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Approach to Distal Left Main Coronary Artery Bifurcation Lesions

REVIEW

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ABSTRACT

Distal left main coronary artery (LMCA) bifurcation lesions are associated with a worse prognosis than other coronary bifurcation lesions. Although coronary artery bypass grafting remains a safe and effective treatment option in this patient population, percutaneous coronary intervention (PCI) has been increasingly adopted in patients with low-to-intermediate anatomical complexity due to its less invasive nature and the favorable long-term outcomes demonstrated in major randomized clinical trials. Given the substantial impact of LMCA revascularization on patient prognosis, meticulous procedural planning and optimization are of paramount importance. The use of intravascular imaging has proven to be of significant value both in making revascularization decisions and in optimizing PCI outcomes. Since the side branch in distal LMCA bifurcation lesions is the left circumflex artery, which supplies a significant portion of the myocardium, accurately predicting and preventing damage to this side branch is of vital importance. Intravascular imaging plays a key role in predicting side branch compromise and in determining the most appropriate stenting strategy, including provisional stenting or an upfront 2-stent approach. Regardless of the stenting strategy employed, achieving optimal minimal stent area targets is essential for improving long-term clinical outcomes. Adverse events following distal LMCA PCI most frequently occur at the left circumflex ostium, highlighting the importance of maintaining long-term side branch patency. Drug-coated balloons, which have demonstrated favorable results in bifurcation interventions, may represent a promising adjunctive therapy for side branch treatment during provisional stenting. However, further large-scale randomized studies are required to establish their role in distal LMCA bifurcation.

Keywords: Drug-coated balloons, intravascular imaging, left main bifurcation lesions, provisional stenting

INTRODUCTION

Assessment of left main coronary artery (LMCA) lesions and decision-making regarding revascularization have always represented a critical challenge for interventional cardiologists. In clinical practice, LMCA disease is encountered in approximately 4%-9% of patients undergoing coronary angiography.[1] In 70% of patients with LMCA lesions, the lesion affects the distal bifurcation. The prognosis for distal lesions is worse than that for ostial-mid LMCA lesions. [2] Intravascular imaging studies have demonstrated that only a small proportion of atherosclerotic plaques involving the LMCA are confined to the left main (LM) segment alone, whereas the majority extend distally into the bifurcation, involving the ostia of the left anterior descending (LAD) and/or left circumflex (LCx) arteries.[3]

The distal left main bifurcation differs from other coronary bifurcations in terms of its unique anatomical and hemodynamic characteristics. The LMCA has a significantly larger diameter than other epicardial coronary arteries, and its diameter typically exceeds 5 mm. Furthermore, a wider bifurcation angle, combined with turbulent blood flow and low endothelial shear stress, contributes to accelerated atherosclerotic plaque formation in this region. Additionally, since the side branch involved in distal LMCA interventions is typically LCx, which supplies a significant myocardial region, the loss of this side branch may have vital clinical consequences.[4,5]

One of the most critical challenges encountered in the treatment of distal LMCA lesions is the variability in bifurcation geometry and the risk of side-branch occlusion.[5] Therefore, careful assessment of lesion morphology, appropriate selection of the stenting strategy, and the use of a 2-stent technique when necessary are essential for the optimal management of distal LMCA bifurcation lesions. In contemporary practice, a provisional single-stent strategy is generally preferred whenever feasible; however, a planned 2-stent approach is recommended in the presence of complex anatomy or significant side branch involvement.[4,6]

In this review, the evaluation of distal LMCA bifurcation lesions, intravascular imaging methods, interventional treatment strategies, and current technical approaches will be discussed in view of the literature.

INTRAVASCULAR IMAGING METHODS FOR LEFT MAIN CORONARY LESIONS

Conventional angiography has important limitations in the evaluation of LMCA disease, particularly with respect to the assessment of lesion severity, disease distribution, and plaque morphology. The complex anatomy of the LMCA, characterized by vessel angulation, distal branch overlap, foreshortening, calcification, and the difficulty in obtaining true orthogonal views of the bifurcation, makes it difficult to accurately measure the degree of stenosis, which leads to significant variability among observers and potentially inadequate treatment outcomes.[7]

In contrast, intravascular imaging methods such as intravascular ultrasound (IVUS) and optical coherence tomography (OCT) provide high-resolution imaging of vascular wall morphology, lumen structure, and atherosclerotic plaque characteristics, which facilitates a more accurate assessment of lesions and optimizes the interventional decision-making process.[8] These techniques help optimize the procedure by determining the appropriate stent diameter and length, selecting the optimal segments for stent placement, and ensuring that the stent achieves full apposition to the vessel wall with adequate expansion. They also enable early detection and prevention of stent-related procedural complications, such as edge dissection and intramural hematoma.[8,9] Each method has its own advantages. Intravascular ultrasound offers a wider field of view and is superior for assessing plaque burden and aorto-ostial lesions. Optical coherence tomography, on the other hand, is better suited for evaluating calcification, stent malposition, deformation, and edge dissection. Although OCT provides higher resolution (10-20 µm vs. 30-40 µm with contemporary high-definition IVUS systems), its tissue penetration is more limited, making IVUS more suitable for the assessment of large-caliber vessels such as the LMCA.[4] In addition, OCT requires contrast injection to clear blood from the imaging field, whereas IVUS does not require additional contrast administration. Therefore, IVUS may offer a distinct advantage in patients with advanced chronic kidney disease or in clinical scenarios where minimizing contrast volume is desirable.[4,8]

Recent meta-analyses, including the RENOVATE-COMPLEX-PCI, ILUMIEN IV, and OCTOBER studies, have shown that intravascular imaging guidance during LM coronary interventions leads to improvements in clinical outcomes such as mortality and target vessel failure.[10] Nevertheless, the results of the OPTIMAL trial, published in 2026, have raised important questions regarding the clinical benefit of intravascular imaging guidance. In this international, multicenter, randomized study, 806 patients with LM coronary artery disease were assigned to undergo percutaneous coronary intervention (PCI) under either IVUS guidance or angiographic guidance. During follow-up, no significant differences were observed between the 2 groups with respect to the incidence of death, myocardial infarction (MI), or repeat revascularization.[11] However, when interpreting the results of the OPTIMAL trial, several important methodological differences compared with previous studies should be taken into consideration. The trial was conducted in high-volume, experienced centers, and the vast majority of procedures in both groups were completed with post-dilatation and proximal optimization technique (POT). Furthermore, additional optimization based on post-procedural IVUS findings was required in only approximately 30% of patients in the IVUS-guided group, suggesting an overall high procedural

HIGHLIGHTS

- In meta-analyses, incorporating long-term outcomes from major randomized trials such as Evaluation of XIENCE versus Coronary Artery Bypass Surgery for Effectiveness of Left Main Revascularization (EXCEL) and Nordic-Baltic-British Left Main Revascularization Study (NOBLE) in left main coronary artery (LMCA) stenosis, no significant difference in mortality has been demonstrated between coronary artery bypass grafting (CABG) and percutaneous coronary intervention (PCI) in selected patient populations.
- The findings of the OPtimal Therapy for Left Main Coronary Artery Disease (OPTIMAL) trial appear insufficient to conclude that intravascular ultrasound (IVUS) provides limited benefit in LMCA. Intracoronary imaging modalities continue to play an important role in left main interventions.
- According to the latest European Association of Percutaneous Cardiovascular Interventions/European Bifurcation Club (EAPCI/EBC) consensus recommendations, optimal post-PCI expansion targets in distal left main (LM) bifurcation interventions are an LM minimal stent area (MSA) of 10-12 mm^2 and an left anterior descending (LAD MSA) of 7-8 mm^2, with an LCx minimal lumen area (MLA) > 4 mm^2 after provisional stenting, and LM, LAD, and LCx MSA targets of 10-12 mm^2, 7-8 mm^2, and 6-7 mm^2, respectively, after planned 2-stent treatment.
- Hybrid approaches using drug-coated balloons (DCB) in provisional stenting for distal LMCA lesions appear to have the potential to improve long-term outcomes of side-branch ostial patency; however, large randomized controlled trials are needed.

quality. Consistent with this, the minimal stent area (MSA) values achieved in the IVUS arm were 14.3 mm^2 in the proximal LMCA, 12.3 mm^2 at the polygon of confluence, 8.02 mm^2 in the LAD, and 6.71 mm^2 in the left circumflex artery, all of which were in line with or exceeded the currently recommended optimization targets.[11]

Along with the findings reported by Hong et al, the results of the OPTIMAL trial may indicate that the incremental value of IVUS guidance becomes less evident when complex PCI procedures are performed by highly experienced operators under optimal technical conditions. Notably, Choi et al[12] demonstrated that the clinical benefit associated with IVUS guidance was particularly pronounced among operators with less than 5 years of PCI experience and in the setting of complex coronary interventions.

However, in light of current evidence, the use of intracoronary imaging techniques in the evaluation and treatment of LMCA disease remains a Class I recommendation in current European guidelines.[13] The European Bifurcation Club (EBC) supports the use of IVUS or OCT in main coronary interventions and recommends that operators choose the imaging technique in which they have the most experience and confidence in interpretation, or which they believe is most appropriate for the patient, lesion anatomy, and procedural characteristics.[4]

INTRAVASCULAR ULTRASOUND–BASED ASSESSMENT AND OPTIMIZATION CRITERIA FOR LESIONS IN THE LEFT MAIN CORONARY ARTERY

Minimal lumen area (MLA) is the principal intravascular imaging parameter used for the assessment of lesion severity. In the evaluation of LMCA disease, MLA measurements should be obtained from pullbacks performed in both the LAD and LCx arteries, with the lowest measured value considered for clinical decision-making. An IVUS-derived MLA cutoff of 6 mm^2 remains the most commonly accepted threshold for determining the functional significance of LM lesions.[14] However, findings from studies conducted in Asian populations have highlighted the limitations of applying a single absolute cutoff value irrespective of patient size, leading to the proposal of a lower MLA threshold of 4.5 mm^2.[15] It is recommended that physiological assessment be used for lesions ranging from 4.5 to 6 mm^2.[4]

According to the latest joint consensus statement from the European Association of Percutaneous Cardiovascular Interventions (EAPCI) and EBC, revascularization decisions should not rely solely on MLA measurements but should also incorporate plaque morphological characteristics. The presence of high-risk plaque features, including plaque disruption (rupture or erosion), with or without intraluminal thrombus, as well as intraplaque hemorrhage, may favor proceeding with revascularization.[4]

Intravascular ultrasound plays a crucial role in both making treatment decisions and optimizing treatment. In 2 stent strategies, the "5-6-7-8 rule" was previously defined, defining optimal MSA criteria for LCx, LAD, bifurcation, and distal LM, respectively.[16] However, recent studies involving Western populations have called into question the classic 5-6-7-8 criteria, which were originally identified in the Korean population and predict angiographic restenosis at 9 months. In the IVUS subgroup analyses of the EXCEL and NOBLE studies, the mean MSA values within the LM were found to be 9.9 ± 2.3 mm^2 (n = 504) and 12.5 ± 3.0 mm^2 (n = 224), respectively.[17,18] For this reason, there has been debate over whether there are significant differences between Eastern and Western populations.

Subsequently, Kang and colleagues proposed target MSA cutoff values of 11.8 mm^2 for the distal LMCA, 8.3 mm^2 for the LAD ostium, and 5.7 mm^2 for the LCx ostium.[19] These threshold values appear to align more closely with data derived from Western populations. Nevertheless, the prognostic value of IVUS-derived MSA criteria for long-term clinical outcomes remains imperfect. In the study by Kang et al[16], MSA measurements at the LAD and LCx ostia were predictive of adverse clinical events, whereas the distal LM MSA was not significantly associated with outcomes. Likewise, the 9.8 mm^2 distal LM MSA threshold identified in the EXCEL trial demonstrated only limited predictive performance.[16,18]

In 2023, Bangalore and Maehara introduced the concept of "magic numbers" for IVUS-guided LM PCI optimization, proposing target MSA thresholds of >6-8-10 mm^2 and optimal MSA values of >7-9-12 mm^2.[7] They also suggested that, in patients with smaller coronary vessel dimensions, relative MSA may be more appropriate than absolute cutoff values. Relative MSA is defined as the ratio of the MSA to the reference vessel area within the same segment, and a threshold exceeding 40% was proposed as a reliable surrogate that closely approximates the conventional absolute MSA targets.[7]

In a study aimed at identifying optimal MSA areas in PS, the MSA threshold values were determined as ≥11.4 mm^2 for the proximal LMCA, ≥8.4 mm^2 for the distal LMCA, and ≥8.1 mm^2 for the LAD ostium. An MSA value of <11.4 mm^2 in the proximal LMCA doubled the 5-year risk of MACE. The presence of under-expansion in both the distal LMCA and the LAD ostium was also found to be associated with high rates of major adverse cardiovascular events (MACE).[20]

Building on these observational data, the most recent joint EAPCI/EBC consensus provides a contemporary framework for IVUS-guided LM PCI optimization. Rather than replacing the previously proposed "magic numbers," the consensus integrates the available evidence into practical recommendations according to the revascularization strategy.[4] The consensus recommends MSA values of 10-12 mm^2 for the LMCA and 7-8 mm^2 for the LAD, with MLA > 4 mm^2 for the LCx, in the provisional approach; and 10-12 mm^2 for the LMCA, 7-8 mm^2 for the LAD, and 6-7 mm^2 for the LCx in the dual-stent strategy. The latest EAPCI/EBC consensus statement suggests that IVUS-guided optimization should incorporate not only absolute MSA targets but also relative stent expansion indices based on the reference vessel area. A relative stent expansion of approximately 80%-90% is considered an appropriate optimization criterion, with a target of 90% for normal LM anatomy and 80% for tapering

LM segments to reduce the risk of overexpansion and vessel perforation. Importantly, the consensus emphasizes that relative expansion indices should be interpreted alongside absolute MSA targets and that excessive stent expansion, particularly in the LM, should be avoided.[4]

PHYSIOLOGICAL ASSESSMENT OF LEFT MAIN CORONARY ARTERY STENOSES

Physiological assessment of LMCA disease has several limitations compared with intravascular imaging modalities. During fractional flow reserve (FFR) measurement, the guiding catheter should be disengaged from the LM ostium to avoid interference from an ostial lesion, and pressure measurements are recommended to be obtained separately in both the LAD and LCx arteries. However, in the presence of diffuse atherosclerotic disease involving the distal LAD and LCx, FFR values may be falsely increased, potentially leading to an underestimation of LM lesion severity. An FFR value >0.80 in both the LAD and LCx is generally considered indicative of a hemodynamically non-significant LM lesion.[21]

In the provisional stenting strategy, FFR can be used to assess the function of a side branch. Supporting this, it has been shown that an FFR value >0.80 measured in the LCx following LMCA–LAD crossover stenting is associated with a better prognosis in terms of long-term clinical outcomes (particularly at 5-year follow-up).[22]

CORONARY ARTERY BYPASS RAFTING VERSUS PERCUTANEOUS CORONARY INTERVENTION IN THE MANAGEMENT OF DISTAL LEFT MAIN CORONARY ARTERY DISEASE

Determining the revascularization strategy for LMCA disease requires a multidisciplinary approach that considers anatomical, clinical, and functional parameters. In this process, the decision should be made using the "heart team" approach, while considering patient preference and the experience of the center and the operator.[13]

In patients with high surgical risk, as assessed by the EuroSCORE II or Society of Thoracic Surgeons (STS) score, PCI may be favored, whereas coronary artery bypass grafting (CABG) remains the preferred strategy in those with a low operative risk. Factors supporting a CABG-based approach include a high SYNTAX score, the presence of diabetes mellitus, reduced left ventricular ejection fraction (LVEF ≤ 35%), contraindications to dual antiplatelet therapy, recurrent in-stent restenosis, and the need for concomitant cardiac surgery. Conversely, PCI may be preferred in patients with low-to-intermediate SYNTAX scores, isolated LM disease, advanced frailty or significant comorbidities, a history of thoracic radiotherapy, porcelain aorta, previous cardiac surgery, or presentation with ST-segment elevation myocardial infarction (STEMI).[8,23]

Apart from these, determining the most appropriate revascularization strategy for patients who are suitable for both methods has been a subject of intense debate and a key research area in large-scale, multicenter studies over the past 2 decades.

Although CABG remains the standard of care for treating LMCA lesions, advances in stent technology and intravascular imaging have improved the outcomes of PCI. Data from large-scale clinical trials and meta-analyses support the emerging evidence for the use of PCI in the treatment of LMCA disease.[23]

A meta-analysis incorporating the 4 major randomized trials comparing PCI and CABG for LM disease (Synergy Between PCI With Taxus and Cardiac Surgery [SYNTAX], Premier of Randomized Comparison of Bypass Surgery versus Angioplasty Using Sirolimus-Eluting Stent in Patients with Left Main Coronary Artery Disease [PRECOMBAT], NOBLE, and EXCEL) demonstrated no significant difference in all-cause mortality between the 2 revascularization strategies.[24] Among these studies, EXCEL and NOBLE are the most contemporary, both utilizing second-generation drug-eluting stents (DES). Approximately 80% of the LM lesions included in these 2 trials involved distal bifurcation disease. While no difference was observed in the primary endpoints in the 5-year results of the EXCEL trial, all-cause mortality and MI were found to be higher in the PCI arm. Differences in the definition of periprocedural MI in the EXCEL trial and the fact that the difference in mortality rates was largely attributable to non-cardiovascular deaths have raised questions.[25]

In 2025, the 10-year follow-up data from the NOBLE trial were published, confirming the absence of a significant difference in all-cause mortality between PCI and CABG. Interestingly, this finding was observed irrespective of SYNTAX score. However, the relatively limited number of patients with high SYNTAX scores included in the study raises questions regarding the robustness of this subgroup analysis. Another notable observation was that, among patients presenting with LMCA acute coronary syndrome (ACS), PCI was associated with a lower rate of all-cause mortality than CABG.[26]

In fact, all these findings demonstrate that both approaches can be used as treatment strategies and highlight the importance of a patient-centered approach to treatment rather than relying solely on a single scoring system. According to current myocardial revascularization guidelines, PCI is indicated as Class I for cases with significant LM disease and a low SYNTAX score, and as Class 2a for lesions of moderate complexity (SYNTAX 23-32).[13,27]

STENTING STRATEGY FOR LEFT MAIN CORONARY ARTERY BIFURCATION LESIONS

One of the most commonly used classifications for evaluating the complexity of bifurcation lesions is the DEFINITION (Definitions and impact of complEx biFurcation lesIons on clinical outcomes after percutaNeous coronary IntervenTIOn using drug-eluting steNts) criteria. Based on this classification, a complex bifurcation lesion is defined by the presence of at least 1 major criterion and 2 accompanying minor criteria. For LM bifurcations, a side-branch lesion length of >10 mm and a side-branch stenosis of more than 70% are among the major criteria (Table 1).[28]

In the DEFINITION II trial, which compared provisional single-stent and planned 2-stent strategies in patients with

Table 1. Definition Criteria

Major Criterion (for LM)	Minor Criteria
SB lesion length ≥ 10 mm	> mild calcification
SB stenosis rate ≥ 70%	Multiple lesions
	Bifurcation angle <45° or >70°
	MV- RVD < 2.5 mm
	MV lesion length ≥ 25 mm
	Thrombus-containing lesion

A complex bifurcation is defined as either 2 major criteria or 1 major criterion with 2 minor criteria fulfilled.

LM, left main; MV, main vessel; RVD, reference vessel diameter; SB, side branch.

complex coronary bifurcation lesions (CBL), the use of a 2-stent approach was associated with a significant reduction in target lesion failure (TLF) at 12 months. Notably, distal LM bifurcation lesions accounted for approximately 29% of the study population, and the double kissing (DK)-crush technique was the predominant 2-stent strategy, being used in 77.8% of patients assigned to the dual-stent arm.[28]

There are 2 important randomized studies comparing provisional stent strategies with dual stent approaches in distal LMCA bifurcation lesions. The first of these is the DKCRUSH-V study. In this trial, 484 patients with Medina 1,1,1 or 0,1,1 distal LM bifurcation lesions were randomized to undergo either provisional stenting (PS) or DK-crush stenting and were assessed for the primary endpoint of 1-year TLF. Among patients with true distal LM bifurcation disease, the DK-crush strategy achieved a comparable relative reduction in TLF across both simple and complex lesion subsets compared with provisional stenting ($P = .65$). Nevertheless, the absolute clinical benefit was greater in the complex lesion subgroup (11.2% vs. 4.1%). The superiority of the DK-crush strategy even in patients with simple lesions further suggests that the study cohort largely consisted of anatomically true bifurcation lesions.[29]

The use of IVUS in the study was about 40% and was left to the operator's discretion. In angiographic evaluations, restenosis in the provisional stent group was most frequently observed at the side branch (SB) ostium. This finding demonstrates that one of the primary challenges in distal LM bifurcation procedures is the optimal treatment of the side branch ostium. In 2019, the 3-year results of this study showed that the dual-stent strategy maintained its benefit in terms of primary endpoints. The DKCRUSH-V results contribute to the evidence that, when performed by experienced operators, the antegrade 2-stent strategy may be the most appropriate approach in selected patients with complex underlying anatomy.[30]

Another landmark study comparing provisional stenting with an upfront 2-stent strategy for the treatment of distal LMCA bifurcation lesions is the EBC Left Main (EBC MAIN) trial. In the study, the primary endpoint was defined as a composite of all-cause mortality, MI, and target lesion revascularization (TLR) within 12 months. The primary endpoint occurred in 34 patients (14.7%) in the provisional stenting group (n = 230) and in 42 patients (17.7%) in the planned 2-stent group, with no significant difference observed between the treatment strategies (hazard ratio [HR] ≈ 0.80, $P = .34$). Analysis of the secondary endpoints similarly demonstrated no significant between-group differences. In the PS arm, the rates of MI, TLR, and stent thrombosis were 10.0%, 6.1%, and 1.7%, respectively, compared with 10.1%, 9.3%, and 1.3% in the planned 2-stent arm.[31,32]

The 1-year results of the EBC MAIN study show that the provisional stenting approach in patients with true left main bifurcation lesions yields clinical outcomes similar to those of the planned dual-stent strategy. In the 3-year follow-up results, no significant differences were observed for most endpoints; however, a significant advantage in favor of provisional stenting was reported in terms of target vessel revascularization.[31,32]

On the other hand, when the EBC MAIN and DKCRUSH-V studies are evaluated together, it becomes apparent that many factors—such as the patient characteristics, lesion complexity, operator experience, and the techniques used—play a role in the differing results. In the DKCRUSH-V study, higher operator experience, patients exhibiting more complex characteristics (higher SYNTAX scores and longer side-branch lesions), and a higher frequency of dual-stent requirements (47% vs. 22%) stand out as key factors influencing the results. Moreover, the fact that the culotte technique was the predominant 2-stent strategy in the EBC MAIN trial (53%), whereas crush-based techniques were used in only a small proportion of cases (5%), raises the possibility that differences in stenting technique may, at least in part, have influenced the study outcomes.[29,31]

When all these data are evaluated together, it becomes clear that the optimal approach to distal LMCA bifurcation lesions must be tailored to the complexity of the lesion. In complex bifurcation lesions, planned dual-stent strategies—particularly the DK crush technique—may be a more appropriate option, whereas in simpler lesions, the provisional stent approach remains a rational and effective treatment option.[8]

PREDICTORS OF SIDE BRANCH COMPROMISE IN LEFT MAIN CORONARY INTERVENTIONS

In left main coronary procedures, whether a direct, planned dual-stent strategy or a provisional approach is used, it appears that a significant proportion of MACE is attributable to side branches.[33] The EAPCI and EBC recommend current guidelines that combine IVUS and coronary angiography to identify predictors of side-branch loss and, if necessary, to initiate treatment of the side branch from the outset. According to this consensus:

- Angiographic LCx diameter stenosis ≥ 70%
- LCx minimal lumen area (MLA) < 4 mm^2 or plaque burden > 55% as assessed by intravascular imaging
- LCx lesion length > 10 mm
- In the presence of moderate-to-severe LCx calcification, intravascular imaging is recommended; lesions with a calcium arc > 180°, calcium length > 5 mm, and calcium

thickness > 0.5 mm are considered to be at particularly high risk.

- Evidence of plaque instability, with or without the presence of intraluminal thrombus, is also considered a predictor of side branch compromise.[4]

PROVISIONAL STENTING TECHNIQUE FOR LEFT MAIN CORONARY ARTERY BIFURCATION LESIONS

In its latest recommendations, the EBC, based on the EBC MAIN study results, recommends provisional stenting regardless of lesion complexity. Provisional stenting of the LM differs from that of other bifurcations in that the side branch is the LCx artery, which already has clinical significance.[34]

Initially, guidewires should be advanced into both the LAD and LCx. A crossover stent is then implanted from the LM into the LAD, with stent sizing determined according to the diameter of the distal main vessel. After stent deployment, POT should be systematically performed using a short noncompliant (NC) balloon sized to the proximal main vessel, ensuring complete apposition of the proximal stent segment.

Proximal optimization technique is a key component of the provisional stenting strategy. Properly performed POT can correct carina shift induced by main vessel stenting, optimize expansion of the side branch ostium, and minimize the risk of suboptimal rewiring through a proximal stent cell during subsequent side branch access. As a result, POT facilitates easier and more accurate distal side branch rewiring, thereby improving the efficacy of any further bifurcation optimization maneuvers.[34,35]

The benefit of routinely performing kissing balloon inflation (KBI) after POT is unclear, and data are limited. Studies on non-LM bifurcation lesions have shown that not performing KBI slightly increases the risk of stenosis and thrombosis during follow-up; however, this risk generally does not lead to clinically significant outcomes.[36]

In 2022, Yoon et al[37] argued that performing routine KBI following a provisional strategy in 255 LMCA patients could have adverse outcomes. The 15th EBC Consensus Report emphasized that, while the absence of KBI in provisional LMCA procedures does not make a difference in terms of MACE, there are concerns regarding fenestrated restenosis.[38]

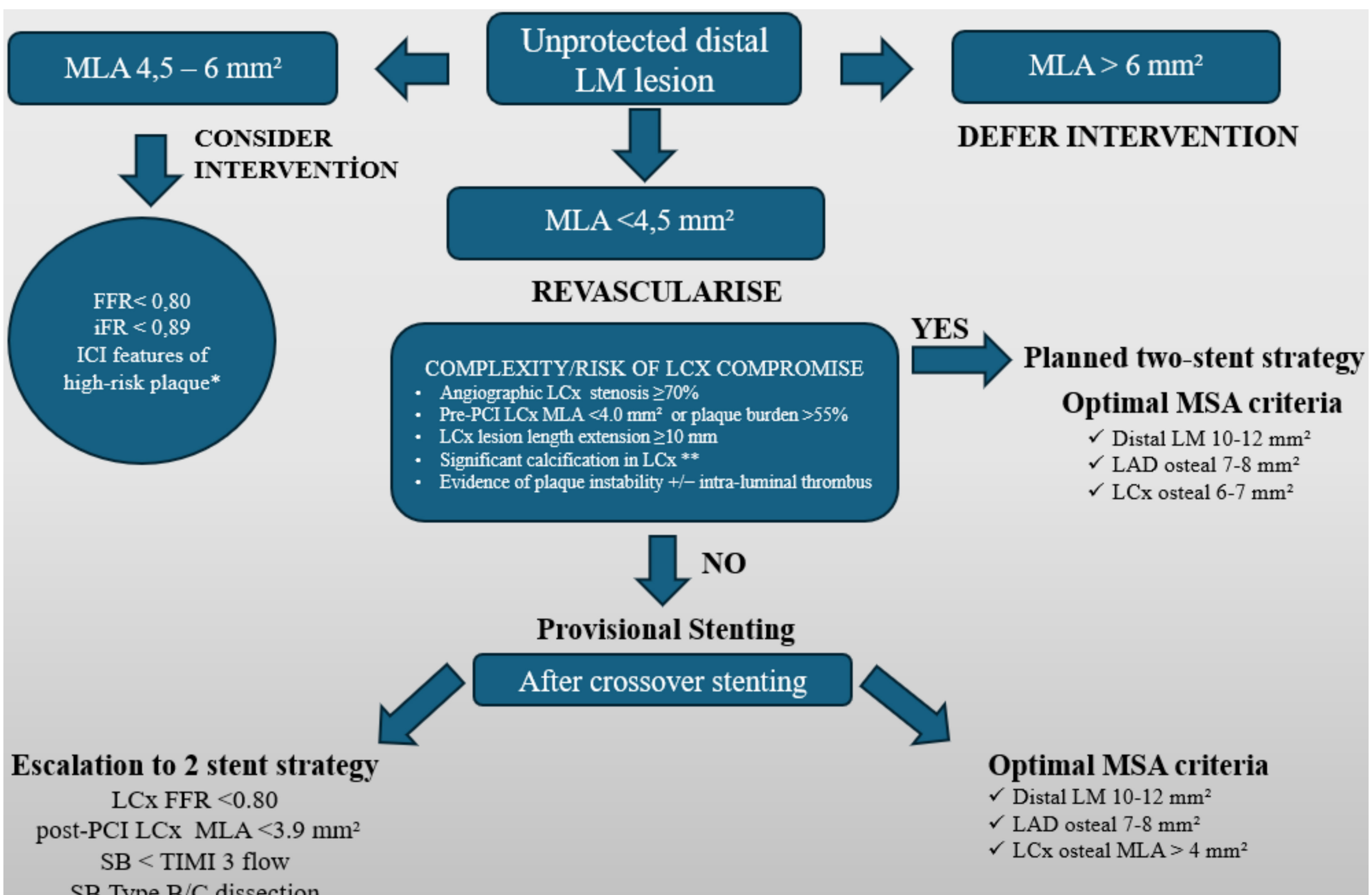

Figure 1. Management algorithm for unprotected distal left main coronary artery lesions. FFR, fractional flow reserve; ICI, intracoronary imaging; iFR, instantaneous wave-free ratio; LAD, left anterior descending artery; LCx, left circumflex artery; LM, left main coronary artery; MLA, minimal lumen area; MSA, minimal stent area; PCI, percutaneous coronary intervention; SB, side branch. *Plaque disruption - with or without luminal thrombus, or intra-plaque hemorrhage. **ICI-defined calcification with arc > 180°, >5 mm in length, and >0.5 mm thickness.

It should be noted that, in addition to all this data, KBI is also routinely applied in the EBC-MAIN study.[31] The ongoing IKISS-LM (Impact of Kissing Balloon Inflation in Provisional Left Main Coronary Bifurcation PCI) trial, a prospective, multicenter, randomized controlled study, is expected to provide further insight into this issue.[39]

Following KBI, elliptical deformation of the main vessel stent may occur, characterized by loss of its circular geometry. Therefore, repeat proximal optimization technique (re-POT) should be performed to restore the optimal stent configuration within the main vessel. After re-POT, the side branch should be carefully reassessed. Conversion to a 2-stent strategy should be considered in the presence of significant side branch compromise, including >90% ostial stenosis, TIMI 1-2 flow, type B/C dissection, or evidence of ischemia and/or angina. The choice of 2-stent technique should be guided by bifurcation anatomy, including bifurcation angle and side branch diameter, with T-stenting/T and small protrusion (T/TAP) generally favored for bifurcation angles > 70°, and culotte or reverse crush techniques considered for angles < 70°.[38,40] The contemporary approach to unprotected left main coronary artery bifurcation lesions, based on current evidence, is schematically illustrated in Figure 1.

ROLE OF DRUG-COATED BALLOONS IN LEFT MAIN CORONARY ARTERY BIFURCATION LESIONS

Evidence from clinical trials has shown that drug-coated balloons (DCBs), when compared with conventional balloon angioplasty, significantly reduce late lumen loss and restenosis in the SB. In addition, DCB-based strategies may simplify PCI procedures by reducing the need for extensive stent implantation. Furthermore, hybrid approaches combining DCBs with DES have been reported to provide superior clinical and angiographic outcomes compared with DES-only strategies in patients with true CBL.[40]

Given that most events in LM interventions occur in side branches, this suggests that DCB may be useful in ensuring side-branch patency, particularly in provisional procedures without increasing the metal burden.

The DCB-BIF trial (Drug-Coated Balloon Angioplasty of the Side Branch During Provisional Stenting: The Multicenter Randomized DCB-BIF Trial) evaluated the use of DCBs versus non-compliant (NC) balloons angioplasty in compromised SB following provisional stenting of true CBL. Drug-coated balloons treatment was associated with lower rates of MI and a reduction in the primary composite endpoint. Nevertheless, the generalizability of these findings to distal LMCA bifurcation disease remains limited, as complex bifurcation lesions were excluded and only 10%-15% of the study population consisted of distal LMCA lesions.[41]

A retrospective study comparing a hybrid DES + DCB approach with upfront dual stent strategies in distal LMCA bifurcation lesions demonstrated no significant difference in MACE between these groups. Double kissing-crush was the predominant 2-stent technique employed. However, elective angiographic follow-up revealed a significantly larger MLA at the LCx ostium and lower late lumen loss (LLL) in the DES + DCB group ($P < .05$). Despite these encouraging angiographic findings, the small study population and the limited use of intravascular imaging warrant cautious interpretation, and larger prospective studies are required to confirm these results.[42]

In real-world data involving 597 patients, the DES + DCB combination was associated with lower rates of clinical TLR (2.91% vs. 9.42%; $P = .007$), TLF (9.60% vs. 17.14%; $P = .026$), and stent thrombosis (0.00% vs. 2.89%; $P = .030$) at 2-year follow-up compared to a strategy using DES alone (provisional or dual-stent).[43]

The use of DCBs in bifurcation lesions has been described using 2 distinct strategies based on the timing of DCB use relative to main vessel stenting. In the first strategy, lesion preparation and DCB treatment of the SB are performed before main vessel stenting, followed by POT. In cases where the SB result remains suboptimal, additional optimization with KBI and re-POT may be required. Nevertheless, it has been hypothesized that these additional balloon inflations could alter the distribution of the antiproliferative drug previously delivered to the side branch, thereby potentially attenuating its therapeutic effect.[40]

In the other method, MV stent implantation involves rewiring the SB after POT, performing a KBI, followed by DCB in the side branch, and concluding the procedure with POT. The disadvantages of this method are thought to include the possibility that interaction between the DCB and the stent struts during DCB advancement into the SB may lead to drug loss and suboptimal drug distribution, as well as inadequate preparation of the SB lesion. In studies conducted to date on LMCA lesions, DCB has been administered primarily after main vessel stenting.[40]

CONCLUSION

In summary, PCI has become an increasingly utilized revascularization strategy for distal LMCA disease. Intravascular imaging appears to be essential for optimizing procedural outcomes and improving long-term prognosis, supporting its routine use during both pre- and post-procedural assessment. While the EBC recommends a provisional stenting strategy regardless of bifurcation complexity, the DK-crush technique has emerged as the preferred planned 2-stent approach in patients at high risk for side branch compromise. Hybrid strategies combining provisional stenting with DCB treatment of the LCx ostium represent a promising approach for maintaining long-term side branch patency. However, the available evidence in distal LMCA bifurcation PCI remains limited, as only approximately 10%-15% of patients enrolled in the DIF-BIF and DCB studies had distal LMCA lesions. Therefore, their role in distal LMCA bifurcation PCI requires confirmation in adequately powered randomized clinical trials specifically designed for this lesion subset.

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