Clinical use of intracoronary imaging modalities in Poland. Expert opinion of the Association of Cardiovascular Interventions of the Polish Cardiac Society

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A B S T R A C T

The article presents the most common, current indications for the use of intravascular invasive imaging diagnostic techniques, i.e. intravascular ultrasound and optical coherence tomography in Polish invasive cardiology centers. The application of the above-mentioned techniques in the diagnosis of stenosis of the left main coronary artery, optimization of stent implantation procedures, treatment of calcified lesions, and other clinically important issues are discussed.

Key words: intravascular ultrasound, optical coherence tomography, stent implantation, left main coronary artery

INTRODUCTION

This expert opinion presents the current views and indications for the clinical use of intravascular invasive diagnostic imaging techniques, i.e. intravascular ultrasound (IVUS) and optical coherence tomography (OCT). The document was developed by experts appointed by the Board of the Association of Cardiovascular Interventions of the Polish Cardiac Society.

According to the published registry of Polish authors [1], IVUS/OCT techniques are rarely used, as an experienced operator uses them every 5 weeks, while the results of the registry conducted by the European Association of Percutaneous Cardiovascular Interventions (EAPCI) [2] indicate that half of the operators use these techniques only in over 15% of patients. The main indications for the use of IVUS/OCT were optimization of stent implantation and angioplasty procedures in the area of the left coronary artery. The authors of the listed registries indicate that the main factors limiting the use of IVUS/OCT in clinical practice are costs and the duration of the procedure.
IntRAvAsCul AR utRAsound And optICAl CohEREnCE  tomogRAthy

Intravascular ultrasound is based on coronary tissue-mediated sound wave reflection and image acquisition [3]. A miniaturized ultrasound transducer generates ultrasound waves that reflect from structures in a coronary artery, return to the transducer, and are converted into an image (a two-dimensional and grayscale cross-section, Figure 1A and B). Detailed information on analyzing IVUS images can be found in expert documents describing this methodology [4]. In recent years, high-definition intravascular ultrasound modalities have been widely introduced into clinical practice [5].

OCT is a technique utilizing a near-infrared light source with a wavelength range of 1250–1350 nm. The use of a light beam allows for the acquisition of images with ten times higher resolution than IVUS (from 10 to 20 µm) and enables an OCT probe to move quickly inside a vessel at a speed of 40 mm per second, depending on the OCT system used [6]. A comparison of IVUS and OCT systems is presented in Table 1. Examples of various types of atherosclerotic plaques on IVUS and OCT imaging are presented in Figure 2.

**ASSESSMENT OF INTERMEDIATE LEFT MAIN LESIONS**

Intermediate lesions of the left main coronary artery can be assessed using both invasive functional and imaging methods. However, the latter provides additional data for patients who have unstable plaques resulting in acute coronary syndrome or who are suspected of having spasm within the left main coronary artery. Moreover, they enable the visualization of the advancement of atherosclerosis both in the left coronary artery stem and its branches [7], which is essential when planning percutaneous revascularization.

Jasti et al. [8] showed that the minimum lumen area in the left main coronary artery, which correlates with the

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<th>Intravascular ultrasound</th>
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<tr>
<td>Greyscale</td>
<td>High definition</td>
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<tr>
<td>Ultrasound (20–45 MHz)</td>
<td>Ultrasound (60 MHz)</td>
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<td>100–200 µm/200–300 µm</td>
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| Abbreviations: IVUS, intravascular ultrasound

**Table 1. A comparison of intravascular imaging modalities (IVUS vs. OCT)**

- Ultrasound (20–45 MHz) and (60 MHz)
- Near-infrared light
- Ultrasound waves: 100–200 µm/200–300 µm, 40–60 µm/90–150 µm
- Resolution (axial/lateral): 15–20 µm/20–40 µm
- Tissue penetration: 1–2.5 mm
- Stent expansion: + + +
- Malapposition: + + +
- Thrombus: + + +
- Lipids: + + +
- Calcifications: + + +
- Edge dissection: + + +
Fractional flow reserve (FFR) value <0.75, is 5.9 mm² with high sensitivity and specificity of the results. Based on these observations, Hernandez et al. [9] proved in the LITRO study that postponing the revascularization procedure based on the IVUS result (>6.0 mm²) is safe within a 2-year follow-up period. Data from the publications of Polish authors indicate that the minimum left main coronary artery lumen area correlating with a negative FFR result (>0.75) is 8.9 mm² [10].

On the other hand, Kang et al. [11] showed in a population of 55 patients that the cut-off value for FFR <0.80 is the left main lumen area of 4.8 mm², while for FFR <0.75 it should be 4.1 mm² for the Asian population assessed in this study. It has been calculated that in patients with BMI <24 kg/m² or left ventricular mass <156 g, the surface area of the vessel lumen corresponding to FFR <0.80 should be at least 4.1 mm² [12]. This observation is consistent with the general opinion of experts who point out that the results obtained by the Korean authors are related to the demographic characteristics of Asian populations (body weight, height, overweight), which translates into smaller dimensions of the left main and coronary vessels in general. Recently, it has also been found that ethnic differences can influence the size of coronary arteries independently of parameters that determine body size, such as body weight, height, or body surface area (BSA) [13]. For this reason, the authors of the European position paper on intracoronary imaging recommend treating the interval 4.5–6.0 mm² as a gray zone and, in each case, consider the functional assessment of stenosis in the left main coronary artery [14] (Figure 3).

The use of OCT to assess the significance of intermediate left main stenosis cannot currently be recommended in everyday clinical practice. Data in this regard are limited to one study — Dato et al. [15]. Based on the criteria from their center, the authors assumed that the patient requires revascularization in the case of large plaque volume or the presence of ulceration in the left main or significant lesions in the left anterior descending (LAD) and/or circumflex (Cx) artery ostium [15].

**ASSESSMENT OF INTERMEDIATE NON LEFT MAIN LESIONS**

The use of intracoronary imaging methods to assess the significance of stenosis in non-left main lesions is not currently recommended in the European position paper [14] mainly due to large discrepancies in the results obtained by different authors. A functional evaluation should be the method of choice. In some cases (20%–25%), the results of the significance assessment based on imaging methods were false positive, which was confirmed by the FIRST study [16] and a meta-analysis of clinical trials with IVUS and FFR [17].

**OPTIMIZATION OF CORONARY ANGIOPLASTY PROCEDURES**

**Non left main lesions**

Published studies and meta-analyses of studies using IVUS clearly indicate its benefits during coronary angioplasty procedures with stent implantation [18–25], including a reduction in long-term mortality and the frequency of re-revascularization and restenosis [18–21]. It should be emphasized that this also applies to patients undergoing
comprehensive procedures (bifurcations, left main lesions, long lesions, etc.) [21]. Such clinical trial results and meta-analyses are influenced by at least the following factors — a reduction of the frequency of underexpanded stenting and of the risk of wrong stent position (“geographic miss” [GM], the stent does not cover the entire atherosclerotic plaque), and the treatment of edge dissections [26]. Consequently, the risk of stent failure (STF) is reduced [27], as well as the incidence of periprocedural infarction, which ultimately improves the prognosis in long-term follow-up.

The benefits of optimizing PCI procedures with OCT have been confirmed in the articles by Prati et al. [28], the DOCTORS [29], and ILUMIEN III studies [30]. The meta-analysis by Buccheri et al. [23] confirmed that the risk of death and other cardiovascular events is lower with IVUS or OCT than with procedures performed under angiography guidance. Researchers note that the OCT resolution allows for the identification of abnormalities that require correction, such as malapposition >400 μm and length >1 mm, marginal dissection above 60 degrees of vessel circumference, length >2 mm, or disturbance in the structure of the medial/outer membrane of the vessel [26] (Figures 4 and 5).

In the opinion of the authors of the report, operators who decide to use intracoronary imaging should pay attention to several aspects, such as the reference size of the vessel and the composition of the atherosclerotic plaque (in terms of the occurrence of calcifications and the selection of the technique of lesion preparation). When choosing the method, i.e., IVUS or OCT, it should be remembered that in the OCT examination, the size of the vessel lumen is about

**Figure 4.** Optimization criteria after implantation of stents into non-LMS lesions. The minimal stent area (MSA) should be >5.5 mm² by intravascular ultrasound or >4.5 mm² by optical coherence tomography (red circle). Alternatively, MSA should be >80% of average reference lumen areas (i.e. distal reference — green circle). Additional criteria as follows: no significant dissection (<60 degrees, flap limited to the intima and <2 mm in length), no extensive protrusion, no significant strut malapposition (<1 mm in length, axial distance <0.4 mm), and finally plaque burden at stent edge <50 % without lipid pool) [26]

**Figure 5.** Intracoronary periprocedural imaging using optical coherence tomography and examples of post-percutaneous coronary intervention. A. Malapposition of stent struts (the malapposition distance was determined). B. Edge dissection (the blue arrows). C. Tissue protrusion (the red arrows). D. Thrombus (the green arrow) *Wire shadow
10% smaller than in IVUS [31]. Additionally, the reference segments (without changes observed on angiograms) usually have atherosclerotic plaque covering about 30%-50% of the vessel area [32]. The optimal site selected as the reference segment in the IVUS/OCT assessment should be the section of the vessel in which the plaque covers less than 50% of the vessel area. Both edges of the stent should be in such places. If this is not possible, the area with the smallest burden of the atherosclerotic plaque should be chosen. In the opinion of the authors of the report, it is additionally necessary to pay attention to the morphological features of the plaque — avoiding calcification, “soft” plaques (with a high lipid load), which could be responsible for a greater risk of dissection or flow disorders [26].

In the opinion of the authors, the selection of the stent diameter should be based on the criteria taken from the OPINION study [33]. The size (diameter) of the implanted stent should not exceed the obtained vessel diameter measurement (EEM diameter, the so-called media-to-media diameter measurement, dimension based on the outer membrane) increased by a maximum of 0.25 mm [33]. Dimensioning based on the averaged dimensions of two diameters (maximum and minimum) was also allowed — it is a good solution when the shape of the vessel is far from the circle [21].

Analyzing the results of clinical trials in terms of the minimum stent lumen area reducing the risk of adverse events during the observation period, it was found that it should be 5.5 mm² [34] in the case of IVUS studies and 4.5 mm² in the case of OCT [35], which also was confirmed by the European recommendations [14]. Alternatively, the second method of assessing the minimum stent area (MSA) is a reference vessel lumen area criterion (Figure 4) of at least 80% of the averaged proximal and distal lumen area of the vessel. It is also known that obtaining an MSA value larger than the lumen area in the distal reference segment allowed reducing the incidence of cardiac events by up to 1.5% per year [20].

At this point, it is necessary to mention the more and more widely used mnemonic principle of minimal lumen diameter (MLD) MAX, which helps in optimizing angioplasty procedures using OCT. More information can be found in the literature [36].

Another context, in which the authors of the opinion recommend the use of intracoronary imaging, especially OCT, is the failure of stent implantation (STT). It applies not only to in-stent restenosis, but primarily to stent thrombosis and the identification of pathologies that such underexpansion, edge dissection, GM, neoatherosclerosis, and stent struts fractures in OCT [37]. The use of IVUS/OCT imaging is, in the opinion of the authors, very useful in planning the re-treatment of revascularization and in identifying potential threats to these procedures (calcification, TCFA, etc.). Additionally, the resolution of OCT helps to identify the causes of acute coronary syndromes associated with neoatherosclerosis [38].

**Left main lesions**

The use of intra-coronary ultrasound during stent implantation in the left main coronary artery resulted in a significant reduction of the composite endpoint compared to angiography-guided procedures, including those performed in the distal segment of the left coronary artery [39, 40]. In other studies, the use of IVUS by operators reduced the incidence of stent thrombosis during the long-term follow-up [41, 42].

In a study assessing the mechanisms of in-stent restenosis, Kang et al. [43] showed that immediately after stent implantation in the two-stent technique in the left main coronary artery, the minimum lumen area should be 8.2 mm² in the left main coronary artery, 6.3 mm² at the ostium of the LAD and 5.0 mm² at the ostium of the Cx. The literature refers to it as the Kang criteria (Figure 6). They are now commonly used in the clinical practice of invasive cardiologists to evaluate the outcome of stent implantation in the left main coronary artery. However, they are obtained in populations of patients with lower body weight, and, due to ethnic differences, they may be of limited use in the Polish population. At this point, it should be noted that the reports from a conference based on European and American patients indicate higher values of the minimum stent surface areas after left main coronary artery angioplasty. In the work of the Spanish authors [44], using predefined optimization criteria for left main coronary artery angioplasty significantly reduced the frequency of
the composite endpoint compared to procedures guided only by angiography [44].

In the opinion of the authors of the statement, IVUS in conjunction with the above-mentioned optimization criteria should take place in each case of left main coronary angioplasty. Operators should also take into account ethnic differences and strive for maximum optimization of the stent dimensions in accordance with the principle “bigger is better”. Indeed, this issue requires further research.

The work of Fujino et al. [45] showed that it is possible to perform OCT in the left main both before and after angioplasty. However, visualizing the entire left main segment is relatively tricky (ostial lesions), although detecting malapposition is significantly more frequent than in the case of intracoronary ultrasound. A recent report by Cortese et al. [46] revealed that the correction of underexpansion and malapposition of the stent struts might affect the angiographic outcome of the procedure in distal stenosis, although without a statistically significant change in the clinical prognosis.

It should be mentioned here that publications of the first clinical trials in which OCT was used to optimize left main stem (LMS) stent implantation procedures are already available in the literature. We talk about the LEMON [47] and ROCK II [48] studies.

Identification of culprit lesions in acute coronary syndrome

Invasive imaging should be recommended in patients with acute coronary syndrome who do not present typical coronary changes on angiography. It has been shown that the incidence of unstable lesions in patients with MINOCA reaches 25% despite angiographically normal coronary arteries or with a slight intensity of atherosclerotic lesions [49] in the vessel responsible for acute coronary syndrome (ACS). Unstable plaques are also found in patients with Tako-tsubo cardiomyopathy [50, 51], as described above.

In patients with acute coronary syndromes, it has been shown that changes that may be responsible for ACS affect many places in the coronary arteries [52], and the type of pathology associated with its occurrence may include atherosclerotic rupture or erosion, spontaneous coronary dissection, or coronary spasm [53]. Moreover, it should be emphasized that intracoronary imaging plays a significant role in the diagnosis of spontaneous dissection of the coronary artery [54].

The resolution of the OCT examination allows for the detection of a small thrombus, invisible in other imag-

<table>
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<th>Clinical scenario</th>
<th>Statement</th>
<th>Choice IVUS/OCT</th>
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<tr>
<td>Optimization of native coronary artery stenting</td>
<td>In the case of native coronary artery stenting, intracoronary imaging should be considered both before (for vessel sizing, assessment of calcifications, etc.) and after the procedure (assessment of stent expansion, edge dissections, geographic miss, etc.). It is recommended to achieve 5.5 mm² (MLA) (in IVUS) or 4.5 mm² (in OCT) and/or &gt;80% of a vessel lumen area in its distal reference segment. An operator should be focused on correcting strut’s malposition and large edge dissections. In the case of long lesions and CTO recanalization procedures, it is recommended to use intracoronary imaging at every stage of the procedures.</td>
<td>IVUS = OCT</td>
</tr>
<tr>
<td>Optimization of revascularization in patients with coronary calcifications</td>
<td>Intra-coronary imaging is recommended to select an appropriate therapeutic technique, including ablation, in selected patients with moderate to severe coronary calcifications. Its use after stent implantation allows for optimizing prosthesis expansion</td>
<td>OCT &gt; IVUS</td>
</tr>
<tr>
<td>Assessment of intermediate left main lesions</td>
<td>IVUS is recommended to assess an intermediate left main stenosis. The examination should evaluate the orifices of both main vessels, as well as morphology and extent (plaque continuity) of atherosclerosis. It is recommended to consider 6 mm² as the cut-off point for revascularization/deferral. In questionable cases, the examination may be supplemented with an FFR assessment</td>
<td>IVUS</td>
</tr>
<tr>
<td>Guidance of left main stenting</td>
<td>IVUS should be mandatory in every case of the left main stenting procedure, particularly for two-stent techniques. It is recommended to use IVUS both before (planning) and after stent implantation (verifying stent expansion, malapposition, etc.). OCT imaging for stenting is feasible but has some limitations due to the acquisition technique</td>
<td>IVUS &gt; OCT</td>
</tr>
<tr>
<td>Intracoronary imaging in acute coronary syndromes</td>
<td>Intracoronary imaging is recommended in every case of suspected acute coronary syndrome with no obvious evidence of a culprit lesion. It should be performed to rule out abnormalities, such as plaque erosion or rupture, intravascular thrombus, or spontaneous dissection of a coronary artery. OCT is preferred for diagnosis and treatment of acute coronary syndrome related to stent failure caused by edge dissection, large malappositions, plaque prolapse, and neatherosclerosis.</td>
<td>OCT &gt; IVUS</td>
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<tr>
<td>Imaging for spontaneous coronary artery dissection</td>
<td>Intravascular ultrasound is preferred due to no-contrast imaging that could expand intramural hematoma</td>
<td>IVUS &gt; OCT</td>
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<td>Stent failure</td>
<td>Intracoronary imaging is recommended to rule out mechanical causes of restenosis or stent thrombosis, such as stent underexpansion, edge dissection, acquired malapposition, and neatherosclerosis. It can help choose an appropriate therapy</td>
<td>OCT &gt; IVUS</td>
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<td>Cardiac allograft vasculopathy</td>
<td>Intracoronary imaging (particularly IVUS) is recommended as a routine diagnostic tool for CAV after heart transplantation according to the recommendations of transplant societies</td>
<td>IVUS &gt; OCT</td>
</tr>
<tr>
<td>Assessment of neatherosclerosis</td>
<td>Intracoronary imaging is recommended in every patient with suspected transformation to neatherosclerosis to diagnose the nature of the lesion and plan a revascularization strategy</td>
<td>OCT &gt; IVUS</td>
</tr>
<tr>
<td>Other applications</td>
<td>CTO procedures (wire advancement, true/false lumen navigation) — studies on progression/regression of atherosclerosis</td>
<td>IVUS/OCT</td>
</tr>
</tbody>
</table>

Abbreviations: CAV, cardiac allograft vasculopathy; CTO, chronic total occlusion; FFR, fractional flow reserve; IVUS, intravascular ultrasound; OCT, optical coherence tomography.
ing tests, and therefore should be recommended as an additional diagnostic tool in the case of suspected acute coronary syndrome and no significant lesions on the coronary angiography.

The OCT resolution also allows direct measuring of the thickness of the fibrous cap of the plaque. Sawada et al. [55] showed in a population of 56 patients that neither VH-IVUS nor OCT used alone were sufficient for reliable identification of TCFA (thin cap fibrous atheroma). Moreover, the use of OCT enables the detection of intracoronary thrombus, ruptured plaque, and TCFA in vessels not responsible for ACS [55, 56]. This finding confirmed previous IVUS observations that plaque instability is a general coronary phenomenon [52].

THE ROLE OF INVASIVE IMAGING IN CALCIFIED LESIONS

Calcifications are a risk factor for abnormal stent deployment [57]. The work of Hoffmann et al. [58] and Fujino et al. [59] clearly showed that the presence of calcifications covering >180 degrees of the vessel circumference and the length of these calcifications >5 mm in the OCT assessment increase the risk of stent underexpansion. The recently published work by Wang et al. [60] shows that intracoronary ultrasound is more sensitive in detecting calcifications than optical coherence tomography and, of course, contrast angiography. On the other hand, the advantage of OCT is the possibility of measuring the thickness of the calcification [59], which is impossible in the case of IVUS due to the acoustic shadow. This makes it possible, together with the volumetric evaluation, to use OCT as a tool for the stent underexpansion prediction algorithm. The research of Yamamoto et al. [61] shows that high-speed rotablation and orbital atherectomy are effective in the case of superficial calcifications and vessels in which the lumen cross-section is smaller than the size of the devices as mentioned above (burr and orbital crown). At the same time, lithotripsy is effective in the case of lesions with calcifications of both superficial and deep localization [62], which may be necessary in the case of lesions within the left main coronary artery [63]. Figure 7 presents a diagram of the procedure depending on the anatomical conditions and the properties of both methods in detecting calcifications. Examples of other algorithms for dealing with calcified lesions are available in the literature [64].

OTHER APPLICATIONS — CARDIAC ALLOGRAFT VASCULOPATHY

Coronary vasculopathy (CAV) following cardiac transplantation [65] presents as progressive changes in epicardial arteries, often in the absence of lumen-narrowing lesions. For this reason, the use of intracoronary imaging is recommended, along with angiographic examination 4–6 weeks after heart transplantation to exclude coronary artery disease in the donor and its repeat after one year to assess disease progression. The use of OCT requires further research, but the results so far have been promising [66].

**Figure 7.** An algorithm for the management of calcified lesions and technique preference

<table>
<thead>
<tr>
<th>Calcium &gt; 180°</th>
<th>Calcium length &gt; 5 mm</th>
<th>Calcium thickness &gt; 0.5 mm</th>
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<tr>
<td>Mild/moderate calcifications</td>
<td>+ + + + +</td>
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<tr>
<td>Deep calcifications</td>
<td>+ + +</td>
<td>+</td>
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<tr>
<td>Superficial calcifications</td>
<td>+ + +</td>
<td>+ + +</td>
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<tr>
<td>Arc of calcium</td>
<td>+ + +</td>
<td>+ + +</td>
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<tr>
<td>Calcification thickness</td>
<td>0</td>
<td>+ + +</td>
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</table>

**Abbreviations:** PCI, percutaneous coronary intervention; other — see Table 2
OTHER APPLICATIONS — NEOATHEROSCLEROSIS

Long observation periods of patients with implanted coronary stents revealed a new phenomenon — neoatherosclerosis [67]. It often takes the form of in-stent restenosis when the degree of narrowing of the vessel exceeds 50% of the vessel lumen. However, only intravascular imaging allows for precise visualization of the vessel wall pathology (Figure 8), consisting of TCFA lesions, plaque ruptures, calcification, or stent thrombus [68]. For this reason, OCT is the technique of choice to visualize the changes mentioned above.

REFUND POLICY

The reimbursement of intravascular imaging in Poland is carried out based on Regulation No. 38/2017/DSOZ of the President of the National Health Fund of May 29, 2017. The reimbursement covers only intravascular ultrasound, both for chronic and acute coronary syndromes, and is assigned to the code: ICD-9 00.241. However, at the beginning of 2022, OCT was introduced by the Ministry of Health to the list of guaranteed benefits, which gives hope that it might be included in the reimbursement of the National Health Fund. Table 3 presents anatomical and clinical conditions of reimbursement in Poland.

CONCLUSIONS

Data from clinical trials and large registries demonstrate the benefits of intracoronary imaging. The long-term outcomes may be significantly improved with these modalities. In many cases, both these techniques complement each other in obtaining information on pathologies of a coronary artery wall. It should also be emphasized that cost-effectiveness analysis provided arguments in favor of using intracoronary imaging in everyday clinical practice [69], which should translate directly into financing of both intracoronary imaging methods. Nowadays, only intravascular ultrasound is reimbursed in Poland, but it should be highlighted that optical coherence tomography should also be reimbursed with a similar indication as IVUS.

Table 3. Reimbursement conditions in Poland

- Left main lesion severity assessment
- Proximal left anterior descending artery lesion severity assessment
- Multivessel coronary artery lesion severity assessment
- Follow-up of left main stenting
- Assessment of mechanisms and treatment selection in case of stent failure (in-stent restenosis, stent thrombosis, suboptimal acute result suspicion)
- Diagnosis of myocardial infarction in case of ambiguous angiography result
- Diagnosis of cardiac allograft vasculopathy

CONFLICT OF INTEREST


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