Intravascular optical coherence tomography (OCT) is a recently developed technology that is becoming more and more increasingly available in the catheter laboratories. OCT is an easy and safe tool that can provide the operator with many valuable information aiding intervention and making the intervention safer and more predictable. OCT can guide all steps of intervention including target lesion assessment before intervention, stent selection, stent optimization, and post-stenting assessment. This review will summarize the role of OCT in guiding percutaneous coronary intervention.

KEY WORDS: coronary artery disease, optical coherence tomography, percutaneous coronary intervention, stent
after balloon angioplasty were >227° for the calcium arc, and < 0.67 mm for the thickness\(^7\). Another report stated that if there is more than 90° arc free of calcium, adequate stent expansion can be expected.

4. Unstable plaques

Most patients with acute coronary syndrome (ACS) exhibit thrombus overlying a complicated coronary plaque\(^8, 9\). Although plaque rupture is considered the most frequent (60–70%) plaque characteristics responsible for ACS, alternative mechanisms of plaque instability triggering coronary thrombosis do exist\(^10\). Among these, plaque erosion accounts for 20–30% of cases, and calcified nodules for 5–8% of cases\(^9\). OCT can differentiate between different plaque characteristics as an etiology for ACS and further guide the treatment strategy.

Plaque rupture is associated with higher incidence of no reflow and distal embolization following percutaneous coronary intervention (PCI) and a larger infarct size compared with plaque erosion\(^13\). ACS caused by plaque erosion is potentially stabilized by anti-thrombotic therapy without stent implantation\(^13\). Calcified nodule is associated with stent under-expansion, which increases the risk of in-stent restenosis and thrombosis, which also

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Fig. 1  Plaque tissue characterization.
A: Lipid plaque (star) with thin fibrous cap (arrows).
B: Calcified plaque with circumferential calcium (open circles).
C: Fibrous plaque (closed circle).
Asterisk indicates wire artifact.

Fig. 2  Unstable plaques.
A: Plaque rupture with fibrous-cap discontinuity (arrow) and cavity formation (star).
B: Plaque erosion with thrombus (open circle) overlying intact vessel wall.
C: Calcified nodule protruding into the lumen (arrowheads).
Asterisk indicated wire artifact.
III. Stent selection

OCT can easily guide selection of the stent during PCI (Fig. 3). For selection of the stent, distal and proximal reference sites are preferably set where there is no lipid or a lipid arc <180°. The frequency of the stent edge restenosis was significantly higher in the stent edge segment with lipid plaque. The lipid arc of 185° in the stent edge segments at post-PCI was optimal cut-off value for predicting stent edge restenosis\(^\text{15}\). Stent diameter is calculated as 9% greater (0.25–0.5 mm size-up) of lumen diameter at distal reference site\(^\text{16,17}\). Stent length is determined by measuring distance between proximal and distal reference sites\(^\text{16,17}\). Using angio-coregistration tool during OCT assessment helps the operator to recognize the best stent edge landing zone on angiogram. One study showed that online coregistration helps to reduce the geographic miss and without coregistration use there is bigger chance for incomplete lesion coverage\(^\text{19}\).

IV. Post stenting optimization

1. Detection of minimum stent area (MSA)

OCT can measure MSA following stent implantation. Soeda T et al. investigated OCT predictors for 1-year major adverse cardiac events (MACE), including cardiac death, target vessel-related myocardial infarction, target lesion revascularization, and stent thrombosis and concluded that the best cutoff value for...
MSA to predict MACE was 5.0 mm$^2$ for drug-eluting stents (DESs) and 5.6 mm$^2$ for bare-metal stents. Also, Matsuo et al. suggested that MSA of 3.5 mm$^2$ is the best cutoff point to predict late (9 month) in-stent restenosis in 2.5 mm everolimus-eluting stents.

2. Stent under expansion

OCT can detect stent under-expansion, which is one of the main determinants of thrombosis in the early phases after DES implantation. Goal after stent deployment is MSA >5.0 mm$^2$ and/or stent expansion index >80%. Online OCT software allows automatic identification of lumen border and stent struts. The lumen profile view provides graphical representation of the luminal area for every frame and facilitates assessment of MSA and stent expansion index through the stent segment (Fig. 4).

3. Stent malapposition

In OCT, stent surface is located at the center of the stent strut blooming. Stent malapposition is defined when the measured distance from the stent surface to the lumen contour is greater than the total thickness of the stent strut + polymer (Fig. 4 and 5A). OCT can predict late-persistent stent malapposition after DES implantation. Shimamura et al. showed that OCT-estimated stent malapposition distance > 355 µm at post stenting was the best cut-off value for predicting late-persistent stent malapposition at 8–12-month after everolimus-eluting stent implantation.

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**Fig. 4** Stent assessment.
A: Angiography co-registration. OCT-determined stent segment and stent malapposition segment (colored red: expansion index <80%) are indicated on the angiogram.
B: Cross-sectional OCT image. Stent struts are automatically detected. Well apposed struts are colored white (white arrowheads), and malapposed struts are colored yellow (malapposition distance = 200–350 µm, yellow arrowheads) or red (malapposition distance >550 µm, red arrowheads).
C: Lumen profile. Once proximal and distal stent edges are set, MSA, minimum EXP, and proximal and distal reference lumen diameters are displayed. In addition, stent segment with EXP <80% are shown in red. In the present case, as the proximal half of the stent is under expanded (the minimum EXP = 65%), post balloon dilatation (the maximum balloon diameter is calculated as 9% greater [0.25 mm size-up] of lumen diameter at proximal reference site) is recommended.
D: Longitudinal OCT image with stent display and stent apposition indicator.
EXP: stent expansion index, MSA: minimum stent area, OCT: optical coherence tomography. Asterisk indicated wire artifact.
4. Edge dissection

Stent edge dissection is defined as a disruption of the luminal vessel surface in the 5-mm length segments adjacent to the stent proximal and distal borders, with either a intimal flap protruding in the lumen and/or a cavity in the vessel wall (Fig. 5B). Non-flow-limiting, small, and superficial dissections left untreated are benign and heal after late follow-up, while flow-limiting dissections warrant further intervention. Goal for post stenting is no or a dissection flap <60°, limited to intima only, and less than 2 mm in length.

5. Tissue protrusion

Tissue protrusion describes convex-shaped tissue prolapse between adjacent stent struts towards the lumen (Fig. 5C). One study showed that there is correlation between irregular tissue protrusion immediately after stent implantation and clinical events at 1-year follow-up, while flow-limiting dissections warrant further intervention. Goal for post stenting is no or a dissection flap <60°, limited to intima only, and less than 2 mm in length.

6. Intra-stent thrombus

Intra-stent thrombus is identified as an intra-stent irregular mass with a signal-free shadow (Fig. 5D). Goal for post stenting is no or minimal residual intra stent thrombus.

V. Bifurcation

OCT is helpful in case of coronary bifurcation PCI in term of predicting possibility of side branch occlusion and thus further wire/balloon protection. In the assessment of the longitudinal image, the narrower carina tip angle (< 50°) and shorter length between proximal branching point to carina tip (< 1.70 mm) are predictors for side branch occlusions after bifurcation stenting (Fig. 6). Also, a calcified plaque in the main branch especially in the opposite side of the side branch ostium is a risk factor for side branch complications.

Three-dimensional OCT image can be used for selection of most distal cell for rewiring of the jailed side branch for kissing balloon angioplasty or further intervention of the side branch (Fig. 7).

VI. Clinical evidences

The ILUMIEN III trial demonstrated that OCT-guided PCI was safe and resulted in similar MSA to that of IVUS-guided PCI. The OPINION trial revealed the non-inferiority of OCT-guided PCI compared with IVUS-guided PCI in terms of 12-month clinical outcomes (defined as a composite of cardiac death, target-vessel related myocardial infarction, and ischemia-driven target vessel revascularization). Recently, a meta-analysis comparing OCT-guided and angiography-guided PCI showed a lower rate of adverse events for the composite of cardiac deaths, myocardial infarction and repeat revascularizations.

VII. Limitations

The wonderful details of OCT images and the safe and fast acquisition with current technology have led to its increase adop-
Fig. 6  Assessment of bifurcation lesion before PCI.
Measurements of carina tip angle (defined as the angle between lumen contour lines of main branch and side branch at the carina, asterisk) and length between proximal branching point to carina tip (star) in longitudinal OCT image.
MB: main branch, OCT: optical coherence tomography, PCI: percutaneous coronary intervention, SB: side branch.

Fig. 7  3D-OCT in bifurcation PCI.
3D-images reconstructed from the OCT pullback through the MV delineates the stent struts implanted in the MV, SB ostium, and guidewire inserted into the SB.
A: The GW to the SB has passed through the stent cell closest to the carina (asterisk) (i.e. proximal crossing). KBT via proximal crossing guidewire is at high risk of stent deformation and incomplete apposition around the ostium of the SB.
B: The GW was re-inserted through the stent cell without inter-strut link at proximal side of the SB ostium (star) (i.e. distal crossing).
C: KBT via distal crossing guidewire resulted in appropriate stent expansion and good apposition around the ostium of the SB.
3D: three-dimensional, GW: guidewire, KBT: kissing balloon technique, MV: main vessel, OCT: optical coherence tomography, PCI: percutaneous coronary intervention, SB: side branch.

It is equally important, however, to be aware of several limitations of current generation OCT systems in order to avoid over- or misinterpretation. First, OCT has a limited penetration depth (1–2 mm) as compared to IVUS (8–10 mm). Therefore, in many cases, no reliable assessment of plaque volume or of disease states of the deeper layers of the vessel wall can be made. Second, OCT has a difficulty in visualization of tissue covered by thrombus. Especially, red thrombus casts a complete shadow over the underlying vessel wall, making any reliable interpretation impossible. Third, OCT requires blood removal for image acquisition by injecting contrast media into coronary artery. Increased volume of contrast media may be an obstacle in patients with chronic kidney disease. This issue can be solved by using low-molecular-weight dextran L instead of contrast media. Finally, chronic total occlusions and coronary artery ostial lesions are not suitable for OCT imaging because the blood removal in the field of view is diffi-
OCT, although still rather a new technology, is now becoming increasingly incorporated into coronary interventions. OCT can provide a lot of valuable information which help operators in decision making and predicting / avoiding complications during PCI. Thus, OCT guidance will lead to better procedure results and better patient outcomes.

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Abbreviation list

| Term     | Description                                                                 |
|----------|-----------------------------------------------------------------------------|
| ACS      | acute coronary syndrome                                                      |
| DES      | drug-eluting stent                                                          |
| FFR      | fractional flow reserve                                                     |
| IVUS     | intravascular ultrasound                                                    |
| MLA      | minimal lumen area                                                           |
| MSA      | minimum stent area                                                           |
| OCT      | optical coherence tomography                                                |
| PCI      | percutaneous coronary intervention                                         |
| TCFA     | thin-cap fibroatheroma                                                      |

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