Application and Practical Use of Optical Coherence Tomography to Guide Percutaneous Coronary Intervention in Clinical Practice

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- Optical coherence tomography
- Instent restenosis
- Thrombus
- Stent thrombosis
- Edge Dissection

Optical Coherence Tomography Imaging 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 F guiding catheters. A 0.014 in guidewire is positioned distal to the region of interest; the guidewire is then back-loaded through the blue tip and out of the exit port on the Dragonfly catheter.

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.

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 labelling suggests power injector settings of 14 cc of total volume at 4 cc/sec rate at 350 psi and 0 rise. We recommend these settings for the left anterior descending (LAD) and left circumflex (LCX) arteries, and 12 cc of total volume at 4 cc/sec rate at 350 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.

Background

While many hundreds of studies have been published utilising coronary artery optical coherence tomography (OCT), very few have focused on the application of OCT in daily clinical practice. The following case studies are intended to help guide physicians on specific clinical situations in which OCT can help optimise physician treatment strategies.

The cardiac cath lab at Mount Sinai Hospital, New York, New York, is a leader in sharing best practices for improving outcomes in complex coronary cases. Mount Sinai has established guidelines to help drive best practices among interventional cardiologists and fellows in the cath lab. OCT has been adopted as an optimal intravascular imaging modality for specific clinical situations in percutaneous coronary intervention (PCI).

The following cases are illustrative, real-life examples of when and how to best implement OCT in the cath lab. These cases highlight the strengths and pitfalls of OCT use in daily clinical practice. While all cases presented were imaged at the Mount Sinai Hospital Catheterization Laboratory, minor changes have been made to clinical details for educational purposes. Images have not been enhanced or manipulated in any way.
Scenario I – In-stent Restenosis

In-stent restenosis (ISR) is a major clinical problem faced in the cath lab. OCT has the capacity to differentiate ISR from other pathologies and can easily distinguish stent struts. OCT may also provide information about the pathology of the restenotic process by identifying features such as calcification or lipid content, which suggests neoatherosclerosis within the stent. In the following two cases, we highlight how the use of OCT can help to guide clinical decision-making when dealing with ISR.

Case 1

**Age:** 47  
**Gender:** Male

**History:** Hypertension, hyperlipidaemia and previous smoking.

- Previous PCI to mid-LAD in 2009 and in 2010 at an outside hospital. The details of these previous PCIs were unknown and it was unclear how many stents had previously been placed.
- The patient presented to Mount Sinai with Canadian Cardiovascular Society (CCS) Class III angina. Exercise myocardial perfusion imaging revealed a small reversible apical perfusion defect.
- Cardiac catheterisation suggested a stenosis in the mid-LAD region (see Figure 1A).
- As seen in Figure 1B, OCT of the stenotic LAD lesion identified two stent layers; both layers appeared to be well-apposed.
- Based on these OCT findings of well-apposed, double-layered stents, clinical decision-making was simplified, with reasonable options including percutaneous transluminal coronary angioplasty (PTCA), bypass surgery or PTCA with potential brachytherapy.
- Following patient consultation with a cardiothoracic surgeon and interventional cardiologist, a cutting balloon PTCA was performed at 10 atmospheres followed by brachytherapy.

Notably, the high resolution of OCT was able to easily define the two layers of stent and prevented us from placing a third layer of stent in this patient.

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**Figure 1A:** Angiographic Appearance of Mid-left Anterior Descending Stenosis

While it was known there had been two previous percutaneous coronary interventions (PCIs) on this vessel, the details of these interventions were not known.

**Figure 1B:** Optical Coherence Tomography Image of Mid-left Anterior Descending Stenosis

Two distinct layers of stent are easily seen. Both stents appear well-apposed. The mechanism of restenosis is appreciated to be prolific neointimal formation. By optical coherence tomography (OCT), the minimal cross-sectional area (CSA) at the stenosis was 0.98 mm².
Case 2
Age: 57
Gender: Male
History: Hypertension, diabetes and hyperlipidaemia.

- This patient was known to have had previous PCI to the distal RCA on two previous occasions with double-layered stents.
- The patient presented with recurrent CCS Class IV angina while receiving four antianginal medications (nitrate, ranolazine, beta-blocker and calcium channel blocker).
- Cardiac catheterisation suggested a stenosis in the distal RCA (see Figure 2A).
- OCT imaging of the distal RCA revealed that the innermost stent (most recently deployed) was significantly underexpanded (see Figure 2B).
- A high-pressure, non-compliant balloon was used to expand the inner stent.
- Unlike Case 1, and given the issue of suboptimal placement of the previous innermost stent with underexpansion, these options were considered preferable to bypass surgery or initial brachytherapy.

In this patient, the resolution of OCT was able to easily identify the two layers of stent and define underexpansion of the innermost stent as a significant issue.
Scenario II – Assessment of Calcified Lesions
Calcification is another major problem faced in the cath lab. The ability to adequately assess and treat calcified lesions is critical to the success of any PCI programme. While gross arterial calcification may be appreciated by fluoroscopy, in many instances calcification may be more subtle. Here, OCT can be invaluable for assessing these lesions and planning an appropriate PCI strategy.

Case 3
Age: 47
Gender: Male
History: Hypertension, diabetes, hyperlipidaemia and smoking. Presented with CCS Class I angina and dyspnoea on exertion.

- Initial coronary computed tomography (CT) angiography performed by the patient’s primary care physician was suggestive of a stenosis of the LAD.
- Subsequent non-invasive nuclear stress testing was suggestive of inferior ischaemia; although balanced ischaemia involving other territories could not be excluded.
- Cardiac catheterisation revealed a segmental 70–80 % stenosis in the proximal LAD (Figure 3A) and total occlusion of the RCA. Only mild LAD calcification was appreciated based on the angiographic appearance.
- As seen in Figure 3B, OCT of the stenotic LAD revealed severe concentric calcification with a minimal cross-sectional area (CSA) of 1.97 mm².
- These findings were confirmed by intravascular ultrasound (IVUS) (see Figure 3C).
- Based on these OCT findings of severe concentric calcification, the lesion was treated by Rotablator™ rotational atherectomy system (Boston Scientific Corporation, Marlborough, MA, USA) prior to stent implantation.

In this case, OCT helped to define severe calcification and lesion severity, guiding the choice of an aggressive debulking strategy that was used to successfully treat this lesion.
Scenario III – Thrombosis

Plaque rupture with arterial thrombosis is the underlying event in most cases of acute coronary syndrome (ACS). Although it is not necessary to perform OCT for the majority of PCIs performed in the setting of ACS, it is important to appreciate the excellent sensitivity of this imaging tool to detect intra-arterial thrombus. In certain cases, OCT can play an important role in guiding interventional decision-making with respect to thrombus burden and PCI. For example, in a patient with ACS and multiple lesions, OCT can be used to distinguish between a culprit lesion with fresh thrombus versus a chronic total occlusion. Prior to stent implantation, OCT can also assess the success of thrombus aspiration or disruption.

Case 4

Age: 51
Gender: Female

History: Hypertension and previous deep vein thrombosis. Presented with new onset, prolonged substernal chest pain at rest (CCS Class IV) and an elevated troponin I of 0.7, consistent with non-ST-segment myocardial infarction.

- Cardiac catheterisation demonstrated a hazy stenosis in the proximal RCA, with a tail-like filling defect on the downstream side of the lesion suggestive of thrombus (see Figure 4A).
- The operators began to perform PCI. After anticoagulation and wiring of the lesion, a manual thrombus aspiration device was used to reduce the thrombotic burden.
- Following thrombus aspiration, angiography revealed a marked resolution of the previously hazy stenosis with good distal flow (see Figure 4B).
- OCT of the proximal RCA was then performed to evaluate the extent of residual thrombus and the length of the underlying plaque prior to stent implantation (see Figure 4C). OCT revealed only a minimal residual thrombus burden and a minimal CSA of 2.9 mm².
- The lesion was then successfully stented with a 3.5 x 12 mm stent.
- OCT was performed again after stenting (not shown), revealing a well-apposed stent with minimal CSA of 8.5 mm².

In this PCI case, OCT confirmed adequate thrombus removal prior to stenting, which helped to guide stent size by assessing lesion length and vessel diameter and, finally, confirming optimal stent deployment post-PCI.
Case 5
Age: 33
Gender: Male
History: Coronary artery disease but no other cardiovascular risk factors. Presented with a four-hour history of severe chest pain and an electrocardiogram (EKG) consistent with an acute ST-segment elevation anterior myocardial infarction.

- Urgent cardiac catheterisation demonstrated complete occlusion of the proximal LAD (see Figure 5A).
- The operators began to perform PCI. After anticoagulation and wiring of the lesion, a manual thrombus aspiration device was used to reduce the thrombotic burden.
- Following thrombus aspiration, angiography suggested a marked resolution of the previously hazy stenosis, with good distal flow (see Figure 5B).
- OCT was then performed revealing a significant residual thrombus burden (see Figure 5C).
- On the basis of OCT, further manual aspiration thrombectomy was performed.
- Ultimately a 4.0 x 15 mm stent was placed across the lesion.
- Final OCT (not shown) revealed a well-apposed stent with no residual thrombus.
- OCT aided physician decision-making by identifying residual thrombus, guiding stent size and confirming stent deployment post-PCI.

Cases 4 and 5 highlight the use of OCT to define adequacy of thrombus removal prior to stent implantation. While the efficacy of this practice remains to be demonstrated in large clinical trials, the rationale is that distal embolisation is minimised by reducing the thrombus load at the time of stent deployment.

Figure 5A: Urgent Angiography was Performed in this Patient with Acute Anterior ST-segment Elevation Myocardial Infarction

Figure 5B: Further Angiographic Images Acquired After Manual Thrombus Aspiration Showed a Large Left Anterior Descending with Good Distal Flow

Figure 5C: Optical Coherence Tomography Demonstrated Significant Residual Thrombus at the Site of the Prior Left Anterior Descending Occlusion

Angiographically, there appears to have been very successful thrombus removal from the site of the prior occlusion.

On the basis of this optical coherence tomography (OCT)-defined thrombus, further manual aspiration was performed prior to stent implantation.
Scenario IV – Stent Deployment and Malapposition

Optimal stent deployment is an important aspect of successful PCI because it has been well documented that stent malapposition can lead to subsequent stent thrombosis. The superior resolution of OCT (10–20 μm) gives it the distinct advantage of being able to reveal other vascular details that are beyond the capacity of IVUS (100–150 μm), such as tissue prolapse between stent struts or distal edge dissection.

Case 6

Age: 62
Gender: Male

History: Prior myocardial infarction, controlled hypertension, diabetes, hyperlipidaemia, a family history of coronary artery disease and prior stroke. Presented with CCS Class II angina while receiving two antianginal medications (verapamil and long-acting nitrate).

- Cardiac catheterisation demonstrated a long, tubular stenosis of the proximal mid-LAD with minimal CSA demonstrated by an OCT of 1.9 mm² (not shown).
- PCI was performed with placement of a 3.0 x 38 mm stent and a very satisfactory result by angiography was achieved (see Figure 6A).
- OCT was performed after stent implantation; however, revealed gross stent malapposition (see Figure 6B).
- Based on OCT, the stent was post-dilated using a 4.0 x 15 mm non-compliant balloon.
- Final OCT after post-dilation showed optimal stent apposition (see Figure 6C).

In this case, OCT was able to diagnose stent malapposition and was used to guide the post-dilation strategy. OCT also confirmed optimal final stent apposition.
Scenario V – Stent Deployment and Edge Dissection

As an example of the utility of OCT and the superior resolution of this technology, it has become possible to diagnose potentially important problems after stent deployment; such as edge dissection, tissue prolapse or lack of lesion coverage. The significance of these findings remains to be demonstrated, although we have found it is not uncommon to find subtle examples of these problems after stent deployment that appear to be of little or no clinical consequence. However, when OCT imaging identifies a major problem after stent deployment, such as the case below, generally our practice is to address this issue.

Case 7

Age: 47
Gender: Male

History: Hypertension. Presented to an outside hospital and was ruled in for non-ST-segment myocardial infarction with a peak troponin I of 9.95 and an EKG showing inferior T-wave inversion.

- Cardiac catheterisation demonstrated the culprit lesion to be a thrombotic total occlusion of the right posterior descending artery (RPDA) branch, with an additional long 80–90% lesion in the proximal RCA with a pre-PCI minimal CSA of 2.0 mm² by OCT (not shown).
- A single 3.0 x 38 mm stent was deployed across the proximal RCA lesion at 10 atmospheres.
- Angiography suggested a well-deployed stent with no appreciable issues at the distal edge of the stent (see Figure 7A). OCT, however, showed a significant distal edge dissection (see Figure 7B).
- Even though it was not seen on angiography, based on the OCT findings a decision was made to implant a second overlapping stent. A 3.0 x 23 mm stent was then deployed in the mid-RCA, overlapping with the first stent and covering the edge dissection (see Figure 7C).
- Final OCT demonstrated complete coverage of the dissected region and good apposition of the stented segment (see Figure 7D).
- OCT was also used to guide PCI of the culprit occlusion of the RPDA, which was completed uneventfully.

In this case, OCT was able to diagnose a significant distal edge dissection, guide the decision to implant a second stent and optimise PCI of the additional RPDA lesion.

Figure 7A: Angiographic Appearance After Initial Percutaneous Coronary Intervention and Stent Implantation in the Proximal Right Coronary Artery

Figure 7B: Optical Coherence Tomography of the Distal Stent Edge Demonstrated a Significant Dissection Flap Extending Partway into the Lumen

Figure 7C: Based on the Optical Coherence Tomography Results, a Second Stent was then Deployed in the Mid-right Coronary Artery, Overlapping with the Proximal Right Coronary Artery Stent and Providing Complete Coverage of the Edge Dissection

Figure 7D: Final Optical Coherence Tomography Image Showed Coverage of the Dissection Flap at the Distal Edge of the Proximal Right Coronary Artery Stent and Good Stent Apposition

Angiography did not indicate the significant distal edge dissection in this case. The red circle indicates the site of the distal edge dissection.
Scenario VI – Bifurcation Lesion Assessment and Percutaneous Coronary Intervention

Bifurcation stenting remains one of the more technically challenging tasks in interventional cardiology. A major aspect in approaching a bifurcation PCI is choosing between a single versus a dual stent strategy. In our experience, lesion features most likely to require a two-stent approach include ostial side branch disease and a large diameter side branch (≥ 2.5 mm) subtending a large region of myocardium. OCT has the ability to assist in defining these characteristics and aid in the selection of a bifurcation stent strategy. It can also be of value for assessing the post-PCI result including any ‘pinch’ of the side branch ostium. While it often appears adequate to only perform OCT of the main vessel, prior to PCI we are increasingly performing OCT of both the main vessel and side branch, as we have found instances where main vessel imaging (by OCT, IVUS or other modality) does not adequately define the true side branch anatomy. If only a single vessel is to undergo pre-PCI OCT imaging, then imaging of the side branch is often the most informative and helpful in planning the PCI strategy.

Case 8

Age: 63
Gender: Female
History: Hypertension, hyperlipidaemia and asthma. Presented with progressive CCS Class III angina and was found to have a positive exercise EKG stress test.

- Cardiac catheterisation demonstrated single-vessel coronary artery disease with a bifurcation lesion involving the LAD and first diagonal branch (D1) (see Figure 8A).
- OCT was performed to better define the lesion and its anatomy (see Figure 8B), revealing a moderate stenosis of the D1 ostium. Although in this case selective OCT of the D1 branch was not performed, based on the degree of stenosis at the D1 ostium, the D1 diameter and the amount of myocardium subtended, a decision was made to proceed with a two-stent strategy.
- After predilation, a T-stenting with mini-crush technique was chosen. First a 2.5 x 15 mm drug-eluting stent was deployed in the D1 branch with slight protrusion back into the LAD. A 3.5 x 18 mm drug-eluting stent was then deployed in the LAD across the D1 ostium. The D1 was then recrossed with the guidewire, and the procedure completed with final kissing balloon dilation with good final angiographic result (see Figure 8C).
- Final OCT demonstrated complete coverage of carina with widely expanded stents and a lack of residual stent struts in the LAD/D1 lumen (see Figure 8D).

Although our preference is to perform OCT of both the side branch and main vessel, even by imaging only the main vessel OCT was able to aid in the correct selection of a bifurcation stent strategy and confirm proper expansion of the carina post-PCI.
Conclusions

There are many practical uses for OCT in the modern cath lab. As the complexity of lesions treated and the number of devices used continue to increase, applications for OCT are certain to expand. OCT offers several distinct advantages over IVUS and other imaging modalities. In particular, the increased resolution of OCT sets the stage for its use in imaging a wealth of scenarios. We have found that OCT is particularly helpful for situations where fine tissue resolution is required – such as imaging edge dissections, tissue prolapse with stents and thrombus. Furthermore, as illustrated, here we have found that the improved resolution of OCT often provides superior information to traditional IVUS.

In summary, we have presented a series of cases in which the practical use of OCT helped to define lesion pathology, guide interventional treatment and assess post-procedural results. We believe that OCT is an extremely useful addition to any modern cath lab.

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