

OCT: Ready for Prime Time?

Clinical applications of optical coherence tomography.

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Optical coherence tomography (OCT) is an optical analogue of intravascular ultrasound (IVUS). OCT uses near-infrared light to create images. The greatest advantage is its extraordinarily high resolution. OCT has an axial resolution of 10 μm and a lateral resolution of 20 μm , which is approximately 10 times higher than that of IVUS. This new intravascular imaging method can provide more detailed structural information about the coronary artery wall compared to conventional imaging methods (Table 1).¹

PLAQUE CHARACTERIZATION

OCT allows for the identification of the boundary of the intima and media within the coronary arterial wall, which currently cannot be distinguished by IVUS. In an OCT image, the intima is observed as the signal-rich layer nearest to the lumen, and media is visualized as the signal-poor middle layer. The OCT measurement of intimal thickness is well correlated to histological examination.² OCT has the ability to evaluate subtle intimal

thickening in vivo, which may indicate the early phase of coronary atherosclerosis.

Yabushita et al have developed objective OCT image criteria for differentiating distinct components of atherosclerotic tissue in a large series of autopsy specimens.³ In their histology-controlled OCT study, fibrous plaques were characterized by homogeneous, signal-rich regions; fibrocalcific plaques were characterized by signal-poor regions with sharp borders; and lipid-rich plaques were characterized by signal-poor regions with diffuse borders. Validation testing revealed good intraobserver and interobserver reliability ($\kappa = 0.83$ – 0.84), as well as excellent sensitivity and specificity: 71%–79% and 97%–98% for fibrous plaques, 95%–96% and 97% for fibrocalcific plaques, and 90%–94% and 90%–92% for lipid-rich plaques, respectively. These definitions have formed the basis of plaque composition interpretation in clinical OCT studies (Figure 1).

VULNERABLE PLAQUE DETECTION

It has been reported that OCT might be the best

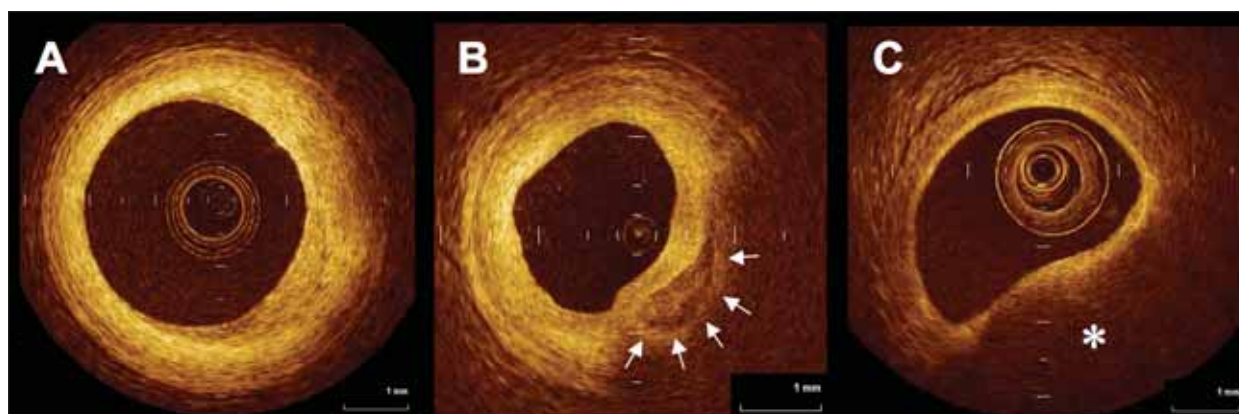


Figure 1. OCT images of coronary atherosclerotic plaques: fibrous plaque (A), fibrocalcific plaque (arrows) (B), and lipidic plaque (*) (C).

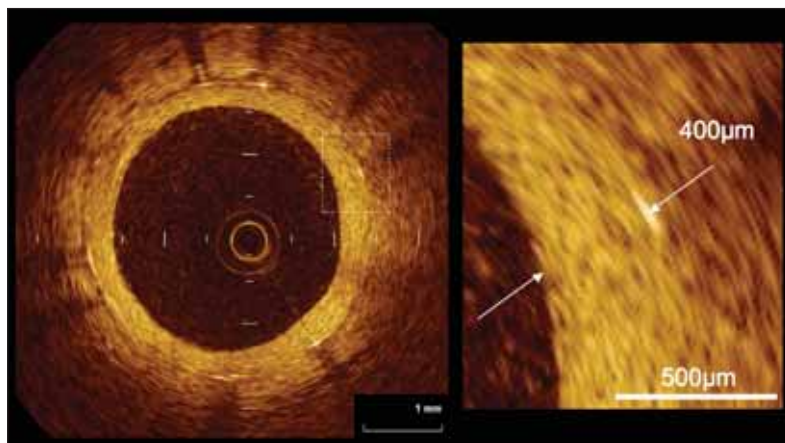


Figure 2. OCT images of neointimal hyperplasia after stent implantation. All stent struts were covered by neointima (left). The thickness of neointimal hyperplasia within the stent was 400 μm (right).

tool available to detect vulnerable plaque.⁴⁻⁷ To assess the ability of each imaging method to detect the specific characteristics of vulnerable plaque, Kubo et al performed OCT, IVUS, and angioscopy in patients with acute myocardial infarction.^{8,9} Their research showed that OCT was superior in detecting plaque rupture (73% vs 40% vs 43%; $P = .021$), erosion (23% vs 0% vs 3%; $P = .003$), and thrombus (100% vs 33% vs 100%; $P < .001$) compared to IVUS and angioscopy. Intraobserver and interobserver variability yielded acceptable concordance for these characteristics ($\kappa = 0.61$ – 0.83). Sawada et al evaluated the feasibility of OCT and virtual histology IVUS for detecting thin-capped fibroatheroma.¹⁰ The high resolution of OCT allows us to identify the thin fibrous cap ($< 65 \mu\text{m}$).^{11,12} Although the positive ratio of virtual histology IVUS for detecting thin-capped fibroatheroma was 45.9%, that of OCT was 77.8%.¹⁰ Kume et al demonstrated the abilities of OCT to differentiate thrombus from the vessel wall and to

evaluate thrombus type. Red thrombi (red-blood-cell-rich) were identified as high-backscattering protrusions with signal-free shadowing inside the lumen of the artery, and white thrombi (platelet-rich) were detected as low-backscattering projections.¹³

Furthermore, Tearney et al proposed the potential of OCT to assess macrophage distribution within fibrous caps.¹⁴ There was a high degree of positive correlation between OCT and histological measurements of fibrous cap macrophage density ($r < 0.84$; $P < .0001$). A range of OCT signal standard deviation thresholds (6.15% to 6.35%) yielded 100% sensitivity and specificity for identifying caps contain-

ing $> 10\%$ CD68 staining.

GUIDANCE OF CORONARY INTERVENTION

Considering the high resolution of OCT, it is not surprising that it provides more detailed morphologic information for monitoring stent deployment than conventional imaging methods. OCT has the ability to detect stent-edge dissection, tissue protrusion, and stent malapposition at a level that is two to three times better than that of IVUS.¹⁵ Moreover, OCT is capable of visualizing the thin-neointimal hyperplasia after drug-eluting stent implantation (Figure 2). Recent studies demonstrated that the rate of sirolimus-eluting stent struts with neointimal coverage was $> 90\%$ at 12-month follow-up, and most of them were covered by thin neointima of $< 100 \mu\text{m}$.¹⁵⁻¹⁸ To determine when antiplatelet therapy could be discontinued, OCT provides important information about chronic drug-eluting stent status.

TABLE 1. COMPARISON OF THE CHARACTERISTICS OF CORONARY IMAGING METHODS

	OCT	IVUS	Angioscopy	Angiography
Resolution (μm)	10–20	80–120	10–50	100–200
Probe size (mm)	0.14	0.7	0.8	NA
Type of radiation	Near-IR light	Ultrasound	Visible light	X-ray
Other	Subsurface tomogram	Subsurface tomogram	Surface imaging only	Images of blood flow

Abbreviations: IR, infrared; IVUS, intravascular ultrasound; NA, not available; OCT, optical coherence tomography.

LIMITATIONS

The present OCT image-acquisition process requires vessel occlusion by means of gentle balloon inflation plus vessel flushing with saline infusion, because the near-infrared light signals are attenuated by red blood cells. This technique is rather cumbersome and time consuming and does not encourage its routine use. To overcome this limitation, Prati et al have developed a simplified technique for coronary blood removal that is achieved through continuous nonionic contrast administration.¹⁹ This nonocclusive technique of OCT image acquisition is safe and effective and promises to reduce the procedural time.²⁰ A further limitation of OCT is the relatively shallow axial penetration depth of 2 mm; the OCT signal does not reach the back wall of thick atherosclerotic lesions. However, the current OCT is well suited for the assessment of the plaque morphologies within 500 μ m of the luminal surface.

CURRENT TECHNOLOGICAL CHALLENGES

Recently, a second-generation OCT technology, termed *frequency-domain OCT*, has been developed and solves the current time-domain OCT problems by imaging at much higher frame rates.²¹ In combination with a short, nonocclusive saline flush and rapid spiral pullback, the higher frame rates generated by frequency-domain OCT enable imaging of the three-dimensional microstructure of long segments of coronary arteries. In addition, frequency-domain OCT facilitates the acquisition of spectroscopic and polarization data for plaque characterization. When this technology is fully utilized, it has the potential to dramatically change the way that physicians and researchers understand coronary artery disease and to better diagnose and treat the disease.

CONCLUSION

The high resolution of OCT provides histology-grade definition of the microstructure of coronary plaque in vivo. OCT provides a greater understanding of the pathophysiology of coronary artery disease and guidance for the appropriate patient-specific therapeutic approach. Although more clinical research and development of this imaging technology are required, we believe OCT will play an important role in the future of cardiology. ■

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