A Practical Approach to Assessing Stent Results with IVUS or OCT

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ABSTRACT: Coronary angiography is routinely used to assess the extent and severity of coronary artery disease and for decision-making during percutaneous coronary interventions (PCI). However, it is sometimes inadequate for deciding a strategy and defining optimal stenting outcomes. In this review, we present a comprehensive and practical approach to PCI using intravascular ultrasound or optical coherence tomography to optimize stent deployment and assess procedural complications after stent implantation.

INTRODUCTION

There have been a number of studies concluding that intravascular ultrasound (IVUS) assessment of minimum lumen area (MLA) enables the prediction of physiologically significant ischemia evaluated with fractional flow reserve (FFR).[2-11] Moreover, meta-analyses have demonstrated that IVUS-guided percutaneous coronary interventions (PCI) for drug-eluting stent (DES) implantation reduces the risk of death, myocardial infarction (MI), stent thrombosis, and repeat revascularization.[12-16] Optical coherence tomography (OCT) is a second intravascular imaging modality that uses the emission and reflection of light to evaluate coronary vessels. Providing 10 times higher resolution compared with IVUS,[17,18] OCT facilitates the visualization of details including vessel anatomy and plaque morphology. In particular, its ability to determine plaque vulnerability (i.e., thin-cap fibrotic atheroma, high-attenuation plaque, and macrophage accumulation)[19,20] is helpful in deciding a PCI strategy in high-risk patients. As with IVUS, the feasibility and safety of OCT-guided PCI have also been reported.[21-23] Preprocedural OCT evaluation of MLA with a cut-off value of 1.6 to 1.9 mm^2 is predictive of physiologically significant ischemia evaluated with FFR[24,25] and also impacts decision-making with regard to PCI strategy and selection of stent size.[21]

After stent implantation, OCT can help optimize stent placement and detect procedure-related complications. This should be done according to the protocol adopted in the ILUMIEN III trial, which compared OCT-, IVUS-, and angiography-guided PCI.[23] In ILUMIEN III, OCT-guided PCI was performed using a specific stent optimization strategy to establish stent length, diameter, and expansion according to reference segment external elastic lamina measurements. The primary end point was post-PCI minimal stent area measured by OCT, which is closely related to the risk of future stent failure. ILUMIEN III showed that all post-PCI parameters measured by OCT were comparable with those of IVUS and that both OCT and IVUS resulted in better post-PCI minimal stent area (MSA) compared to angiography. In effect, both IVUS and OCT can provide more precise planning and guidance for PCI.

STENT OPTIMIZATION

Stent Underexpansion

A number of IVUS studies demonstrate that the MSA is the strongest predictor of stent thrombosis and restenosis,[26,27] and a larger stent area has been associated with improved outcomes.[13,14] Stent underexpansion, the most significant predictor of stent patency and clinical outcome, is diagnosed when a smaller in-stent lumen area is achieved compared with the reference lumen area. OCT can detect lumen contour and immediately provide luminal measurements in the lesions of interest. However, data regarding post-PCI OCT measurement (MSA, percentage area stenosis, etc.) to predict physiological ischemia or clinical outcomes are still limited pending results from the ongoing large-scale randomized ILUMIEN IV study.[28]

If stent underexpansion is detected, post-dilatation with an appropriately sized noncompliant balloon (based on reference lumen diameter) is recommended (Figure 1). On the other hand, post-dilatation in lesions with eccentric plaque, especially hard plaque, may risk coronary rupture. In such settings, physicians should consider the benefits and risks of further intervention to correct stent underexpansion. However, the most important priority is to avoid stent underexpansion altogether through adequate evaluation of underlying plaque morphology followed by appropriate lesion preparation.[29] In this regard, intravascular imaging can help to decide PCI strategy, including lesion preparation, stent sizing, and stent optimization.

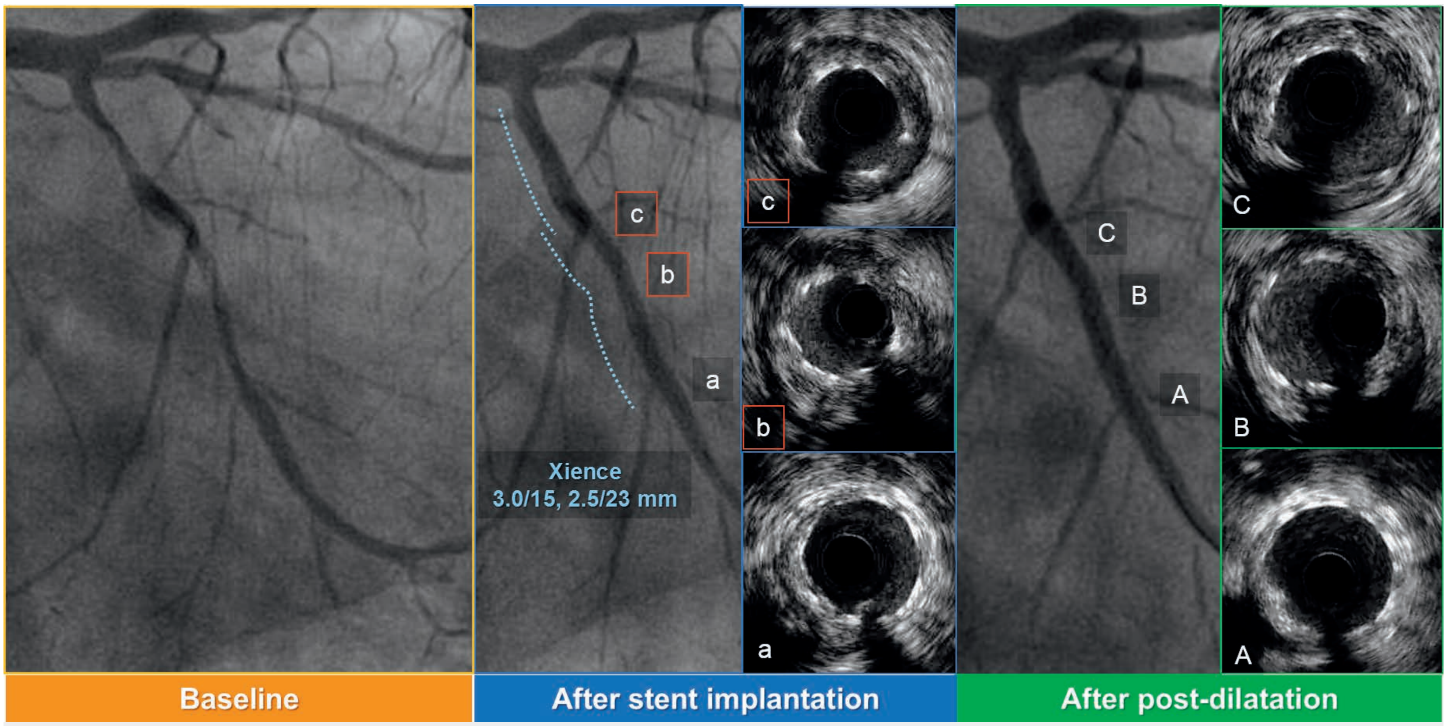

Figure 1.
Intravascular ultrasound (IVUS)-guided post-dilatation for the stent underexpansion. (a-c) IVUS images after stent implantation (b and c show stent underexpansion). Stent area (SA) is 3.45 mm^2 in panel b, 3.81 mm^2 in panel c. (A-C) IVUS images after IVUS-guided post-dilatation with 2.5-mm noncompliant balloon. SA: 4.65 mm^2 in panel B, 6.03 mm^2 in panel C.

Stent Malapposition

Stent malapposition (SM) can be confirmed with IVUS when the stent struts float in the vessel lumen and are not apposed to the vessel wall (Figure 2). Stent malapposition with OCT is more accurate and is confirmed when the struts are not in contact with the vessel wall (Figure 3 and Online Video 1).[30] Substantial malapposition delays stent endothelialization and can be a potential cause of stent thrombosis.[31-33] Malapposition can occur in the presence of eccentric or excessively protruded plaque, severely calcified plaque, or with undersized stent implantation and is most frequently observed at stent edges.[34,35]

During follow-up, some cases of SM can resolve with re-endothelialization. However, due to the multifactorial nature of these events (i.e., stent design, strut thickness, types of polymer, underlying plaque morphology), there is no consensus on the maximum distance between stent struts and vessel lumen that can be associated with endothelialization or adverse events.[32,36] Therefore, the decision to perform further intervention on a SM is most likely left to operator discretion. Once SM is detected, the most frequent correction is post-dilatation with a noncompliant balloon. Selection of appropriate balloon size should, in most cases, be based on reference lumen diameters to avoid stent edge dissections. It is also important to take note of plaque morphology around the stent edge.

PROCEDURE-RELATED COMPLICATIONS

Stent Edge Dissection

Dissection or intramural hematoma are some of the important causes of peri-stent narrowing following implantation. Dissection can occur within the intima (intimal tear) or can reach the media (medial dissection) (Figure 4). As seen in Figure 5, an intramural hematoma can occur with medial dissection, which typically does not have a reentry site. In this case, an imaging study is indispensable to evaluate the location and length, depth (intimal or medial), circumferential and longitudinal extension, side branch involvement, and residual lumen area. Intramural hematoma generally is less likely to propagate since dissection at the proximal edge of the stent is retrograde, and the flap may be suppressed by antegrade flow. However, in cases of distal edge dissection, extreme care should be taken because antegrade dissection may turn into flap dissection and eventually lead to limited blood flow and coronary obstruction. The CLI-OPCI (Centro per la Lotta contro

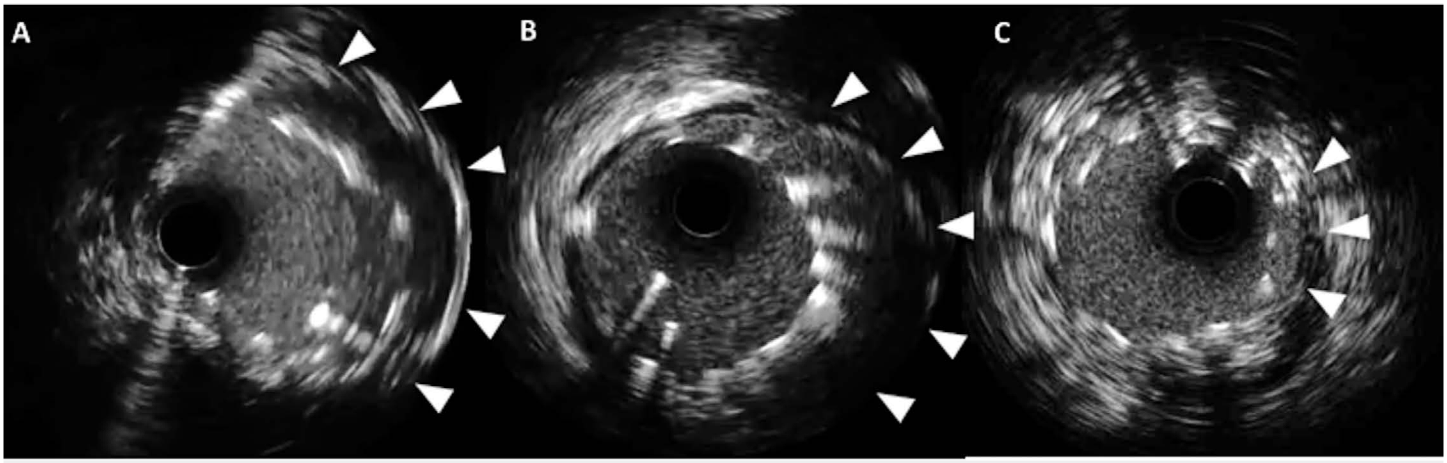

Figure 2.
Three cases of stent malapposition with intravascular ultrasound. (A-C) Substantial malapposition (arrowheads) is identified between vessel wall and stent struts.

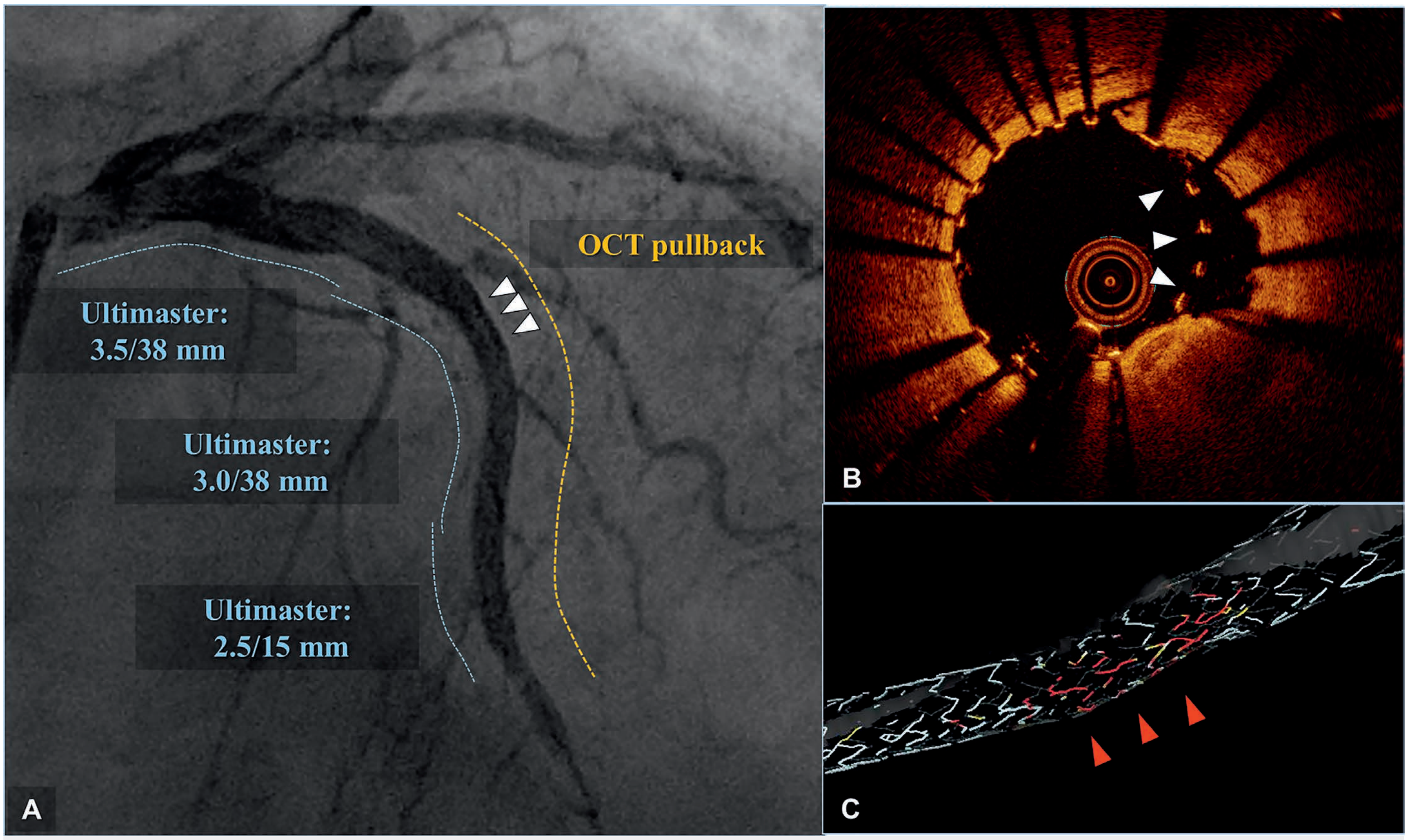

Figure 3 and Online Video 1.
Automatic stent struts detection system (OPTIS™ Stent Optimization Software) of optical coherence tomography (OCT). Angiographic results (A) were excellent after implantation of an Ultimaster (Terumo Corp.) drug-eluting stent for a diffusely diseased left anterior descending artery (dotted lines indicate DES-treated area before [blue] and after OCT pullback [yellow]). However, despite the excellent angiographic results, OCT (B) showed malapposed struts (white arrowheads in 3 A and B), which were automatically detected and highlighted with red in a 3-dimensional reconstruction image (C).

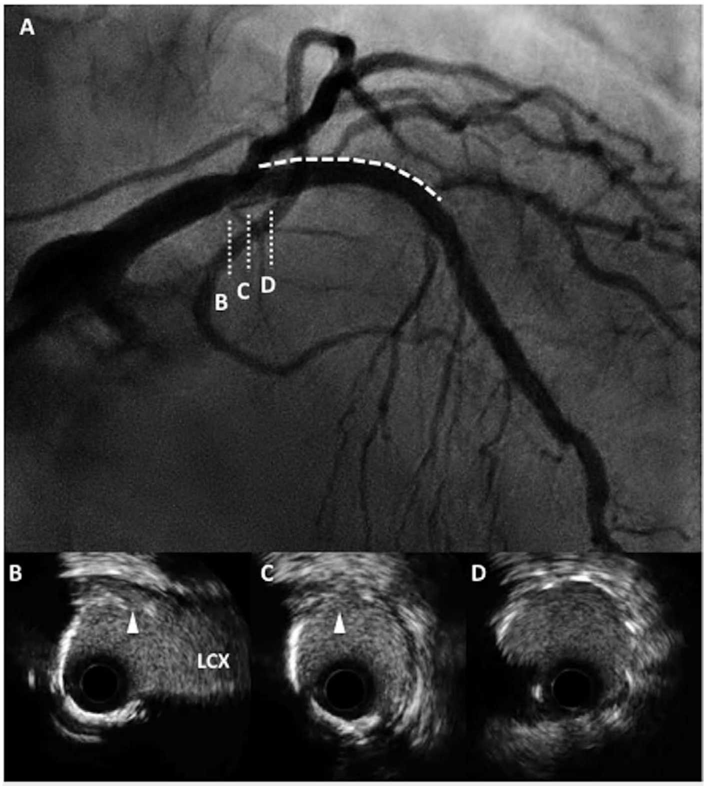

Figure 4.
(A) Coronary angiography (CAG) demonstrates dissection from the proximal edge of the stent (dotted line and D) to the left main trunk (indicated as B, C). (B-D) Cross-sectional intravascular ultrasound images show medial dissection (arrowheads) close to left circumflex artery (LCX).

l'Infarto-Optimisation of Percutaneous Coronary Intervention) registry reported that dissections detected by OCT that were > 200 µm at the distal stent edge were independent predictors of adverse cardiac events (composite of all-cause death, MI, and target lesion revascularization, HR 2.54, 1.3-4.8).[37] Conversely, some studies reported that edge dissections detected by OCT alone (i.e., undetectable with angiography) were not associated with restenosis and stent thrombosis at 1-year follow-up[38]; however, in these studies, edge dissection was defined only by the presence of luminal surface disruptions without cut-off values for width or length. Indeed, "minor" edge dissections, which are detectable with OCT alone and do not limit flow, can frequently heal and have no association with clinical events. Therefore, further prospective studies are needed to clarify cut-off values or features of OCT-detected edge dissections that may require additional intervention.

Tissue Protrusion

Tissue protrusion (TP) within the stent strut can occasionally be identified after stent implantation. The incidence of TP can depend on the underlying plaque morphology (e.g., thin cap fibrotic atheroma and thrombus), clinical presentation, and procedure-related factors (e.g., type of stent, and post-dilatation). With coronary angiography, tissue protrusion is identified as a contrast defect within the stent and can sometimes appear as a stenosis. With IVUS, TP is revealed as a relatively high echogenic signal (Figure 6), whereas with OCT it appears as a smooth surface with high signal attenuation.[39] Resolution with OCT is twice as high as with IVUS,[22,32,39] enabling it to identify plaque protrusions with unprecedented precision; it also can detect plaques that are prone to rupture.[39] One study using post-procedure OCT imaging to identify predictors for device-related clinical end points found a 92.9% incidence of smooth protrusion at 1-year follow-up.[40] Despite its unprecedented resolution, the impact of OCT findings on outcomes/adverse events remains unclear.[37,40]

Tissue protrusion detected by IVUS is reported to be associated with poor short-term outcomes, including no-reflow phenomenon, periprocedural MI, and acute/subacute stent thrombosis.[41] Serial OCT analyses showed that TP was detected in 28% of OCT cross-sections after stent implantation, but all of them resolved at the 8-month follow-up.[32] According to available data, the majority of TPs detected by intravascular imaging can be considered benign; however, further investigations are needed to characterize TPs that require additional intervention. If further intervention is needed, larger-diameter and higher-pressure balloon inflation may push TPs toward the vessel wall, although there is a possibility of distal embolization that might lead to slow flow or no reflow phenomena. If post-dilatation is needed, a protection device should be considered to prevent distal embolization.

Plaque Shift

Mintz et al.[42] reported that balloon angioplasty does not change plaque volume, and lumen enlargement is mainly due to combined plaque dissection, arterial expansion, and plaque redistribution. Although plaque volume reduction can be seen after stenting, especially in unstable lesions,[43] longitudinal plaque redistribution is one of the important mechanisms of lumen enlargement and may result in longitudinal plaque shift.

Coronary Spasm

Coronary spasm represents one of the important causes of peri-stent narrowing after stent implantation. In cases of suspected spasm, an intracoronary injection of nitrate is the first step to determine whether the new stenosis might improve. If the nitrate injection does not resolve coronary narrowing at the edge of the stent, an imaging study can be useful in identifying the cause. Both IVUS and OCT can detect diffuse intimal and medial thickness

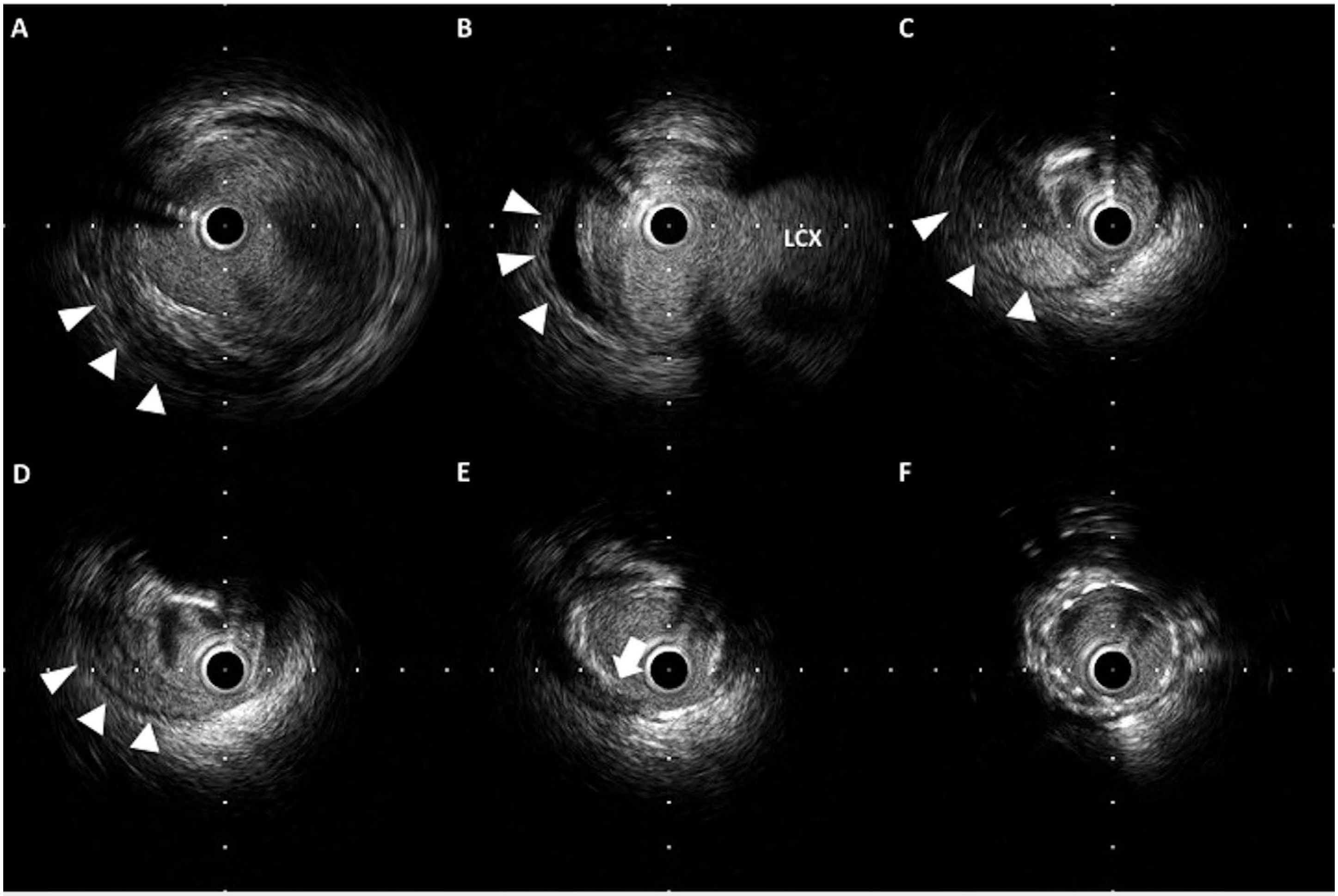

Figure 5.
Retrograde dissection and intramural hematoma. (A-D) Hematoma is observed within the media (arrowheads) and has pushed the lumen inward. (E) The entry site of the hematoma (arrow) reaches the media. (F) Stent is implanted with good apposition.

and luminal narrowing at the spasm site.[44,45] A pathology study suggested that coronary spasm is induced by medial thickening and folding of the internal elastic lamina (IEL).[46] This folding occurs from shrinkage of coronary vessels due to decreased flow from severely stenotic arteries. A peri-medial high echoic band (PHB) detected by IVUS may indicate folding of the IEL and thus the potential to relieve the spasm without mechanical intervention. If the PHB can be seen distal to a chronic total occlusion after recanalization, vessel diameter will eventually enlarge.[47]

ADDITIONAL APPLICATIONS OF INTRAVASCULAR IMAGING

60-MHz High-Resolution IVUS

High-resolution IVUS has a higher frequency than the standard IVUS that is currently used (Figure 7), and three 60-MHz high-resolution systems are now available from ACIST Medical Systems, Boston Scientific, and Terumo. High-resolution IVUS technology can provide many potential advantages, including (1) evaluation after bioresorbable vascular scaffold implantation, (2) assessment of unstable plaque and plaque rupture, and (3) identification of intraplaque hemorrhage and macrophage accumulation. Further studies are warranted to identify the efficacy of high-resolution IVUS for assessing stent results.

Bifurcation Stenting

Bifurcation lesions are some of the most challenging lesion subsets for PCI due to the higher incidence of restenosis and stent thrombosis.[48,49] For most bifurcation lesions, the provisional single-stent approach is the gold standard in terms of short-term efficacy and safety and lower long-term mortality.[50]

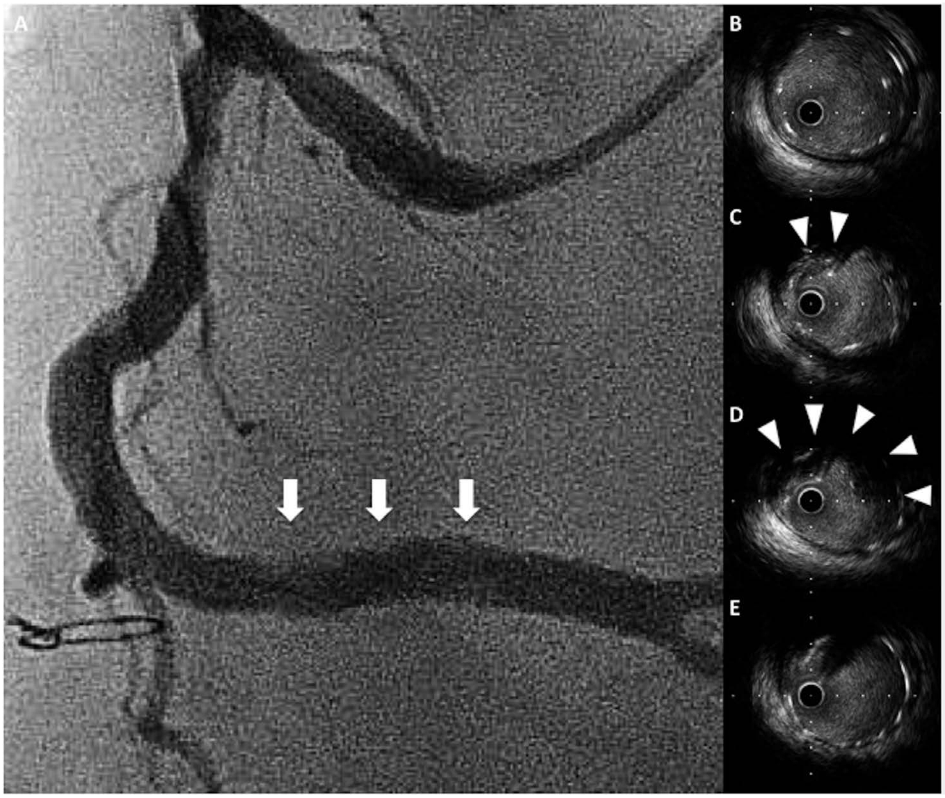

Figure 6.
Tissue protrusion. (A) Coronary angiography demonstrates a hazy appearance within the stent (arrows). (C, D) Cross-sectional IVUS images show tissue protrusion into the stent struts (arrowheads). (B, E) Stent is well-expanded without tissue protrusion.

However, some complex lesions may require a two-stent strategy. In these cases, OCT can immediately provide online 3-dimensional (3D) reconstruction images to help the physician visualize and understand complex bifurcation anatomy and determine the most effective PCI strategy.[51] Moreover, automatic stent struts detection systems[52] can help operators evaluate wire re-crossing points of the main branch stent struts towards the side branch, which may optimize the kissing balloon inflation technique and lead to more favorable results.[53]

LESIONS TREATED WITH BIORESORBABLE VASCULAR SCAFFOLDS

For the best possible results after bioresorbable vascular scaffold (BVS) implantation, the recommended technique is the PSP method: Prepare the lesion using adequate predilatation, Size the vessel/scaffold correctly, and Post-dilate the scaffold to avoid underexpansion.[54] In this regard, intravascular imaging evaluation with IVUS or OCT should be mandatory. Improper implantation of current-generation BVSs have been associated with unfavorable findings such as malapposition, underexpansion, and incorrect sizing (e.g., large BVS implanted in a small vessel) that are associated with a higher risk of scaffold thrombosis.[55] The differential impact between IVUS and OCT guidance on acute procedural results and follow-up clinical outcomes remains unclear; however, with this specific device, OCT plays a crucial role in order to precisely evaluate these results after implantation.

CONCLUSIONS

Intravascular imaging after stent implantation is very helpful in optimizing stent results and contributes to favorable clinical outcomes. In clinical settings, physicians should consider the different features of IVUS versus OCT and decide the best possible strategy based on

KEY POINTS

- Intravascular imaging can provide accurate assessment of stent deployment and procedural complications.
- Stent optimization includes the assessment of stent expansion and malapposition.
- Intravascular imaging is useful in evaluating complications after stent implantation, including stent edge dissection, tissue protrusion, plaque shift, and coronary spasm.
- Additional applications of intravascular imaging including 60-MHz high-resolution IVUS, assessment of bifurcation stenting, and bioresorbable vascular scaffold-treated lesions help optimize both procedural and long-term clinical outcomes.

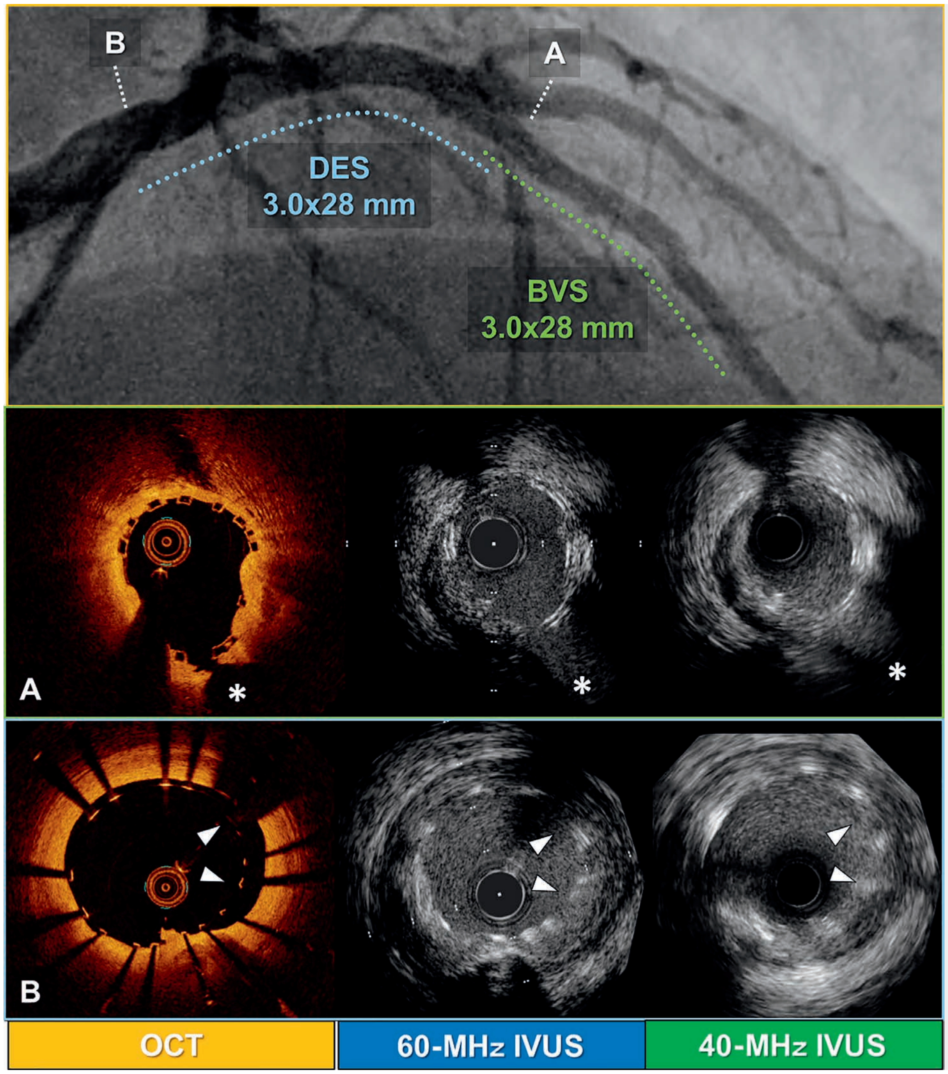

Figure 7.
Comparison of different intravascular imaging modalities (OCT, 40-MHz IVUS, and 60-MHz IVUS) after left main trunk (LMT) to left anterior descending artery (LAD) percutaneous coronary intervention with drug-eluting stent (DES) and bioresorbable vascular scaffold (BVS). (A) Mid-LAD lesion treated with BVS (asterisks indicate septal branch). (B) LMT lesion treated with DES (arrowheads indicate malapposed struts). Top panel shows final coronary angiography after the procedure (dashed lines indicate lesions treated with BVS [green] and DES [blue]).

this assessment. New technologies such as high-resolution IVUS and OCT 3D reconstruction will hopefully provide further clinical implications of intravascular image-guided PCI.

Drs. Hachinohe and Mitomo contributed equally and are joint first authors.

Conflict of Interest Disclosure:
Dr. Latib is a formal advisor for 4-Tech, Valtech Cardio, Mitralign, Medtronic, Edwards, and Abbott Vascular.

Keywords:
intravascular ultrasound, IVUS, optical coherence tomography, OCT, stent optimization, dissection, malapposition

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