Optical Coherence Tomography
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Case presentation: A 56-year-old man presented to the hospital with chest pain and a non-ST-segment elevation myocardial infarction. Thrombotic plaque rupture in the left anterior descending coronary artery was treated with an everolimus-eluting stent. After stent deployment, angiography demonstrated the presence of a hazy opacity at the distal edge of the stent, and there was concern about a possible edge dissection. Optical coherence tomography (OCT) imaging of the opacity showed residual thrombus and no dissection. Subsequent aspiration thrombectomy and balloon dilation effectively treated the lesion without deployment of an additional stent.

Introduction
OCT is an intravascular imaging modality that utilizes near-infrared light to generate cross-sectional blood vessel images. OCT is similar to intravascular ultrasound (IVUS), and both OCT and IVUS provide information about intravascular anatomy that far exceeds the level of detail obtained from conventional contrast angiography. With the use of light rather than ultrasound reflectance, OCT generates in vivo images of coronary arteries and deployed stents with up to 10 to 15 μm of spatial resolution compared with the 100- to 200-μm resolution of IVUS. Although the spatial resolution of OCT is markedly superior to that of IVUS, near-infrared light does not penetrate tissue as effectively as sound, and therefore OCT imaging depths range from 1 to 3 mm into the vessel wall, whereas IVUS imaging depths range from 4 to 10 mm (Table). Additionally, near-infrared light is scattered by red blood cells, and therefore OCT imaging requires transient blood clearing during image acquisition.

OCT Technology
The speed of light was initially a central challenge to developing a “clinically friendly” OCT system. Light travels too quickly for direct measurement of differential reflectance caused by vascular structures, and the original time delay OCT (TD-OCT) systems utilized a moving reference mirror to calibrate reflected light waves for image acquisition. The mirror mechanics were relatively slow, and TD-OCT required arterial balloon occlusion and intra-arterial administration of a clear solution to allow blood-free imaging. In addition to the potential risk of ischemia and vascular damage from occlusive balloon inflation, TD-OCT required cumbersome catheter and wire exchanges to enable placement of the imaging element.

More recently, TD-OCT has been replaced by a second-generation technology known as frequency domain OCT (FD-OCT). FD-OCT indicates frequency domain optical coherence tomography; IVUS, intravascular ultrasound. Adapted from references 1 and 2.
(FD-OCT). Compared with TD-OCT, FD-OCT has ≈3-fold better spatial resolution and 10 times faster image acquisition because it utilizes an ultra-fast frequency swept light source rather than a mechanical reference mirror. FD-OCT can image 54 mm of blood vessel length in just 2.7 seconds. It does not require balloon occlusion because blood is easily cleared during the short acquisition phase by hand or power injection of standard angiography contrast.

FD-OCT was approved for coronary imaging by the US Food and Drug Administration in April 2010, and the LightLab/St. Jude Medical ILUMIEN OCT system is currently in regular use at many US centers. The ILUMIEN OCT system uses a 2.7F monorail C7 Dragonfly Intravascular Imaging Catheter that is easily delivered through a 6F guide over a standard 0.014-inch intracoronary guidewire. The monorail imaging catheter connects to a nonsterile motorized pullback device that is tethered to a central console that contains the light source, image processing software, and imaging display.

**OCT Clinical Applications**
The clinical applications for OCT largely overlap those of IVUS. However, the enhanced spatial resolution of OCT enables visualization of intracoronary pathological features that cannot be seen by IVUS (Figure 1).

**OCT Imaging of Coronary Atherosclerosis**
The initial research validating OCT imaging with spatially coregistered histopathology demonstrated that OCT provides detailed in vivo anatomic information about luminal features and atherosclerotic plaque composition. Although OCT cannot probe into the vessel wall as far as IVUS, OCT provides superior adluminal imaging and can accurately depict aspects of plaque morphology, including fibrous, lipid-rich, and calcified plaque composition (Figure 2). In clinical studies of patients with acute coronary syndrome, OCT outperformed IVUS in detecting fibrous cap disruption, fibrous cap erosion, and presence of intracoronary thrombus. The ability of OCT to accurately distinguish plaque morphology with high resolution has multiple clinical implications. By measuring cap thickness, OCT readily identifies thin-capped fibroatheromas (TCFAs) that are characterized by a lipid-rich core, inflammatory cell infiltration, and a thin fibrous cap. Autopsy studies indicate that TCFAs with cap thickness <65 μmol/L are associated with plaque rupture, and the majority of acute myocardial infarctions result from disruption of previously nonobstructive TCFAs. By enabling the quantification of TCFA, OCT has the potential to facilitate ongoing efforts to develop therapies for these high-risk plaques.

**OCT Imaging and Coronary Intervention**
OCT enables precise measurement of vessel diameter and lesion length and helps to optimize sizing of dilation balloons and stents during percutaneous coronary interventions (PCIs). In addition, OCT evaluation of side branch stenosis can assist in the planning of bifurcation PCI. OCT also readily clarifies indeterminate angiographic abnormalities and the presence or absence of stent edge dissection after stent deployment. Indeed, the high sensitivity of OCT has been demonstrated in clinical studies that performed routine stent imaging. In these investigations, OCT revealed a 97.5% incidence of stent tissue prolapse (>50 μm in depth), an 87.5% incidence of intrastent dissection, a 26.5% incidence of stent edge dissection, and the presence of luminal thrombus in up to 28% of stent segments. In the setting of routine use, the clinical significance of subtle OCT-identified post-PCI abnormalities is unclear because the relationship between these abnormalities and adverse clinical outcomes has not yet been determined.

Clinical trials have firmly established that compared with IVUS, OCT has higher sensitivity for detecting...
small degrees of in-stent restenosis, stent malapposition, and uncovered stent struts. Malapposed and uncovered stents struts are both associated with increased risk of stent thrombosis after IVUS-guided PCI and nonrandomized studies demonstrated reduced stent thrombosis after IVUS-guided PCI versus a standard technique. The potential benefit of routine OCT has not been evaluated in a clinical outcome study. However, if we extrapolate from the IVUS experience, routine use of OCT in unselected cases may not be beneficial. In the present era, OCT is primarily used to evaluate ambiguous angiographic abnormalities, to assess arterial anatomy before PCI procedures, or to guide stent placement and postdilation after complex interventions. When intravascular imaging is necessary, we generally favor OCT over IVUS because OCT unambiguously delineates the blood vessel lumen, juxtaluminal plaque architecture, and stent struts. Because of the need for a blood-free environment for OCT imaging, IVUS may be preferred for imaging of aorto-ostial lesions or very large-caliber arteries, in which it is difficult to adequately displace blood with contrast injection.

**Indications for OCT Utilization**

In initial experience, IVUS guidance during PCI optimized stent size and apposition, and nonrandomized studies demonstrated reduced stent thrombosis after IVUS-guided placement. Initial enthusiasm for routine IVUS use during PCI waned after randomized studies reported similar outcomes with IVUS-guided PCI versus a standard technique. The potential benefit of routine OCT has not been evaluated in a clinical outcome study. However, if we extrapolate from the IVUS experience, routine use of OCT in unselected cases may not be beneficial. In the present era, OCT is primarily used to evaluate ambiguous angiographic abnormalities, to assess arterial anatomy before PCI procedures, or to guide stent placement and postdilation after complex interventions. When intravascular imaging is necessary, we generally favor OCT over IVUS because OCT unambiguously delineates the blood vessel lumen, juxtaluminal plaque architecture, and stent struts. Because of the need for a blood-free environment for OCT imaging, IVUS may be preferred for imaging of aorto-ostial lesions or very large-caliber arteries, in which it is difficult to adequately displace blood with contrast injection.

**OCT Future Directions**

OCT technology is continuing to evolve, and ultrahigh-resolution OCT that has <10-μm resolution is currently in development. Future directions also include functional assessment of plaque pathobiology and inflammation through the use of OCT combined with novel optically active molecular imaging agents.

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**Figure 2.**

A. Normal coronary artery without significant plaque burden. B. Fibrous plaque appears as a homogeneous high-intensity signal without obvious borders (arrow). C. Lipid-rich plaque appears as an area of low-intensity backscatter with irregular and indistinct (blurry) borders (arrow). D. Calcified plaque is present as an area of low-intensity signal with well-circumscribed, distinct borders (arrow). E. Stent malapposition (arrow). F. Ruptured thin-capped fibroatheroma (TCFA) demonstrates disruption of the thin fibrous cap (arrow) above a low-intensity lipid plaque. *Angioplasty wire artifact.
**Conclusion**

OCT is a light-based invasive imaging technology that generates high-resolution intravascular images. Compared with IVUS, OCT provides higher-quality images of the arterial lumen, juxtaluminal plaque, and vascular stents. OCT is recognized as an invaluable research tool for assessment of TCFA, plaque rupture, restenosis, and stent healing. Clinically, OCT is increasingly employed in selected cases as a high-fidelity imaging adjunct during diagnostic catheterization and PCI. Routine use of OCT will require validation in clinical trials to determine whether utilization of this technology will improve clinical outcomes in patients undergoing therapeutic coronary intervention.

**Disclosures**

Dr McCabe reports no disclosures. Dr Croce reports having served as a consultant for St. Jude Medical (minor $<$5000).

**References**


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