Anatomical optical coherence tomography: a photonic endoscopic medical imaging modality

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Abstract

This paper reviews recent research undertaken in the Optical+Biomedical Engineering Laboratory on the application of anatomical optical coherence tomography to endoscopic imaging. The technology is demonstrated for the assessment of pathologies of the human lower airway.

Introduction

Medical imaging modalities provide a critical tool for medical clinicians, both in disease diagnosis and assessment of patient response to treatment. Amongst the range of recent imaging technologies currently under development, optical coherence tomography (OCT) [1] occupies a unique position because of its high spatial resolution and use of non-ionising radiation. OCT has the potential to provide real-time, anatomical images without the use of an exogenous contrast agent.

However, the utility of OCT has been restricted due its limited penetration depth in tissue. Due to rapid signal attenuation, this is typically in the range 2-3mm. Because of this limited penetration depth, OCT systems have generally been designed to image over this short range, excluding them from use in the assessment of larger organs.

Endoscopic imaging offers a solution to overcome the limited penetration depth of OCT. Endoscopic OCT involves miniaturising the OCT probe, allowing it to be inserted into the body, typically through an opening such as the patient's airway. OCT may then be used to image structures deep within the body 'from the inside', avoiding the need to penetrate the patient's outer tissue.

Anatomical optical coherence tomography (*a*OCT) [2,3] is a long-range variant of OCT, designed to image over a distance of several centimetres. This allows OCT to capitalise on the advantages of endoscopic imaging.

This paper reviews recent research in endoscopic applications of *a*OCT, undertaken at the Optical+Biomedical Engineering Laboratory (OBEL) at the University of Western Australia. The technology is explored in the context of a specific clinical application: assessment of pathologies of the human lower airway.

Anatomical Optical Coherence Tomography

OCT uses coherence-gated light in the near infra-red spectrum to obtain a structural image of a biological sample. A broadband light beam is focused into the tissue, and reflections from different tissue depths are distinguished using low coherence interferometry. By redirecting the beam to different locations, it is possible to acquire 2D and 3D images of the tissue.

At OBEL, we have developed novel *a*OCT scanners for endoscopic use in the human airway. These systems utilize a frequency-domain optical delay line (FDODL), allowing the system to achieve a delay line length of 36mm. A-scans are acquired at a frequency of 500Hz. The light source has a centre wavelength of 1310nm, with a bandwidth of 32nm. Details are given in [2,3,4].

The *a*OCT system utilizes a novel, rotating fibre-optic endoscopic probe. In clinical use, the probe is encased in a transparent plastic catheter with outer diameter of 2.2mm and attached to the image acquisition system by 1.8m of optical fibre encased in a biplex torque-transmission stainless steel coil. The light beam is focused using a 1.0mm diameter gradient index lens, and redirected at right angles to the probe head with a right-angle prism of 0.7mm width. A 2D axial image is acquired by rotating the probe at approximately 2.5Hz. A 3D data set may be generated by retracting the rotating probe using a translation stage, allowing a sequence of adjacent axial images to be combined.

Clinical background

As part of our ongoing clinical program with the West Australian Sleep Disorders Research Institute, *a*OCT has been applied to imaging of the lower airway [5,6]. The lower airway is subject to several important pathologies, including stenosis. A stenosis is a focal narrowing of the airway, resulting in obstruction to airflow and subsequent clinical conditions. The causes of such stenosis include inflammation due to intubation, and malignant growths from primary lung, oesophageal and metastatic cancer.

Clinical treatment includes laser resection of the obstruction, physical dilation, and insertion of a stent to open the airway. In each case, accurate imaging of the cross-sectional area and length of the stenosis is critical for optimal patient treatment.

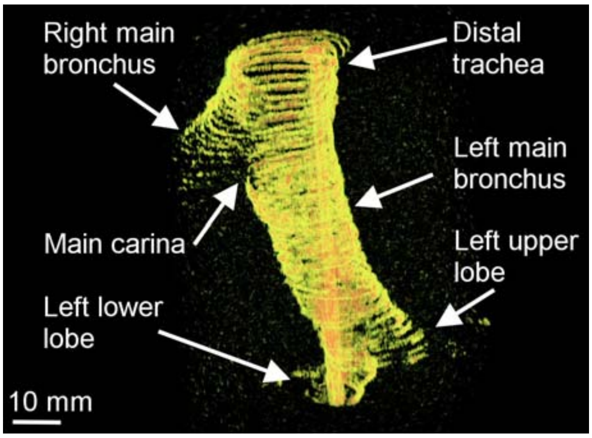

Figure 1: *a*OCT of a human lower airway, showing the trachea, through the left main bronchus and into the left lower lobe.

Results and Discussion

We have utilized endoscopic *a*OCT to acquire images of the airway during the clinical intervention. Figure 1 shows a 3D reconstruction of a human lower airway from an *a*OCT scan. Multiple cross-sectional axials scans were acquired to construct the 3D volume. As this data was acquired during the clinical intervention, it reflects the shape and geometry of the airway during treatment.

*a*OCT images have been used to quantify the size and extent of stenosis in the airway. Such intra-operative imaging provides critical information to the medical clinician when assessing the appropriateness and possible implications of laser resection, stenting or dilation of such pathologies.

Conclusion

This paper has presented an overview of the application of *a*OCT to endoscopic imaging. Results were demonstrated for the intra-operative assessment of pathologies of the human lower airway.

Acknowledgment

The author wishes to thank his colleagues in the Optical+Biomedical Engineering Laboratory; and the West Australian Sleep Disorders Research Institute, Sir Charles Gairdner Hospital for their collaboration in these research projects.

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