Image Acquisition Techniques

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In recent times, clinical usefulness of optical coherence tomography (OCT) is showing greater potential in the intracoronary imaging field. In this chapter, we will discuss about basic characteristics and imaging acquisition technique during Frequency-domain OCT (FD-OCT) examination.

11.1 Introduction

Optical coherence tomography (OCT) is a catheter-based invasive coronary imaging system. Using light source instead of ultrasound, OCT provided high-resolution coronary plaque image and state of deployed stent. Naohiro Tanno and James G. Fujimoto developed OCT in 1991

[1], and they first performed OCT on the human retina. Intravascular OCT was performed in 2002 (Fig. 11.1) [2, 3]. Intravascular OCT requires a single fiber-optic wire that both emits light and records the reflection while being simultaneously rotated and pulled back along the coronary artery [4]. As compared to intravascular ultrasound (IVUS), OCT provided ten times higher resolution (10–15 versus 100 μm). OCT cannot be able to make an image through the blood and more shorter penetration into the tissue (2 versus 1 cm) compared to IVUS [2, 5]. However, OCT provided high-resolution image of coronary plaque and detailed information of coronary atherosclerosis (Table 11.1), which may aid in future diagnosis and treatment of coronary artery disease.

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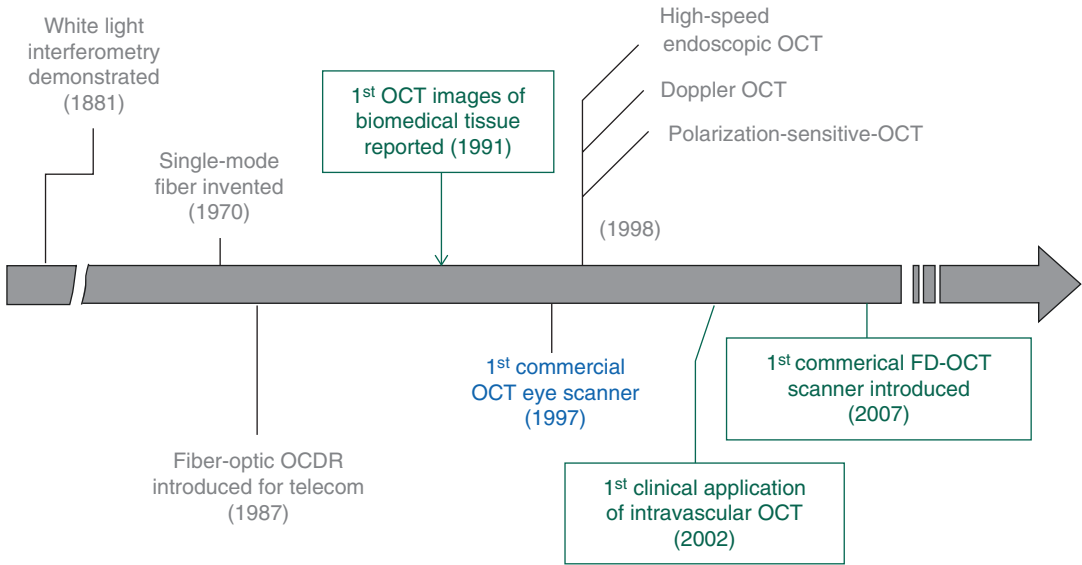e-mail: kiseok@jejunu.ac.kr

White light
interferometry
demonstrated
(1881)

Single-mode
fiber invented
(1970)

1st OCT images of
biomedical tissue
reported (1991)

High-speed
endoscopic OCT

Doppler OCT

Polarization-sensitive-OCT

(1998)

1st commercial
OCT eye scanner
(1997)

1st commerical FD-OCT
scanner introduced
(2007)

Fiber-optic OCDR
introduced for telecom
(1987)

1st clinical application
of intravascular OCT
(2002)

Fig. 11.1 History of the OCT development. Naohiro Tanno and James G. Fujimoto developed OCT in 1991, and they first performed OCT on the human retina. Intravascular OCT was performed in 2002. The first commercial second-generation FD-OCT introduced in 2007, which overcomes the limitation of TD-OCT system

Table 11.1 Performance comparison between intravascular ultrasound (IVUS) and frequency-domain optical coherence tomography (FD-OCT)

	IVUS	FD-OCT
Axial resolution (μm)	100–200	12–15
Beam width	200–300	20–40
Frame rate (frames/s)	30	100
Pullback speed (mm/s)	0.5–1	20
Scan diameter (mm)	15	10
Tissue penetration (mm)	10	1.0–2.0
Line per frame	256	500
Lateral sampling (μm)	225	19
Frame rate (frames/s)	Not required	Required

11.2   History of OCT Development

Intracoronary OCT catheter is connected to a rotary junction, which uses a motor to rotate the optical fiber in the catheter and couples light from this rotating fiber to light from the reference arm [6]. The rotary junction mounted to an automated pullback device (Fig. 11.2). There are two types of OCT system: time domain and frequency domain. The first-generation OCT is time domain (TD-OCT) which requires balloon occlusion in the proximal
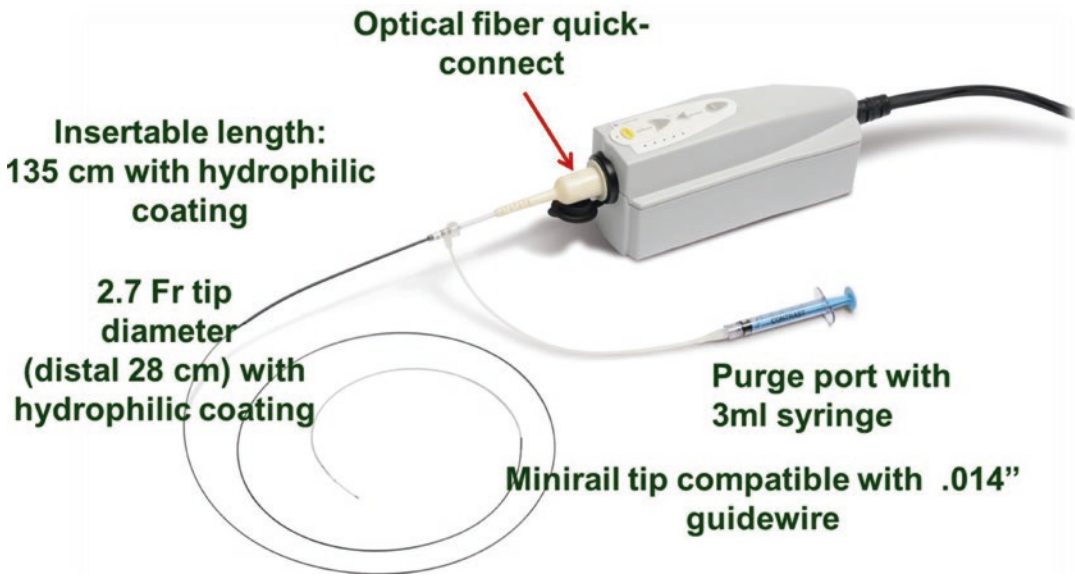
Fig. 11.2 Dragonfly OCT catheter and DOC system. Intracoronary OCT catheter connected to a rotary junction, which uses a motor to rotate the optical fiber in the catheter and couples light from this rotating fiber to light from reference arm. The rotary junction mounts to an automated pullback device

vessel, which provides blood clearing during image generation. The problem of TD-OCT was prolonged examination time, shorter lengths of imaging segment, and intermediate imaging quality [7]. The first commercial second-generation FD-OCT was introduced in 2007, which overcomes the limitation of the TD-OCT system (Tables 11.2 and 11.3) [8].

Table 11.2 Difference of time-domain versus frequency-domain optical coherence tomography (OCT)

	TD-OCT	FD-OCT
Scan method	Mechanically scans a reference mirror	Electronically scans the laser wavelength
Imaging speed	Slow	Fast
Image quality	Moderate	Exceptional

TD-OCT Time-domain OCT, *FD-OCT* frequency-domain OCT

Table 11.3 Performance comparison between TD-OCT and FD-OCT

	TD-OCT	FD-OCT
Axial resolution (μm)	12–15	15–20
Frame rate (frames/s)	100	15–20
Pullback speed (mm/s)	20	2–3
Scan diameter (mm)	10	6.8
Tissue penetration (mm)	1.0–2.0	1.0–2.0
Line per frame	500	200
Lateral sampling (μm)	19	39

TD-OCT Time-domain OCT, *FD-OCT* frequency-domain OCT, *s* second

11.3 Principle of FD-OCT Image Acquisition

Using the FD-OCT system, the OCT probe is first positioned over a regular guidewire, distal to the region of interest. Identification of the pullback starting point is a simple task as a dedicated marker identifies the exact position of the OCT beam, located at 20 mm proximal to the marker itself. When the OCT catheter is positioned and blood clearance is visually obtained distally through the contrast injection, the acquisition of a rapid OCT image sequence with fast pullback can be automatically commenced by injecting a bolus of solution through the guiding catheter, with the pullback speed of 20 mm/s (Fig. 11.3). The infusion rate of contrast is usually set to 3–4 ml/s for the left coronary artery and 2–3 ml/s for the right coronary, but can be modified based on the vessel runoff and size. This contrast agent is recommended for low arrhythmogenic potential and high viscosity, which help to prolong imaging time [9]. Most expert users advocate the use of automated contrast injection to optimize image quality. The pullback can start automatically when blood clearance is distally recognized or can be manually activated. An acquisition speed of 20 mm/s enables the acquisition of 200 cross-sectional image frames over a 5 cm length of artery in 2.5 s with a total infused volume of 14 ml of contrast [4]. This may represent a concrete advantage of FD-OCT for use in percutaneous
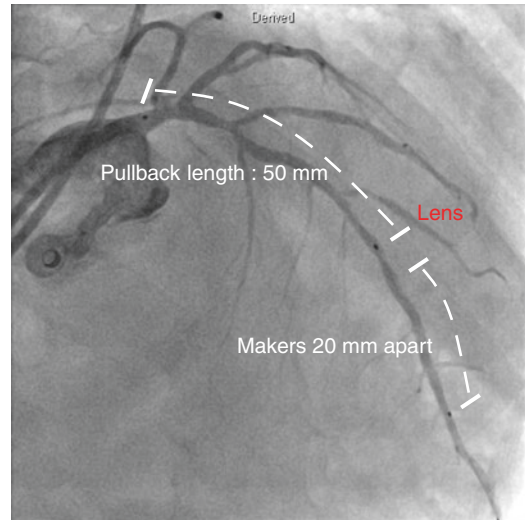

Fig. 11.3 OCT imaging catheter insertion and positioning. Using the FD-OCT system, the OCT probe is first positioned over a regular guidewire, distal to the region of interest. Identification of the pullback starting point is a simple task as a dedicated marker identifies the exact position of the OCT beam, located at 20 mm proximal to the marker itself

coronary interventions (PCI), allowing quick evaluation of the stent and of the landing zones and avoiding geographical miss. The FD-OCT pullback speed is too fast to interpret the run during the acquisition, but the recorded images are stored digitally and can be reviewed in a slow playback loop [10].

11.4 FD-OCT Image Acquisition Protocol

The St. Jude Medical OCT system and the Dragonfly intravascular imaging catheter are used to perform OCT intravascular imaging after intracoronary injection of 200 μg of nitroglycerin through conventional 6 Fr guiding catheters without side hole. A 0.014 in guidewire is positioned distal to the region of interest. The Dragonfly catheter is wiped proximal to the shaft to activate hydrophilic coating and gently purge the catheter with 100% contrast until three drops exit the
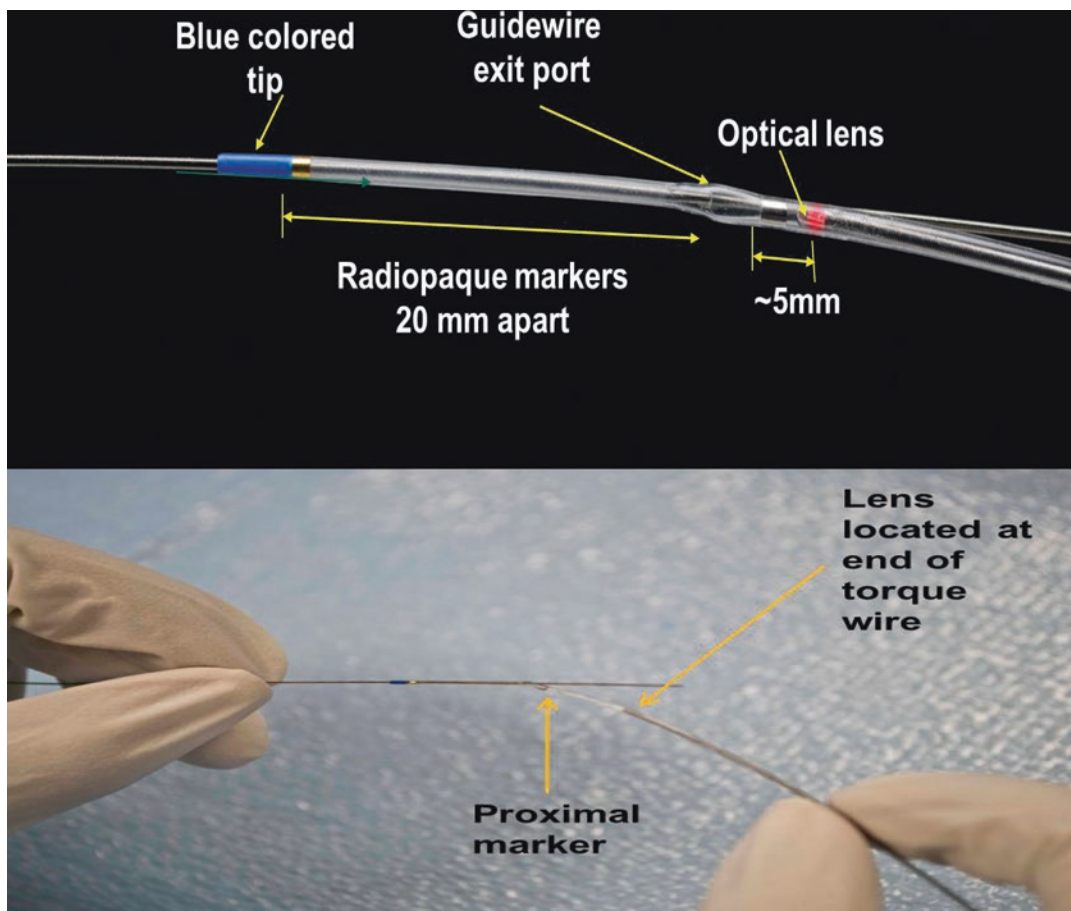
Fig. 11.4 OCT imaging catheter preparation. The Dragonfly catheter is wiped proximal to the shaft to activate hydrophilic coating and gently purge catheter with 100% contrast until three drops exit the catheter tip. The guidewire is then back-loaded through the blue tip and out of the exit port on the Dragonfly catheter. A slight bend is recommended to help ease the guidewire out of the exit portal

catheter tip. The guidewire is then back-loaded through the blue tip and out of the exit port on the Dragonfly catheter. A slight bend is recommended to help ease the guidewire out of the exit portal (Fig. 11.4). The Dragonfly catheter is advanced until the proximal radiopaque marker is distal to the target lesion. A test injection of 1–2 cc of 100% contrast is used to ensure guide catheter positioning. Before pullback procedure, purging is necessary to remove residual blood in the catheter lumen (Fig. 11.5a, b). During live scan, use a puff of contrast to evaluate clarity (Fig. 11.5c, d). Once the pullback is enabled on the system, the coronary blood flow is replaced by continuous flushing of 100% contrast media using a power injector or manual injection. The system labeling suggests power injector settings of 14 ml of total volume at 4 ml/s rate at 300 psi and 0 rise. We recommend these settings for the left anterior descending (LAD) and left circumflex (LCX) arteries and 12 ml of total volume at 4 ml/s rate at 300 psi and 0 rise for the right coronary artery (RCA). We find these settings to provide consistent, high-quality images. Measurements are performed using the system after proper calibration settings of the Z-offset [11].

Fig. 11.5 OCT imaging catheter preparation before pullback procedure. Before pullback procedure, purging is necessary to remove residual blood in the catheter lumen (**a**, **b**). During live scan, use a puff of contrast to evaluate clarity (**c**, **d**)
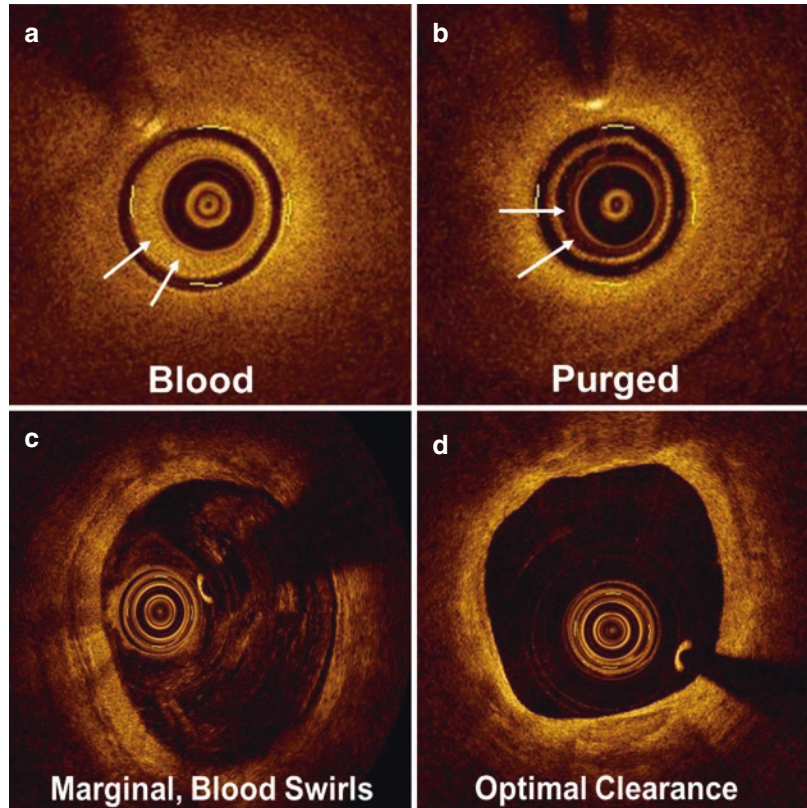
11.5   FD-OCT Imaging Acquisition: Tips and Trick

In our experience, the fiber-optic OCT catheter is softer and less amenable to pulling than the IVUS catheter, and even the diameter (2.7 Fr) is less than IVUS. Before the operator advances the fiber-optic catheter, 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. Vessel sizes range from 2.0 to 3.75 mm in diameter, which is ideal for OCT imaging. Thus, operators should be aware of "out-of-screen" loss of image, 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 (Table 11.4).

Table 11.4 Summary of optical coherence tomography mage acquisitioni

Do not use less than 6 Fr guiding catheter and side-hole guiding catheter
Use soft standard 0.014″ coronary guidewire
Diffuse, long, calcified, or bending lesion should be carefully prepared
Ideal vessel size is 2.0–3.75 mm in diameter
To ensure firm catheter engagement with good coaxial alignment can avoid blood attenuation
Inject non-diluted iodine contrast at rates of 3–5 ml/s in 4–5 s

11.6 Artifact of OCT

Residual blood attenuates the OCT light beam and may defocus the beam if red cell density is high. This will reduce brightness of the vessel wall, especially at large radial distances from the image wire. Blood swirls are caused by turbulent flow between flushing contrast fluid and blood. Flush fluid dose not filling the vessel lumen or end of bolus flush injection (Fig. 11.6a). Blood Speckling occurred by red blood cell (RBC) mixed into flush fluid or diluted with saline make less viscosity, which does not remove all RBS during image formation (Fig. 11.6b).
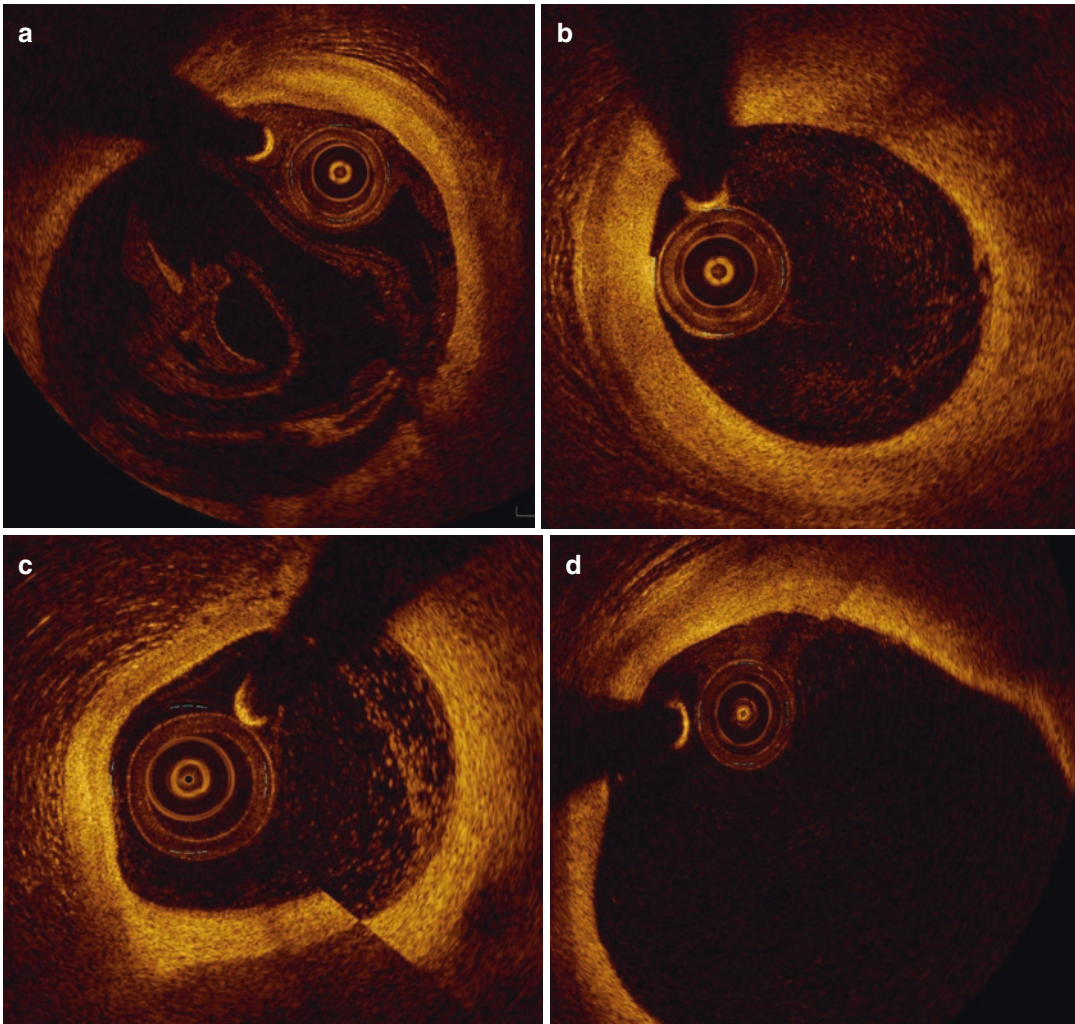
Fig. 11.6 Imaging artifact during pullback procedure. Blood swirls is caused by turbulent flow between flushing contrast fluid and blood. Flush fluid is not filled in the vessel lumen or the bolus injection of contrast is ended (**a**). Blood speckling occurs by red blood cell (RBC) mixed into flush fluid or diluted with saline make less viscosity, which does not remove all RBS during image formation (**b**). Sew-up artifact is the result of rapid artery or imaging wire movement in single-frame imaging formation, leading to single-point misalignment of the lumen border (**c**). Fold-over artifact is more specific to the new generation of FD-OCT. Typical examples are side branch and large vessels (**d**)

Sew-up artifact is the result of rapid artery or imaging wire movement in single-frame imaging formation, leading to single-point misalignment of the lumen border (Fig. 11.6c).

Fold-over artifact is more specific to the new generation of FD-OCT. It is the consequence of the "phase wrapping" or "alias" along the Fourier transformation when structure signals are reflected from outside the system's field of view. Typical examples are side branch and large vessels (Fig. 11.6d).

11.7 Summary

The advanced FD-OCT system provides more detailed coronary plaque information to plan an appropriate PCI procedure. A recent clinical trial (ILUMIEN III) has shown that OCT-guided PCI is not inferior to IVUS-guided PCI. Precise FD-OCT catheter manipulation and imaging acquisition technique will provide coronary vessel information and improve PCI outcomes.

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