Advances in Automated Assessment of Intracoronary Optical Coherence Tomography and Their Clinical Application

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KEYWORDS

• Optical coherence tomography • OCT • Intravascular imaging • Image processing
• Automated image analysis • Stent • Atherosclerosis

KEY POINTS

- Intravascular optical coherence tomography (OCT) is capable of acquiring 3-dimensional (3D) data of coronary arteries allowing for the assessment of plaques, stents, thrombus, side branches, and other relevant structures in a 3D fashion.
- Given that state-of-the-art OCT systems acquire images at a very high frame rate (up to 200 frames per second), typically a very large number of images per pullback (ie, 500 or more) need to be analyzed.
- The manual assessment of stents, plaques, and other structures is time-consuming, cumbersome, and inefficient and thus not suitable for on-line analysis during percutaneous coronary intervention procedures; similarly, manual analysis is also inefficient in the setting of preclinical studies and clinical trials.

INTRODUCTION

Intravascular optical coherence tomography (OCT) is a high-resolution imaging technique using a near-infrared laser source (wavelength of ~1310 nm) and interferometry acquiring images of vessel wall microstructure and morphology.[1] State-of-the-art OCT has an axial resolution less than 15 μm and a lateral resolution ~30 to 60 μm, and it shows a penetration depth up to 3 mm in the coronary artery wall.[2] If compared with other imaging techniques, such as intravascular ultrasound (IVUS), computed tomographic scan, MRI, and MR angiography, it provides orders of magnitudes improvement in terms of image resolution.[3] Similarly to IVUS, OCT is an invasive catheter-based imaging technique, capable of acquiring multiple cross-sectional images of long segments of coronary arteries (typically 5–10 cm) in a few seconds, using a contrast injection to get the vessel lumen cleared from blood.

OCT is extensively used for the assessment of intravascular devices (i.e., intracoronary stents) and for the assessment of human atherosclerosis in vivo.[4,5] It allows quantification of both acute

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and late stent strut apposition to the vessel wall, the latter of which has been correlated with late stent failure.[6] Similarly, it allows assessment of the lack of stent strut neointimal coverage, a predictor of stent thrombosis.[7] OCT is able to discriminate stable plaques (e.g., fibrotic or calcific) from high-risk thin-cap fibroatheromas (lipid/necrotic core).[5] Moreover, OCT acquires 3-dimensional (3D) data of coronary arteries, allowing for the assessment of plaques, stents, thrombus, side branches, and other relevant structures in a 3D fashion.[8] As such, OCT is extensively used in assessing the safety and efficacy of novel therapies and interventions for the management of stable coronary artery disease and acute coronary syndromes as well as for the optimization of percutaneous coronary interventions (PCI).[9,10]

Given that state-of-the-art OCT systems acquire images at a very high frame rate (up to 200 frames per second), typically a very large number of cross-sectional images per pullback (ie, 500 or more) need to be analyzed. As such, manual analysis is very time-consuming, making the manual assessment of stents, plaques, and other structures very cumbersome and inefficient and thus not suitable for on-line analysis during PCI. Similarly, manual analysis is also very inefficient for clinical/preclinical studies and trials, where typically a very high number of images need to be analyzed.

This article focuses on currently available automated methods for the analysis of OCT datasets and discusses future directions and current needs of the OCT community.

METHODS FOR AUTOMATED INTRAVASCULAR OPTICAL COHERENCE TOMOGRAPHY IMAGE ANALYSIS

Several methods and software prototypes to analyze OCT data, with many different aims and objectives, have been developed over the past few years. These methods and software prototypes can be broadly divided into 4 different groups: (1) automated assessment of lumen morphology; (2) automated analysis of stents; (3) automated plaque analysis and tissue characterization; and (4) advanced methods for the analysis of other structures and OCT image features (eg, macrophages and thrombus).

Although some software prototypes are currently available for research purposes, currently there is neither standardization nor a common validation dataset for the different methods. Efforts from the OCT community will be required to define a standard for the validation and use of the recently proposed methods.

Automated Assessment of Lumen Morphology

OCT allows for the visualization of vessel morphology with great detail. One of the most direct and useful applications of OCT is the automated assessment of lumen contour, quantifying minimal cross-sectional area (eg, lumen narrowing), the extension of the lesion and reference (i.e., normal) vessel diameter in a 3D fashion through an entire OCT pullback (Fig. 1).

For this purpose, many different approaches have been developed, typically showing a very high correlation with respect to the gold standard (i.e., manual analysis).[11,12] These different approaches are currently available on commercial OCT systems (St. Jude Medical, St. Paul, MN, USA; and Terumo Corporation, Tokyo, Japan).[13] Such strategies typically segment the lumen contour through an entire intravascular OCT dataset in an automated fashion, eventually allowing the user to manually correct segmentation results in case of artifact or challenging situations. These methods are typically based on the gray-scale analysis of OCT images taking advantage of vessel spatial continuity to achieve a robust segmentation of the vessel wall.

Such algorithms typically allow for a reliable 2-dimensional (2D)/3D representation of vessel area complementing angiography during PCI and may be of help for the identification and characterization of the culprit lesion (e.g., plaque extension) as well as for a better assessment of in-stent restenosis. Moreover, the segmentation of vessel lumen is not only a useful tool to automatically quantify vessel area but also one of the basic features for more advanced processing algorithms that aim to automatically quantify stent strut apposition/coverage as well as perform tissue characterization and automated 3D renderings.

Automated Stent Analysis

Among the many applications of intravascular OCT, its use for the quantitative assessment of stent strut apposition and coverage is one of the most important. Given that persistent stent strut malapposition and lack of neointimal coverage have been correlated with adverse events (e.g., late stent thrombosis), OCT findings have been used extensively as a surrogate marker for the safety and efficacy profile of coronary stents. Manual analysis of stents by OCT must quantify the amount of malapposed struts, the severity of malapposition, and the amount of struts not showing sufficient neointimal coverage (i.e., lack of coverage) (Fig. 2). This kind of analysis requires manual detection and