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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DOI: 10.33963/KP.a2022.0071

Received:
March 11, 2022

Accepted:
March 11, 2022

Early publication date:
March 15, 2022

ABSTRACT

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.

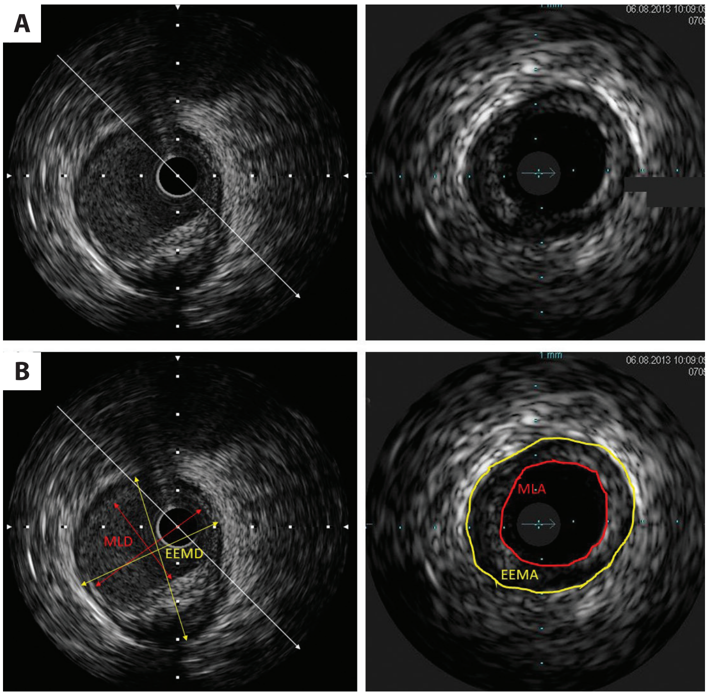


Figure 1. A. Ultrasound images obtained with a 40 MHz mechanical probe (Boston Scientific) (left panel) and a 20 MHz electronic probe (Philips IGT Co, Volcano Co) (right panel). In the first case, a single crystal emitting an ultrasound wave is mounted on a rotating shaft, which scans the vessel's circumference at an appropriate speed — the reflected echo is processed in the IVUS machine. In the second case (on the right), the probe is made of 64 piezoelectric crystals, which are electrically activated and send successively ultrasound waves, which are then processed in the IVUS machine. **B.** Examples of IVUS cross-sectional measurements — on the left side, there are examples of vessel diameter measurements — vessel diameter (external elastic membrane diameter, EEMD) and minimal lumen diameter (MLD). At least two measurements are made in perpendicular lines, determining the maximum and minimum dimensions — their quotient is the vessel/lumen symmetry index. On the right, measurements of the vessel area (external elastic membrane area, EEMA) and measurements of the vessel lumen area (minimal lumen area, MLA)

Abbreviations: IVUS, intravascular ultrasound

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

Intravascular ultrasound			Optical coherence tomography
Greyscale	**High definition**		
Ultrasound (20–45 MHz)	Ultrasound (60 MHz)	Image source	Near-infrared light
100–200 µm/200–300 µm	40–60 µm/90–150 µm	**Resolution (axial/lateral)**	15–20 µm/20–40 µm
10 mm	4–8 mm	Tissue penetration	1–2.5 mm
+ + +	+ + +	Stent expansion	+ + +
+ +	+ +	Malapposition	+ + +
+	++	Thrombus	+ + +
+	++	Lipids	+ +
+ +	+ +	Calcifications	+ + +
+ +	+ ++	Edge dissection	+ + +

INTRAVASCULAR ULTRASOUND AND OPTICAL COHERENCE TOMOGRAPHY

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

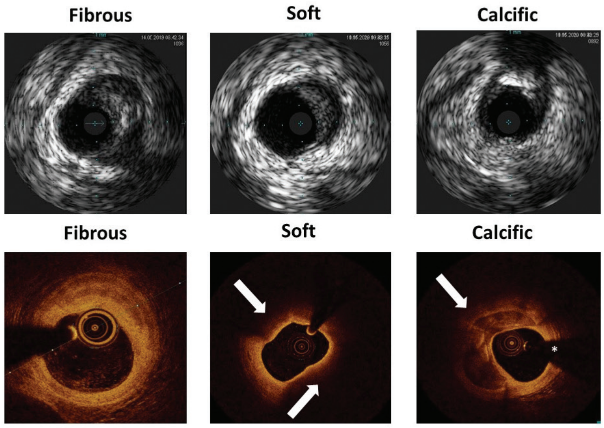


Figure 2. Examples of atherosclerotic plaques in intravascular ultrasound (top line) and optical coherence tomography (bottom line) imaging

fractional flow reserve (FFR) value <0.75, is 5.9 mm^2 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 mm^2) 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 mm^2 [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 mm^2, while for FFR <0.75 it should be 4.1 mm^2 for the Asian population assessed in this study. It has been calculated that in patients with BMI <24 kg/m^2 or left ventricular mass <156 g, the surface area of the vessel lumen corresponding to FFR <0.80 should be at least 4.1 mm^2 [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 mm^2 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].

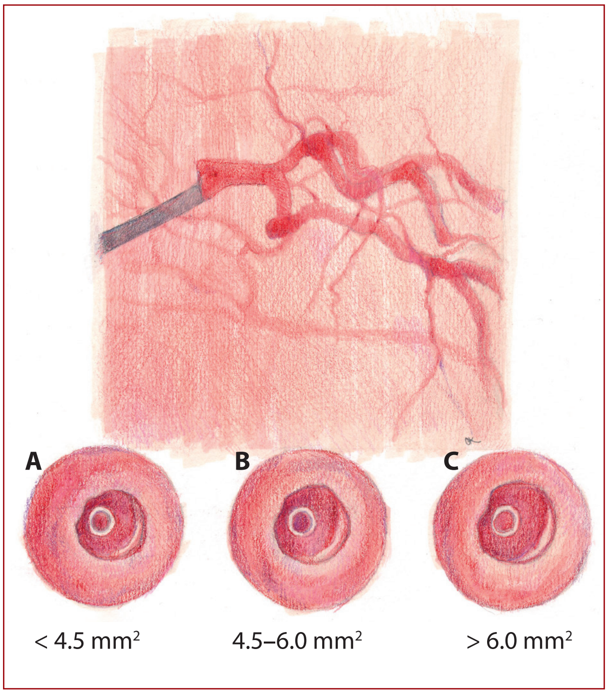


Figure 3. Schematic representation of borderline left main minimal lumen area seen on an intravascular ultrasound. According to [14], a lumen area less than 4.5 mm^2 (**A**) requires revascularization, but the lumen presented in subpanel **C** could be deferred from treatment. Values in between should be diagnosed with additional techniques (**B**, i.e. fractional flow reserve)

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

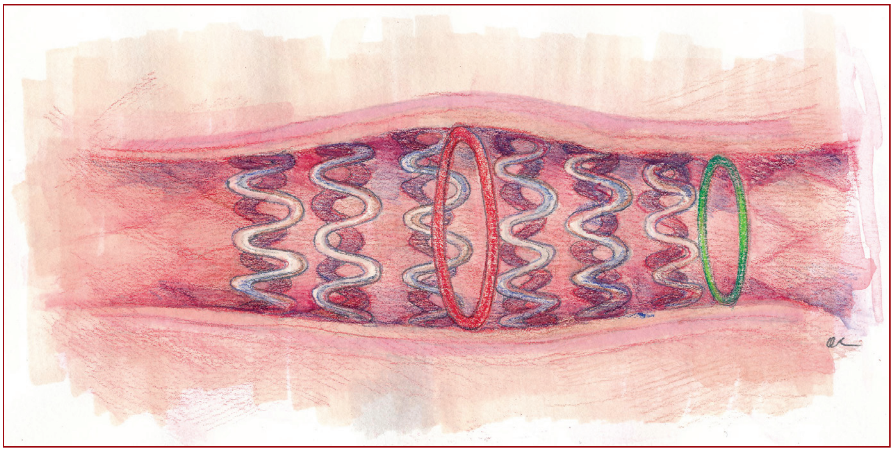


Figure 4. Optimization criteria after implantation of stents into non-LMS lesions. The minimal stent area (MSA) should be >5.5 mm² by intravascular ultrasound or >4.5 mm² by optical coherence tomography (red circle). Alternatively, MSA should be >80% of average reference lumen areas (i.e. distal reference — 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 malapossition (<1 mm in length, axial distance <0.4 mm), and finally plaque burden at stent edge <50 % without lipid pool) [26]

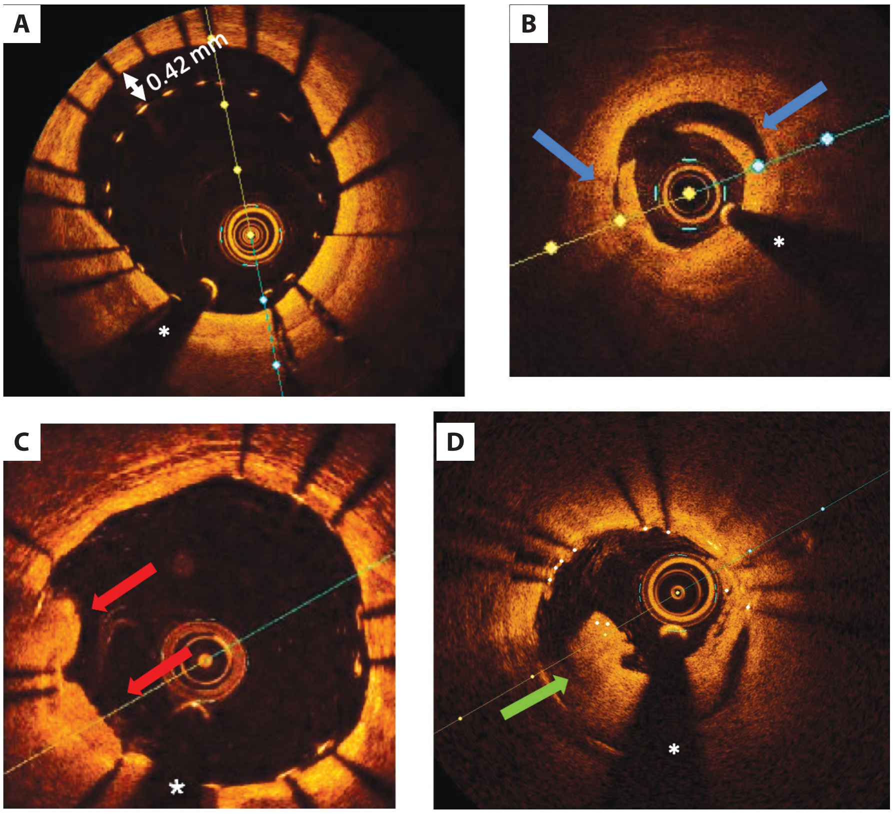


Figure 5. Intracoronary periprocedural imaging using optical coherence tomography and examples of post-percutaneous coronary intervention. **A**. Malapposition of stent struts (the malapposition distance was determined). **B.** Edge dissection (the blue arrows). **C.** Tissue protrusion (the red arrows). **D.** Thrombus (the green arrow)

*Wire shadow

comprehensive procedures (bifurcations, left main lesions, long lesions, etc.) [21]. Such clinical trial results and meta-analyzes 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

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 mm^2 [34] in the case of IVUS studies and 4.5 mm^2 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 (STF). It applies not only to in-stent restenosis, but primarily to stent thrombosis and the identification of pathologies such as stent 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].

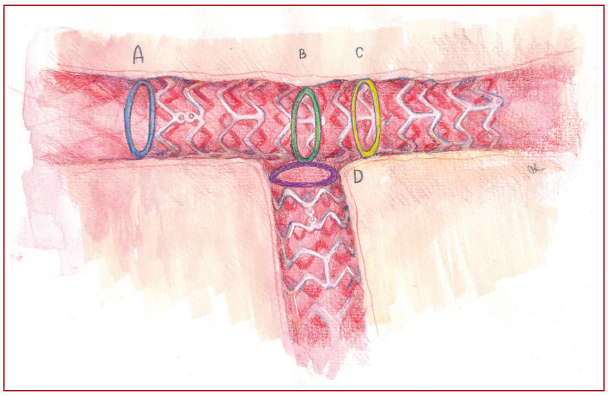


Figure 6. Schematic representation of optimal minimal lumen areas after left main stent implantation. The different values were shown in the Asian (Kang criteria) and in the European (EXCEL study) populations; **A** represents minimal stent area at the left main trunk (8.2 mm^2 for Kang and 9.3 mm^2); **B** indicates POC-transitional zone (polygon of confluence) and the 7.0 mm^2 for Kang criteria and no data for Excel study; **C** represents left anterior descending artery with 6.3 mm^2 of Kang criteria and 6.9 mm^2 for EXCEL trial; **D** indicates ostium of the circumflex artery and 5.0 mm^2 of Kang data and 5.3 mm^2 for EXCEL data

EXCEL data presented during Fellow Course 2021 (unpublished)

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 mm^2 in the left main coronary artery, 6.3 mm^2 at the ostium of the LAD and 5.0 mm^2 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

Table 2. A summary of the experts' opinion on the clinical use of intravascular imaging

Clinical scenario	Statement	Choice IVUS/OCT
Optimization of native coronary artery stenting	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 >80% of a vessel lumen area in its distal reference segment. An operator should be focused on correcting struts' malapposition 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	IVUS = OCT
Optimization of revascularization in patients with coronary calcifications	Intracoronary 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	OCT >IVUS
Assessment of intermediate left main lesions	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	IVUS
Guidance of left main stenting	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	IVUS >OCT
Intracoronary imaging in acute coronary syndromes	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 malappositons, plaque prolapse, and neoatherosclerosis	OCT >IVUS
Imaging for spontaneous coronary artery dissection	Intravascular ultrasound is preferred due to no-contrast imaging that could expand intramural hematoma	IVUS >OCT
Stent failure	Intracoronary imaging is recommended to rule out mechanical causes of restenosis or stent thrombosis, such as stent underexpansion, edge dissection, acquired malapposition, and neoaterosclerosis. It can help choose an appropriate therapy	OCT >IVUS
Cardiac allograft vasculopathy	Intracoronary imaging (particularly IVUS) is recommended as a routine diagnostic tool for CAV after heart transplantation according to the recommendations of transplant societies	IVUS >OCT
Assessment of neoatherosclerosis	Intracoronary imaging is recommended in every patient with suspected transformation to neoatherosclerosis to diagnose the nature of the lesion and plan a revascularization strategy	OCT >IVUS
Other applications	CTO procedures (wire advancement, true/false lumen navigation) — studies on progression/regression of atherosclerosis	IVUS/OCT

Abbreviations: CAV, cardiac allograft vasculopathy; CTO, chronic total occlusion; FFR, fractional flow reserve; IVUS, intravascular ultrasound; OCT, optical coherence tomography

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

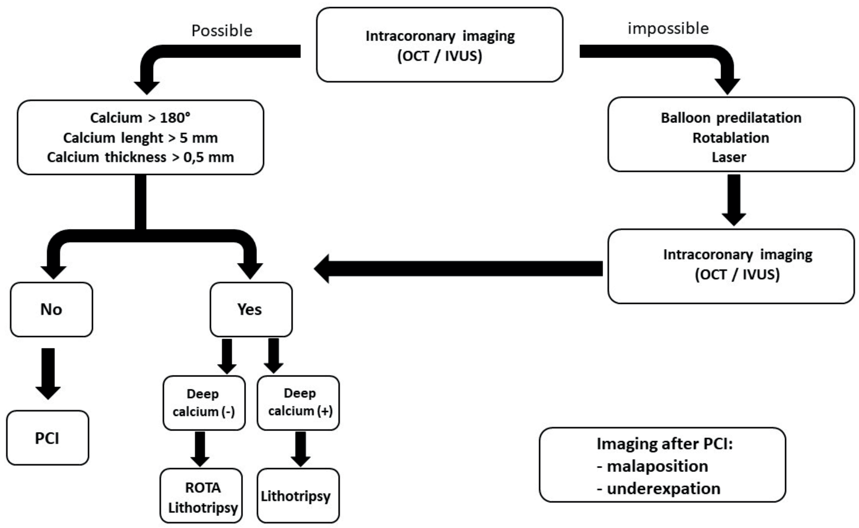
Invasive imaging should be recommended in patients with acute coronary syndrome who do not present typical coronary changes on angiography. It has been shown that the incidence of unstable lesions in patients with MINOCA reaches 25% despite angiographically normal coronary arteries or with a slight intensity 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-

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

	IVUS	OCT
Mild/moderate calcifications	+ +	+ + +
Deep calcifications	+ + +	+ +
Superficial calcifications	+ + +	+ + +
Arc of calcium	+ + +	+ + +
Calcification thickness	0	+ + +



Abbreviations: PCI, percutaneous coronary intervention; other — see Table 2

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].

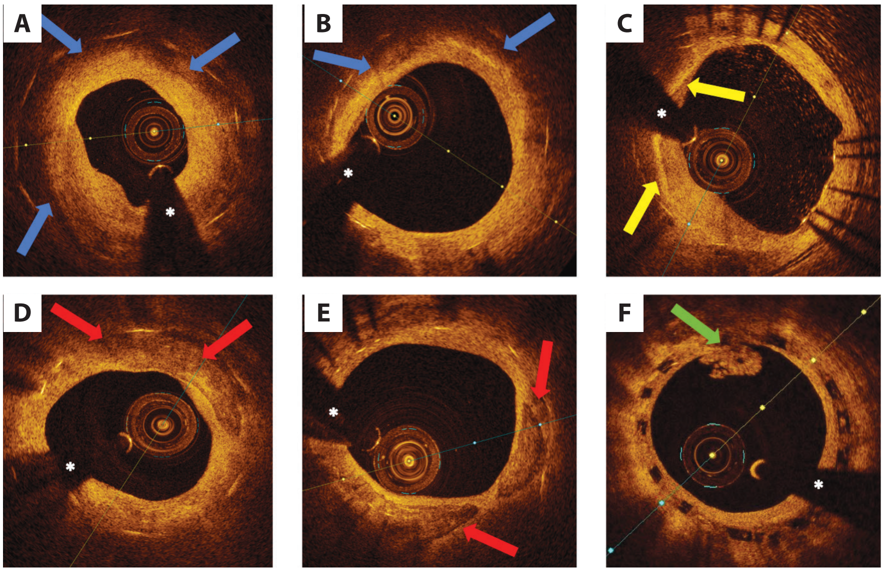


Figure 8. Long-term follow-up after percutaneous coronary angioplasty. **A–D.** Examples of neoatherosclerosis after bare-metal stent/drug-eluting stent implantation. The red arrows — calcifications; the blue arrows — lipid accumulation; the yellow arrows — macrophage accumulation, the green arrow — thrombus

*Wire shadow

Table 3. Reimbursement conditions in Poland

- Left main lesion severity assessment
- Proximal left anterior descendent 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

OTHER APPLICATIONS — NEOATHEROSCLEROSIS

Long observation periods of patients with implanted coronary stents revealed a new phenomenon — neoaterosclerosis [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.

Article information

Conflict of interest: TP reports speaking honoraria from Philips IGT and Abbott Vascular. JL reports speaking honoraria from Philips IGT and Abbott Vascular. JK reports Philips IGT and Abbott Vascular. JP reports speaking honoraria from Boston Scientific. WW reports speaking honoraria from Abbott Vascular and Boston Scientific. AW reports speaking honoraria from Abbott Vascular and Boston Scientific and proctoring fee from Boston Scientific. RG reports Philips IGT, Abbott Vascular, and proctoring fees from Philips IGT.

REFERENCES

1. Gąsior P, Bryniarski K, Roleder M, et al. Knowledge of intravascular imaging in interventional cardiology practice: results of a survey on Polish interventional cardiologists. Kardiol Pol. 2019; 77(12): 1193–1195, doi: 10.33963/KP.15077, indexed in Pubmed: 31782752.
2. Koskinas KC, Nakamura M, Räber L, et al. Current use of intracoronary imaging in interventional practice — Results of a European Association of Percutaneous Cardiovascular Interventions (EAPCI) and Japanese Association of Cardiovascular Interventions and Therapeutics (CVIT) Clinical Practice Survey. EuroIntervention. 2018; 14(4): e475–e484, doi: 10.4244/EIJY18M03_01, indexed in Pubmed: 29537966.
3. Yock PG, Linker DT, Angelsen BA. Two-dimensional intravascular ultrasound: technical development and initial clinical experience. J Am Soc Echocardiogr. 1989; 2(4): 296–304, doi: 10.1016/s0894-7317(89)80090-2, indexed in Pubmed: 2697308.
4. Mintz G, Garcia-Garcia H, Nicholls S, et al. Clinical expert consensus document on standards for acquisition, measurement and reporting of intravascular ultrasound regression/progression studies. EuroIntervention. 2011; 6(9): 1123–1130, doi: 10.4244/eijv6i9a195.
5. Ono M, Kawashima H, Hara H, et al. Advances in IVUS/OCT and Future Clinical Perspective of Novel Hybrid Catheter System in Coronary Imaging. Front Cardiovasc Med. 2020; 7: 119, doi: 10.3389/fcvm.2020.00119, indexed in Pubmed: 32850981.
6. Prati F, Regar E, Mintz GS, et al. Expert review document on methodology, terminology, and clinical applications of optical coherence tomography: physical principles, methodology of image acquisition, and clinical application for assessment of coronary arteries and atherosclerosis. Eur Heart J. 2010; 31(4): 401–415, doi: 10.1093/eurheartj/ehp433, indexed in Pubmed: 19892716.
7. Oviedo C, Maehara A, Mintz GS, et al. Intravascular ultrasound classification of plaque distribution in left main coronary artery bifurcations: where is the plaque really located? Circ Cardiovasc Interv. 2010; 3(2): 105–112, doi: 10.1161/CIRCINTERVENTIONS.109.906016, indexed in Pubmed: 20197513.
8. Jasti V, Ivan E, Yalamanchili V, et al. Correlations between fractional flow reserve and intravascular ultrasound in patients with an ambiguous left main coronary artery stenosis. Circulation. 2004; 110(18): 2831–2836, doi: 10.1161/01.CIR.0000146338.62813.E7, indexed in Pubmed: 15492302.
9. Hernandez Jd, Hernandez FH, Alfonso F, et al. Prospective application of pre-defined intravascular ultrasound criteria for assessment of intermediate left main coronary artery lesions. J Am Coll Cardiol. 2011; 58(4): 351–358, doi: 10.1016/j.jacc.2011.02.064, indexed in Pubmed: 21757111.
10. Legutko J, Dudek D, Jakala J, et al. TCT-309 Correlation between fractional flow reserve and intravascular ultrasound in patients with isolated ambiguous left main stenosis. J Am Coll Cardiol. 2012; 60(17): B88, doi: 10.1016/j.jacc.2012.08.333.
11. Kang S, Lee J, Ahn JI, et al. intravascular ultrasound-derived predictors for fractional flow reserve in intermediate left main disease. J Am Coll Cardiol Intv. 2011; 4: 1168–1174, doi: 10.1016/j.jcin.2011.08.009, indexed in Pubmed: 22115656.
12. Park SJ, Ahn JM, Kang SJ, et al. Intravascular ultrasound-derived minimal lumen area criteria for functionally significant left main coronary artery stenosis. J Am Coll Cardiol Cardiovasc Interv. 2014; 7(8): 868–874, doi: 10.1016/j.jcin.2014.02.015, indexed in Pubmed: 25147031.
13. Skowronski J, Cho I, Mintz GS, et al. Inter-ethnic differences in normal coronary anatomy between Caucasian (Polish) and Asian (Korean) populations. Eur J Radiol. 2020; 130: 109185, doi: 10.1016/j.ejrad.2020.109185, indexed in Pubmed: 32771813.
14. Johnson TW, Räber L, Di Mario C, et al. Clinical use of intracoronary imaging. Part 2: acute coronary syndromes, ambiguous coronary angiography findings, and guiding interventional decision-making: an expert consensus document of the European Association of Percutaneous Cardiovascular Interventions. EuroIntervention. 2019; 15(5): 434–451, doi: 10.4244/EIJY19M06_02, indexed in Pubmed: 31258132.
15. Dato I, Burzotta F, Trani C, et al. Optical coherence tomography guidance for the management of angiographically intermediate left main bifurcation lesions: Early clinical experience. Int J Cardiol. 2017; 248: 108–113, doi: 10.1016/j.ijcard.2017.06.125, indexed in Pubmed: 28709701.
16. Waksman R, Legutko J, Singh J, et al. FIRST: Fractional Flow Reserve and Intravascular Ultrasound Relationship Study. J Am Coll Cardiol. 2013; 61(9): 917–923, doi: 10.1016/j.jacc.2012.12.012, indexed in Pubmed: 23352786.
17. Nascimento B, de Sousa M, Koo B, et al. Diagnostic accuracy of intravascular ultrasound- derived minimal lumen area compared with fractional flow reserve — meta-analysis pooled accuracy of IVUS luminal area versus FFR. Catheter Cardiovasc Interv. 2014; 84(3): 377–385, doi: 10.1002/ccd.25047, indexed in Pubmed: 23737441.
18. Gil RJ, Pawłowski T, Dudek D, et al. Comparison of angiographically guided direct stenting technique with direct stenting and optimal balloon angioplasty guided with intravascular ultrasound. The multicenter, randomized trial results. Am Heart J. 2007; 154(4): 669–675, doi: 10.1016/j.ahj.2007.06.017, indexed in Pubmed: 17892989.
19. Parise H, Maehara A, Stone GW, et al. Meta-analysis of randomized studies comparing intravascular ultrasound versus angiographic guidance of percutaneous coronary intervention in pre-drug-eluting stent era. Am J Cardiol. 2011; 107(3): 374–382, doi: 10.1016/j.amjcard.2010.09.030, indexed in Pubmed: 21257001.
20. Hong SJ, Mintz GS, Ahn CM, et al. Effect of intravascular ultrasound-guided drug-eluting stent implantation: 5-year follow-up of the IVUS-XPL randomized trial. J Am Coll Cardiol Cardiovasc Interv. 2020; 13(1): 62–71, doi: 10.1016/j.jcin.2019.09.033, indexed in Pubmed: 31918944.
21. Gao XF, Ge Z, Kong XQ, et al. Intravascular ultrasound versus angiography-guided drug-eluting stent implantation: the ULTIMATE trial. J Am Coll Cardiol. 2018; 72(24): 3126–3137, doi: 10.1016/j.jacc.2018.09.013, indexed in Pubmed: 30261237.
22. Choi KiH, Song YB, Lee JM, et al. Impact of intravascular ultrasound-guided percutaneous coronary intervention on long-term clinical outcomes in patients undergoing complex procedures. J Am Coll Cardiol Cardiovasc Interv. 2019; 12(7): 607–620, doi: 10.1016/j.jcin.2019.01.227, indexed in Pubmed: 30878474.
23. Buccheri S, Franchina G, Romano S, et al. Clinical outcomes following intravascular imaging-guided versus coronary angiography-guided percutaneous coronary intervention with stent implantation: a systematic review and bayesian network meta-analysis of 31 studies and 17,882 patients. J Am Coll Cardiol Cardiovasc Interv. 2017; 10(24): 2488–2498, doi: 10.1016/j.jcin.2017.08.051, indexed in Pubmed: 29153502.
24. Ahn JM, Kang SJ, Yoon SH, et al. Meta-Analysis of outcomes after intravascular ultrasound–guided versus angiography-guided drug-eluting stent implantation in 26,503 patients enrolled in three randomized trials and 14 observational studies. Am J Cardiol. 2014; 113(8): 1338–1347, doi: 10.1016/j.amjcard.2013.12.043, indexed in Pubmed: 24685326.
25. Gao XF, Ge Z, Kong XQ, et al. 3-Year outcomes of the ULTIMATE trial comparing intravascular ultrasound versus angiography-guided drug-eluting stent implantation. J Am Coll Cardiol Cardiovasc Interv. 2021; 14(3): 247–257, doi: 10.1016/j.jcin.2020.10.001, indexed in Pubmed: 33541535.
26. Räber L, Mintz GS, Koskinas KC, et al. Clinical use of intracoronary imaging. Part 1: guidance and optimization of coronary interventions. An expert consensus document of the European Association of Percutaneous Cardiovascular Interventions. Eur Heart J. 2018; 39(35): 3281–3300, doi: 10.1093/eurheartj/ehy285, indexed in Pubmed: 29790954.
27. Doi H, Maehara A, Mintz GS, et al. Impact of post-intervention minimal stent area on 9-month follow-up patency of paclitaxel-eluting stents: an integrated intravascular ultrasound analysis from the TAXUS IV, V, and VI and TAXUS ATLAS Workhorse, Long Lesion, and Direct Stent Trials. JACC Cardiovasc Interv. 2009; 2(12): 1269–1275, doi: 10.1016/j.jcin.2009.10.005, indexed in Pubmed: 20129555.
28. Prati F, Di Vito L, Biondi-Zoccai G, et al. Angiography alone versus angiography plus optical coherence tomography to guide decision-making during percutaneous coronary intervention: the Centro per la Lotta contro l'Infarto-Optimisation of Percutaneous Coronary Intervention (CLI-OPCI) study. EuroIntervention. 2012; 8(7): 823–829, doi: 10.4244/EIJV8I7A125, indexed in Pubmed: 23034247.
29. Meneveau N, Souteyrand G, Motreff P, et al. Optical coherence tomography to optimize results of percutaneous coronary intervention in patients with non-st-elevation acute coronary syndrome: results of the multicenter, randomized DOCTORS study (Does Optical Coherence Tomography

Optimize Results of Stenting). Circulation. 2016; 134(13): 906–917, doi: 10.1161/CIRCULATIONAHA.116.024393, indexed in Pubmed: 27573032.
30. Ali ZA, Karimi Galougahi K, Maehara A, et al. Optical coherence tomography compared with intravascular ultrasound and with angiography to guide coronary stent implantation (ILUMIEN III: OPTIMIZE PCI): a randomised controlled trial. Lancet. 2016; 388(10060): 2618–2628, doi: 10.1016/S0140-6736(16)31922-5, indexed in Pubmed: 27806900.
31. Kubo T, Akasaka T, Shite J, et al. OCT compared with IVUS in a coronary lesion assessment: the OPUS-CLASS study. J Am Coll Cardiol Cardiovasc Imaging. 2013; 6(10): 1095–1104, doi: 10.1016/j.jcmg.2013.04.014, indexed in Pubmed: 24011777.
32. Mintz GS, Painter JA, Pichard AD, et al. Atherosclerosis in angiographically „normal" coronary artery reference segments: an intravascular ultrasound study with clinical correlations. J Am Coll Cardiol. 1995; 25(7): 1479–1485, doi: 10.1016/0735-1097(95)00088-l, indexed in Pubmed: 7759694.
33. Otake H, Kubo T, Takahashi H, et al. Optical frequency domain imaging versus intravascular ultrasound in percutaneous coronary intervention (OPINION trial): results from the OPINION imaging study. J Am Coll Cardiol Cardiovasc Imaging. 2018; 11(1): 111–123, doi: 10.1016/j.jcmg.2017.06.021, indexed in Pubmed: 28917678.
34. Hong MK, Mintz GS, Lee CW, et al. Intravascular ultrasound predictors of angiographic restenosis after sirolimus-eluting stent implantation. Eur Heart J. 2006; 27(11): 1305–1310, doi: 10.1093/eurheartj/ehi882, indexed in Pubmed: 16682378.
35. Prati F, Romagnoli E, Burzotta F, et al. Clinical impact of OCT findings during PCI: the CLI-OPCI II study. J Am Coll Cardiol Cardiovasc Imaging. 2015; 8(11): 1297–1305, doi: 10.1016/j.jcmg.2015.08.013, indexed in Pubmed: 26563859.
36. Ali ZA, Galougahi KK, Mintz GS, et al. Intracoronary optical coherence tomography: state of the art and future directions. EuroIntervention. 2021; 17(2): e105–e123, doi: 10.4244/EIJ-D-21-00089, indexed in Pubmed: 34110288.
37. Hong SJ, Lee SY, Hong MKi. Clinical implication of optical coherence tomography-based neoatherosclerosis. J Korean Med Sci. 2017; 32(7): 1056–1061, doi: 10.3346/jkms.2017.32.7.1056, indexed in Pubmed: 28581259.
38. Lee SY, Hur SH, Lee SG, et al. Optical coherence tomographic observation of in-stent neoatherosclerosis in lesions with more than 50% neointimal area stenosis after second-generation drug-eluting stent implantation. Circ Cardiovasc Interv. 2015; 8(2): e001878, doi: 10.1161/CIRCINTERVENTIONS.114.001878, indexed in Pubmed: 25613674
39. Park SJ, Kim YH, Park DW, et al. Impact of intravascular ultrasound guidance on long-term mortality in stenting for unprotected left main coronary artery stenosis. Circ Cardiovasc Interv. 2009; 2(3): 167–177, doi: 10.1161/CIRCINTERVENTIONS.108.799494, indexed in Pubmed: 20031713.
40. de la Torre Hernandez J, Alonso JB, Hospital JG, et al. Clinical impact of intravascular ultrasound guidance in drug-eluting stent implantation for unprotected left main coronary disease. JACC Cardiovasc Interv. 2014; 7(3): 244–254, doi: 10.1016/j.jcin.2013.09.014, indexed in Pubmed: 24650399.
41. Andell P, Karlsson S, Mohammad MA, et al. Intravascular ultrasound guidance is associated with better outcome in patients undergoing unprotected left main coronary artery stenting compared with angiography guidance alone. Circ Cardiovasc Interv. 2017; 10(5), doi: 10.1161/CIRCINTERVENTIONS.116.004813, indexed in Pubmed: 28487356.
42. Gao XF, Kan J, Zhang YJ, et al. Comparison of one-year clinical outcomes between intravascular ultrasound-guided versus angiography-guided implantation of drug-eluting stents for left main lesions: a single-center analysis of a 1,016-patient cohort. Patient Prefer Adherence. 2014; 8: 1299–1309, doi: 10.2147/PPA.S65768, indexed in Pubmed: 25278749.
43. Kang SJ, Ahn JM, Song H, et al. Comprehensive intravascular ultrasound assessment of stent area and its impact on restenosis and adverse cardiac events in 403 patients with unprotected left main disease. Circ Cardiovasc Interv. 2011; 4(6): 562–569, doi: 10.1161/CIRCINTERVENTIONS.111.964643, indexed in Pubmed: 22045969.
44. de la Torre Hernandez JM, Garcia Camarero T, Baz Alonso JA, et al. Outcomes of predefined optimisation criteria for intravascular ultrasound guidance of left main stenting. EuroIntervention. 2020; 16(3): 210–217, doi: 10.4244/EIJ-D-19-01057, indexed in Pubmed: 32011286.
45. Fujino Y, Bezerra HG, Attizzani GF, et al. Frequency-domain optical coherence tomography assessment of unprotected left main coronary artery disease-a comparison with intravascular ultrasound. Catheter Cardiovasc Interv. 2013; 82(3): E173–E183, doi: 10.1002/ccd.24843, indexed in Pubmed: 23359350.
46. Cortese B, Burzotta F, Alfonso F, et al. Role of optical coherence tomography for distal left main stem angioplasty. Catheter Cardiovasc Interv. 2020; 96(4): 755–761, doi: 10.1002/ccd.28547, indexed in Pubmed: 31631525.
47. Amabile N, Rangé G, Souteyrand G, et al. Optical coherence tomography to guide percutaneous coronary intervention of the left main coronary artery: the LEMON study. EuroIntervention. 2021; 17(2): e124–e131, doi: 10.4244/EIJ-D-20-01121, indexed in Pubmed: 33226003.
48. Cortese B, de la Torre Hernandez JM, Lanocha M, et al. Optical coherence tomography, intravascular ultrasound or angiography guidance for distal left main coronary stenting. The ROCK cohort II study. Catheter Cardiovasc Interv. 2022; 99(3): 664–673, doi: 10.1002/ccd.29959, indexed in Pubmed: 34582631.
49. Opolski M, Spiewak M, Marczak M, et al. Mechanisms of Myocardial Infarction in Patients With Nonobstructive Coronary Artery Disease. J Am Coll Cardiol Cardiovasc Imaging . 2019; 12(11): 2210–2221, doi: 10.1016/j.jcmg.2018.08.022, indexed in Pubmed: 30343070.
50. Eitel I, Stiermaier T, Graf T, et al. Optical coherence tomography to evaluate plaque burden and morphology in patients with Takotsubo syndrome. J Am Heart Assoc. 2016; 5(12), doi: 10.1161/JAHA.116.004474, indexed in Pubmed: 28007746.
51. Pawłowski T, Mintz G, Kulawik T, et al. Virtual histology intravascular ultrasound evaluation of the left anterior descending coronary artery in patients with transient left ventricular ballooning syndrome. Kardiol Pol. 2010; 68(10): 1093–1098.
52. Vergallo R, Ren X, Yonetsu T, et al. Pancoronary plaque vulnerability in patients with acute coronary syndrome and ruptured culprit plaque: a 3-vessel optical coherence tomography study. Am Heart J. 2014; 167(1): 59–67, doi: 10.1016/j.ahj.2013.10.011, indexed in Pubmed: 24332143.
53. Shin ES, Ann SH, Singh GB, et al. OCT-Defined morphological characteristics of coronary artery spasm sites in vasospastic angina. J Am Coll Cardiol Cardiovasc Imaging. 2015; 8(9): 1059–1067, doi: 10.1016/j.jcmg.2015.03.010, indexed in Pubmed: 26298073.
54. Kądziela J, Kochman J, Grygier M, et al. The diagnosis and management of spontaneous coronary artery dissection — expert opinion of the Association of Cardiovascular Interventions (ACVI) of Polish Cardiac Society. Kardiol Pol. 2021; 79(7-8): 930–943, doi: 10.33963/KP.a2021.0068, indexed in Pubmed: 34292564.
55. Sawada T, Shite J, Garcia-Garcia HM, et al. Feasibility of combined use of intravascular ultrasound radiofrequency data analysis and optical coherence tomography for detecting thin-cap fibroatheroma. Eur Heart J. 2008; 29(9): 1136–1146, doi: 10.1093/eurheartj/ehn132, indexed in Pubmed: 18397871.
56. Fujii K, Masutani M, Okumura T, et al. Frequency and predictor of coronary thin-cap fibroatheroma in patients with acute myocardial infarction and stable angina pectoris a 3-vessel optical coherence tomography study. J Am Coll Cardiol. 2008; 52(9): 787–788, doi: 10.1016/j.jacc.2008.05.030, indexed in Pubmed: 18718429.
57. Hong MK, Mintz GS, Lee CW, et al. Intravascular ultrasound predictors of angiographic restenosis after sirolimus-eluting stent implantation. Eur Heart J. 2006; 27(11): 1305–1310, doi: 10.1093/eurheartj/ehi882, indexed in Pubmed: 16682378.
58. Hoffmann R, Mintz GS, Popma JJ, et al. Treatment of calcified coronary lesions with Palmaz-Schatz stents. An intravascular ultrasound study. Eur Heart J. 1998; 19(8): 1224–1231, doi: 10.1053/euhj.1998.1028, indexed in Pubmed: 9740344.
59. Fujino A, Mintz G, Matsumura M, et al. TCT-28 a new optical coherence tomography-based calcium scoring system to predict stent underexpansion. EuroIntervention. 2017; 13(18): e2182–e2189, doi: 10.4244/EIJ-D-17-00962, indexed in Pubmed: 29400655.
60. Wang X, Matsumura M, Mintz GS, et al. In vivo calcium detection by comparing optical coherence tomography, intravascular ultrasound, and angiography. J Am Coll Cardiol Cardiovasc Imaging. 2017; 10(8): 869–879, doi: 10.1016/j.jcmg.2017.05.014, indexed in Pubmed: 28797408.
61. Yamamoto MH, Maehara A, Karimi Galougahi K, et al. Mechanisms of orbital versus rotational atherectomy plaque modification in severely calcified lesions assessed by optical coherence tomography. J Am Coll Cardiol Cardiovasc Interv. 2017; 10(24): 2584–2586, doi: 10.1016/j.jcin.2017.09.031, indexed in Pubmed: 29268891.

62. Ali ZA, Brinton TJ, Hill JM, et al. Optical coherence tomography characterization of coronary lithoplasty for treatment of calcified lesions: first description. J Am Coll Cardiol Cardiovasc Imaging. 2017; 10(8): 897–906, doi: 10.1016/j.jcmg.2017.05.012, indexed in Pubmed: 28797412.
63. Cosgrove CS, Wilson SJ, Bogle R, et al. Intravascular lithotripsy for lesion preparation in patients with calcific distal left main disease. EuroIntervention. 2020; 16(1): 76–79, doi: 10.4244/EIJ-D-19-01052, indexed in Pubmed: 32224480.
64. Shlofmitz E, Ali ZA, Maehara A, et al. Intravascular imaging-guided percutaneous coronary intervention: a universal approach for optimization of stent implantation. Circ Cardiovasc Interv. 2020; 13(12): e008686, doi: 10.1161/CIRCINTERVENTIONS.120.008686, indexed in Pubmed: 33233934.
65. Calé R, Rebocho M, Aguiar C, et al. Diagnosis, prevention and treatment of cardiac allograft vasculopathy. Rev Port Cardiol. 2012; 31(11): 721–730, doi: 10.1016/j.repce.2012.09.007.
66. Dyrbuś M, Gąsior M, Szyguła-Jurkiewicz B, et al. The role of optical coherence tomography and other intravascular imaging modalities in cardiac allograft vasculopathy. Adv Interv Cardiol. 2020; 16(1): 19–29, doi: 10.5114/aic.2020.93909, indexed in Pubmed: 32368233.
67. Park SJ, Kang SJ, Virmani R, et al. In-stent neoatherosclerosis: a final common pathway of late stent failure. J Am Coll Cardiol. 2012; 59(23): 2051–2057, doi: 10.1016/j.jacc.2011.10.909, indexed in Pubmed: 22651862.
68. Joner M, Koppara T, Byrne R, et al. Neoatherosclerosis in patients with coronary stent thrombosis. J Am Coll Cardiol Cardiovasc Interv. 2018; 11(14): 1340–1350, doi: 10.1016/j.jcin.2018.02.029.
69. Mueller C, Hodgson JM, Schindler C, et al. Cost-effectiveness of intracoronary ultrasound for percutaneous coronary interventions. Am J Cardiol. 2003; 91(2): 143–147, doi: 10.1016/s0002-9149(02)03099-0, indexed in Pubmed: 12521624.