Concise Review of Optical Coherence Tomography in Clinical Practice

Min-I Su,1 Chun-Yen Chen,2,3 Hung-I Yeh2,3 and Kuang-Te Wang1

Optical coherence tomography (OCT) is a novel image modality with higher resolution in the catheterization laboratory. It can differentiate tissue characteristics and provide detailed information, including dissection, tissue prolapse, thrombi, and stent apposition. In this study, we comprehensively reviewed the current pros and cons of OCT clinical applications and presented our clinical experiences associated with the advantages and limitations of this new imaging modality.

Key Words: Coronary artery disease • Optical coherence tomography

INTRODUCTION

Optical coherence tomography (OCT) was developed by Naohiro Tanno and James G. Fujimoto during the 1990s, and they first performed OCT on the retina and coronary artery in 1991.1 Coronary OCT uses only a single fiber optic wire that can both generate light and record the reflection while simultaneously rotating and pulling back in comparison to intravascular ultrasound (IVUS). In current OCT technology, optical echoes are analysed by near infra-red interferometry. In cardiology, OCT and IVUS are modern tools that contribute to the understanding of coronary artery disease and percutaneous coronary intervention (PCI). Nevertheless, OCT and IVUS differ in several aspects, as shown in Table 1. For instance, current coronary OCT systems use a central wavelength of approximately 1300 nm and tissue penetration of OCT is limited to 1 to 3 mm, compared with 4 to 8 mm with IVUS. Because the speed of light ($3 \times 10^8$ m/s) is much greater than that of sound (1,500 m/s), OCT as a fiber optic system offers 10 times greater resolution and 40 times faster image acquisition compared with IVUS. Because of the high attenuation of light by blood, complete removal of blood during OCT examination is necessary.

CURRENT OCT SYSTEM

Originally, the first-generation OCT was time-domain OCT (TD-OCT). In that system, TD-OCT requires balloon occlusion in proximal vessels to create a blood-free imaging environment. Previous studies have confirmed the safety of TD-OCT with balloon occlusion in comparison with IVUS. Nevertheless, the former is a complex procedure and its application is limited to ostial coronary disease.2-4 Currently, new generation OCT systems that implement frequency-domain OCT (FD-OCT) imaging methods have been developed to overcome such limitations.5,6

TIPS FOR INTRACORONARY IMAGE ACQUISITION

In Taiwan, the commercially available FD-OCT sys-
tem uses a 2.7 Fr OCT catheter (Dragonfly imaging catheter, St. Jude Medical), a ≥6-Fr-diameter guide catheter is recommended. The OCT can be advanced to distal vessels via a standard 0.014-inch angioplasty guide wire. An automated pull back at a rate of 20 mm/s is started after blood clearance is achieved by non-diluted iodine contrast injection at rates of 3 to 5 mL/s for a total volume of 10 to 20 mL/pull back. The differences between TD-OCT and FD-OCT systems are shown in Table 1. In our experience, the fiber optic OCT catheter is softer and less amenable to pulling than the IVUS catheter, and even the diameter is less than IVUS. Before the operator advances the fiber optic catheter, some coronary lesions, such as diffuse, long, relatively calcified or bending lesions, should be well prepared to avoid breaking the fiber optic catheter. Moreover, OCT should be used to carefully coaxially guide the catheter position and measure firm catheter engagement in the coronary ostium to prevent residual blood attenuation (Figure 1A). Vessel sizes range from 2.0 mm to 3.75 mm in diameter, which is ideal for OCT imaging. Thus, operators should be aware of “out-of-screen” loss of image (Figure 1B), which is a result of the vessel size being larger than the scan diameter (field of view) of OCT, and fold-over artifacts. So far, ostial lesions of the main trunk are still a limitation of OCT due to poor blood washing and catheter engagement. We simply sum up our TIPS of OCT acquisition in Table 2.

CLINICAL IMAGE INTERPRETATION

Because of its high resolution (10-15 μm), OCT can clearly distinguish between the three vessel walls: high backscattering thin intima, low backscattering media, and heterogeneous adventitia (Figure 1C). Fibrous tissue, collagen, and lipids have high birefringence, whereas calcium has low birefringence. Thus, different tissue structures can be distinguished by OCT because of their different composition. Different types of plaque demonstrate the following OCT image appearances: 1) fibrous plaque: a relatively homogeneous high signal region with low attenuation and mainly external elastic membrane; 2) calcified plaque: sharply delineated borders with a low-signal region; and 3) lipid-rich plaque: a

### Table 1. Comparison of IVUS, TD-OCT and FD-OCT

<table>
<thead>
<tr>
<th>Specifications</th>
<th>IVUS</th>
<th>TD-OCT</th>
<th>FD-OCT</th>
</tr>
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<tbody>
<tr>
<td>Max. frame rate, fps</td>
<td>30</td>
<td>20</td>
<td>~200</td>
</tr>
<tr>
<td>Max. pullback speed, mm/s</td>
<td>0.5-2.0</td>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>Scan diameter (FOV), mm</td>
<td>8-10</td>
<td>6.8</td>
<td>~6-11</td>
</tr>
<tr>
<td>Axial resolution, μm</td>
<td>100-150</td>
<td>15</td>
<td>10-15</td>
</tr>
<tr>
<td>Lateral resolution, μm</td>
<td>150-300</td>
<td>25-40</td>
<td>20-40</td>
</tr>
<tr>
<td>Tissue penetration, mm</td>
<td>4-8</td>
<td>1.5-3</td>
<td>2-3.5</td>
</tr>
<tr>
<td>Balloon occlusion</td>
<td>No</td>
<td>Necessary</td>
<td>Optional</td>
</tr>
<tr>
<td>Catheter size, mm</td>
<td>0.8-1.2</td>
<td>0.48</td>
<td>0.8-1.0</td>
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</tbody>
</table>

FD-OCT, frequency-domain optical coherence tomography; FOV, field of view; IVUS, intravascular ultrasound; TD-OCT, time-domain optical coherence tomography.

### Table 2. Our experience in optical coherence tomography acquisition

1. No using less than 6-Fr-diameter guide catheter.
2. To advance a standard 0.014-inch angioplasty guide wire.
3. Diffuse, long, relatively calcified or bending lesions, should be well prepared.
4. The ideal vessel size is from 2.0 mm to 3.75 mm in diameter.
5. To ensure firm catheter engagement with good coaxial alignment can avoid blood attenuation.
6. To inject non-diluted iodine contrast injection at rates of 3 to 5 mL/s in 4 to 5 seconds.
low-signal region and poorly delineated borders with high attenuation (Figure 2A, 2B, 2C).7,8

CLINICAL APPLICATIONS

More than 80% of clinically evident plaque ruptures originate within an inflamed thin-capped fibroatheroma.9 Autopsy studies have demonstrated that fibroatheroma with a thin fibrous cap of < 65 μm [thin-cap fibroatheroma (TCFA)] is associated with plaque rupture in acute coronary syndromes (ACS) and is considered a vulnerable plaque.10 Thus, it is crucial to perform aggressive medical treatment on TCFA patients to improve clinical outcomes. High-resolution OCT can identify a very thin (< 100 μm) fibrous cap covering a lipid core. TCFA, as imaged using OCT, is defined as a lipid-rich plaque (lipid arc within a plaque in ≥ 2 quadrants) with a thin fibrous cap (thickness at the thinnest segment < 65 μm).11 Additionally, OCT can assess plaque characteristics (such as rupture plaque, erosion plaque, red and white thrombi; Figure 2D) in ACS patients more precisely than IVUS.12,13 However, the low tissue penetration of current OCT systems is a major limitation and makes it difficult to distinguish tissue behind a thick cap, lipid core, or calcification.14

OCT-GUIDED PERCUTANEOUS CORONARY INTERVENTION

OCT is a utility that can precisely measure lesion length and vessel diameter in PCI, which is useful in optimizing the size of dilation balloons and stents. Because of the high resolution of OCT, the angle and location of the dissection flap are more accurately identified in OCT systems (Figure 3A). In addition, tissue prolapse, stent edge dissection, and stent malapposition (Figure 3B) can also be visualized in detail.15,16 A previous study has demonstrated that OCT has higher sensitivity than IVUS for assessing stent malapposition.17,18 Many studies have used OCT to demonstrate a delay in neointimal healing following drug eluting stent (DES) implantation compared with implantation of bare metal stents (BMS). Using OCT, second-generation DESs displayed better vascular healing than first-generation DESs.19,20 An autopsy study reported an excessive proportion (49%) of
delayed healing at the culprit site in acute myocardial infarction (AMI) patients treated with DES, but the limitation of this study was the small number of specimens (N = 25). In contrast, compared with post-mortem data, OCT demonstrated a higher rate of vascular healing in both BMS and DES (uncovered struts: 0% vs. 1.98%, respectively). OCT is the preferred modality to study in-stent restenosis (ISR) characterization, and different tissue patterns have been described. Homogeneous fibrotic intimal hyperplasia is typically observed in BMS ISR (Figure 3C); conversely, heterogeneous neo-atherosclerosis caused by lipid accumulation and/or calcification is frequently reported in DES ISR (Figure 3D). In addition, the pathologic study of neo-atherosclerosis demonstrated that neo-atherosclerosis is a frequent finding in DES and occurs earlier than in BMS. Thus, OCT can disclose important information about plaque morphology covering the stent struts.

The three-dimensional (3D) reconstruction of IVUS was first described in 1995, but so far this technology has not shown an obvious, useful clinical application. In contrast, FD-OCT enables better 3D reconstruction of coronary vessels and stent struts because of faster frame rate, and unrivalled resolution and pullback speed. After the first application of 3D reconstruction of the human coronary artery, 3D OCT reconstruction technology (Figure 3E) has promptly developed its clinical utility, such as for bifurcation lesion treatment, assessment of jailed side branches, and AMI management. However, real-time 3D reconstruction is not currently available in Taiwan and we do not have enough clinical experience to define the clinical impact of 3D OCT technology.

**Table 3.** Pros and cons of OCT versus IVUS

<table>
<thead>
<tr>
<th>Instrument</th>
<th>OCT</th>
<th>IVUS</th>
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<tr>
<td><strong>Pros</strong></td>
<td></td>
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<tr>
<td>- Higher image resolution and 3D reconstruction.</td>
<td>- Higher tissue penetration.</td>
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<td>- Apposition, dissection detecting and follow up.</td>
<td>- Plaque burden measuring.</td>
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<td>- Rapid pullback less than 3 seconds.</td>
<td>- Left main coronary artery lesion.</td>
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<td>- Excellent lesion identification (lipid, calcium, fiber, thrombus).</td>
<td>- No more contrast flush.</td>
<td></td>
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<tr>
<td>- Bioabsorbable stents.</td>
<td>- Big market penetration rate.</td>
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| **Cons**   |     |      |
| - Insufficient patient outcome data. | - Complete patient outcome data. |
| - Left main coronary artery or right ostial coronary lesion. | - Real-time collaboration tool for re-entry in chronic total occlusion vessel. |
| - Poor tissue penetration. | - Lower image resolution. |
| - Very tight or large lesions. | - Inferior detection of lipid, thrombus, stents, dissections. |
| - Increase extra contrast load. | - Over-reliance on operator experience. |

IVUS, intravascular ultrasound; OCT, optical coherence tomography; PCI, percutaneous coronary intervention.
CONCLUSIONS

OCT is a newly available modern intravascular imaging modality in Taiwan. Because of its unrivalled resolution, interventional cardiologists can use it more precisely to evaluate clinical and research parameters of coronary artery disease.

CONFLICTS OF INTEREST

None.

REFERENCES


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