked in estimating the inner diameter of the tube samples. The results demonstrated that the proposed method was feasible to detect a sub-millimeter deformation for thin tubes with an ultrasound transducer of relatively low center frequency and electronic circuit of limited temporal resolution.

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