DOI：10.6314/JIMT.2017.28(4).01 內科學誌 2017：28：199-205

專題報導

Optical Coherence Tomography in Clinical Practice

Yueh-Hung Lin[1,2], Cheng-Ting Tsai[1,2], and Ta-Chuan Hung[1,2]

[1]Division of Coronary and Vascular Intervention, Division of Cardiology, Cardiovascular Center/ Department of Internal Medicine, MacKay Memorial Hospital, Taipei, Taiwan;
[2]Department of Medicine, Mackay Medical College, New Taipei City, Taiwan

Abstract

Currently, there are two intracoronary imaging techniques available to complement angiography in the management of coronary artery disease, namely intravascular ultrasound (IVUS) and optical coherence tomography (OCT). Optical coherence tomography (OCT) is a high-resolution arterial wall imaging technique with great versatility of applications. This article reviews the use of OCT for assessment of lesion severity, guidance of intracoronary stenting, and evaluation of long-term results. (J Intern Med Taiwan 2017; 28: 199-205)

Key Words: Optical coherence tomography, Intracoronary image

Introduction

Optical coherence tomography (OCT) was first described for use in ophthalmology field and was widely used to assess retinal diseases[1]. OCT is a novel invasive diagnostic tool in percutaneous coronary intervention. First generation OCT is based on a time domain OCT (TD-OCT) imaging method that relies on a moving reference mirror to scan each depth position in the image pixel. Due to several limitations of TD-OCT, second generation of OCT: Fourier-domain OCT systems, also known as frequency domain OCT (FD-OCT) was developed. FD-OCT systems offer faster image acquisition speeds, greater scan depths, rapid pullback system and more simple procedure than TD-OCT[2-7]. OCT images have 10-fold higher resolution (10-15μm) than intravascular ultrasound (IVUS) images and allow for more accurate assessment of vascular lumen size, vascular pathology, presence of thrombus, coronary stent strut apposition, and vascular response to previously placed coronary stents.

Clinical Application

Concomitant Medication, Patient, and Lesion Selection

Like IVUS, heparinization is recommend before inserting the guidewire into the coronary artery. To minimize the potential catheter-induced vasospasm, intracoronary nitroglycerin administration is recommended if not contraindicated. While performing OCT, it needs to use contrast medium to flush the coronary artery to clear blood for full vessel visualization. In patients with severe left ven-

Reprint requests and correspondence：Dr. Cheng-Ting Tsai
Address：Division of Cardiology, Cardiovascular Center/Department of Internal Medicine, Mackay Memorial Hospital, No. 92, Chung-Shan North Road, 2nd Section, Taipei, Taiwan

tricular function impairment, a single remaining vessel, renal function impairment or known allergy to the flushing media, OCT should be used carefully.

Evaluation of Coronary Pathology

Normal Coronary Artery

There are three layers in normal coronary arterial wall: intima, media and adventitia.

The intima is the innermost layer and is seen as a highly backscattering and signal-rich thin band on OCT (Figure 1A). The media is below the intima and seen as a dark band delimited by the internal elastic lamina (IEL) and external elastic lamina (EEL). The media layer is low backscattering, signal poor and heterogeneous on OCT.

With OCT, the adventitia layer is heterogeneous, highly back scattering and signal-rich band. The internal elastic membrane (IEM) is defined as the border between the intima and media, and the external elastic membrane (EEM) is defined as the border between the media and the adventitia.

Atherosclerotic Plaque Assessment

Table 1 summarizes image characteristics of optical coherence tomography.

Histologically, coronary plaques are generally classified as lipid-rich, fibrous, or calcified plaques

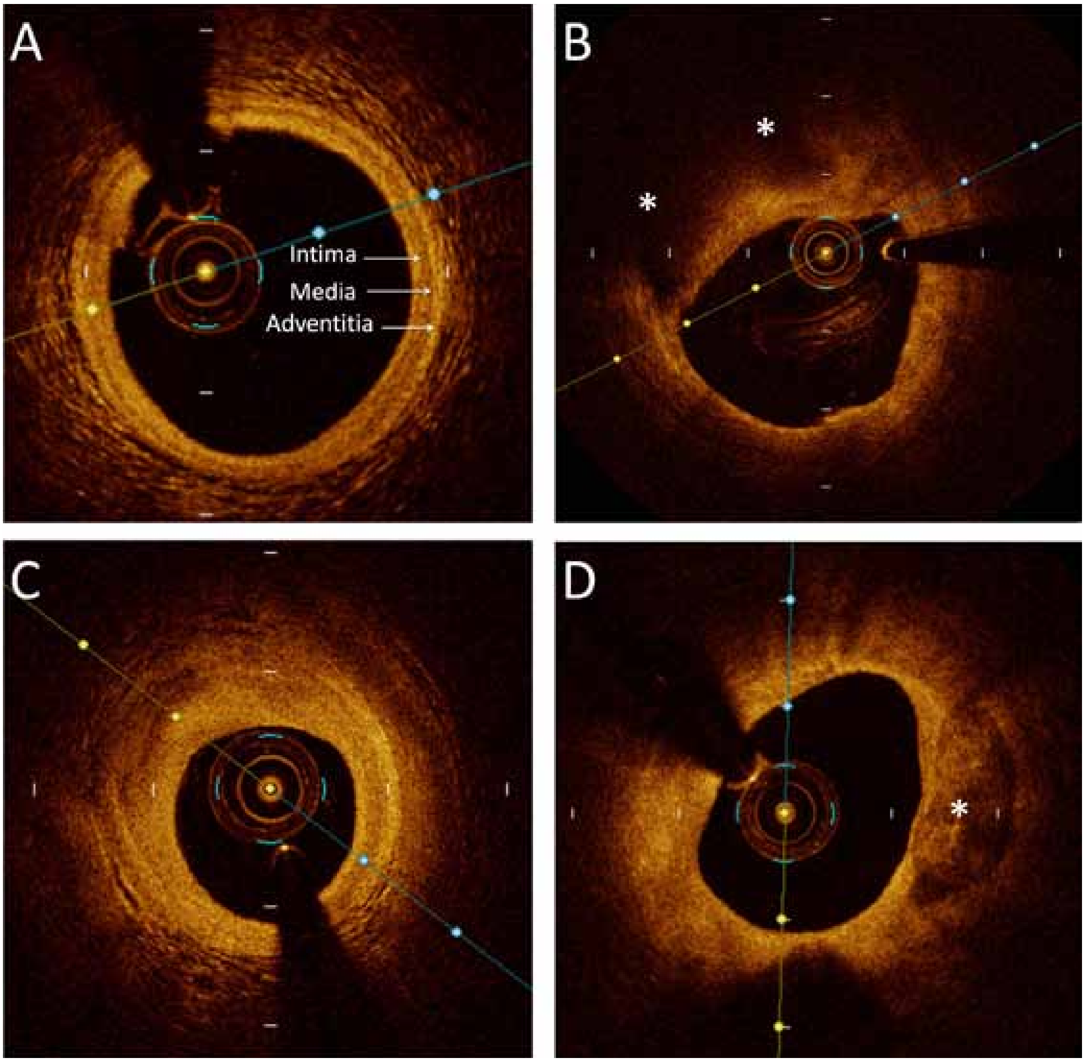

Figure 1. Optical coherence tomography shows the three layer appearance of normal vessel wall (A), lipid plaque (B), fibrous plaque (C) and calcified plaque (D).

Table 1. Image characteristics of optical coherence tomography

Tissue type	Image characteristics
Lipid	Low signal, Homogenous, Diffuse edges, high reflectivity, high attenuation
Fibrotic	High signal, Homogeneous, Poorly delineated, high reflectivity, Low attenuation
Calcium	Low signal, Heterogeneous, Well-lineated, Sharp border, Low reflectivity, Low attenuation
Red thrombus	Superficial signal rich, low penetration, signal-free shadowing, high attenuation
White thrombus	Superficial signal rich, more penetration than for red thrombus, low attenuation

based on their tissue compositions. An atherosclerotic plaque is identified as focal thickening or loss of the normal three-layered structure of the vessel wall. OCT has high sensitivity and high specificity for lipid plaque, fibrous plaque, and calcified plaque[8].

1. Lipid Plaque

Necrotic lipid pools are low signal, heterogeneous areas with diffuse edges resulting from backscatter and rapid attenuation from the lipid-containing region located below a fibrous cap (Figure 1B). The fibrous cap is typically a homogeneous signal-rich band overlying the signal-poor lipid core. Lipid plaque is more heterogeneous back scattering than fibrous plaques. There is a strong contrast between lipid-rich cores and fibrous regions within OCT images. The minimal thickness of the fibrous cap is critical for identifying thin-cap fibroatheromas (TCFAs).

2. Fibrous Plaque

Fibrous plaques consist of homogeneous areas with high reflectivity and low attenuation (Figure 1C). This is distinct from lipid pools which are signal-poor areas with diffuse borders and high attenuation[9].

3. Calcified Plaque

The features of calcification within plaques are identified by the presence of well-delineated, low-signal, slow backscattering heterogeneous regions and heterogeneous regions with sharp border (Figure 1D).

Intraluminal and Intramural Pathology

Plaque Rupture

Ruptured plaques are the main mechanism of STEMI and NSTEMI. The features of plaque rupture are intimal tearing, disruption, or dissection of the cap (Figure 2A). When injected with optically transparent crystalloid or contrast media, these defects may have little or no OCT signal and may appear as a cavity.

Thrombus

Thrombi are identified by the presence of irregular masses protruding into the vessel lumen either attached to the vessel wall or free within the vessel lumen. Platelet-rich white thrombi are characterized by a homogeneous superficial signal-rich, and low attenuation resulting in minimal shadowing[10] (Figure 2B, 2C). Red thrombi consist mainly of red blood cells and are characterized as superficial signal rich, low penetration and high attenuation with signal free shadowing (Figure 2D).

Rule of OCT in Coronary Intervention

Pre-stent Deployment

Before stenting, high resolution of OCT makes it a powerful tool to provide accurate assessment of the vessel size, lesion severity, lesion character and lesion length, which provide appropriate stent sizing. OCT also provides information on lesion characteristics such as the presence and type of thrombus, TCFA, plaque ulceration, or superficial calcification that can help to guide the procedure. It will suggest the need for ancillary devices or for dedicated stents. Plaque dissections are common findings after balloon angioplasty and are associated with ruptured plaques visualized by OCT. They are identified as rims of tissue protruding into the lumen.

Immediate Post-stent Deployment

One of the key points of a successful intervention is adequate stent expansion resulting in a well-apposed stent. OCT can accurately and quickly provide information on expansion, sizing, and apposition of the stent after stent implantation.

Stent malapposition is defined as the distance from the stent strut to the vessel wall greater than the nominal stent strut thickness (Figure 3A). Stent underexpansion is minimum stent area (MSA) lower than both the nominal stent and distal reference vessel areas. Stent undersizing is MSA lower than the reference vessel area higher than the nominal stent area. OCT can measure MSA and lumen area of the reference vessel semi-automatically that gives a quick and accurate estimation of the expansion and sizing of the stent. In OCT, metallic stent struts are highly reflective and generate a strong signal with shadowing behind the stent strut. Bioresorbable Vascular Scaffold are made of polylactide, a crystallised translucent polymer that can be pene-

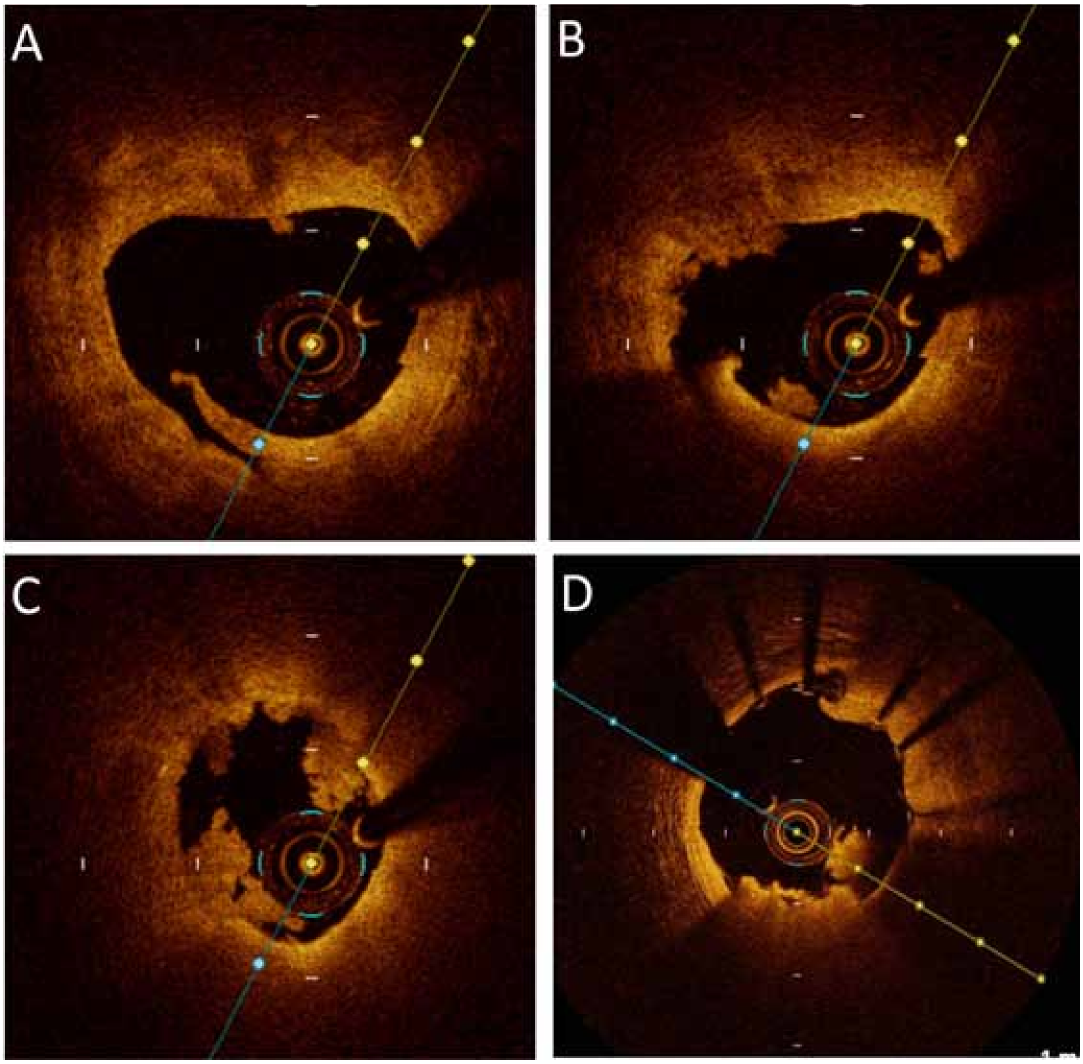

Figure 2. Example of a patient admitted for myocardial infarction and optical coherence tomography showed a superficial ruptured plaque (A) and white thrombus (B,C). Red thrombus is superficial signal rich, low penetration and high attenuation with signal free shadowing (D).

trated by optical radiation and do not cause shadowing (Figure 3D, 3E). Absorbable stents with metallic scaffolds appear similar to typical metal stents at implantation but overtime become less reflective and lose the blooming effect. In addition to inadequate stent expansion, OCT frequently identifies vessel dissection (a disruption in the vessel surface), intra-stent thrombus, and tissue prolapse (protrusion of tissue between stent struts) post intervention.

Late Stent Evaluation

In long-term stent follow up, OCT is a useful examination after stent implantation.

An ideal coronary stent would allow for a thin layer of stent coverage without significant neointimal hyperplasia. Delayed coverage or failure to cover an exposed stent with neointima or regenerated endothelium could cause late stent thrombosis.

Neoatherosclerosis is pathologically distinct from neointimal hyperplasia and characterized by presence of calcification and lipid pools within the intima and formation of fibroatheromas. OCT can identify in-stent restenosis and characteristics with homogeneous appearance and a smooth lumen contour (Figure 3C, 3F). In addition to the stent strut coverage, stent strut apposition, tissue coverage, neointimal growth and are also important in long-term follow-up of stents.

Limitation of OCT

Table 2 summarize comparisons of Characterization of Pathology Using OCT and IVUS.

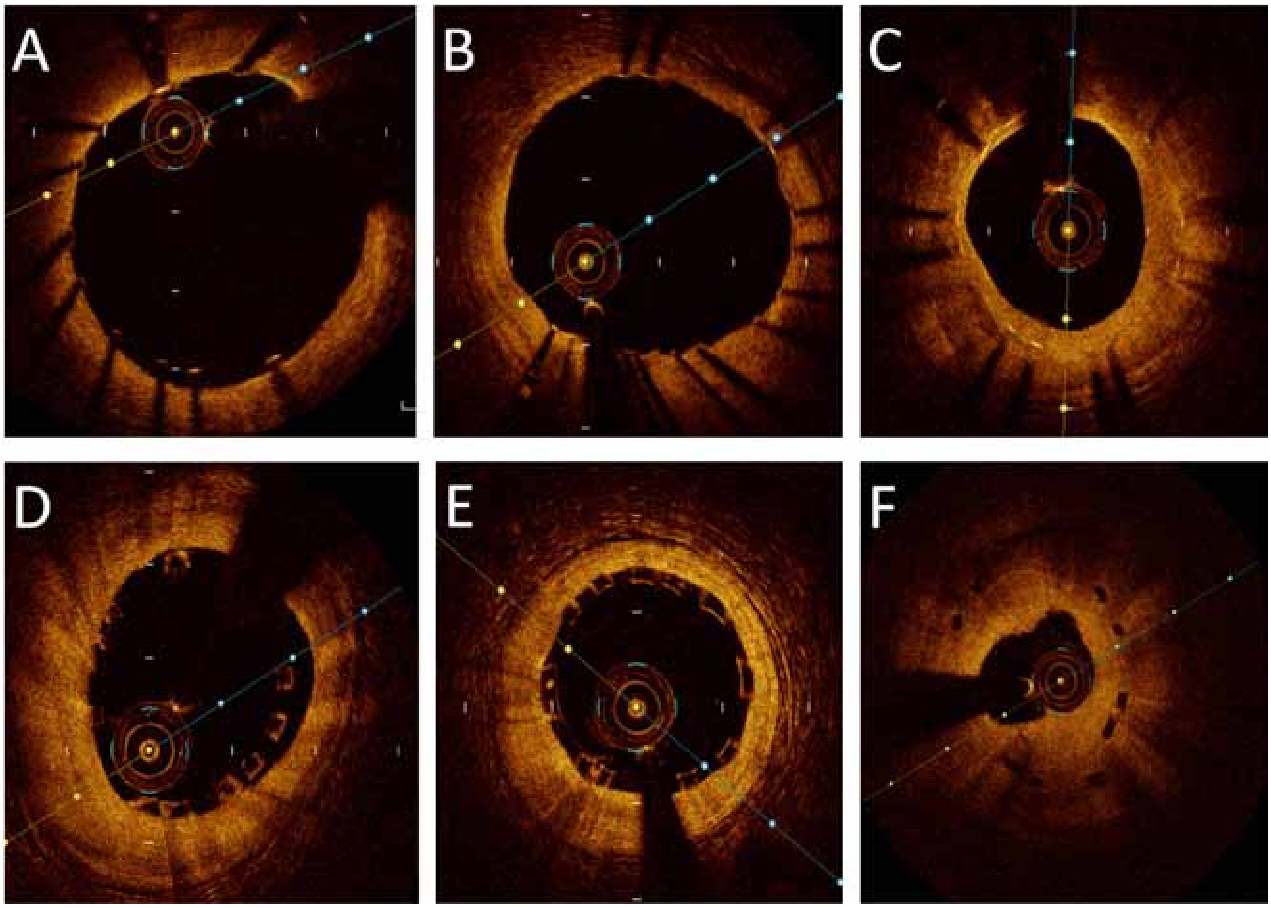

Figure 3. Optical coherence tomography images immediately post-PCI and follow-up imaging of coronary stents. (A) malapposed stent, (B) Well-apposed stent, (C) In-stent restenosis, (D) malapposed bioresorbable vascular scaffold (BVS) restenosis, (E)Well-apposed BVS, (F) BVS restenosis.

Table 2. Comparison of characterization of pathology using OCT and IVUS

	OCT	IVUS
Lipid core	+++	++
Fibrous plaque	+++	+
Thrombus	++	+
Calcium	++	+++
Dissection	+++	++
Stent apposition	+++	++
Stent strut surface coverage	+++	+
Thin-cap fibroatheroma	+++	-
Ostial lesion evaluation	+	++
Plaque burden	+	+++

+++ = *excellent capability*; ++ = *good capability*; + = *poor capability*; - = *impossible*.

Though OCT offer high-resolution arterial wall imaging, there are some limitations.

The main limitation of OCT is poor penetration power and provide between 0.5 and 1.5 mm of imaging depth. If the thickness of plaque burden exceeds than 1.5 mm, it does not allow visualization of the media and adventitia well and hampers the evaluation of vessel wall remodeling[11-13]. The second limitation OCT is that OCT requires clearing or flushing blood from the lumen. In severe stenosis lesion, the probe of OCT may occlude vessels and disturb image acquisition and interpretation. In addition, measurement of severity of plaques in large-diameter vessels located at aorto-ostial locations is difficult to assess with the current stage of technology.

References

1. Huang D, Swanson EA, Lin CP, et al. Optical coherence tomography. Science 1991; 254: 1178-81.
2. Gonzalo N, Tearney GJ, Serruys PW, et al. Second-generation optical coherence tomography in clinical practice. High-speed data acquisition is highly reproducible in patients undergoing percutaneous coronary intervention. Rev Esp Cardiol 2010; 63: 893-903.
3. Herrero-Garibi J, Cruz-Gonzalez I, Parejo-Diaz P, et al. Optical coherence tomography: its value in intravascular diagnosis today. Rev Esp Cardiol 2010; 63: 951-62.
4. Abtahian F, Jang IK. Optical coherence tomography: basics, current application and future potential. Curr Opin Pharmacol 2012; 12: 583-91.
5. Gutierrez-Chico JL, Alegria-Barrero E, Teijeiro-Mestre R, et al. Optical coherence tomography: from research to practice. Eur Heart J Cardiovasc Imaging 2012; 13: 370-84.
6. Tearney GJ, Regar E, Akasaka T, et al. Consensus standards for acquisition, measurement, and reporting of intravascular optical coherence tomography studies: a report from the International Working Group for Intravascular Optical Coherence Tomography Standardization and Validation. J Am Coll Cardiol 2012; 59: 1058-72.
7. Terashima M, Kaneda H, Suzuki T. The role of optical coherence tomography in coronary intervention. Korean J Intern Med 2012; 27: 1-12.
8. Kume T, Akasaka T, Kawamoto T, et al. Assessment of coronary arterial plaque by optical coherence tomography. Am J Cardiol 2006; 97: 1172-5.
9. Kume T, Akasaka T, Kawamoto T, et al. Measurement of the thickness of the fibrous cap by optical coherence tomography. Am Heart J 2006; 152: 755 e1-4.
10. Kume T, Akasaka T, Kawamoto T, et al. Assessment of coronary arterial thrombus by optical coherence tomography. Am J Cardiol 2006; 97: 1713-7.
11. Bezerra HG, Attizzani GF, Sirbu V, et al. Optical coherence tomography versus intravascular ultrasound to evaluate coronary artery disease and percutaneous coronary intervention. JACC Cardiovasc Interv 2013; 6: 228-36.
12. Waksman R, Kitabata H, Prati F, et al. Intravascular ultrasound versus optical coherence tomography guidance. J Am Coll Cardiol 2013; 62: S32-40.
13. Magnus PC, Jayne JE, Garcia-Garcia HM, et al. Optical coherence tomography versus intravascular ultrasound in the evaluation of observer variability and reliability in the assessment of stent deployment: the OCTIVUS study. Catheter Cardiovasc Interv 2015; 86: 229-35.

光學同調斷層掃瞄在臨床上的應用

林岳鴻[1,2] 蔡政廷[1,2] 洪大川[1,2]

[1]馬偕紀念醫院 心血管中心冠狀動脈暨周邊介入醫學科
[2]馬偕醫學院 醫學系

摘 要

血管內超音波(Intracoronary ultrasound, IVUS)已廣泛地應用於介入性心導管治療，光學同調斷層掃瞄(Optical Coherence Tomography, OCT)是一種結合紅外線與雷射掃描技術結合的層析成像技術，OCT擁有比IVUS更高的影像解析度，能夠更準確的評估冠狀動脈狹窄程度、動脈斑塊性質及提供冠狀動脈支架置放資訊，本文回顧了OCT於臨床上之應用。