Intracoronary imaging: review and clinical use
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ABSTRACT
Invasive coronary angiography is the standard approach in the routine clinical practice. Intracoronary imaging modalities provide real-time images of intracoronary anatomy. On this basis, optical coherence tomography and intravascular ultrasound have a positive impact on diagnosis and percutaneous coronary intervention. This summary provides an insight on these imaging modalities for the interventional and clinical cardiologist with the currently available evidence.

Keywords: Intravascular ultrasound. Optical coherence tomography. Invasive coronary angiography.

INTRODUCTION
Coronary artery disease is still the leading cause of death across the world and can manifest through a wide range of presentations given its dynamic nature.1 Coronary angiography (CA) is the gold standard approach to assess the presence and severity of coronary artery disease. However, it is limited by qualitative assessment although improvements have been made such as the development of quantitative coronary angiography.2 New imaging modalities for coronary assessment have emerged over the last few decades to improve patient outcomes.3 Intracoronary imaging (ICI) modalities provide an in-depth understanding of the aspects that contribute to the pathogenesis of coronary artery disease, but also help us guide the decision-making process. Intravascular ultrasound (IVUS) and optical coherence tomography (OCT) produce real-time cross-sectional images of the coronary artery. Data from clinical studies have suggested improved outcomes during complex ICI-guided percutaneous coronary interventions (PCI).4,5 Both the American and the European clinical guidelines on myocardial revascularization allocate a Class II recommendation—American College of Cardiology/American Heart Association: Class IIa6 and European Society of Cardiology: Class

Abbreviations
the vessel wall, characterize tissue composition, and tackle PCI allows the interventional cardiologist to evaluate the integrity of tissues reflecting on the surfaces according to the acoustic properties. These returned soundwaves are formatted into a grayscale image with dynamic contrast resolution. This modality ties of the tissue.

The quality of the images depends on the soundwave, transducer, and tissue properties. The resulting image resolution is greater at shorter distances (near-field), but it appears less clear in the deep fields (far-field) due to beam scattering. Flow properties also make it more difficult to distinguish the lumen from the tissues. Mechanical or rotational catheters work at 40-60 MHz frequencies, as opposed to electronic ones that operate at 20 MHz frequencies and have greater axial and lateral resolution. Overall, the best images are obtained when the catheter is coaxial to the vessel, the beam is perpendicular to the lesion, and with clear lumens.\(^9\)

IVUS image acquisition should be routinely performed with IV anticoagulation and intracoronary nitrates to prevent device-related complications.\(^9\) Vessel interrogation can be performed with manual or automatic pullback starting, at least, 10 mm distal to the target lesion until the aorta or the guiding catheter can be seen. In the case of aorto-ostial lesions, the guiding catheter must be disengaged to unmask ostial lesions. Automatic pullbacks have the advantage of providing measurements of lesion length, which is estimated with the average time and pullback speed. Multiple lesions are considered when distance is > 5 mm within the same coronary segment. However, spatial orientation is a major limitation.\(^9\) The main features of IVUS are shown on table 1 and table 2.

IVUS catheters are rapid exchange catheters that have a piezoelectric crystal that produces soundwaves through transducers when electrically excited. Soundwaves propagate through the different tissues reflecting on the surfaces according to the acoustic properties of the tissue. These returned soundwaves are formatted into a grayscale image with dynamic contrast resolution. This modality allows the interventional cardiologist to evaluate the integrity of the vessel wall, characterize tissue composition, and tackle PCI challenges (stent malapposition and underexpansion).\(^5\)

The review seeks to summarize the evidence available to portray all the potential advantages and downsides of these 2 catheter-based imaging modalities in the routine clinical practice.

### IMAGING MODALITIES

#### IVUS

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IVUS, intravascular ultrasound; OCT, optical computed tomography; NA, not applicable.

\(^a\) Includes OptiCross (Boston Scientific, United States), Volcano (Phillips, United States), Infraredx (Burlington, United States), ACIST CVI (ACIST, United States), and Fastview (Terumo, Japan).

\(^b\) Includes OPTIS (Abbott Vascular, United States), and Lunawave (Terumo, Japan).

\(^c\) Includes Novasight Hybrid (Conavi Medical, Canada), and Dual Sensor (Terumo, Japan).

Iia—IXIVUS-guided PCI,\(^7\) being the OCT-guided PCI an alternative with the exception of ostial left main coronary artery disease.\(^6,7\) However, its use is still uneven worldwide.

This review seeks to summarize the evidence available to portray all the potential advantages and downsides of these 2 catheter-based imaging modalities in the routine clinical practice.

### Table 1. General characteristics of intracoronary imaging modalities

<table>
<thead>
<tr>
<th>Intracoronary imaging modality</th>
<th>Source of image</th>
<th>Frequency (MHz)</th>
<th>Wavelength (μm)</th>
<th>Minimal guide catheter (Fr)</th>
<th>Axial resolution (μm)</th>
<th>Lateral resolution (μm)</th>
<th>Tissue penetration (mm)</th>
<th>Pullback length (mm)</th>
<th>Pullback speed (mm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVUS(^a)</td>
<td>Ultrasound</td>
<td>20-60</td>
<td>40-50</td>
<td>5</td>
<td>20-170</td>
<td>50-260</td>
<td>3-8</td>
<td>100</td>
<td>0.5-10</td>
</tr>
<tr>
<td>OCT(^b)</td>
<td>Infrared light</td>
<td>NA</td>
<td>1.3</td>
<td>5</td>
<td>15-20</td>
<td>20-40</td>
<td>1-3</td>
<td>75</td>
<td>10-40</td>
</tr>
<tr>
<td>Hybrid (OCT/IVUS)(^c)</td>
<td>Ultrasound and Infrared light</td>
<td>40</td>
<td>1.3</td>
<td>5</td>
<td>200/15</td>
<td>200/30</td>
<td>3-8</td>
<td>100-150</td>
<td>0.5-40</td>
</tr>
</tbody>
</table>

#### Table 2. Main advantages and drawbacks of intracoronary imaging modalities

<table>
<thead>
<tr>
<th>Intravascular ultrasound</th>
<th>Optical computed tomography</th>
</tr>
</thead>
<tbody>
<tr>
<td>• More penetration capabilities, capable of assessing plaque volume and deeper plaques.</td>
<td>• Higher resolution, fewer artifacts, and facilitates the identification of subtle details.</td>
</tr>
<tr>
<td>• Better suited for CTO, aorto-ostial junction, LMCAD, and stent sizing assessment.</td>
<td>• More user friendly.</td>
</tr>
<tr>
<td>• Does not require contrast.</td>
<td>• Capable of assessing calcium thickness.</td>
</tr>
<tr>
<td>• Less penetration capabilities, cannot adequately evaluate ostial lesions.</td>
<td>• Better suited for strut and thrombus evaluation.</td>
</tr>
<tr>
<td>• Requires anticoagulation and additional time.</td>
<td>• Requires anticoagulation and additional time.</td>
</tr>
<tr>
<td>• Image interpretation requires experience and expertise.</td>
<td>• Image acquisition requires blood clearance through contrast or other means.</td>
</tr>
<tr>
<td>• Cannot penetrate calcium or adequately evaluate thrombi.</td>
<td>• Image interpretation requires experience and expertise.</td>
</tr>
<tr>
<td>• Expensive.</td>
<td>• Expensive.</td>
</tr>
</tbody>
</table>

CTO, chronic total coronary occlusions; LMCAD, left main coronary artery disease.

CA-guided PCI, IVUS was associated with less cardiac death (risk ratio [RR], 0.63; 95% confidence interval [95%CI], 0.54–0.73), and PCI-related complications. Similarly, the risk of myocardial infarction (RR, 0.71; 95%CI, 0.58–0.86), target lesion revascularization (RR, 0.81; 95%CI, 0.70–0.94), and stent thrombosis (RR, 0.57; 95%CI, 0.41–0.79) was lower with IVUS-guided PCI.\(^10\)

Optical coherence tomography

OCT image generation is based on infrared light (1.3 μm wavelength). Compared to IVUS, this imaging modality provides greater axial resolution (10-20 μm vs 50-150 μm) with limited soft tissue penetration (1-2 mm vs 5-6 mm except for calcium evaluation).\(^3,4,11\)

Current devices are 5-Fr compatible through a rapid exchange system that also allows automatic pullbacks with angiography co-registration and automatic lumen measurements and calcium detection. The quality of the images depends on the interaction of light with the surrounding tissues (echo-time delay). As such, light reflection, refraction, and attenuation (absorption) determine the final image resolution. Metal devices and fibrous plaques are considered strong reflectors while low reflectors are calcium and necrotic cores (lipid-rich). Red blood cells cause light scattering that requires contrast washout causing the
OCT imaging is also routinely performed with IV anticoagulation and intracoronary nitrates to prevent complications. The study of the vessel begins 10 mm distal to the target lesion, the catheter is then purged with contrast, and an automatic pullback with co-registration (if available) is performed. The average pullback speed of 10-40 mm/s usually allows a single bolus injection of contrast to achieve a blood-free environment.12 The general OCT features are shown on table 1 and table 2.

Compared to the CA-guided PCI, observational studies have suggested a potential benefit of OCT-guided PCI with lower rates of major adverse cardiovascular events (MACE) and stent-related complications.13 Furthermore, the OCT provides more reliable and reproducible images with less inter-observer variability compared to the IVUS. In this regard, the OCT may be superior to assess stent and lumen diameters.14,15

**SPECIFIC SCENARIOS**

**Acute coronary syndromes**

Acute coronary syndromes are mostly caused by coronary thrombosis due to plaque rupture, plaque erosion or an eruptive calcified nodule.16 Accurate diagnosis may have prognostic implications. The rupture of the plaque is associated with a greater rate of no-reflow and distal embolization. Plaque erosion can be conservatively managed in non-critical stenoses. Calcified nodules are associated with a higher rate of stent restenosis and thrombosis17 (figure 1).

The OCT is often used for the perioperative identification of culprit lesions after careful evaluation of the morphological characteristics of the fibrous cap.16 The plaque classification algorithm through OCT classifies plaques based on the state of fibrous caps, thereby showing an intact fibrous cap in plaque erosion, a disrupted cap as the hallmark of a ruptured plaque or a calcified nodule. The OCT can also determine thrombus burden, but is not necessary to ascertain the culprit lesion. However, a recent publication that compared near infrared spectroscopy combined with IVUS to OCT in 276 patients found that the former can accurately characterize culprit lesions after the characterization of calcium, plaque cavity, and the maximum lipid core burden index with 93% and 100% sensitivity and specificity, respectively.19

Moreover, data supports the preference of ICI-guided PCI to improve outcomes in the management of acute coronary syndrome. A meta-analysis of 26 610 patients reported a net benefit of IVUS regardless of the presence of acute coronary syndrome with a lower rate of MACE [RR, 0.57; 95%CI, 0.41-0.79] compared to the CA-guided PCI.16 Similarly, an observational Korean registry of 11 731 patients treated with primary PCI reported a lower rate of cardiac death, target vessel reinfarction, and target lesion revascularization with either IVUS- or OCT-guidance.20

**Bifurcated lesions**

Coronary bifurcation lesions are found in 15% to 20% of all patients treated with PCI.21 The main challenge when treating bifurcation lesions is selecting the right PCI strategy to avoid target lesion failure or side-branch occlusion. The importance of careful evaluation is evident with the distal left main coronary artery disease (LMCAD). The European Bifurcation Club recommends intracoronary imaging to treat bifurcated lesions.22

The risk of side-branch compromise can be diminished with both the IVUS and the OCT by selecting the proper stent (type and size), landing zone, and evaluation of post-PCI results [stent expansion and apposition; distal dissection]. Intracoronary imaging can identify a “spiky” carina in cases of distal LMCAD, which has been associated with restenosis due to carina shift. Also, some predictors of side-branch compromise with IVUS [minimum lumen area of side-branch and plaque burden]19 and OCT [angle < 50° and branching point to carina tip length < 1.70 mm]21 have been reported.

Also, both imaging modalities can be used for stent sizing in bifurcation lesions; however, areas with high plaque burden or lipid plaques where both imaging modalities are useful should be avoided as landing zones. Overall, ICIcs are also useful to treat bifurcations with PCI since they evaluate side-branch wire entry, calcification, lesion length, and post-stent-related complications that may interfere with the clinical outcomes. Two randomized control trials are currently evaluating the role of OCT in patients with bifurcated lesions [NCT03171311; NCT03507777].

**Coronary artery calcification**

Coronary artery calcification increases PCI complexity by impairing stent deployment, expansion, and apposition, which in turn increases the risk of stent thrombosis and restenosis.24 CA can detect—with a low-to-moderate sensitivity—the presence of coronary artery calcification with severe cases being visible without cardiac motion and contrast injection.25

Calified plaques appear as hyperechoic structures with a characteristic acoustic shadowing on the IVUS (figure 2).26 The IVUS can assess coronary artery calcification quantitatively [angle and length], semiquantitatively [absent or quadrant distribution], and qualitatively [depth of acoustic shadowing based on plaque and medial thickness]. A study that compared IVUS to CA in 67 chronic total coronary occlusions (CTO) lesions found that IVUS was superior regarding the identification of calcium deposits (96% vs 61%).26 However, IVUS cannot evaluate microcalcifications (> 5 μm), but it can estimate the depth or thickness of calcium deposits.27
On the OCT, calcification appears as a heterogeneous structure with well-defined borders that can be used to offset some of the limitations of IVUS. Although the OCT has less depth penetration capabilities, it’s evaluation of the calcium thickness, area, and volume is more precise and reliable. The ICI analysis of calcium features can provide some insights for efficient planning to prevent stent underexpansion or malapposition. Therefore, calcium circumferences > 180º, thicknesses > 0.5 mm or lengths > 5 mm on the ICIs should involve adjunctive therapies to plaque modification. The OCT analysis of 31 patients from the Disrupt CAD study showed that calcium fractures were the leading mechanism of action of coronary lithotripsy and a tendency towards more adequate stent expansion was observed. Similar results were reported with rotational atherectomy where a tendency towards more adequate stent expansion was observed. 31 The ICI analysis of calcium features can provide some insights for efficient planning to prevent stent underexpansion or malapposition. The OCT analysis of 31 patients from the Disrupt CAD study showed that calcium fractures were the leading mechanism of action of coronary lithotripsy and a tendency towards more adequate stent expansion was observed. Similar results were reported with rotational atherectomy where a tendency towards more adequate stent expansion was observed. 31

The major obstacle of the OCT in PCIs performed on CTOs is the need for contrast washout and the propagation of dissections due to the need for blood clearance, which is why it has been considered inadequate. However, this imaging modality could find its way into optimized PCIs performed on CTOs and follow-up monitorizations. A retrospective study reported a higher rate of stent malapposition and uncovered struts at 6-months after OCT examinations of patients with successful PCIs performed on CTOs. The ALSTER-OCT-CTO registry reported similar results after evaluating 111 lesions with OCT and saw a higher rate of malapposed and uncovered stent struts in CTOs vs non-CTO lesions at the 12-month follow-up. 

Coronary artery aneurysms

Coronary artery aneurysms are often clinically silent and can be identified in approximately 5% of all the patients undergoing CA. The most common causes are atherosclerosis in adults and Kawasaki disease in children. Coronary artery aneurysm is defined as a focal dilation of at least > 1.5 times the adjacent normal coronary artery while diffuse dilation is considered as coronary artery ectasia. Morphologically, when looked at from their maximum diameter, saccular and fusiform aneurysms can be seen with the former greater transverse rather than longitudinal diameter.

Dionne et al. conducted an analysis of coronary artery aneurysms using OCT in a pediatric population with a past medical history of Kawasaki disease. The OCT proved to be safe, and similar findings (intimal hyperplasia, fibrosis, and media disruption) were observed in aneurysmal lesions compared to former histopathological studies. Nonetheless, these findings were also seen in non-aneurysmal coronary segments, which could drive the higher risk of ischemia in patients with a past medical history of Kawasaki disease.

Left main coronary artery disease

The prevalence of LMCAD is 4% and, traditionally, coronary artery bypass graft has been the standard treatment with growing evidence to this date supporting PCI. Selecting the right imaging modality is important to determine accurately the clinical significance of LMCAD. CA remains the standard evaluation of choice, but it is subject to a high inter and intra-observer variability in the detection of intermediate lesions (30% to 70%). Consequently, intracoronary imaging can improve the assessment of LMCAD, and the long-term outcomes.

The importance of IVUS assessing the anatomy of LMCAD is evident given its more consistent tissue penetration capabilities that allows proper plaque evaluations. Former studies described...
significant LMCAD with minimal lumen areas between 6 mm² and 9 mm² estimated using IVUS with values < 6 mm² showing a good correlation with fractional flow reserve < 0.75. However, smaller areas have been reported in the Asian population. A multicenter prospective study that evaluated LMCAD with IVUS reported a similar rate of cardiac events after 2-years in patients undergoing revascularization with minimum lumen areas (MLA) < 6 mm² (5.5%), as well as in those with MLAs ≥ 6 mm² (2.3%) with revascularization deferral. Therefore, an angiographically ambiguous LMCAD with an IVUS-derived MLA > 6 mm² can be considered non-ischemic whereas those with a MLA ≤ 4.5 mm² could be deemed as ischemia-generating LMCAD. However, for those with a MLAs from 4.5 mm² to 6 mm², additional invasive or non-invasive assessment tools are required to rule out the presence of ongoing ischemia.

Former studies have demonstrated that plaque burdens > 60% in non-LMCAD is a predictor of MACE and can be recognised when assessing the risk of future events after PCI. Through IVUS analysis, it was shown that the larger the plaque burden in the LMCAD, the greater the overall plaque burden in the coronary tree. However, in the PROSPECT study a greater plaque burden was not associated with a higher rate of MACE as opposed to the overall plaque burden (hazard ratio, 1.06; 95%CI, 1.01–1.11; P = .02). Therefore, the IVUS assessment of the LMCAD plaque burden can identify high-risk patients with coexisting non-LMCAD atherosclerotic disease.

The role of IVUS in LMCAD is not limited to diagnosis only. A meta-analysis that compared IVUS-guided vs CA-guided PCI in LMCAD found that the former was associated with less cardiovascular mortality (RR, 0.47; 95%CI, 0.33–0.66; P < .001), new target lesion revascularization (RR, 0.43; 95%CI, 0.25–0.73; P = .002), and stent thrombosis (RR, 0.28; 95%CI, 0.12–0.67; P = .004). Also, de la Torre Hernández et al. reported that IVUS-guided PCI was particularly useful in distal lesions with a lower event rate compared to non-IVUS guided PCI (hazard ratio, 0.54; 95%CI, 0.34–0.90). Other studies have proposed a role for IVUS in the optimization of LMCAD after stent deployment where minimum lumen areas were associated with stent underexpansion and could predict in-stent restenosis with different thresholds regarding the assessed segment (8 mm² for the proximal left main coronary artery, 6 mm² for the ostium of the left anterior descending coronary artery, and 5 mm² for the ostium of the left circumflex artery).

On the contrary, the OCT has limited utility in the assessment of LMCAD given its average diameter (3 mm to 5 mm) and inability to evaluate aorto-ostial lesions where blood-free fields are difficult to achieve. A multicenter retrospective study (ROCK cohort II) recently reported a lower 1-year rate of target lesion failure in intravascular imaging guided vs angiographically guided distal PCIs on the LMCA (12.7% vs 21.2%; P = .039) with similar outcomes between the OCT and the IVUS (P = .26). However, future prospective data supporting OCT-guided PCI is expected to better define the optimal clinical management of patients with LMCAD.

### Table 3. Invasive coronary angiography vs intracoronary imaging for percutaneous coronary interventions on chronic total coronary occlusions

<table>
<thead>
<tr>
<th>Reference</th>
<th>Type of study</th>
<th>IVUS vs CA (n)</th>
<th>Primary endpoint</th>
<th>Study outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tian et al.</td>
<td>Prospective RCT</td>
<td>130 vs 130</td>
<td>In-stent late lumen loss</td>
<td>• Rate of stent restenosis (3.9% vs 13.7%; P = .021)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Adverse event rate after 2 years (21.7% vs 25.2%; P = .64)</td>
</tr>
<tr>
<td>Hong et al.</td>
<td>Retrospective</td>
<td>206 vs 328</td>
<td>Stent thrombosis</td>
<td>• Similar rate of MACE in the matched cohort</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Lower stent thrombosis in IVUS-guided PCI (0% vs 3%; P = .015)</td>
</tr>
<tr>
<td>Kim et al.</td>
<td>RCT</td>
<td>201 vs 201</td>
<td>Cardiac death</td>
<td>• Less MACE (HR, 0.35; 95%CI, 0.13–0.97) and stent thrombosis (0% vs 1.5%; P = .11)</td>
</tr>
</tbody>
</table>

CA, coronary angiography; IVUS, intravascular ultrasound; MACE, major adverse cardiovascular event; PCI, percutaneous coronary intervention; RCT, randomized controlled trial; OCT.

### Table 4. Summary of the studies that evaluated invasive coronary imaging for the assessment of left main coronary artery disease

<table>
<thead>
<tr>
<th>Reference</th>
<th>Type of study</th>
<th>ICI use</th>
<th>Follow-up time</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>De la Torre Hernandez et al.</td>
<td>Prospective multicenter</td>
<td>IVUS</td>
<td>2 years</td>
<td>Defer PCI with MLA &gt; 6 mm² is safe</td>
</tr>
<tr>
<td>Fassi et al.</td>
<td>Prospective</td>
<td>IVUS</td>
<td>3 years</td>
<td>Defer PCI with MLA ≥ 7.5 mm² is safe</td>
</tr>
<tr>
<td>Jasti et al.</td>
<td>Prospective</td>
<td>IVUS</td>
<td>3 years</td>
<td>MLA &lt; 5.9 mm² is well correlated with a FFR &lt; 0.75</td>
</tr>
<tr>
<td>Park et al.</td>
<td>Prospective</td>
<td>IVUS</td>
<td>NA</td>
<td>FFR &lt; 0.8 had a good correlation with MLA ≤ 4.5 mm² among Asians</td>
</tr>
</tbody>
</table>

ICI, intracoronary imaging; IVUS, intravascular ultrasound; MLA, minimum lumen area; PCI, percutaneous coronary intervention.

Spontaneous coronary artery dissections

Spontaneous coronary artery dissection is a classically misdiagnosed life-threatening condition that can occur in otherwise healthy individuals. Coronary flow is compromised after the development of a false lumen through an "inside-out" or "outside-in" mechanism. The Yip-Saw coronary classification has revealed the limitations of spontaneous coronary artery dissection. Diagnosis is particularly challenging with type 2 (diffuse smooth stenosis) and type 3 (mimic atherosclerotic stenosis) spontaneous coronary artery dissections.

The benefits of implementing ICIs (table 6) for diagnostic purposes or even to guide coronary intervention in spontaneous coronary artery dissections are their higher resolution. IVUS has a deeper power of penetration to visualize the vessel wall and intramural hematoma, consequently, it is also recommended for proximal dissections. It can also differentiate between true and false lumens once fused with color interpolation. However, the OCT is more sensitive regarding the
Transplantation classifies allograft vasculopathy into 4 categories: fibromuscular dysplasia. The International Society for Heart and Lung Transplantation classifies allograft vasculopathy into 4 categories:

- **Primary endpoint** was all-cause mortality
- **Secondary endpoints** were MI, TVR, and the composite endpoint of all-cause mortality, SR, and ST.
- **Potential adverse events** include wire (10.7%) or advancement of the OCT catheter (3.5%).
- **Guidewire position** can be visualized through IVUS only. Former studies have reported that an intimal thickening > 0.5 mm from baseline is associated with a higher rate of adverse events within the first year after the heart transplant.

Heart transplant patients may present with an intimal thickening identifiable through IVUS only. Former studies have reported that an intimal thickening > 0.5 mm from baseline is associated with a higher rate of adverse events within the first year after the heart transplant.

### Table 5. Summary of the studies that compared IVUS-guided vs coronary angiography-guided percutaneous coronary interventions on left main coronary artery disease

<table>
<thead>
<tr>
<th>Reference</th>
<th>Endpoints</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Park et al.</td>
<td>Primary endpoint was all-cause mortality</td>
<td>IVUS-guided PCI was associated with a lower rate of overall mortality (HR, 0.31; 95% CI, 0.19–0.51), and MI (HR, 0.47; 95% CI, 0.33–0.67). The risk of TVR (HR, 0.47; 95% CI, 0.33–0.67) did not decrease with IVUS guidance.</td>
</tr>
<tr>
<td>De la Torre Hernandez et al.</td>
<td>Primary endpoint was MACE (cardiac death, MI, TVR)</td>
<td>The 3-year rate of all-cause mortality was lower with IVUS-guided PCI (4.7% vs 16%; P = .048). Lower rate of ST with IVUS-guided PCI (0.6% vs 2.2%; P = .04). IVUS-guided PCI of LMCAD was associated with minor adverse events in distal lesions (HR, 0.34; 95% CI, 0.34–0.91), and in the overall population (HR, 0.70; 95% CI, 0.52–0.99).</td>
</tr>
<tr>
<td>Gao et al.</td>
<td>Primary endpoint was the 1-year rate of MACE (cardiac death, MI, TVR)</td>
<td>The 1-year rate of MACE in the IVUS-guided group was lower (14.8% vs 27.7%). Coronary angiography-guided PCI was associated with a higher rate of ST (2.7% vs 0.5%; P = .028).</td>
</tr>
<tr>
<td>Tan et al.</td>
<td>2-year rate of MACE (death, MI or TLR)</td>
<td>Similar event rate regarding SR (3.28% vs 8.15%; P = .11), and ST (1.8% vs 3.2%; P = .568)</td>
</tr>
<tr>
<td>Andell et al.</td>
<td>Primary endpoint was a composite endpoint of all-cause mortality, SR, and ST</td>
<td>The IVUS group was associated with fewer composite endpoints (HR, 0.65; 95% CI, 0.58–0.74) and a lower all-cause mortality rate (HR, 0.62; 95% CI, 0.47–0.82).</td>
</tr>
<tr>
<td>Hernandez et al.</td>
<td>Secondary endpoints were all-cause mortality, SR, ST, and unexplained death within 30-days</td>
<td>Not differences were seen in the rate of ST and SR</td>
</tr>
</tbody>
</table>

### Table 6. Benefits of intravascular imaging modalities in spontaneous coronary artery dissection

<table>
<thead>
<tr>
<th>IVUS</th>
<th>OCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intramural hematoma (complete visualization of the vessel wall)</td>
<td>Detail characterization of the intimal flap (intimal-medial disruption)</td>
</tr>
<tr>
<td>True and false lumen (with IVUS and ChromaFlo®)</td>
<td>Connection between true-false lumen (entry tear)</td>
</tr>
<tr>
<td>Thrombosis of the false lumen</td>
<td>Involvement of side branches and/or thrombus</td>
</tr>
<tr>
<td>Guidewire position</td>
<td>Guidewire position</td>
</tr>
</tbody>
</table>

**IVUS**, intravascular ultrasound; **OCT**, optical computed tomography. * ChromaFlo Volcano (Philips, United States).

Heart transplant vasculopathy

The clinical presentation of cardiac allograft vasculopathy is often silent. It is characterized by aggressive and concentric diffuse fibromuscular dysplasia. The International Society for Heart and Lung Transplantation classifies allograft vasculopathy into 4 categories based on graft function and angiographic findings having CAV2 and CAV3 the worst prognosis of all. CAV is considered the gold standard technique for routine screening and definitive diagnosis.

Heart transplant patients may present with an intimal thickening identifiable through IVUS only. Former studies have reported that an intimal thickening > 0.5 mm from baseline is associated with a higher rate of adverse events within the first year after heart transplant. Consistent with these findings, volumetric studies with IVUS have shown that the combination of intimal thickening plus negative remodelling of the proximal left anterior descending coronary artery were associated with acute rejection and major adverse events within the first year. However, the OCT can identify early stages of intimal thickening in the form of intimal hyperplasia (thickness > 100 μm), and improve the clinical outcomes.

**Post-stent findings**

Both imaging modalities have been used to identify stent underexpansion, incomplete apposition, and edge dissection as potential causal mechanisms of stent failure.

In this regard, minimal stent area (MSA) is associated with both restenosis and stent thrombosis. IVUS studies reported MSAs between 5.3 mm² and 5.7 mm² with smaller areas identified in patients with definitive stent restenosis at the short-term follow-up after stent implantation. Similarly, 2 studies reported that MSAs < 5 mm² as seen on the OCT were associated with a higher rate of target lesion revascularization and stent thrombosis with drug-eluting stents. On the contrary, stent patency assessed through the OCT suggested that values > 4.5 mm² had a lower rate of MACE, but higher cut-off values for proximal (> 8 mm²) and distal (> 7 mm²) LMCA with IVUS assessment. Therefore, clinical guidelines recommend a post-PCI MSA/mean reference lumen of > 80%.

A series of OCT registries observed that a common leading mechanism responsible for early [1 to 30 days], late [1 to 12 months], and very late (> 1 year) thrombus formation is the malapposition (axial distance > 0.4 mm with a longitudinal extension > 1 mm) of stented.
Consistent with this, stent edge dissection is also associated with adverse events as seen on the CLI-OPCI II study, where distal stent edge dissections > 200 µm had a higher rate of MACE.\(^\text{76}\)

SAFETY

The development of ICI techniques has resulted in significant clinical improvements, but they are not free from procedural complications [figure 3].

Safety trials on IVUS have reported an estimated rate of complications between 1% to 3%, mostly associated with the size of the catheter. The setback of CA is the use of contrast materials to enhance image quality with the inherent risk of contrast-induced nephropathy.\(^\text{81}\) On this regard, a small retrospective study of 37 patients with advanced kidney disease evaluated the safety of IVUS-guided zero contrast PCI without a higher rate of renal replacement therapy or MACE being reported.\(^\text{82}\) Similar findings were described in a prospective and multicenter study,\(^\text{83}\) and a randomized control trial.\(^\text{84}\) Safety and feasibility have also been assessed on the OCT without a higher rate of MACE,\(^\text{85}\) procedural complications or acute kidney injury being reported.\(^\text{86}\) Additionally, data from 2 prospective studies suggests that contrast-less OCT would be a feasible imaging modality.\(^\text{87,88}\)

In former studies that compared ICI modalities [table 7], similar complication rates were reported.\(^\text{89-91}\) Van der Sijde et al. used a prospective study to compare the procedural complications of both IICs and did not observe a higher event rate during image acquisition. Also, they did not identify any potential risk factors regarding major adverse events suggesting that both the safety and feasibility of IICs are greater than expected and unrelated to the operator’s experience.\(^\text{92}\)

### Table 7. Summary of studies comparing IVUS vs OCT and/or CA for PCI guidance

<table>
<thead>
<tr>
<th>Reference</th>
<th>Type of study</th>
<th>ICI modality</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ali et al.(^\text{89})</td>
<td>Multicenter RCT</td>
<td>OCT vs IVUS vs CA</td>
<td>No differences in procedural MACE(^c) were reported between OCT (3%) and IVUS (1%; (P = .37)) and CA (1%; (P = .37)) Similar rate of procedural complication</td>
</tr>
<tr>
<td>Habara et al.(^\text{90})</td>
<td>Prospective RCT</td>
<td>OCT vs IVUS</td>
<td>Similar rate of procedural time (40 ± 16.4 min vs 47 ± 17.6 min; (P = .09)), and fluoroscopy time (20.4 ± 8.4 min vs 24.8 ± 10.4 min; (P = .05)) Similar rate of complications, no deaths reported ((P &gt; .99))</td>
</tr>
<tr>
<td>Kubo et al.(^\text{91})</td>
<td>Prospective multicenter RCT</td>
<td>OCT vs IVUS</td>
<td>Similar rates of cardiac death (0% vs 0.2%; (P = .99)) and MACE(^b) (2.9% vs 3.5%; (P = .81)) No contrast-induced nephropathy reported with a similar rate of complications between the groups</td>
</tr>
<tr>
<td>Van der Sijde et al.(^\text{92})</td>
<td>Single-center Prospective</td>
<td>OCT vs IVUS</td>
<td>Similar rate of procedural cardiac events (&lt; 1%) No predictors of adverse events were identified</td>
</tr>
</tbody>
</table>

CA, coronary angiography; ICI, intracoronary imaging; IVUS, intravascular ultrasound; MACE, major adverse cardiovascular event; OCT, optical computed tomography; RCT, randomized controlled trial.

\(^a\) Defined as procedural complications (angiographic dissection, perforation, thrombus, or acute closure), and active procedures (balloon inflations, additional stent implantations or pericardiocentesis).

\(^b\) Defined as a composite of cardiac death, myocardial infarction or ischemia-driven target lesion revascularization.

\(^c\) Defined as angiographic dissection, perforation, thrombus, or acute closure.

\(^\text{SAFETY}\)
CONCLUSIONS

Beyond the limitations of coronary angiography, coronary assessment remains complex given the different forms of presentation. Therefore, the ideal imaging modality would be one that is easy to use, interpret, and safe. Intracoronary imaging guidance is widely recognized for diagnosis, PCI planning, and to guide post-PCI treatment. However, there is still room for improvement, and future randomized studies will contribute to the wider adoption of these imaging modalities in all cath labs.

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AUTHORS’ CONTRIBUTIONS

Á. Aparisi drafted the original manuscript. Á. Aparisi, H. Cubero-Gallego, and H. Tizón-Marcos were involved in the process of critical revision of the manuscript regarding significant intellectual content, and eventually wrote the final version. All authors read and gave their publication consent for this version of the manuscript.

CONFLICTS OF INTEREST

None reported.

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