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Integrated optical coherence tomography - ultrasound system and miniaturized probes for intravascular imaging

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ABSTRACT

We report on the development of a multimodal optical coherence tomography (OCT) – ultrasound (US) system and miniaturized OCT-US probe for intravascular imaging. Both OCT optical components and a US transducer were integrated into a single probe, enabling both OCT and US imaging at the same time. A miniaturized OCT-US probe using a single element transducer was designed with a maximum outer diameter of 0.8 mm, which is suitable for *in vivo* intravascular imaging. The integrated OCT-US imaging system adopted a two-channel data acquisition card to digitize both OCT and US signals. Simultaneous OCT and US data processing and image display were also achieved using our home-developed software. *In vitro* OCT and US imaging of human aortic tissue was performed using this multimodal imaging system, which demonstrated the feasibility of the OCT-US system in intravascular imaging and its potential in detection of atherosclerotic plaques.

Keywords: multimodal imaging, optical coherence tomography (OCT), intravascular ultrasound (IVUS)

1. INTRODUCTION

Atherosclerosis is one of the leading causes of morbidity and mortality in developed countries. Early detection and assessment of atherosclerotic plaques are essential for the prevention of major advances in coronary artery diseases (1). Optical coherence tomography (OCT) and intravascular ultrasound (IVUS) are considered two complementary imaging techniques in the detection and diagnosis of atherosclerosis (2). OCT permits cross-sectional visualization of micron-scale features of atherosclerotic plaque, and IVUS offers full imaging depth of the vessel wall. Furthermore, minimal amounts of flushing agent will be needed to obtain OCT imaging of the interested area under the guidance of IVUS. Last but not least, an integrated OCT-US imaging system with a single probe provides both OCT and US images simultaneously, which would significantly reduce a physician's operating time and prevent additional cost compared to using separate probes. In our previous studies (3)(4), integrated OCT-US probes were developed with a single element transducer and a ring shaped transducer, respectively. Both designs had outer diameters of lager than 2 mm; OCT and US signals were acquired by two data acquisition cards and processed separately. In this paper, we report on a single-element-transducer-based OCT-US probe with a maximum outer diameter of 0.8mm, which is suitable for *in vivo* application. The system was further integrated by using a two-channel data acquisition

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card and home-developed software, so that both OCT and US data were acquired and processed simultaneously.

2. MATERIALS AND METHODS

As shown in figure 1, a single element US transducer was combined with OCT optical components. A 0.5 mm diameter gradient index (GRIN) lens was used to focus light from a single mode fiber tip, followed by a microprism reflecting the focused light beam into tissue. All the components at the optical tip of the OCT probe were sealed in a glass tube to prevent contamination from blood. As for the US part, a single element, unfocused US transducer (PZT-5H, 40 MHz, aperture area 0.16 mm^2) was fabricated. The transducer and OCT probe were fixed into a thin wall polyimide tube with epoxy on which a window was made to allow both sound wave and light beam to exit. Finally, the transducer wire and the flexible stainless steel tube for protecting the optical fiber were sealed in a thin wall fluorinatedethylenepropylene (FEP) tube. The maximum outer diameter of the probe was 0.8 mm. The axial and lateral resolutions of the OCT system with the probe were 8 µm and 20 µm, respectively. Resolutions of the US part were approximately 38 µm and 400 µm, respectively.

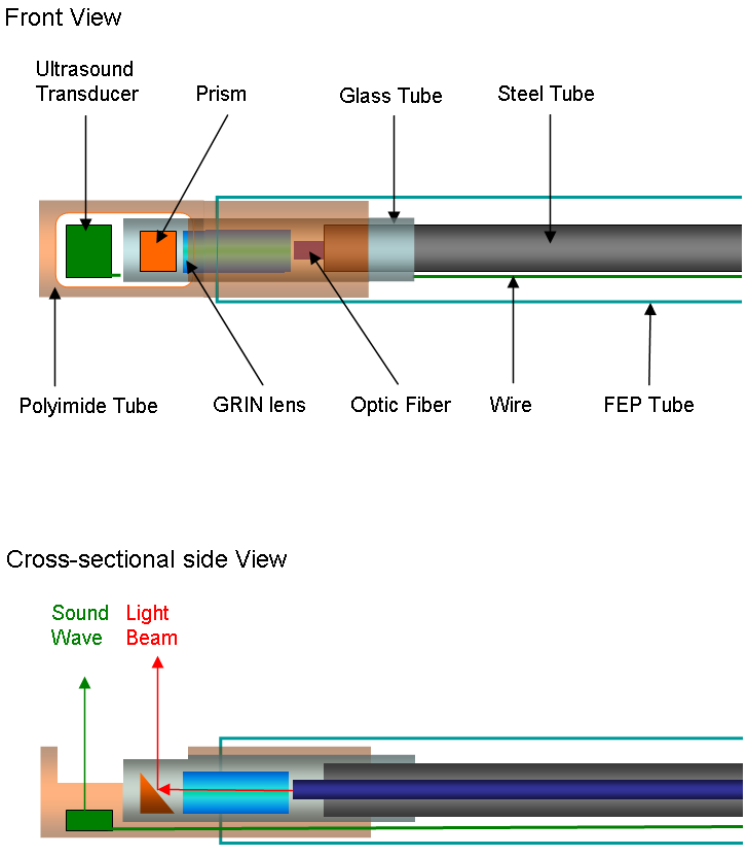

Figure 1. Schematic of OCT-US probe using a single element US transducer.

The OCT-US probes were connected to the OCT-US system. The OCT optical part was previously reported in reference [3]. As for the US part, a two-way pulse-echo measurement was performed using a pulser/receiver.

The detected OCT and US echo signals were digitized by a two-channel, 12 bit data acquisition card working at a sampling rate of 250 MHz. A 20 KHz trigger signal to the pulser/receiver and the data acquisition card was provided by the swept source laser. Multi-thread software was developed to handle OCT and US data processing and image display. Rotational scanning was achieved using a rotational motor and a rotary joint, which consisted of a fiber optic rotary joint and an electrical slip ring, to enable transmission of both electrical and optical signals between rotary and stationary parts of the system.

3. RESULTS AND DISCUSSION

In vitro imaging of human aorta with atherosclerotic plaque was performed using the OCT-US imaging system to demonstrate its feasibility in intravascular imaging. OCT and US images of a calcified plaque, which was high lighted by yellow arrows, were shown in figure 2. It is clear that the OCT image offers higher resolution than the ultrasound image and provides more detailed information on tissue. The maximum penetration depth of the OCT image was around 0.9 mm. On the other hand, although its resolution is inferior to that of OCT, the ultrasound image provides full-depth cross-sectional imaging of the aorta.

Due to size constrain, the microprism of OCT part and the transducer of US part were separated and thus the two were looking at different imaging sites. This problem can be easily solved by building a phantom and then measuring the actual offset between OCT and US images. Since 3-D scanning was performed, one could find the matching OCT and US images. The contours of the aorta in figure 2 correspond well to each other.

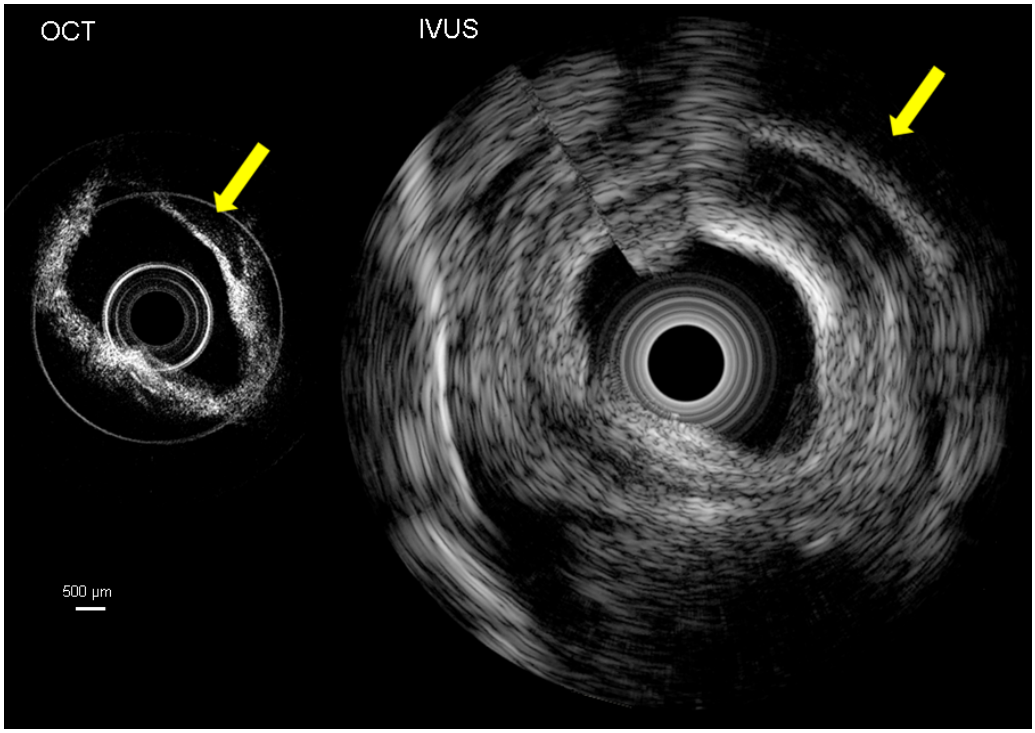

Figure 3. OCT and ultrasound images of human aorta.

Further research will focus on *in vivo* experiments using this miniaturized OCT-US probe and further improvement of probe design, which will ensure optimized imaging quality for both OCT and US and enhanced flexibility for *in vivo* detection of atherosclerotic plaques.

4. CONCLUSION

We have presented an OCT-US imaging system for the application of intravascular imaging. A miniaturized OCT-US probe with a diameter of 0.8 mm has been developed, enabling both OCT and ultrasound imaging at the same time. *In vitro* images of human aorta with pathology were acquired using this imaging system, which demonstrated its feasibility in intravascular imaging and its potential in detection and characterization of atherosclerotic plaques. Integration of the two imaging modalities combines the unique advantages of OCT and ultrasound which cannot be obtained by using either of them alone; an integrated OCT-US probe can provide both OCT and ultrasound imaging simultaneously so that the cost and physician's time will be reduced significantly compared to using separate probes.

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