Treatment of Coronary Bifurcation Lesions

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46.1 Introduction

Coronary bifurcation lesions represent about 20% of lesions requiring percutaneous coronary intervention (PCI) [1, 2]. Lesions involving bifurcations are a challenging subset as they are fraught with lower procedural success and higher rates of adverse events than nonbifurcation lesions. The objectives of this review are to provide an objective analysis of bifurcation lesions (basic data, definitions, classifications, quantification, imaging techniques); to summarize the results of randomized studies, large registries, and meta-analyses; and to describe the most currently used techniques. Treatment of unprotected left main (LM) lesions is only briefly discussed because there is little difference from treatment in other bifurcation locations.

46.2 Basic Concepts

46.2.1 Structure and Function Relationships in Coronary Trees

There is a functional/anatomical relationship inherent to all coronary trees [3]. The function accounts for a homogeneous distribution of oxygenated blood in the myocardium according to its need [4]. Coronary trees are constructed according to the hypothesis of minimum energy cost [5]. They are constituted of a «distributive» epicardial segment, and a «delivering» intramyocardial segment. The latter is characterized by an increased number of bifurcations. The sum of the vascular areas and the mean blood flow velocity are constant in the distributive part. Further downstream, the total vascular area increases and flow velocity is reduced in order to allow adequate contact time for capillary exchange. Instantaneous blood flow velocity is maximal during diastole and minimal, or even inverted, during systole.

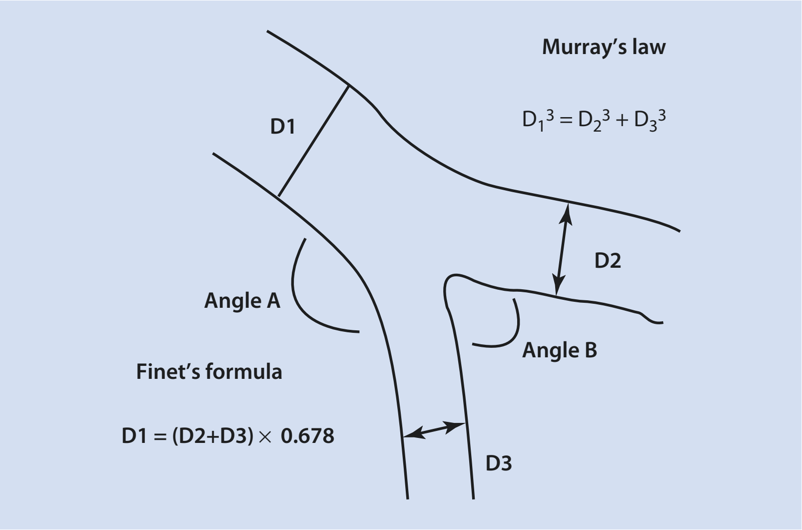
In epicardial arteries, coronary bifurcations follow a pattern of fractal geometry and a self-similarity principle [6]. Indeed, asymmetrical bifurcations are recursive in the coronary tree in accordance with Murray's law [7, 8]:

(Diameter proximal main)^3 = (Diameter distal main)^3 + (Diameter side branch)^3.

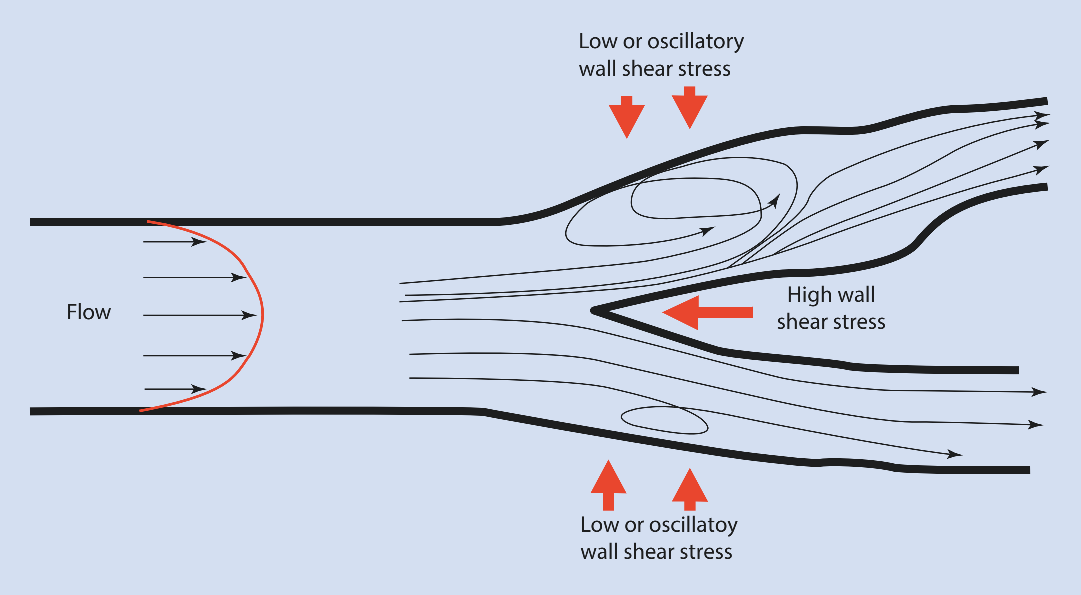
The law was modified with respect to its exponent, which is now known to be 2.3 for human coronary arteries [9]. Finet's formula, confirmed by intravascular ultrasound (IVUS) in normal human coronary arteries, is even simpler and can be applied in daily routine practice:

(Diameter proximal main) = (Diameter distal main + Diameter side branch) × 0.678. [10]

These formulae are analogous to the continuity formula applied to flow. Therefore, a coronary bifurcation is not divided into a main vessel and a side branch (SB); it consists of three segments, each with a distinct diameter (proximal main, PM; distal main, DM; and side branch, SB) (■ Fig. 46.1). Furthermore, the diameter of a coronary artery does not follow a linear decreasing pattern from the proximal to the distal segment but remains constant between two bifurcations.



■ **Fig. 46.1** The modulus of the pseudofractal coronary tree according to laws of Murray and Finet. Angles between the PM (*D1*) and SB (*D3*) (*angle A*) and between DM (*D2*) and SB (*angle B*) are also displayed



■ **Fig. 46.2** Characteristics of flow in straight vessels and bifurcations (Adapted from Chatzizisis et al. [13])

This anatomical/functional structure has several practical consequences. Among others, nondedicated quantitative coronary angiography (QCA) software and measurement methods are not adapted to coronary bifurcation analysis (see ► Sect. 46.2.2). The diameter/length relationship identifies the DM segment as the longest and/or largest segment. In the coronary arborescence, there are linear relationships between flow and diameter, diameter and distal length, length/flow and diameter, and length/flow and perfused myocardium mass. [4, 11]

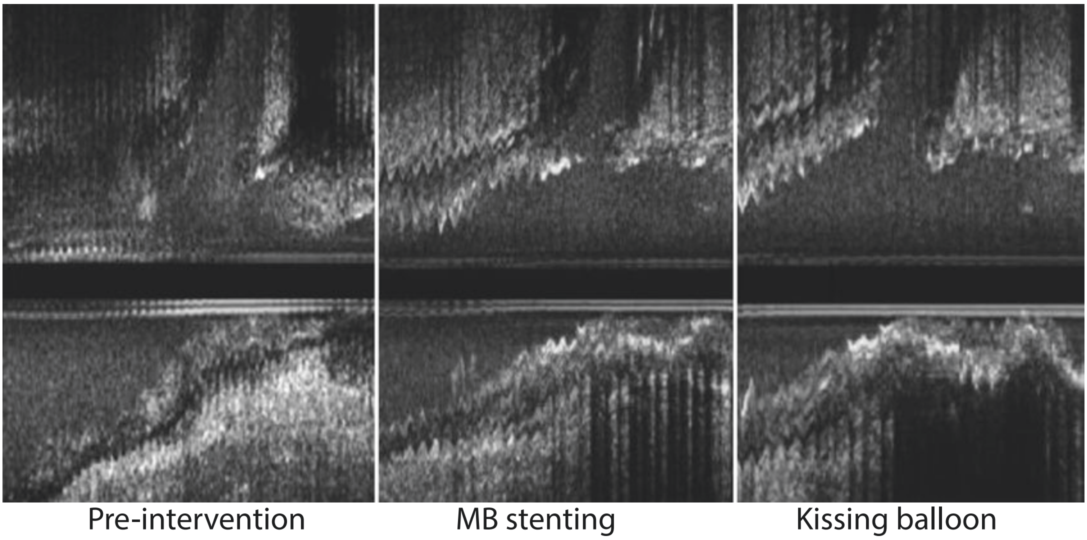
46.2.2 Flow in Coronary Bifurcations: A Proatherogenic Factor

Intracoronary flow in straight, nonbifurcated segments is laminar. It exerts friction on the vessel wall, designated as wall shear stress (WSS) [12]. A low WSS is a documented and well-recognized proatherogenic factor [13]. Low WSS occurs as a result of slow, turbulent, or inverted flow, especially in bifurcations, along the internal wall of a bend or behind an obstacle (atheroma plaque, stent, etc.). In bifurcations, flow velocity is high and laminar at the level of the carina (■ Fig. 46.2) and, conversely, turbulent and recirculating on the arterial wall facing the flow divider. Anatomopathological and IVUS studies have consistently shown that atheroma is often present in bifurcations. More specifically, atheroma is found in areas exposed to low WSS, namely the arterial wall facing the flow divider, whereas the carina is often free of atheroma [14, 15]. However, atheroma progression is also the consequence of flow disturbance caused by expansion of the initial plaque following an anterograde and circular pattern [16]. This can account for the results of various IVUS studies underlining the presence of atheroma at the level of the flow divider in up to 30% of cases [17]. It has been shown that in-stent restenosis follows the same flow principles, with neointimal proliferation occurring at the site of the initial plaque in cases where treatment has restored the original anatomical configuration of the bifurcation [18].

46.2.3 How to Define, Classify, Designate, Measure, and Image Coronary Bifurcation Lesions and Their Treatment

Definition

Coronary angiography provides two-dimensional (2D) visualization of a three-dimensional (3D) environment. This can be misleading in bifurcations, where the main vessel and its distal branches are in distinct planes. The operator should obtain



◘ **Fig. 46.3** IVUS documentation of carina-shifting phenomenon. On the longitudinal display (*top*), the takeoff of the SB (demarcated as echo-free space in the *top left* image) shifts in the longitudinal direction after PM to DM stenting (*top center*). This is corrected with kissing balloon inflation (*top right*). *Bottom*: Radial display (From Koo et al. European Bifurcation Club Meeting, 2008)

optimal angiographic views in order to visualize, describe, and classify bifurcation lesions. More and more patients are undergoing coronary computed tomography (CT) angiography as a noninvasive test for coronary artery disease. CT angiography allows operators to plan and predetermine optimal angiographic views for various structural heart interventions [19]. Whether the same can be done for bifurcation intervention is under investigation.

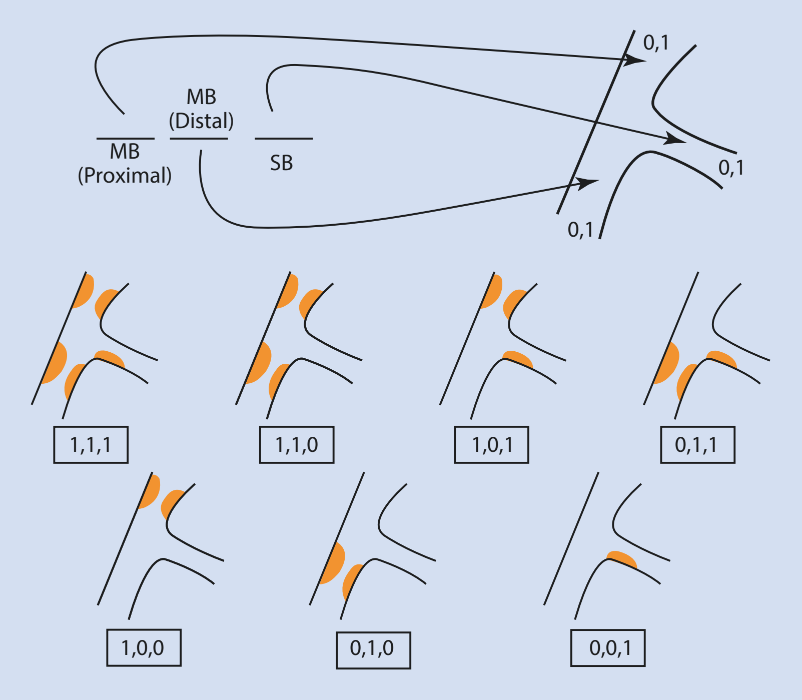
A lesion involving a coronary bifurcation may be overlooked because of inadequate angiographic views. Stenting of a bifurcation involving one of the distal branches can cause significant narrowing or occlusion in the other branch. This can be accounted for by the axial plaque shifting phenomenon. The increase in arterial lumen diameter is proportional to the increase in external vessel diameter, and is the result of longitudinal shifting of incompressible plaque [20]. Another (probably predominant) phenomenon that can lead to deterioration of the SB ostium as a result of DM stenting is shifting of the carina (◘ Fig. 46.3) toward the SB [21]. These various mechanisms interact and generate a «bifurcation issue» that did not exist at the beginning of the procedure. This helps to distinguish between true bifurcation lesions with significant lesions in both vessels and false bifurcation lesions where the SB is initially lesion-free.

SB occlusion has long been considered a relatively insignificant occurrence, resulting only in transient chest pain and mild creatine phosphokinase (CPK) increase [22]. However, the NIRVANA study demonstrated a significant risk of myocardial infarction with or without Q-waves (CPK greater than five times the normal value) associated with SB occlusion [23].

Several definitions of coronary bifurcation lesions have been proposed, all of which take into account the diameter of the SB (1.5–2.5 mm) or the potential consequences of SB occlusion. These definitions are difficult to standardize because of factors such as the objective risk of occlusion (which has still not been adequately outlined), myocardial viability, potential collateral or collateralizing status, and global ventricular function of the patient.

The European Bifurcation Club (EBC) has adopted a simple and open definition: a coronary bifurcation lesion is «a coronary artery narrowing occurring adjacent to, and/or involving, the origin of a significant SB.» A significant SB is a branch that should not be lost in the global context of a particular patient (symptoms, location of ischemia, branch responsible for symptoms or ischemia, viability, collateralizing vessel, left ventricular function, etc.) [24].

Fig. 46.4 Medina classification: Before the first comma, a 1 or 0 denotes the presence or not of >50% stenosis in the proximal main vessel; between the two commas, the same for the distal main vessel; after the second comma, the same for the side branch



Classifications

Many classification systems have been published [25–31]. They are expressed using a combination of letters or digits to describe the angiographic position of lesions in the bifurcation. The main problem is that they are difficult to memorize. Medina's classification, proposed in 2006 and adopted by the EBC, solved the memorization issue by providing a very simple description of lesion characteristics (Fig. 46.4) [29].

This classification was not intended as a prognosis tool or treatment index, which would be incompatible with the purpose of research. It is merely a practical classification based on the presence or absence of a >50% lesion in each of the three segments of the bifurcation by visual estimate. This is undoubtedly a very incomplete classification as it does not take into account quantitative data such as lesion length, diameter of segments, angle measurement, or semiquantitative data such as calcifications, thrombus, and lesion extension from one segment to another. It can, however, be refined using dedicated QCA software, intravascular imaging, multislice CT, or fractional flow reserve (FFR) [32, 33].

Reliable measurement of the bifurcation angles (angle B between the two distal segments and angle A, for access, from proximal segment to SB; Fig. 46.1) can only be achieved using 3D imaging tools such as 3D angiography or multislice CT (MSCT) [34–36].

Designation of Coronary Bifurcations

QCA measurement, Medina lesion classification, and subsequent accurate definition of the technique used all require clear designation of the SB prior to treatment initiation.

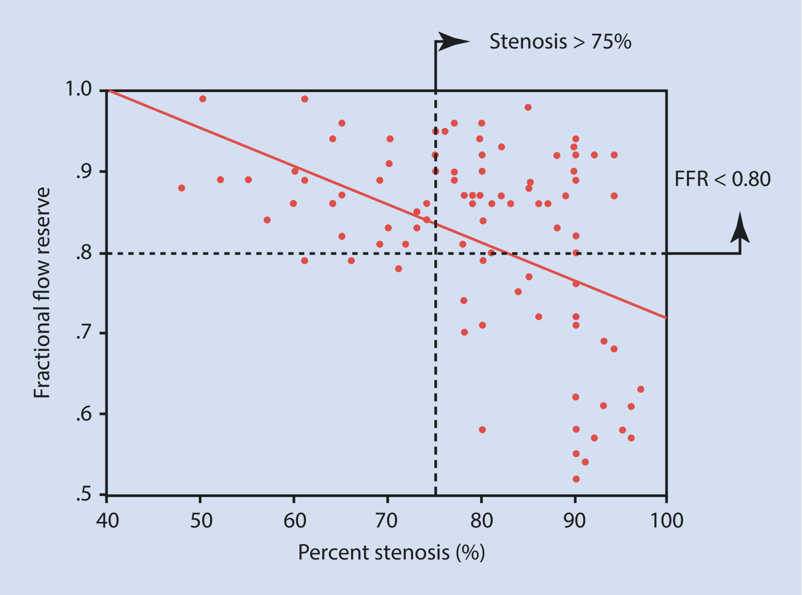
How to Define the Side Branch?

A nosological definition can be used, given that diagonal and marginal vessels are SBs. For the sake of consistency with fundamental data, the SB should be defined as the segment with the smallest diameter and shortest distal length. The operator may choose to adapt this definition in the presence of a bypass graft on one of the two branches, presence of major collateral flow, or the absence of myocardial viability related to one of the two branches. The EBC recommends using the Medina classification system to designate bifurcations [24].

Quantitative Coronary Angiography of Bifurcation Stenosis

Bifurcation lesion analysis using nondedicated software produces inaccurate results for the interpolated reference diameter of the stenosed segment

Fig. 46.5 Poor correlation between angiographic (% stenosis) and functional (FFR) evaluation of SB stenosis (Adapted from Koo et al. [40])



and the percent stenosis. Measurement discrepancies increase when the lesion is close to the bifurcation and when the SB is large [32]. This concept was confirmed in a recent imaging study where lesions appeared worse in 2D QCA than in 3D QCA [37]. In addition, using 3D QCA, the anatomic location of the highest diameter stenosis was relocated to a different bifurcation subsegment in a considerable proportion of patients compared with when 2D QCA was used.

A good correlation has been demonstrated between 3D QCA and functional assessment by FFR in both the DM and SB [38, 39]. The same correlation was found between dedicated three-branch 2D QCA and FFR, but not with conventional 2D QCA (Fig. 46.5) [38]. In intermediate lesions, both 2D and 3D QCA dedicated software have low accuracy in predicting FFR values of <0.75 [39]. FFR should be the default diagnostic tool in those circumstances. Dedicated software allowing automated analysis of bifurcation lesions is now available [36, 37, 41, 42]. Unfortunately, these systems have not been implemented beyond clinical research, are time consuming, and provide anatomical severity without functional information related to stenoses.

Physiological Analysis of Coronary Bifurcation Lesions

FFR is a physiological parameter that represents the fraction of maximal myocardial flow that can be maintained in the presence of an epicardial coronary stenosis. FFR is measured by calculating the ratio of coronary pressure distal to a coronary lesion to aortic pressure, in the context of pharmacologically induced hyperemia. Coronary lesions with an FFR value of <0.80 are associated with inducible myocardial ischemia.

A potential limitation of using FFR for bifurcation management is the anticipated difficulty in crossing stent struts with the FFR wire. However, in a recent meta-analysis, the rates of failure to cross into the SB with an FFR wire or with a regular coronary wire were similar, below 4% [43]. With the improved hydrophilic coating of new FFR wires (e.g., Opto wire; Opsens, Québec, Canada), crossing struts toward the SB should become less of an issue. Another option is placing the FFR wire in the SB *before* main branch (MB) stenting, and performing FFR measurement on the jailed wire [44]. If final kissing balloon inflation (FKB) is deemed necessary, the MB (conventional) wire is then advanced through the struts and the FFR wire is exchanged into the MB. An FFR measurement of the MB can also be performed at this stage.

No long-term difference in clinical outcomes was found between FFR-guided and non-FFR-guided bifurcation PCI [45]. However, FFR was shown to reduce the need for unnecessary interventions in bifurcation PCI, which is clinically relevant [45].

Endoluminal Imaging

IVUS and optical coherence tomography (OCT) have dramatically changed our understanding of coronary atherosclerotic disease and of the response to PCI. For instance, IVUS has revealed that the extent of atherosclerotic disease is significantly more diffuse and that localized calcifications are present much more commonly than is appreciated by angiography [46]. Imaging techniques can help recrossing into the distal strut of the jailed SB (see ► Sect. 46.4.7), and achieve distal MB rewiring and favorable stent positioning against the SB ostium [47]. Repeated OCT examinations at follow-up can identify the extent of strut coverage, a potential predictor of late stent thrombosis [48, 49]. However, for bifurcation stenting, this issue remains controversial because, despite better anatomy understanding, no study has shown any benefits of IVUS- or OCT-guided bifurcation stenting compared with angiographically guided stenting. This could be due to the relatively low diagnostic accuracy of intravascular imaging modalities to predict the functional significance of bifurcation lesions [45]. Only the MAIN-COMPARE registry has shown, by post hoc analysis, that not using IVUS for LM stenting was associated with a higher death rate at mid-term follow-up. Nevertheless, IVUS should be used in all cases where there are uncertainties either during or at the end of the procedure [50].

Bench Testing

Bench testing has provided considerable insight into stent deployment and how different techniques might impact clinical outcomes. It is an indispensable tool in supporting the safety and effectiveness of coronary stents and their delivery systems. These simulation models have allowed evaluation of technical strategies whose clinical outcome was uncertain, such as selection of the crossover stent diameter in provisional stenting and the proximal optimization technique (POT). Digital simulation provides crucial data on device function and prediction of clinical outcomes as well as stenting techniques. It assesses flow geometry before and after stenting, circumferential and shear stresses generated by stenting (overdilatation) with documented clinical impact and mapping, and the significance of low WSS areas in bifurcations with neointimal hyperplasia opposite the carina [51, 52].

46.3 Classifications of Coronary Bifurcation Stenting Techniques

Many stenting techniques for coronary bifurcation lesions have been developed over the years. Although indexing these techniques facilitates their description, especially for those deriving from one another technique, very few classifications have been published. The classification reported by our group in 1996 was expanded with the advent of new techniques in 2004 [53]. The challenge is to make these classifications simple, exhaustive, and useful in daily practice. Exhaustiveness can only be achieved by keeping classifications open.

Any classification based on final stent positioning in a bifurcation is inadequate because it does not take into account the order in which stents are implanted. For instance, when implementing the culotte stenting strategy, the first stent may be implanted from the PM to the DM or to the SB, which is very different from a technical point of view. In contrast, associating a specific strategy to the final position of stents helps to keep the classification open. Defining a strategy according to the position of the first stent serves to create a filiation between techniques and simplify their description.

The MADS classification (◘ Fig. 46.6) proposed and adopted by the EBC in 2007 seems to meet the requirements for simplicity, usefulness, and exhaustiveness [24]. It cannot, however, reflect the creativity of every single operator as this would require a detailed description of all potential guidewire and balloon maneuvers. All techniques recorded in the MADS classification have been either reported or published. The four MADS families (categories) are identified by letters. «M» (main) signifies that the first stent is implanted in the PM. «A» (across) means that the first stent has been deployed from the PM to the DM across the SB. «D» (double) is used to describe a family of somewhat heterogeneous techniques, whereby one or two stents are delivered on two guidewires and in two lumens without recrossing the stent struts. «S» (side) defines technical strategies in which a stent is placed in the SB first with or without protrusion. In all cases, the procedure may be completed by the placement of one or two additional stents. The inversion of distal branches defines the «inverted techniques» (◘ Fig. 46.7).

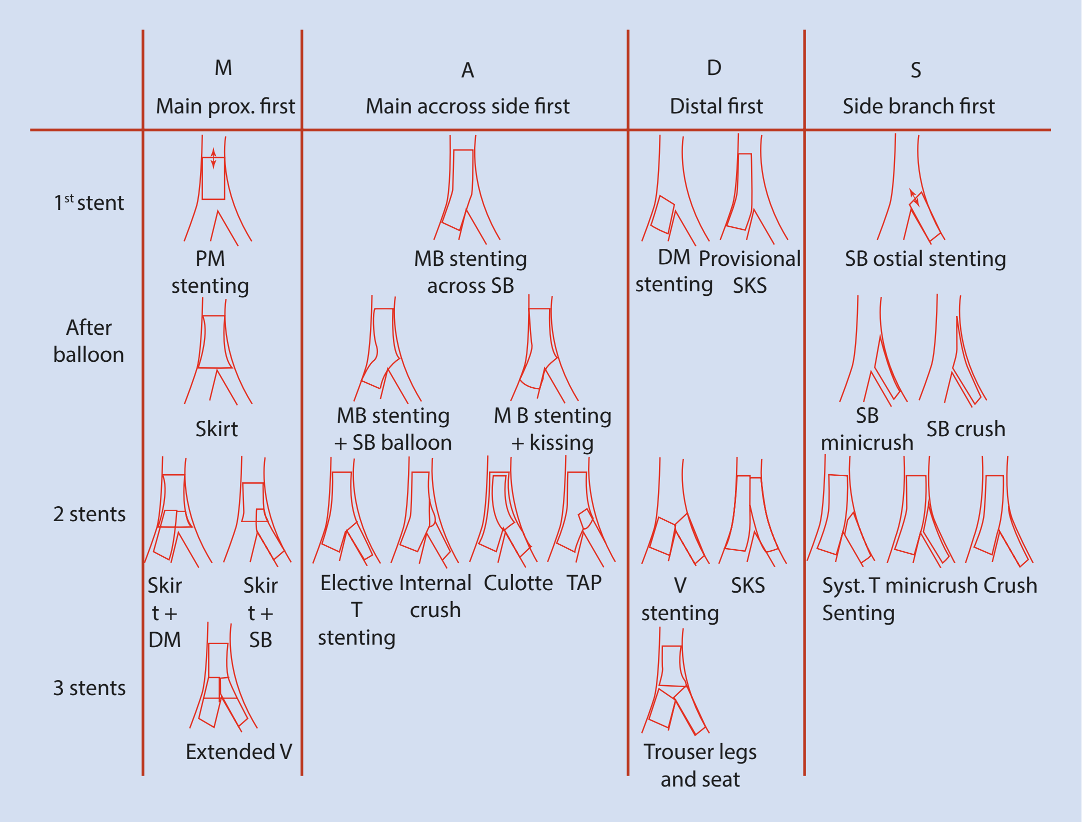


Fig. 46.6 MADS classification of techniques (straight techniques) [24]

46.3.1 Randomized Controlled Trials, Series, and Meta-analyses Dedicated to the Treatment of Coronary Bifurcation Lesions

This section compares angioplasty techniques (mainly one- versus two-stent strategies) through the different eras of coronary stents. A step-by-step description of each technique is provided in ► Sect. 46.4.

Bare-Metal Stent Era

In the era of bare-metal stents, there were no randomized trials comparing the outcomes of one- versus two-stent strategies. Several registries compared the results of stenting the MB combined with angioplasty of the SB through the struts versus stent placement in both branches. The common conclusion of all these series was the absence of superiority of systematic double stenting with bare-metal stents (Fig. 46.8). The angiographic outcome was usually better in the double-stenting group, but in-hospital outcome was inferior. The restenosis rate, particularly in the SB, tended to be higher in the double-stenting group, as were clinical event rates and midterm target lesion revascularization (TLR) [55].

Drug-Eluting Stent Era

Provisional Versus Two-Stent Techniques

Several studies have compared provisional SB stenting with double stenting using DESs [56–62] (Table 46.1). Caution should be used when comparing studies, as crossover rates from one to two stents in the provisional groups vary greatly (from 2.1 to 51.2%). Studies with lower crossover rates favor the provisional technique (Table 46.1). Whether this is a result of patient characteristics or operator comfort with the provisional technique is unclear.

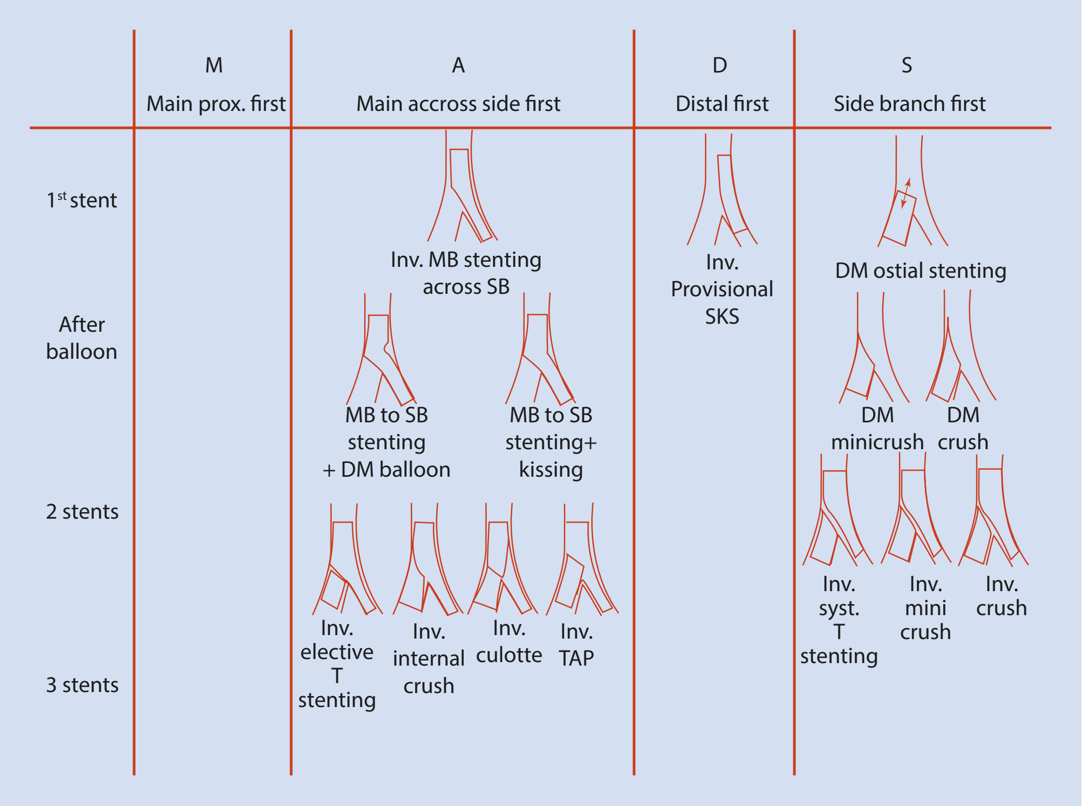


Fig. 46.7 MADS classification of techniques (inverted techniques) [24]

Fig. 46.8 Meta-analysis of randomized and nonrandomized studies showing the outcome after placement of a bare-metal stent (BMS) or drug-eluting stent (DES), with or without an additional side branch stent; *MACE* major adverse cardiac events [54]

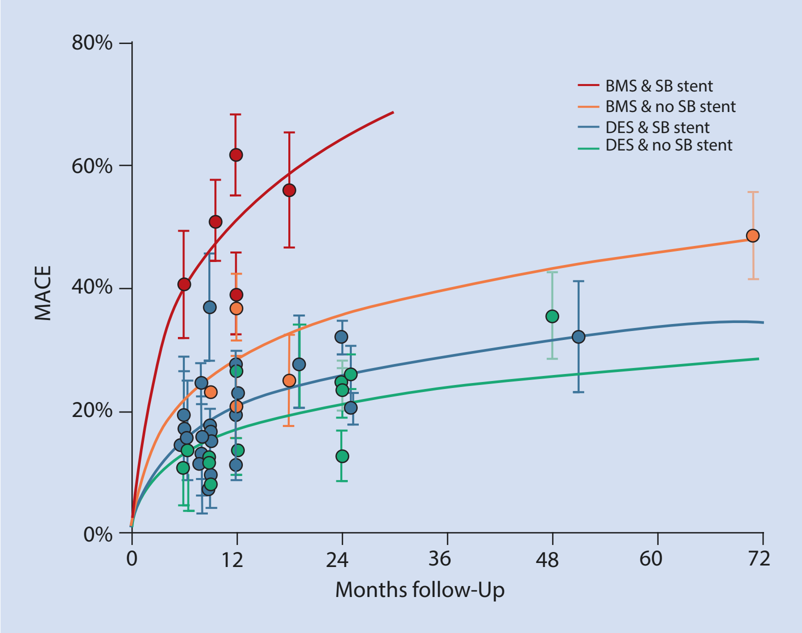


Table 46.1 Summary of major adverse cardiac events, comparing randomized bifurcation studies

Trial (publication year)	Two-stent group (%)	Provisional group (%)	*P*-value	Number of patients (two-stent/provisional)	Crossover rate (from one to two stents in provisional group) (%)	Follow up (months)
Colombo et al. (2004) [56]	23	22	ns	63/22	51.2	6
Pan et al. (2004) [57]	8.5	7	ns	47/44	2.1	6
CACTUS (2009) [60]	15.8	15	ns	173/177	31.2	6
BBC-1 (2010) [61]	15.2	8.0	0.009	249/248	2.8	9
DK-CRUSH-II (2011) [62]	10.3	17.3	0.07	185/185	28.6	12
NORDIC-I (2013) [63]	28.2	18.3	0.03	202/202	4.4	60
BBK I (2015) [64]	22.9	22.8	ns	101/101	18.8	60
PERFECT (2015) [65]	17.9	18.5	ns	213/206	28.2	12
TRYTON (2015) [66]	18.6	13.2	0.06	335/349	8.0	9
Nordic-Baltic IV (2015, abstract)	8.3	12.9	ns	229/221	3.7	24
EBC-TWO (2015, abstract)	8	10	ns	97/103	15.5	24

ns not significant

The earliest of these studies, conducted by Colombo et al., was characterized by a very high rate of crossover from single-stent implantation to double stenting, which precluded any intent-to-treat analysis [56]. Results were in favor of the single-stent strategy. The study by Pan, which was conducted in a very small population, showed a clear trend toward a decreased restenosis rate in the SB with the simple strategy [57].

The first large randomized study was the NORDIC I study ($n = 413$) [58]. Patients randomized to the provisional approach were stented in the main vessel (MV) with a sirolimus-eluting stent and had SB postdilatation only if TIMI flow was <3. Furthermore, the SB was stented only if TIMI flow was 0 after postdilatation. The 6-month outcome did not show any differences in the rate of major adverse cardiac events (MACE) (MV + SB stenting 3.4%; MV only 2.9%; *P* ns). The two-stent strategy, however, was more time-consuming and was associated with increased X-ray exposure and contrast medium use. A higher frequency of biomarker elevation was also observed in patients undergoing double stenting. At 5 years, the combined outcome of all-cause mortality, MI, target vessel revascularization (TVR), and stent thrombosis was significantly lower in the provisional approach [63].

The BBK I study by Ferenc was characterized by the fact that FKB was performed in all patients and by its angiographic endpoint (percent diameter stenosis of the SB at 9-month angiographic follow-up) [59]. The results were not significantly different after provisional T-stenting compared with routine T-stenting (23.0 ± 20.2% versus 27.7 ± 24.8%, $P = 0.15$), with an identical restenosis rate in the SB and MB and no differences in the rate of TLR at 1 year. These results were confirmed up to 5 years with respect to TLR and MACE [64].

The CACTUS study, conducted by Colombo et al., compared provisional SB stenting to the crush technique and was characterized by a 31% crossover rate to crush stenting in the provisional group [60]. The primary endpoint (MACE) was similar in both groups. No differences were reported in the restenosis rates (crush, 4.6% and 13.2% in the MB and SB, respectively; provisional, 6.7% and 14.7% in the MB and SB, respectively; *P* ns).

In the BBC ONE study, the primary endpoint (a composite of death, MI, and target-vessel failure at 9 months) occurred in 8.0% of the provisional group versus 15.2% of the complex group ($P = 0.009$), a difference mainly driven by periprocedural MI rate (3.6 versus 11.2%, $P = 0.001$) [61]. Procedure duration, amount of contrast media used, and X-ray dose favored the simple approach. At 5 years, all-cause mortality was lower in the provisional group (2.9 versus 5.9%, $P = 0.17$) [67]. When pooling these results with those of the NORDIC I study, the lower rate of all-cause mortality with the provisional strategy reached statistical significance at 5 years (3.8 versus 7%, $P = 0.04$) [67].

The DK-CRUSH II (Double Kissing Crush Versus Provisional Stenting Technique for Treatment of Coronary Bifurcation Lesions) trial compared the provisional stenting strategy to the double-kissing (DK) crush technique in patients with true bifurcation lesions (Medina 1,1,1 or 0,1,1) [62]. This randomized trial, which included 185 patients in each study group, observed no significant clinical differences at 6 months, but significant differences in TLR and TVR at 12 months, favoring the two-stent strategy. These results can be largely explained by an «occulo-stenotic» reflex caused by the systematic angiographic follow-up at 8 months. On the other hand, the PERFECT trial observed no differences between the DK crush and the provisional strategies in bifurcations involving a SB stenosis [65]. More recently, results from the NORDIC IV and EBC 2 showed no difference between provisional and two-stent techniques with respect to MACE.

Many meta-analyses dedicated to bifurcation lesions have been reported or published [2, 54, 68–75]. Meta-analyses of randomized studies have shown similar results with respect to mid-term clinical events in patients undergoing provisional stenting versus those treated with two stents. No differences in terms of mortality, TLR, or definite stent thrombosis were evidenced.

One of the meta-analyses comparing MB stenting with double stenting (using BMSs or DESs) in 42 studies involving 66 groups and a total of 6825 patients confirmed the superiority of DESs over BMSs and that of simple stenting versus double stenting with respect to the rate of MACE [54].

Comparison of Various Two Stent Techniques

Assessment of the optimal complex technique was carried out in the NORDIC II study, which compared the culotte and crush techniques [76]. The crush strategy was performed using a stent or a minicrush balloon with FKB. The culotte implantation started with the main stent (straight culotte). Crush and culotte bifurcation stenting techniques were associated with similar clinical results for MACE (crush 4.3%, culotte 3.7%, $P = 0.87$) and biomarker release (crush 15.5%, culotte 8.8%, $P = 0.08$). Angiographic findings showed a significantly reduced in-stent restenosis rate following culotte stenting compared with crush (MB 6.6 versus 12.1%, $P = 0.10$; SB 4.5 versus 10.5%, $P = 0.046$).

46.4 The Provisional Side-Branch Stenting Strategy: A Step-by-Step Approach

Most bifurcation PCIs can be undertaken through the radial approach using a 6F guiding catheter. A larger guide (7F) can be considered when using adjunctive technology such as rotational atherectomy (>1.75 mm burr size) or a strategy that requires simultaneous use of two stents or three balloons. ◻ Figure 46.9 displays the steps of the provisional approach [77]. As described in ◻ Table 46.1, when the provisional approach is properly performed, over 95% of bifurcation lesions can be treated with one stent. This rate also depends on the criteria used to justify the requirement for a second stent (i.e., the level of conservativeness).

46.4.1 Side-Branch Wire Protection

The EBC-recommended strategy is to systematically wire the SB at the beginning of the procedure [78, 79]. Situations where the MB should be wired first are discussed in ▶ Sect. 46.4.3. The presence of a wire in the SB favorably modifies the angle between the proximal segment of the MB and the SB, thereby facilitating subsequent wire exchange, balloon insertion, and placement of a second stent if necessary. The wire also helps maintain SB patency and is a useful target for wire exchange if the SB becomes occluded.

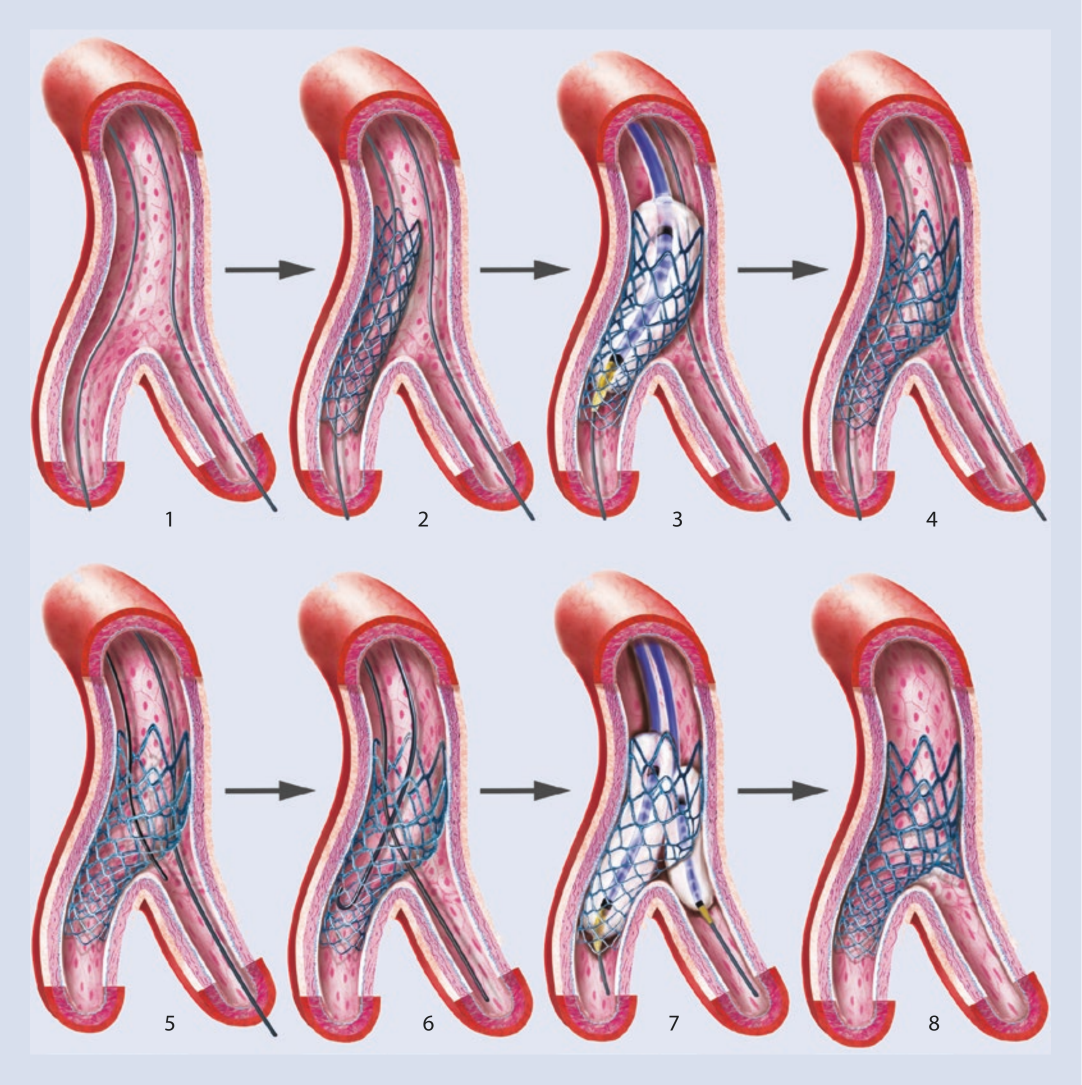


Fig. 46.9 The provisional side-branch (SB) stenting approach: (*1*) Insertion of a wire into each distal branch, starting with the most difficult branch in order to avoid wire wrap. Systematic placement of a wire in the SB helps to open the access angle, keep the SB patent, and serve as a marker in cases of closure. A long shape on the MB wire facilitates SB rewiring during wire exchange after MB stenting. It is preferable not to predilate the SB in order to avoid recrossing both the stent struts and a dissected SB segment after MB stenting. (*2*) Stenting of the MB. The diameter of the MB stent implanted across the SB should be selected according to the distal MB diameter in order to decrease the risk of carina shifting. Selection of the MB stent length is also very important so that enough space is left proximal to the bifurcation to postdilate the proximal part of the MB stent (POT), which is under-deployed. (*3*, *4*) POT allows the operator to match the proximal segment of the MB stent with the MB diameter by means of a short balloon with a diameter adapted to the proximal segment. (*5*) Guidewire exchange is performed to allow kissing balloon inflation. The wire positioned in the stented vessel is removed with its tip pointing toward the SB, and subsequently inserted into the SB through the distal cell using a long angulated distal tip. (*6*) Then, the jailed wire is withdrawn carefully to avoid abrupt guiding catheter intubation, and is subsequently advanced into the distal MB (a short angulated shape helps to recross the MB stent with a loop). (*7*, *8*) Kissing balloon inflation is carried out with two short balloons, with diameters compatible with both distal branches. The SB balloon should be noncompliant to avoid dissection

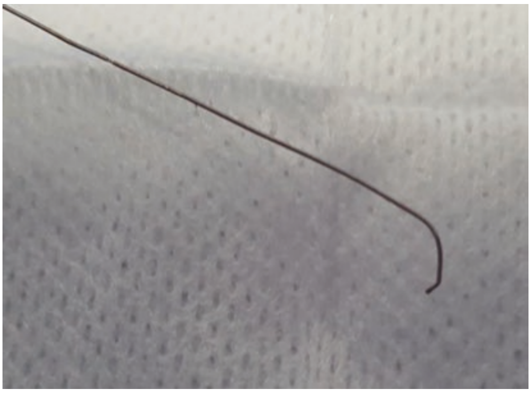


Fig. 46.10 MB wire shape. The main J-tip should be longer than the MB reference diameter. A very short, secondary J-shape can be added to the tip to facilitate hooking onto stent struts during wire exchange

46.4.2 Wire Selection and Wire Shaping

Selection of the SB wire must take into account the fact that the wire will be jailed between the stent and the main vessel wall [80]. Hydrophilic and nonhydrophilic wires can be used, as polymer shearing and wire fracture are uncommon [81, 82]. However, it is not safe to jail the radiopaque tip of a wire.

To facilitate the procedure, all successive wire maneuvers should be anticipated. The MB wire should be shaped to allow easy wire exchange through the struts, toward the SB, after stent placement in the MB. The tip should be longer than the MB reference diameter. A very short, secondary J-shape can be added to the MB wire tip to facilitate hooking onto stent struts during wire exchange (Fig. 46.10). The SB wire should have a short tip. A tip with a sharp angle allows, upon wire exchange, looping and easy passage of the wire through the MB stent without crossing outside the stent struts.

46.4.3 Wire Insertion and Manipulation

One of the difficulties generated by the use of two wires is the crisscrossing of wires, which can hinder subsequent balloon and stent advancement. The following tips can reduce the risk of wire crisscrossing:

1. Insert the first wire into the branch that seems the most difficult to access. This allows unlimited rotations of the wire because there is no other wire to wrap around.
2. Limit second wire rotation to less than 180° in one direction or the other. The use of a torquer is strongly recommended.
3. Keep wires separated on the table in the same position throughout the procedure, even after wire exchange. Crisscrossing of the wires on the table can be propagated up to the bifurcation lesion when balloons or stents are advanced.

Another potential issue is that of SB wiring. When angle A is acute, wires tend to loop in the MB rather than advance in the SB. Several progressive methods can be implemented, such as shaping the wire to form a loop distal to the SB. The loop is then pulled and the wire resumes its normal shape in the SB (Fig. 46.11). The deflectable Venture mircocatheter (Vascular Solutions) or the preshaped SuperCross microcatheter (Vascular Solutions) can prove useful in difficult cases (Fig. 46.12). In addition, dual-lumen microcatheters such as the Twin-Pass (Aquilant Interventional) or the FineDuo (Terumo) can be used once the MB is wired. In cases of failed attempts to engage the SB, the PM should be dilated up to the carina with balloons of gradually increasing diameters, despite the risk of SB closure. This can modify the bifurcation geometry to allow subsequent SB wire placement. The use of rotational atherectomy has been shown to be helpful [80].

46.4.4 Predilatation

Main branch predilatation depends on the lesion characteristics and operator preference. Optimal lesion preparation is recommended. Whether or not the SB should be predilated is a controversial topic. In cases where the selected strategy is to stent the MB across the SB, it is recommended *not* to routinely predilate the SB in order to avoid propagating a potential dissection during wire exchange. SB predilatation also increases the risk of stent requirement in the SB. Predilatation with an undersized balloon can be considered in the case of a very calcified SB, severe SB ostial stenosis, or SB with a difficult access.

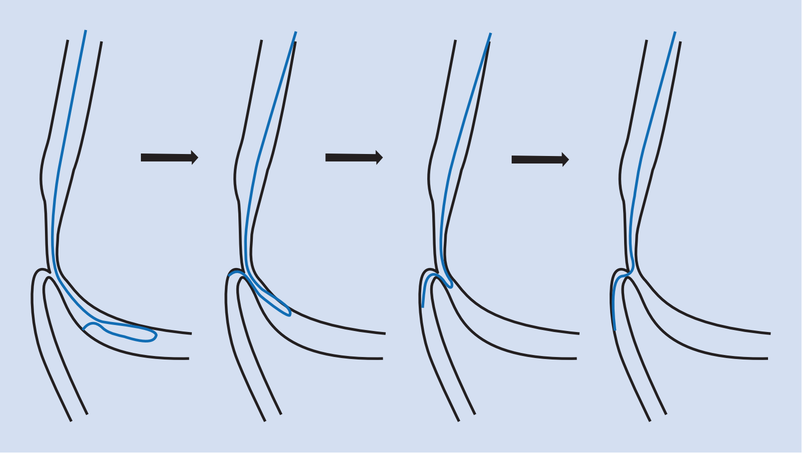


Fig. 46.11 Long U-shape reverse wire technique

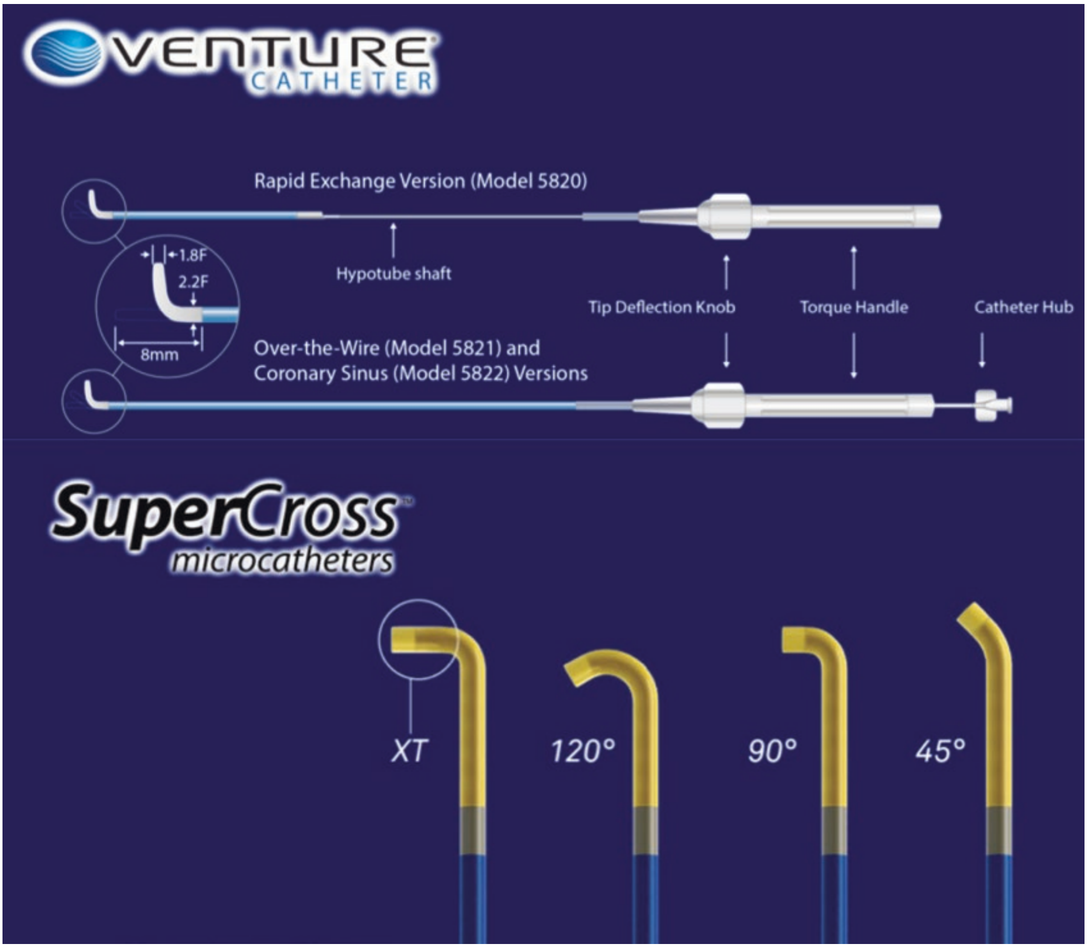


Fig. 46.12 Useful microcatheters for difficult SB wiring

46.4.5 Main Branch Stenting

New generation DESs have been clearly shown to improve the outcome of patients with bifurcation lesions and should be the default stent type.

Stent diameter should be selected according to the diameter of the DM segment, with a 1:1 stent-to-DM artery ratio. This, however, results in stent malapposition in the PM, for which POT is mandatory (see ► Sect. 46.4.6). Stent length should take into account the necessity of having at least 8 mm of stent in the PM to allow for proximal optimization.

The non recommended implantation of a larger stent matching the PM diameter (instead of the DM) can result in dissection or perforation of the DM, as well as significant carina shift leading to SB occlusion [83]. This is especially true in cases with a narrow B angle. Sizing stents according to DM is also likely to modify the plane in which the SB can be accessed. The plane becomes parallel to the MB axis, making the access for wire exchange more complex and potentially hindering subsequent insertion of balloons and stents toward the SB.

46.4.6 The Proximal Optimization Technique

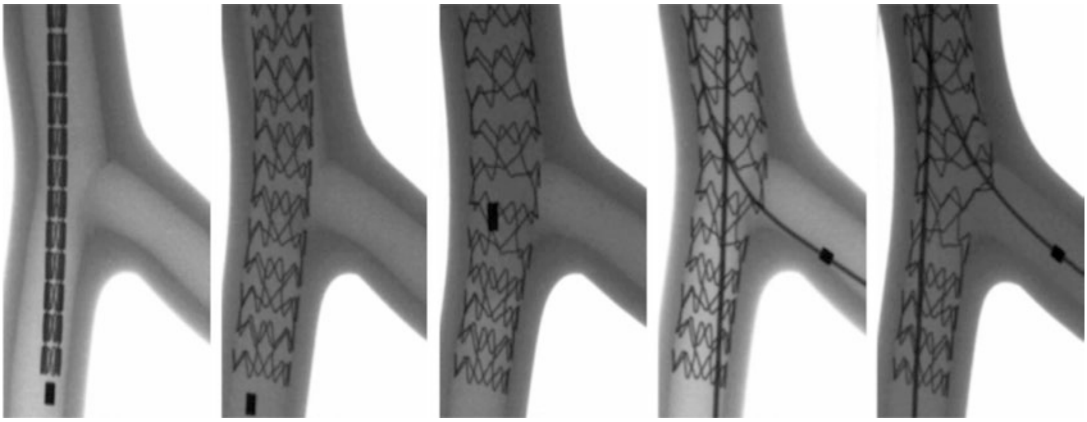
POT can be implemented to obtain two distinct diameters for a single stent implanted in two distinct segments [84] (◘ Fig. 46.13). This technique is mandatory in the presence of large SBs with a significant difference between the PM and the DM. Because stent diameter is selected on the basis of DM, postdilatation of the PM is necessary to obtain correct stent apposition.

Currently, POT requires that the stent length in the PM be at least 6 mm, which corresponds to the shortest balloon length available. However, 6 -mm balloons have only one central radio-opaque marker, making precise positioning nearly impossible. Practically, stent length into the PM should be at least 8 mm, because 8-mm balloons have a proximal and distal radio-opaque marker. Semicompliant or noncompliant balloons can be used for POT.

The diameter of the balloon used for POT must match that of the PM. The distal marker of the balloon should be placed just proximal to the carina (◘ Fig. 46.13). The result is optimization of the proximal segment of the stent as well as the projection of struts toward the SB and cell enlargement, which facilitate guidewire access through the distal strut of the MB stent [85].

46.4.7 Guidewire Exchange: Tips and Tricks

Exchanging wires or recrossing the SB with a free wire is performed with the objective of dilating the SB ostium, which results in MB stent distortion. Consequently, it should performed using the kissing technique or a sequential POT-side-POT technique. SB dilatation can be performed to



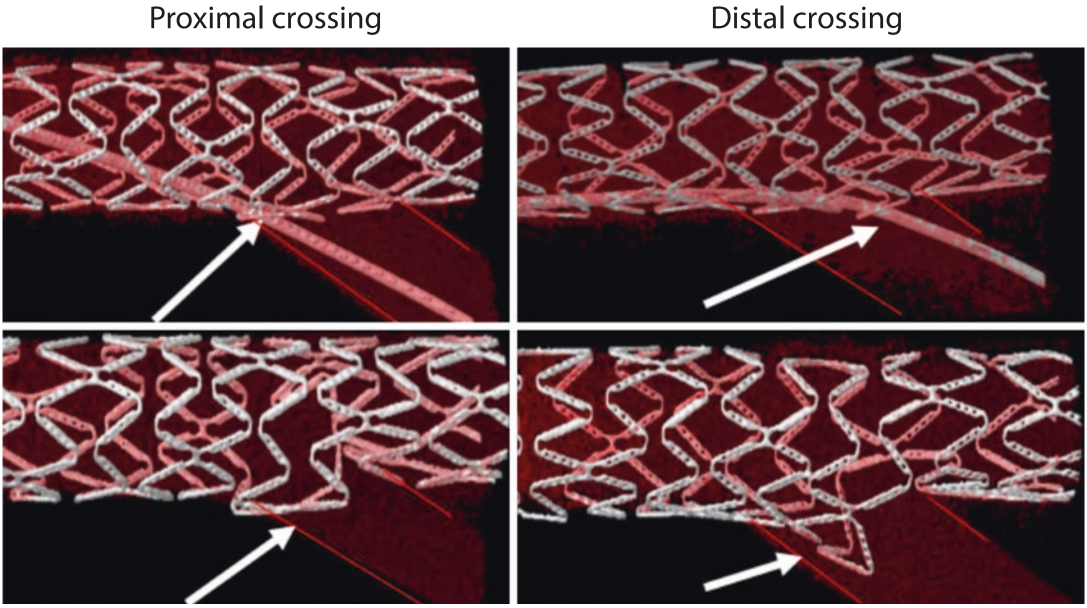
◘ **Fig. 46.13** Proximal optimization technique (POT). POT with the Kaname stent (Terumo). From *left* to *right*: (*1*) Stent size is selected according to distal reference; (*2*) stent fully apposed distally but not proximally; (*3*) POT with the distal balloon marker just proximal to the carina; (*4*) access through the distal strut for FKB; (*5*) good SB scaffolding after FKB improve an inadequate result in the SB. It can also be carried out systematically to open the MB stent strut toward the SB to avoid disrupting SB blood flow, reduce the risk of thrombosis, and allow further SB access. Deciding not to treat a small SB branch not amenable to stenting, with normal flow and no angina or signs of ischemia, is probably justified.

The guidewire exchange maneuver starts with the pulling of the MB wire and redirection through struts into the SB. When treating a bifurcation with a large SB, two strut openings are often available for crossing into the SB. A very important aspect of the technique is to select the *most distal* strut (i.e., closest to the carina) for crossing. This projects more struts in the ostial segment of the SB opposite to the carina (◘ Fig. 46.14). The jailed wire, used as a reference, is usually located too proximal, and attempts at crossing the struts should be made distal to it.

The following tips are suggested for facilitating the maneuver:

1. Preshape the wire into an elongated form.
2. Add a very short secondary J-shape to facilitate hooking to the desired strut (◘ Fig. 46.10).
3. Repeat the POT with a larger balloon or at higher pressure.
4. If uncertainty persists with respect to the selected strut after crossing, the wire can be left in place and a new wire (or the jailed wire) used to try to cross at a more distal location. High resolution angiography (without contrast) allows the operator to compare the location of both wires and select the one with the most distal strut crossing.

In cases where the SB is occluded and cannot be recrossed, a bailout technique can be implemented (◘ Fig. 46.15). A small balloon (1.2–1.5 mm) is placed on the jailed wire and inflated to restore flow in the SB and allow passage of the second wire through the MB stent struts. In cases of persistent failure to cross the strut, the strategy can be converted into an inverted crush technique, with a larger balloon on the jailed wire crushing the MB stent (after removal of the MB wire to avoid jailing in the crushed stent). Subsequently, a second stent is placed from the PM to the SB, followed by FKB [86, 87].



◘ **Fig. 46.14** Proximal versus distal crossing in the SB, demonstrating the importance of distal cell recrossing after main vessel stenting. Recrossing through the strut closest to the carina allows better scaffolding of the SB ostium compared with proximal recrossing, which pushes the struts inward toward the main vessel lumen

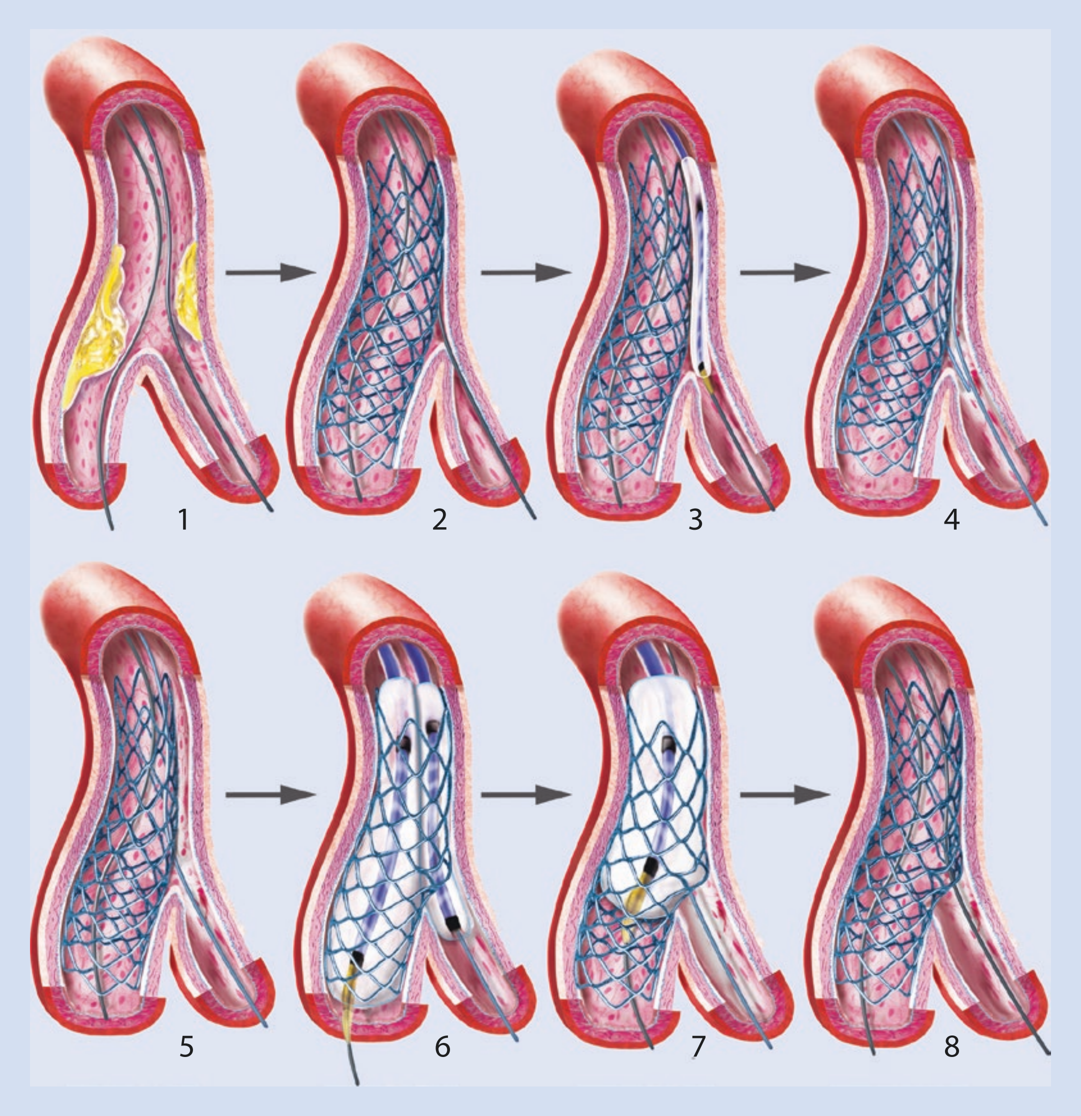


Fig. 46.15 Bailout technique in the case of ostial SB occlusion (*1*). Inflating a small diameter balloon on the SB jailed wire, behind the MB stent, can reopen the SB ostium (*2*, *3*). The MB wire can then be withdrawn to cross the MB stent into the SB (*4*). After guide wire exchange, kissing balloon is performed (*5*–*8*)

When withdrawing the jailed wire from the SB, the left hand should keep traction on the guiding catheter to avoid abrupt unintended guiding-catheter intubation. The latter can result in vessel dissection or longitudinal stent distortion, especially in the context of LM stenting (Fig. 46.16). Preshaping the wire into a short accentuated form allows recrossing through the PM stent by forming a loop to avoid passage outside the struts, which is unlikely after POT. Excessive torqueing should be avoided because crisscrossing of the wires is also possible at this stage.

46.4.8 Kissing Balloon Inflation

The next step is the opening of the MB stent strut toward the SB. However, using a single balloon from PM to SB results in marked distortion of the stent as a result of malapposition of the MB stent opposite to the SB takeoff [88]. This issue is avoided by performing final kissing balloon inflation (FKB) or a POT-side-POT technique.

The benefit of performing FKB after implantation of a single stent is still a matter of debate [89–94]. As previously mentioned, a small SB

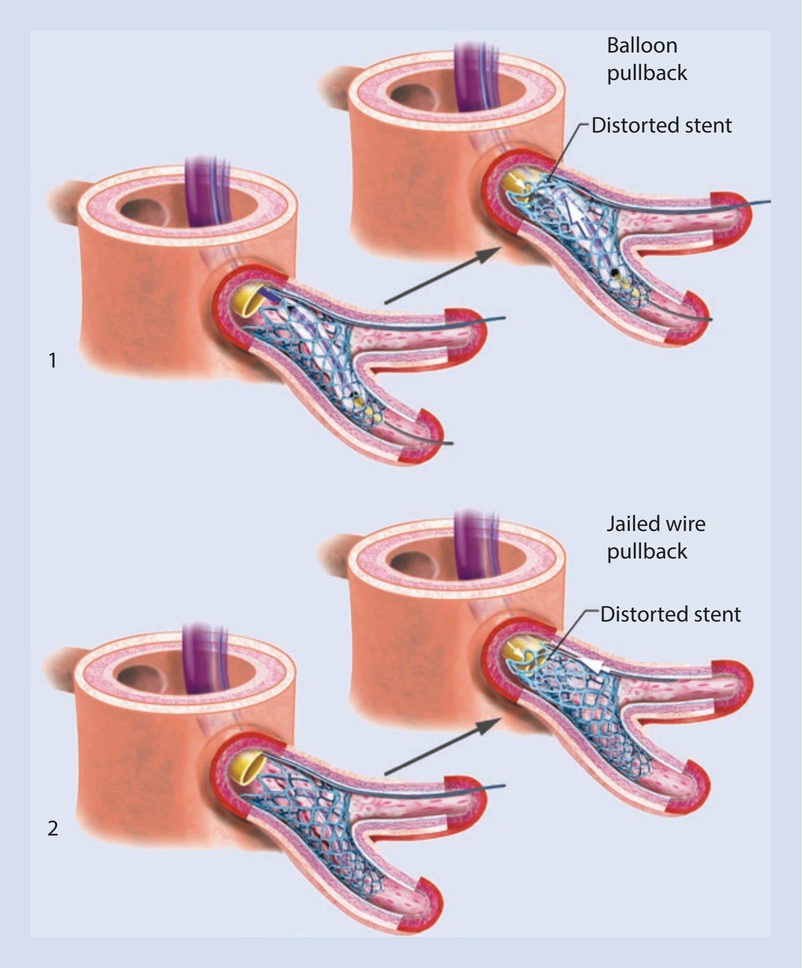


Fig. 46.16 Two mechanisms of stent longitudinal distortion when stenting the LM coronary artery. *Top*: The balloon delivery system or POT balloon is pulled back too early after deflation. *Bottom*: Pullback of the jailed wire can attract the guiding catheter and damage the stent. Optimal control of the guide with the left hand is crucial

unsuitable for stenting (<2 mm), with normal flow and no angina or electrocardiogram signs, does not require intervention. However, it is recommended that the SB ostium be dilated when inadequate results are achieved, antegrade flow is impaired (TIMI flow <3), severe ostial SB narrowing is present, or the FFR of the SB is <0.80. The benefit of systematic final kissing in securing further access to the SB has not been demonstrated.

In the NORDIC III trial, no clinical differences between FKB and no-FKB were evidenced at 6 months, but the 8-month outcome showed a difference in the rate of restenosis between the two strategies in favor of FKB [90]. The binary restenosis rate of the MV was identical (3.1 versus 2.5%, $P = 0.68$), but inferior in the FKB group for the SB (7.9 versus 15.4%, $P = 0.039$). The difference for the SB was more pronounced in the group of patients with true bifurcation lesions (7.6 versus 20.0%, $P = 0.024$).

In patients with new, non-flow-limiting SB stenosis *appearing after MB stenting*, the benefit of FKB was challenged in the CROSS study [65]. Patients in the FKB group had a significantly higher rate of restenosis in the MB compared with those in the no-FKB group (15.1 versus 3.7%, $P = 0.004$). This could be a result of MB stent distortion caused by overlapping balloons or by greater barotrauma in FKB [95, 96]. These results are contrary to those obtained in the COBIS II registry, where FKB reduced both MACE (HR 0.50; $P = 0.01$) and TLR in the MB (HR 0.51; $P = 0.03$) [92]. These results were consistent, regardless of the presence of a true bifurcation lesion or not.

The use of noncompliant balloons reduces the risk of excessive SB dilation, which can lead to dissection requiring stenting. This was shown in the COBIS II registry, where SB dissection and MACE were significantly reduced in cases where

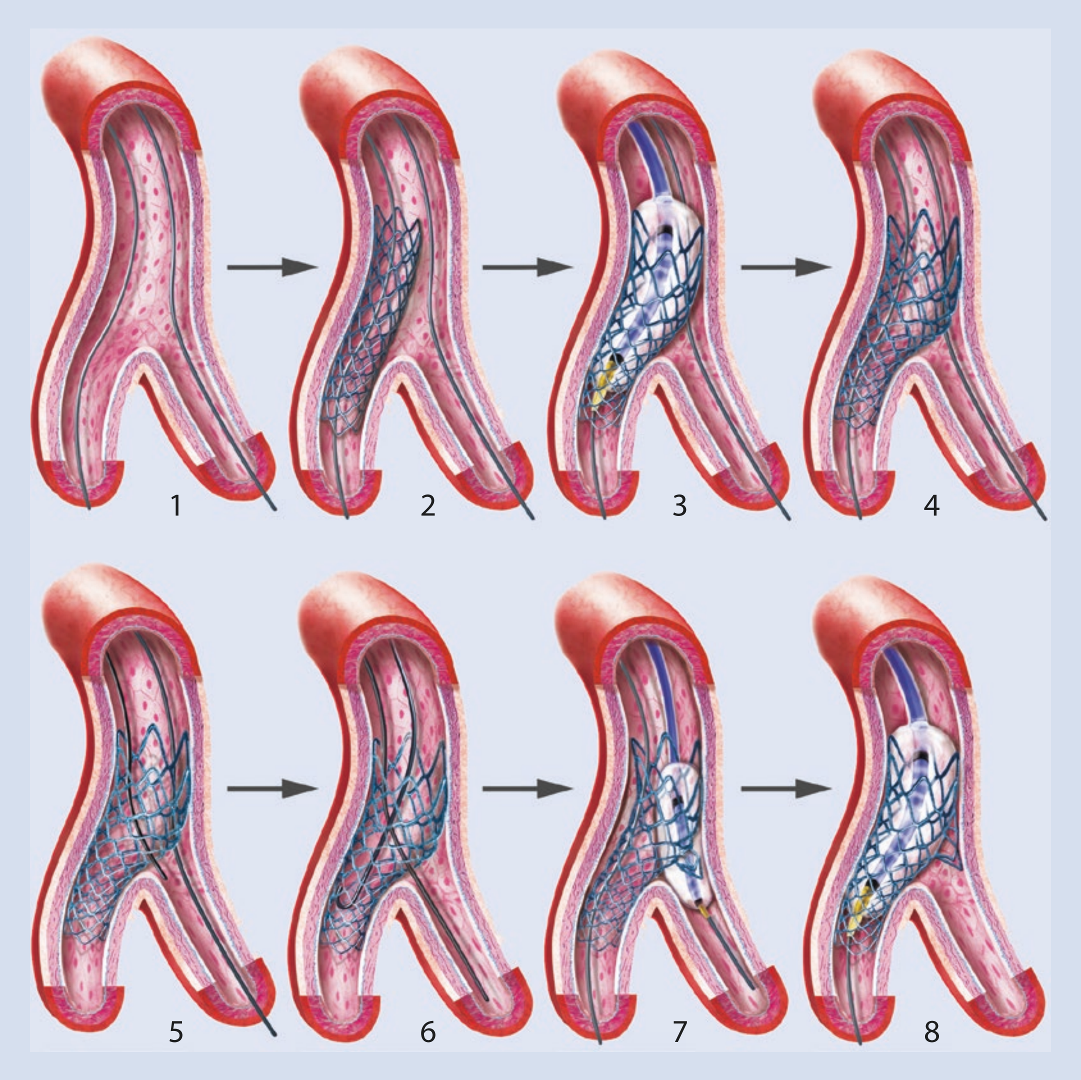


Fig. 46.17 POT-side-POT technique. (*1*) Wiring both branches. (*2*) MB stenting using a stent diameter according to the distal MB reference. (*3*, *4*) Initial POT with balloon diameter according to proximal MB reference. (*5*, *6*) Wire exchange (wiring the SB through the MB distal strut). (*7*) SB opening using a short noncompliant balloon to avoid SB dissection. (*8*) Re-POT to restore stent distortion opposite to the SB

only noncompliant balloons were used (SB dissection 0.1 versus 1.1%; $P = 0.046$; MACE 8.2 versus 12.3%; $P = 0.01$) [97]. Similarly, the use of short balloons is recommended in order to avoid geographic miss and ovalization of the PM stent caused by the two overlapping balloons. However, ovalization can be corrected by performing a final POT. As described by Foin et al., we recommend inflating the SB balloon first, deflating it partially to 4 atm, inflating the MV balloon to the desired pressure, and finally increasing pressure in the SB balloon back to the desired pressure before simultaneous deflation [98]. This leads to significantly reduced proximal deformation, with an unchanged rate of malapposed struts and reduced rates of SB ostial stenosis.

Another technique that can be used is POT-side-POT (Fig. 46.17). After wire exchange, a single noncompliant balloon is inflated in the SB, followed by a final POT. This technique, which has yet to be compared to the FKB technique, has the advantage of maintaining circular geometry of the PM stent. This has been shown in a bench model by Finet and colleagues [99]. It also has the advantage of simplicity: only one balloon is inserted at a time, which facilitates positioning, and only one indeflator is required. Importantly, the final POT must be performed with exquisite precision (distal marker at the level of the carina) in order to properly re-appose the struts in the MB facing the SB.

Failure to advance a balloon to the SB can occur as a result of several factors, including wire wrap, poor support, extreme angulation, or SB wire position outside the stent in the PM. The latter can occur if a new wire is used to cross the struts into the SB, or if the main vessel wire is retracted outside the stent before crossing into the SB. The most common cause is extensive wire torqueing and ensuing wire wrap. Wire wrap can be identified when the DM wire is seen retracting back while pushing the SB balloon.

Advancement into the SB can be facilitated by the following:

1. Retrieving and rewiring the MB in order to unwrap the wires.
2. Inflating the balloon at low pressure (3 atm) as close as possible to the SB, then advancing the balloon through the struts as it deflates.
3. Using a lower profile (semicompliant) balloon of smaller diameter than the SB.
4. Re-POT with higher pressure or bigger balloon in the proximal MB to increase strut size at SB.
5. Using the anchoring balloon technique with inflation of a balloon to nominal pressure in the stented DM, which improves catheter support and allows crossing of the balloon into the SB.
6. Using a dedicated ultrashort Glider balloon (Glider, TriReme Medical, Pleasanton, CA, USA) with a beveled tip that allows tip rotation [100].

Assessment of the procedure outcome following FKB or POT-side-POT is the key moment of the provisional SB stenting strategy. The results are evaluated according to the initial objectives: SB patency with good flow and absence of significant stenosis in an anatomically or functionally important vessel. The interest of this strategy lies in the fact that, after stenting the most significant vessel, the operator can decide whether or not to stent the SB.

46.4.9 Side Branch Stenting

The decision to stent the SB is often dictated by the occurrence of a complication or the presence of less than TIMI 3 flow, chest pain, and ST segment elevation or severe dissection.

The existence of a tight residual stenosis raises the issue of the discrepancy between angiographic measurement and endoluminal, physiological measurements. Indeed, Koo et al. showed that in instances where an ostial SB stenosis is less than 75% after stenting, FFR measurement in the SB is always greater than 0.75 [40]. When the residual stenosis is >75%, FFR <0.75 is observed in only 27% of cases. Such a poor correlation between angiographic and FFR evaluation can have multiple reasons: (1) the use of nondedicated QCA; (2) the flow characteristics in the bifurcation (recirculation opposite the carina causing inadequate filling of the SB); and (3) the oval shape of the SB ostium combined with poor angiographic view of the lesion. An important concept to remember is that the narrower the B angle, the more oval is the ostium of the SB. The working angiographic projection usually shows the minor (i.e., worse-looking) axis of the ostium. An orthogonal view shows the major axis of the SB; unfortunately, significant overlap with the MB is present in that projection.

Implantation of a second stent can be carried out using several techniques: T-stenting, T-stenting and protrusion (TAP), or straight culotte. The T-stenting technique is most appropriate for bifurcations with a wide B angle, whereas the other techniques are recommended for narrow B angles to obtain optimal SB ostium scaffolding. However, when SB access is performed through a distal strut, excellent SB scaffolding is obtained and T-stenting is possible (◘ Fig. 46.18). T-stenting requires that the stent position be checked in at least two distinct views visualizing the SB ostium; the distance between the position of the stent on the balloon and the proximal marker should also be taken into account.

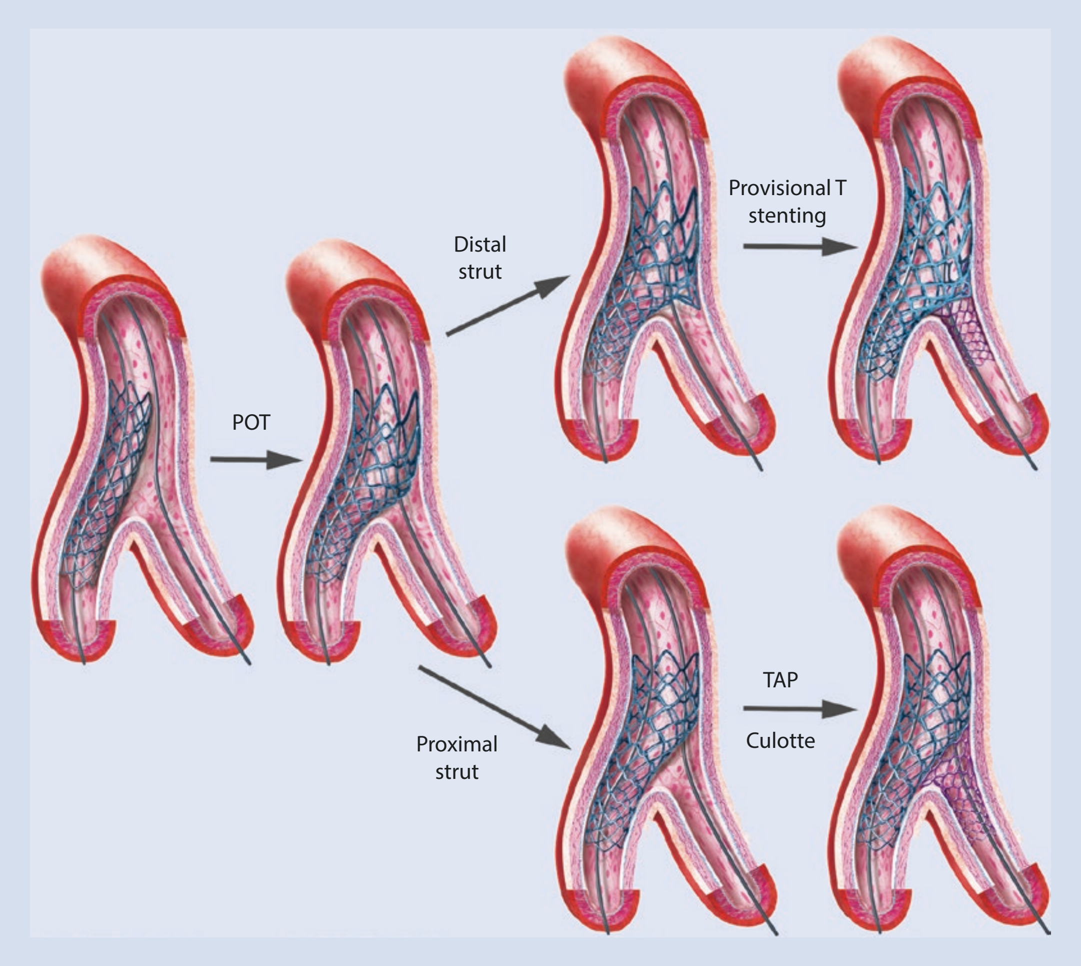


Fig. 46.18 Provisional approach according to strut crossing. After POT, the stent is fully apposed in the distal MB and proximal MB. If the SB needs attention, wires are exchanged. If the MB wire is inserted in the SB in a strut close to the carina (*upper panel*), the SB ostium is covered by the MB stent after kissing balloon inflation and a SB stent is not needed in most cases. If a SB stent is necessary (dissection, long lesion), T-stenting can be done and TAP is not necessary. In the case of access through a more proximal strut (*lower panel*), the SB ostium is not covered by the MB stent after kissing balloon inflation. If a SB stent is needed, the two-stent technique should be a TAP or a culotte in order to cover the SB ostium

If the SB ostium is not properly covered by the MV stent, an overlapping technique is necessary. When TAP is used, the SB stent is deployed with minimal protrusion into the MV while maintaining an uninflated balloon in the MV (■ Fig. 46.19). This slight protrusion allows full coverage of the bifurcation and creates a short neocarina. Kissing balloon inflation is mandatory to finish the procedure [101].

46.5 When and How to Perform Complex Bifurcation Stenting

The decision to perform a two-stent technique can take place at different time points of the intervention. A two-stent strategy can be chosen *electively* in cases where both the DM and the SB have long lesions (>5 mm beyond the ostium) susceptible to lead to significant ischemia (vessel

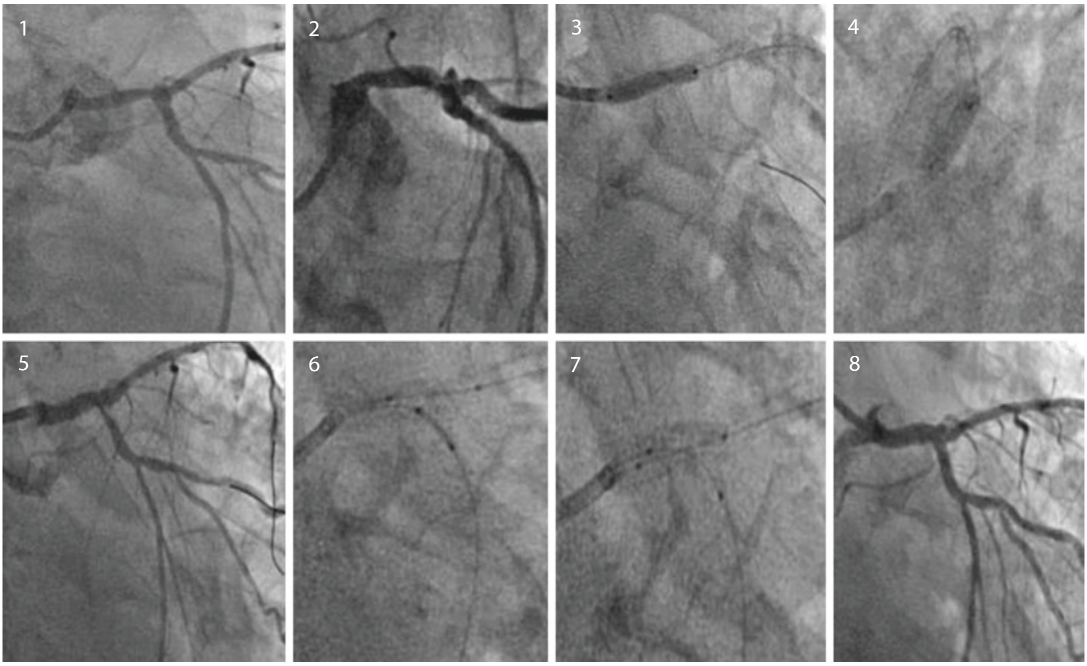


Fig. 46.19 Provisional T-technique converted to TAP stenting. (*1*, *2*) Left main coronary artery (LM), left anterior descending artery (LAD), and left circumflex artery (LCX); 1,1,0 bifurcation lesion. Although LM does not appear to be severely diseased, one should note that the LM is smaller in size than LCX and same size as the LAD. (*3*) Direct stenting with a 3.0 × 18 mm Onyx (Medtronic) stent from LM to LAD with a «jailed» protective wire in the LCX, diameter chosen from the DM diameter. (*4*) POT technique with a short 4.5 mm × 8 mm balloon, diameter chosen from the PM diameter. (*5*) Severe plaque and carina shift on the ostium of LCX, with FFR (not shown) of 0.78. (*6*) 3.5 × 12 mm Onyx stent positioned with minimal protrusion into the LM, with a deflated balloon parked in LM to LAD. (*7*) FKB with 3.0 and 3.5 mm NC balloons, diameter chosen from DM and SB diameters. (*8*) Final angiogram showing excellent results with the TAP technique

diameter >2.5 mm). Short SB lesions are usually adequately addressed by a single-stent strategy, as mentioned. Next, a two-stent technique can be adopted *before implanting the MB stent* in the case of a difficult access SB with a 1,1,1 or 0,1,1 bifurcation, even if the SB lesion does not meet the above criteria. In that situation, an inverted TAP technique can be performed, whereby the first stent is placed from PM to SB so as not to lose it, and then a second stent is implanted in the DM. A classic culotte strategy can also be chosen. Finally, when selecting a single-stent provisional strategy, two-stent strategies can always be performed *after implanting the MB stent*, in the case of SB dissection for example, as discussed.

To summarize, SB stenting should be considered (1) when the SB is diseased beyond its ostium and large enough to lead to significant residual ischemia (this can be confirmed using FFR); (2) when there is significant SB flow impairment (TIMI <3); (3) in the presence of a major SB dissection; and (4) when future access to the SB may be important.

The first stent of a two-stent strategy may be implanted in the SB. The EBC has suggested that this approach should only be performed in cases where (1) access to the SB is expected to be very difficult and (2) the risk of SB occlusion may be associated with severe hemodynamic deterioration.

The complex techniques most often used are the crush techniques [102, 103], illustrated in ◘ Fig. 46.20, and the culotte technique [101], illustrated in ◘ Fig. 46.21.

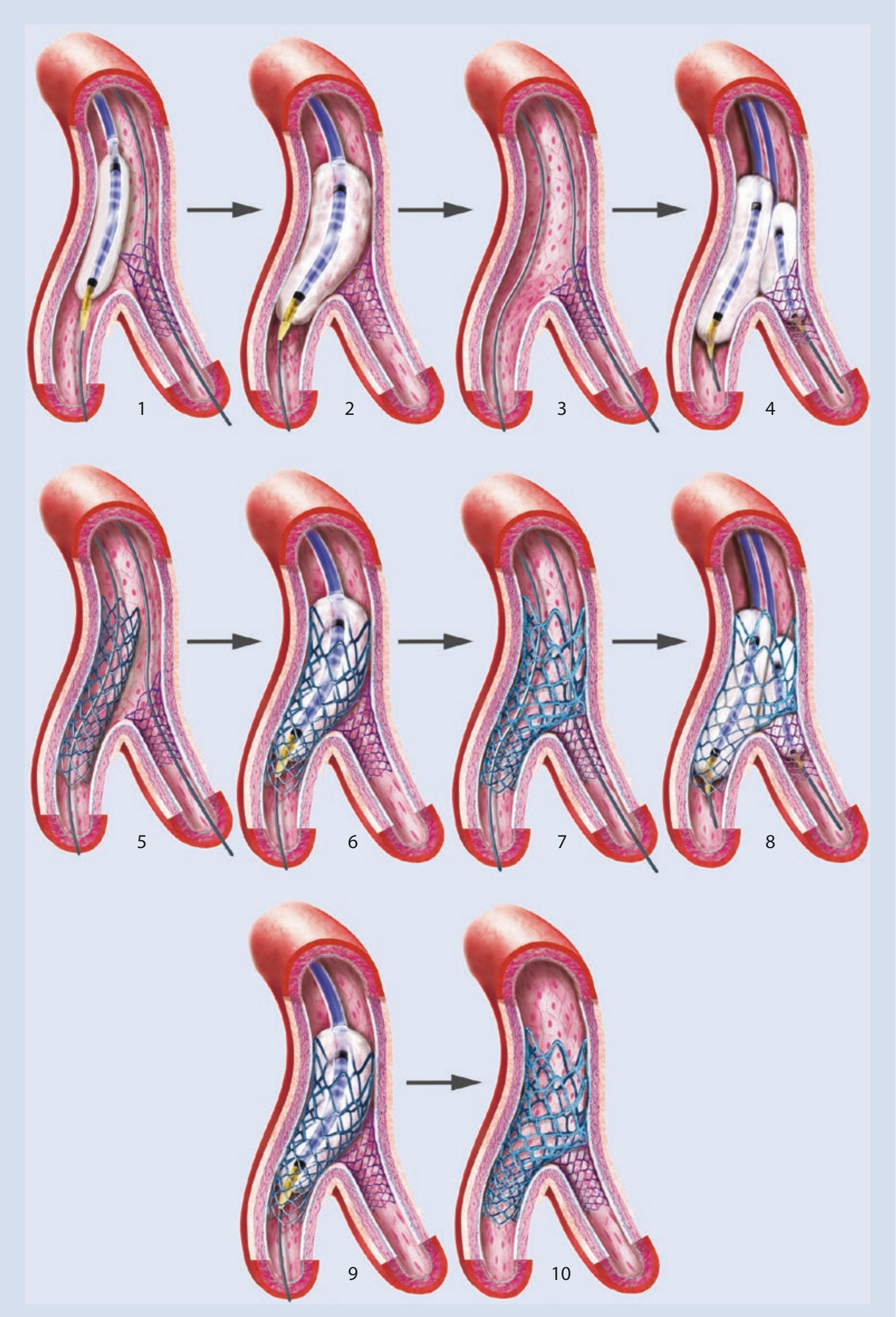


Fig. 46.20 The double-kissing minicrush technique, step by step: (*1*) stenting the SB (with 1–2 mm protrusion in the PM) and a deflated balloon in the PM to DM; (*2*) PM to DM balloon crush; (*3*) proximal wiring of SB access through the crushed stent and SB strut dilatation; (*4*) first kissing balloon inflation; (*5*) stenting the MV; (*6*) POT; (*7*) re-SB wire access; (*8*) final kissing balloon inflation; (*9*) final Re-POT; (*10*) final result

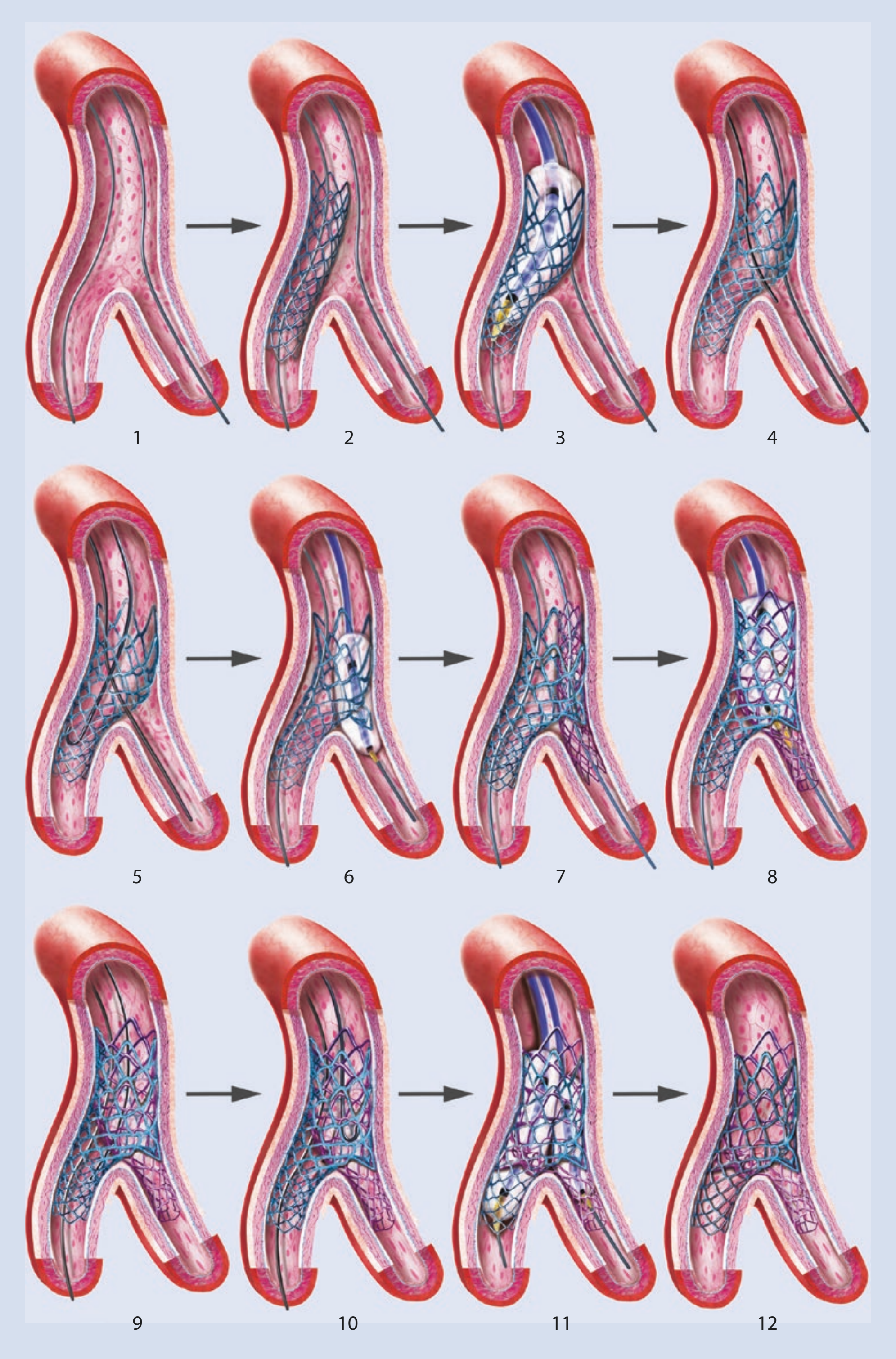


Fig. 46.21 The straight culotte technique, step by step: (*1*) insertion of a wire into each distal branch; (*2*) first stent deployed in the MB using a stent diameter according to the distal MB reference; (*3*) first POT; (*4*, *5*) wire exchange; (*6*) dilatation of stent struts into SB; (*7*) second stent deployed from the SB into the MB branch using a stent diameter according to the distal SB reference; (*8*) second POT; (*9*, *10*) second wire exchange; (*11*) FKB; (*12*) final result. The technique can also be performed with the first stent deployed in the SB (classic culotte technique)

In contrast to the provisional SB stenting approach in which guidewire recrossing is distal, recrossing the SB in DK crush should be carried out through the most proximal strut [103]. It is also preferable to limit the segment of crushed stent in the PM (very similar to modified T-stenting).

There are two distinct culotte techniques. The first technique is part of the provisional strategy. The second strategy begins with stent implantation in the PM segment toward the SB, in order to avoid losing the SB [104]. As the difference between the PM and SB diameters is usually significant, the second technique requires POT in the PM on the SB wire immediately after implantation of the first stent to prevent the occurrence of wire exchange outside the stent toward the DM, which would result in unintended crush. Stents with large expansion capabilities are, therefore, needed. POT is also very useful after MB stent deployment.

46.6 How Different Is a Distal Left Main Bifurcation from Other Bifurcations?

The distal LM bifurcation is the most proximal bifurcation of the left coronary tree. The diameters of its three or four segments (trifurcation) comply with the law of coronary ramification common to all bifurcations. The diameters, flow, and perfused myocardial mass are proportional to each other (in equal proportions). Formation of atheroma occurs for the same reasons and in the same locations as in non-LM bifurcations. There are no fundamental differences between the LM bifurcation and other bifurcations, but there are at least four nonspecific, quantitative rather than qualitative, factors that characterize LM bifurcations:

1. At least two of the three segments have large diameters.
2. The B angle between the two distal branches is wide and the A angle between the LM and the circumflex artery is usually sharp.
3. The volume of perfused myocardium increases the risks associated with the procedure.
4. Not all stents currently available are fully adapted to this setting. This is mainly related to the maximal expansion characteristics of the stent. For example, the minimal lumen dimeter for a 3.0-mm Xience (Abbott) stent is 4.0 mm when postdilated with a 5.0 noncompliant balloon (▣ Table 46.2) [105]. Depending on circumflex diameter, this may be insufficient to allow a proper POT to be performed in the LM (if the circumflex diameter is 3.5 mm, the LM should be 4.3 mm according to Finet's formula). In such a scenario, two strategies can be considered: (a) using a 3.0-mm Ultimaster or Resolute Onyx stent, which both have a lumen diameter of 4.3 mm after postdilatation; and (b) using a 3.5-mm Xience stent, inflated at low pressure, then performing the POT as desired.
5. The aspect of diffuse LM disease can be misleading and may appear disease-free if not carefully assessed. We should keep in mind the principles of Murray's branching law as this allows identification of diffuse LM disease when the reference diameter of the LM is identical to that of the LAD [106].
6. Trifurcations are encountered in about 10–15% of cases and may require a strategy where multiple wires and three balloons are needed for FKB [107].
7. Calcifications are more frequent.
8. The stented proximal segment is close to or at the level of the guiding catheter. This has important implications with respect to longitudinal stent distortion, as mentioned.

The justification for LM PCI and the indications of stenting and CABG are not discussed in this chapter. However, the technique selected for LM stenting can influence the results of comparison between PCI and CABG. Subanalyses of the recently published EXCEL and NOBLE trials may bring insight into this complex issue [108, 109].

There are no randomized studies comparing the outcomes of the two techniques in the distal LM, or even a single-stent versus a two-stent strategy. Most techniques reported in the treatment of non-LM bifurcations have been used in the distal LM.

Multiple large studies analyzing various technical options have provided data that are remarkably similar to those for non-LM coronary bifurcation stenting. Registries reported by Palmerini [110] and Kim [111] have shown that

Table 46.2 Stent minimal lumen diameter following post-dilatation

Stent name	Sizes (same platform) (mm)		Max postdilatation balloon (mm)		MLD (mm)
Xience	2.25, 2.5, 2.75, 3.0	→	5.0 NC	→	4.0
	3.5, 4.0	→	6.0 SC	→	5.6
Ultimaster	2.25, 2.5, 2.75, 3.0	→	5.0 NC	→	4.3
	3.5, 4.0	→	6.0 SC	→	5.8
BiomatrixA/Chroma	2.25, 2.5, 2.75, 3.0	→	5.0 NC	→	4.1
	3.5, 4.0	→	6.0 SC	→	5.8
Orsiro	2.25, 2.5, 2.75, 3.0	→	5.0 NC	→	4.0
	3.5, 4.0	→	6.0 SC	→	5.2
Synergy	2.25, 2.5, 2.75	→	5.0 NC	→	3.6
	3.0, 3.5	→	5.0 NC	→	4.2
	4.0	→	6.0 SC	→	5.7
Resolute Onyx	2.25, 2.5	→	4.0 NC	→	3.3
	2.75, 3.0	→	5.0 NC	→	4.3
	3.5, 4.0	→	6.0 SC	→	5.5
	4.5, 5.0	→	6.0 SC	→	5.9

Adapted from Ng et al. [106]
MLD minimal lumen diameter, *NC* noncompliant, *SC* semicompliant. All postdilatation balloons were inflated to 14 atm

the single-stent strategy is associated with a lower MACE rate at follow-up. The J-Cypher 5-year follow-up study underlined a threefold decrease in TLR in patients treated with a simple strategy (12.1 versus 33.5%; $P = 0.002$) [112]. A recently published study with 10-year follow-up showed that patients treated with provisional stenting of LM bifurcation had comparable rates of TLR compared with a two-stent strategy (19 versus 25%; $P > 0.05$) [113]. Issues with all these nonrandomized studies include the presence of residual confounding, which can only be addressed by a well-designed randomized trial. The ongoing EBC MAIN randomized trial comparing one versus two stents in LM stenosis true bifurcations will provide important information on the optimal treatment of LM bifurcation lesions [114].

Intravascular imaging, with either IVUS or OCT, is recommended for LM stenting and, should be performed at the completion of the procedure to assess stent apposition and deployment. The MAIN-COMPARE registry has shown, by post hoc analysis, that not using IVUS for LM stenting is associated with a higher death rate at midterm follow-up [50].

46.7 Are Dedicated Stents the Future of Coronary Bifurcation Stenting?

Many dedicated stent platforms have been developed for the treatment of coronary bifurcation lesions, but none have proven superior in safety and efficacy compared with a provisional strategy using conventional stents, and few have had a durable commercial life. There are currently three dedicated stents commercially available worldwide: the BIOSS stent (Bifurcation Optimization Stent System, Balton, Warsaw, Poland), the Axxess stent

(Biosensors International, Singapore), and the Tryton stent (Tryton Medical, Durham, NC, USA).

The BIOSS stent is a DES crimped on a bottle-shaped balloon with two diameters. This mimics (but does not obviate) a POT in the PM segment. Outcomes with the paclitaxel-eluting platform were similar to those of conventional provisional stenting with DES [115]. Results with the newer sirolimus-eluting platform in a 60-patient, one-arm registry are encouraging. [116]

One particular dedicated stent (the Axxess stent, a conical, self-expandable stent coated with biolimus) entails a technique whereby the PM is stented first. One or both distal branches may be subsequently stented with DES. The COBRA trial compared results between the Axxess stent and a culotte strategy using everolimus-eluting stents [117]. The drawbacks associated with these techniques are the number of stents necessary, the cost, and the learning curve for precise stent implantation, especially in calcified lesions [118, 119].

The Tryton stent is a balloon-expandable bare-metal stent intended for «true» bifurcation lesions requiring a two-stent technique. The stent design allows optimal coverage of the SB as well as loose coverage of the PM, facilitating access to the DM and placement of a DES in the MB. The Tryton stent failed to demonstrate noninferiority compared with the provisional strategy in a randomized trial [66]. At 9 months, the primary endpoint (target vessel failure) was 17.4% in the Tryton group compared with 12.8% in the provisional group. However, the inclusion criteria, especially the SB size of >2.5 mm, were not adequately fulfilled in this study. In those patients meeting the inclusion criteria, the Tryton stent appeared to be noninferior [120, 121].

Although a paradigm shift toward dedicated bifurcation stents has yet to occur, this objective is not unattainable.

46.8 Conclusion

Coronary bifurcation lesions are a daily issue for interventional cardiologists, who are increasingly faced with the management of patients with multivessel disease. Coronary angioplasty of these complex lesions remains technically challenging and the development of optimal strategies adapted to each individual patient is crucial.

Consensual approaches have been adopted over the past 10 years on the basis of very simple principles: the MB is the primary branch and the SB is a secondary branch; coronary bifurcations are subject to the natural laws of flow distribution; and bifurcations have three reference diameters (PM, DM, and SB).

A provisional one-stent strategy should be the go-to strategy for most patients. Stent sizing should be done according to the DM, and POT should be performed in all cases. A second stent can be used in specific situations in case of SB compromise. All data gathered so far indicate that it is preferable to use a provisional SB approach, even in the distal LM coronary artery.

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