Highly Sensitive Intravascular Photoacoustic Imaging with a Collinear Catheter Probe

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Abstract: A collinear catheter for label-free intravascular photoacoustic imaging was developed with a diameter of 1.6 mm. The collinear overlap between optical and acoustic waves enabled photoacoustic imaging of a human coronary artery from lumen to perivascular fat.
OCIS codes: (110.5120) Photoacoustic imaging; (120.4570) Optical design of instruments.

1. Introduction

Atherosclerosis is the major form of cardiovascular disease, the No. 1 cause of death in the developed countries during the past century [1]. As an emerging tool, intravascular photoacoustic (IVPA) imaging provides sufficient imaging depth and chemical information to identify the vulnerable plaques [2]. Recently reported IVPA imaging systems were largely based on cross overlap between the illumination light beam and ultrasound detection, which had limited imaging depth. A coaxial IVPA catheter based on a ring transducer allowed good overlap of sound wave and photons, but had a relatively large diameter that needs to be further reduced to meet the clinical requirements [3]. Here, we report a novel IVPA catheter based on collinear alignment of the optical and acoustic waves, which allows IVPA imaging over 6 mm depth. High-quality imaging of a human coronary artery from lumen to perivascular fat is demonstrated.

2. Design and fabrication of the IVPA catheter

The schematic design of the catheter is shown in Fig. 1. A multimode fiber with one end polished to 45 ° was used to deliver the excitation laser beam forward. An ultrasonic transducer parallel to the fiber with its sensing area facing the polished fiber plane was served to detect the generated photoacoustic wave collinear with the excitation beam. The transducer also performed ultrasound imaging through the same trace with a proper delay. A 1-mm-diameter rod mirror reflects both the optical and acoustic waves to the perpendicular direction for cross-sectional imaging. These components were installed in a 3D printed housing. A photo of the lab-fabricated collinear catheter is displayed in Fig. 1(d), showing a probe diameter of 1.6 mm.

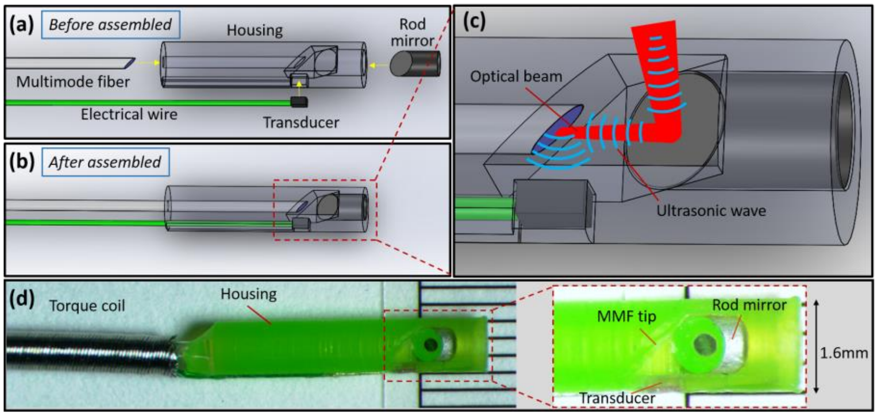

Fig. 1. Schematic of the collinear catheter probe. (a) Main components of the probe, (b) assembled catheter probe structure, (c) Zoom-in view of the catheter tip, (d) a photo of the fabricated catheter probe with a diameter of 1.6 mm.

3. Characterization of spatial resolution

The spatial resolution of our IVPA imaging system is measured with a 7-µm carbon fiber. IVPA images of the carbon fiber were obtained at different axial distances as shown in Fig. 2(a). Axial and lateral resolutions at these

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positions were obtained with a Gaussian fit of the photoacoustic signal at the carbon fiber position and plotted in Fig. 2(b). Relatively constant values of 80 μm and 400 μm for axial and lateral resolutions are observed. The amplitude of photoacoustic signals at these axial positions exhibits an exponential decay. The signal at 6.2 mm axial distance can be clearly distinguished, indicating an imaging depth over 6 mm for our imaging system.

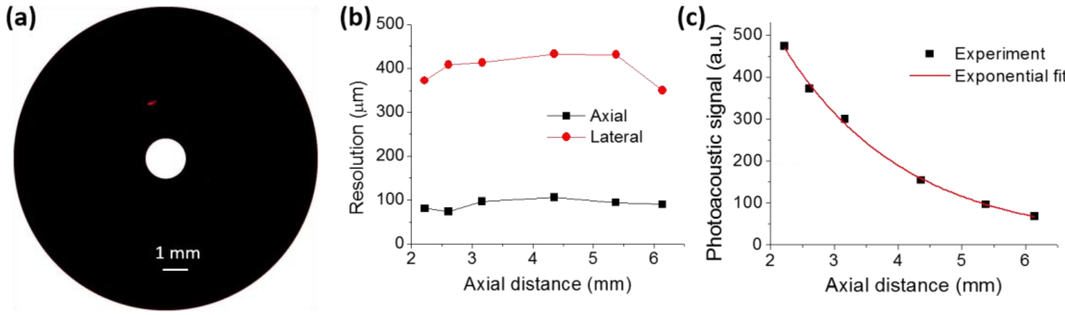

Fig. 2. Performance of the IVPA catheter. (a) IVPA image of the 7-μm carbon fiber, (b) measured axial and lateral resolutions and (c) photoacoustic amplitude of the carbon fiber at different axial positions.

4. Intravascular imaging of a human coronary artery *ex vivo*

After validated for lipid absorption with a lab-built optical parametric oscillator at 1.7 μm [4], our imaging system was carried out for intravascular imaging of a fresh human coronary artery *ex vivo* at an imaging speed of 1 frame per second. To provide complementary information, intravascular ultrasound (IVUS) was performed simultaneously for the artery with the embedded transducer. The imaging results are shown in Fig. 3. The lumen size and vessel structure can be visualized from IVUS (Fig. 3(b)), while IVPA image reveals lipid depositions in the arterial wall, as well as outside the vessel boundary as perivascular fat with an axial distance ~4.3 mm.

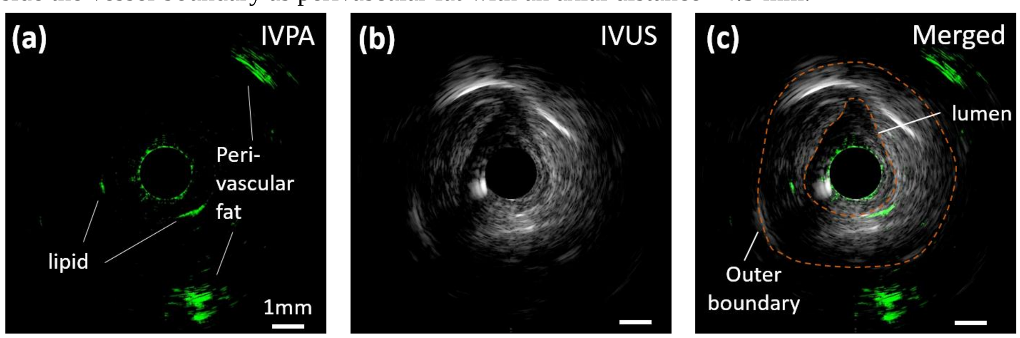

Fig. 3. Registered IVPA/IVUS image of a human coronary artery. (a) IVPA image, (b) IVUS image, and (c) merged result.

5. Conclusion

We developed and fabricated an IVPA catheter with a collinear overlap between the optical and acoustic waves. An imaging depth over 6 mm was achieved with this design by using a 7-μm carbon fiber as a target. Our imaging system was performed for co-registered IVPA/IVUS imaging of a human coronary artery, resulting in the ability of visualizing the entire arterial wall, from lumen to perivascular fat. Our collinear catheter design greatly improved the performance of an IVPA imaging system with extended imaging depth and higher sensitivity, which fastens the realization of *in vivo* IVPA imaging in clinic.

6. References

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