

論文 / 著書情報
Article / Book Information

題目(和文)	レーザダイオードを用いた光音響測定による細い血管における動脈硬化の評価
Title(English)	Characteristics of arteriosclerosis in thin blood vessel through laser-diode-based photoacoustic measurement
著者(和文)	
Author(English)	Kun Wang
出典(和文)	学位:博士(工学), 学位授与機関:東京工業大学, 報告番号:甲第12904号, 授与年月日:2024年9月20日, 学位の種別:課程博士, 審査員:中村 健太郎,徳田 崇,山口 雅浩,和田 裕之,鈴木 左文
Citation(English)	Degree:Doctor (Engineering), Conferring organization: Tokyo Institute of Technology, Report number:甲第12904号, Conferred date:2024/9/20, Degree Type:Course doctor, Examiner:,,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

(博士課程)
Doctoral Program

論文要旨

THESIS SUMMARY

系・コース : 電気電子
Department of, Graduate major in ライフエンジニア
リング 系
コース

申請学位 (専攻分野) : 博士
Academic Degree Requested Doctor of (Engineering)

学生氏名 :
Student's Name Wang Kun

審査員主査 :
Chief Examiner 中村健太郎

In recent years, arteriosclerotic diseases have been on the rise, and as they progress, they are more likely to cause myocardial infarction and cerebral infarction. Although several diagnostic methods have been studied for relatively large blood vessels, hardening also occurs in small blood vessels. Photoacoustic imaging is considered useful for evaluating the effects of treatment because it has good resolution to capture minute vascular lesions and changes in the progression of atherosclerosis, which are difficult to detect with conventional imaging methods. Previous studies focused on the characterization of the geometrical structure of a thin tube and investigated the acoustic resonances in liquid-filled thin tubes embedded in a soft phantom through photoacoustic excitation. Based on those studies, it has been shown that photoacoustic signals generated from thin tubes do not have a uniform frequency response but rather resonate within the tube, resulting in a signal with a mode and resonant frequency. In this study, we utilized the resonance phenomenon of photoacoustic signals generated from a tube to compare the characteristics of photoacoustic signals from blood vessels in a healthy state and those with atherosclerotic features using a biological phantom. Based on the experimental studies, an evaluation platform for arteriosclerosis in thin blood vessels was proposed, leading to the expectation of developing a simpler, painless, and cheaper method to detect arteriosclerosis in the human body.

First, the principle of photoacoustic excitation and the acoustic modes in the tube were described. An ideal stiff-boundary cylindrical structure was used to simulate this specific situation. The

acoustic field and corresponding resonance mode were studied and theoretically derived from the fundamental wave equation and the stiff boundary condition. Then, we present numerical and experimental studies on the effects of tube hardness on the directivity of the generated photoacoustic signal. A thin glass capillary and silicone tube of 1 mm in diameter were tested using pulsed light of 637 nm wavelength. Black ink was confined in the glass capillary and silicone tube as photoacoustic sample material. In the glass capillary, acoustic resonance modes in the glass capillary were efficiently excited, and clear directivity was observed in the generated photoacoustic signals. On the other hand, little resonance was stimulated in the silicon tube due to the acoustic impedance matching between the sample and the surrounding media, resulting in the weak confinement of acoustic waves.

Second, we prepared a thin silicone tube filled with a mixture of red ink and olive oil as a model that mimics arteriosclerosis. The tube was embedded in a soft phantom. Photoacoustic measurements were performed using 405 nm and 520 nm laser diodes. As a result, the 405 nm laser produced a higher photoacoustic signal as the oil concentration in the mixture increased, whereas the 520 nm laser produced lower photoacoustic signals as the oil concentration increased. By focusing on the difference in optical absorption at different wavelengths between the red ink and oil, it was shown that there was a possibility of estimating the oil concentration from the ratio of photoacoustic signals between different wavelengths.

Third, a platform was designed for the quantitative evaluation of the degree of vascular occlusion using a low-power pulsed semiconductor laser and a MHz-range ultrasonic transducer to satisfy the demand for realistic evaluation. To replicate clogged blood vessels, we partially filled a silicone tube with commercially available beef fat. After creating five samples with varying degrees of occlusion, we experimentally investigated the photoacoustic characteristics of each sample. In addition to differences in the amplitude of the photoacoustic signals, we focused on the acoustic

impedance differences between the beef fat and the silicone tube. We evaluated the degree of occlusion in the tubes based on the resonance frequency and the strength of the resonance for each sample.

Finally, instead of using a biological phantom, we investigated the photoacoustic signals generated from the thin blood vessels in the author's finger. The photoacoustic signals generated from the actual blood vessels were similarly not very strong in resonance, akin to the silicone tubes in the biological phantom. However, unlike the single-layer structure of the silicone tube, the actual blood vessels have a multi-layer structure, which allowed us to observe multiple resonance peak frequency characteristics compared to the silicone tubes.

Through this study, we performed a component analysis of sample liquids, detected the presence of plaques, and confirmed the photoacoustic signals from actual blood vessels in a finger using photoacoustic measurements. One of the next steps is to develop a simple photoacoustic device to scan and image the blood vessels in an actual finger. Subsequently, through clinical studies, we will compare the photoacoustic characteristics of healthy and atherosclerotic groups to define the criteria for distinguishing between normal and abnormal conditions. Finally, based on the established criteria, we plan to apply color mapping to the imaging results.