Chapter 10

Considerations and Step-by-Step Approaches to Bifurcation Stenting

Jennifer Frampton DO, MPH[1], Eric Rothstein MD[1], Aaron V. Kaplan MD[1]

[1]Dartmouth-Hitchcock Medical Center Heart and Vascular Center, Lebanon, New Hampshire

Abbreviations

DK	Double Kissing
DES	Drug Eluting Stent
DMB	Distal Main Branch
MV	Main Vessel
PCI	Percutaneous Coronary Intervention
PMB	Proximal Main Branch
POT	Proximal Optimization Technique
PS	Provisional Stenting
SB	Side Branch
SKI	Simultaneous Kissing Inflations
ST	Stent Thrombosis
TLR	Target Lesion Revascularization

Introduction

As the field of interventional cardiology has progressed, operators are tackling increasingly complex coronary lesions percutaneously. Despite many advances in both equipment and technique, appropriate treatment of bifurcation lesions remains a challenge for interventional cardiologists. Coronary bifurcation lesions are typically defined as a lesion at or near a significant branch (measuring at least 2.5 mm in diameter), dividing the artery into the main vessel (MV) and side branch (SB). These lesions comprise approximately 20% of all percutaneous coronary intervention (PCI). [1,2] Treatment of these lesions is complex, as procedural and clinical outcomes are often suboptimal and once treated, these patients have a high burden of adverse events including an increased risk of in-stent restenosis (ISR), stent thrombosis (ST) and peri-procedural myocardial infarction (MI). [3-5]

Below we outline an approach to the treatment of bifurcation disease which is based on the literature and clinical experience.

Lesion Assessment and Characterization

Careful angiographic assessment of a bifurcation lesion is of crucial importance prior to treatment. Generally, coronary bifurcations are evaluated using the Medina classification of angiographic apparent disease at three segments. These segments include the proximal main branch (PMB), which then divides into the distal main branch (DMB) and side branch (SB). Using the Medina classification, angiographic disease (defined as >50% stenosis) is characterized as being present (1) or absent (0) for each of the bifurcation segment using the format (PMB, DMB, SB), as shown in **Figure 1A-D**.[6]

A more recent paper by Chen and colleagues [7] further classified bifurcation lesions as simple or complex based on a set of retrospectively generated major and minor criteria, termed the definition criteria **(Figures 2A-2B).** The aim of these criteria is to help guide operators in the optimal approach with regards to treating different types of bifurcation lesions. Outcomes data suggest that patients with lesions categorized as simple benefitted from a more straightforward one-stent approach, while those with complex lesions benefited from a more complicated two-stent approach.

Careful angiography with clear lesion visualization in 2 orthogonal views with nitroglycerin pretreatment is essential when characterizing a lesion and selecting the optimal treatment strategy. The initial assessment is based on the determination of SB significance, i.e., does the SB perfuse a sufficiently large myocardial mass to warrant intervention if it were compromised. This typically corresponds to a SB with a diameter >2.5 mm.

One-stent versus two-stent approaches

After adequate characterization of the lesion, an operator must then decide on a one-stent or two-stent approach. The majority of studies support a one-stent approach for most cases, otherwise known as provisional stenting (PS), detailed in **Figure 3A-G**. Multiple randomized trials exist comparing provisional stenting to elective two-stent approaches, and no studies have shown a clear advantage for routine two-stent approaches over PS of the MV. [4,8-12] Provisional stenting is also supported by data from a meta-analysis of randomized control trials, detailed by Ford and colleagues, who found that longer term outcomes (at least > 1 year after the procedure) showed PS to be associated with lower all-cause mortality. It also showed that there was no difference in major adverse cardiac events (MACE), MI, target lesion revascularization (TLR), or ST between the PS and two-stent approach groups. Lastly, this analysis also reinforced that the PS group had lower procedure times and used less contrast when compared with the two-stent counterparts.[13]

Worth noting however, is that lesions that would be classified as complex bifurcations according to definition criteria are generally not well represented in these trials.[14] Newer data has shown promising results in favor of two-stent approaches when compared with PS, specifically with use of the double kissing (DK) crush technique. In the DK CRUSH-II trial by Chen and colleagues, they found no statistically significant difference in major adverse cardiac events between the group who received PS and the group who received DK crush. Additionally the investigators found that the DK crush group had lower rates of recurrent target vessel revascularization.[15] Moreover, the subgroup analysis showed that those with complex bifurcation lesions, according to definition criteria, had worse outcomes, specifically with a higher rate of TLR in the PS group.[15] This suggests that some two-stent techniques may be appropriate for those with complex lesions.

Overall, the literature suggests that PS is appropriate for the majority of bifurcation lesions, however a two-stent approach should be considered in certain situations. Specifically, a two-stent approach should be considered for "true" bifurcation lesions (Medina 1,1,1 or 1,0,1 or 0,1,1), when the side branch is ≥ 2.5 mm in diameter with >50% stenosis extending 5mm beyond the ostium, when the diseased side branch supplies a large myocardial territory, if the side branch has severe disease that extends well beyond the ostium (10-20 mm or more) or if the side branch has an unfavorable angle for re-crossing after the main vessel is stented. [16-18]

General Bifurcation Intervention Pearls

1. All strategies discussed below require a kissing balloon inflation (KBI). This cannot be accomplished through a 5F guide catheter, so the minimum recommended guide catheter diameter is 6F.
2. Two angioplasty balloons (regardless of compliance) typically cannot be reliably delivered through a 6F or 7F guide extension catheter, requiring operators to strongly consider upfront use of a guide catheter with increased support
3. Predilation angioplasty of the SB is somewhat controversial as this may make re-crossing through a stent strut more challenging should a SB dissection occur
4. Multiple strategies are available for keeping track of the location of multiple guidewires, including:
    a. Utilizing guidewires of different colors
    b. Curving the back end of one wire
    c. Placing a towel between wires to separate them
    d. Gently moving one wire under fluoroscopy (*last resort)

One Stent-Provisional Stenting

As detailed above, most advocate for a single stent/provisional approach as the default strategy unless lesion characteristics indicate a high risk of SB occlusion or need for stenting due to SB disease. In a one stent provisional strategy, the lesion treatment begins with wiring of the main vessel, and a safety wire placed in the side branch. A stent is then placed in the main branch jailing the side branch wire. The goal is that the main branch is stented first with subsequent side branch treatment only as required, i.e., occlusion or high grade ostial narrowing, which occurs between 4 to 30% of the time.[13]

The following is a step by step approach to provisional stenting

1) Select the proper guide catheter
    a. PS approach can generally be completed with a 6Fr guide catheter and therefore radial access is usually sufficient.
    b. Use of 5 Fr guides is generally discouraged in that it limits the ability use of two balloons.
    c. Operators should consider a larger guide catheters (7 or 8Fr), more aggressive shapes, and/or femoral access if it is expected that increased support will be required or if there is a plan to use rotational atherectomy.
2) Select the appropriate guidewires - two of the same guidewire or two different wires may be selected for access to the MV and SB.
    a. Hydrophilic or polymer jacket tip wires are often avoided for the SB wire due to concern about striping of coating with removal after the wire becomes trapped following stent deployment.
3) Shape the wires, with the intention of both initial wiring as well as for re-crossing into the SB.

a. If different shapes are required for different phases of wiring (proximal vessel, side branch and recrossing), consider the use of an over the wire balloon or microcatheter (with or without angulation) to "save position" and allow for reshaping wires as needed

4) Cross the lesion and position the first guidewire distal in the main branch

5) Using the second guidewire, cross into the side branch, with the intention to maintain SB patency following MB stenting and to widen the bifurcation angle, which may facilitate reentry following stent placement across SB origin (jailing)[16]

   a. If it is quite angulated, access may be difficult requiring use of specialized techniques starting with reshaping the wire. Should this shape make navigation proximal to the lesion challenging, a microcatheter or over-the-wire balloon may prove helpful in successful wire delivery to the side branch.

      NOTE: For side branches that prove very difficult to wire, the reverse-wire (hairpin wire) technique, use of an angulated microcatheter, use of a dual-lumen microcatheter, or distal balloon inflation (wire deflection technique) are all advanced strategies that may facilitate wire entry into a difficult side branch[19]

6) Pre-dilation of the MV is usually performed prior to stent insertion

   NOTE: SB lesion angioplasty prior to main branch stenting is typically avoided due to concerns about propagating a dissection when re-accessing the side branch.

7) Select a standard drug eluting stent (DES) with a length sufficient to cover the entire MB lesion with a diameter appropriate for the DMB. It is optimal to have a minimum of 10 mm of stent proximal to the SB origin to allow for angioplasty (POT and kissing balloon inflations) within deployed MB Stent.

   a. NOTE: placement of this stent will jail the SB, trapping the safety/side branch wire

8) Perform post-dilation of the stent in the PMB, known as proximal optimization technique (POT), to ensure proximal stent apposition and to facilitate SB re-cross.

9) Repeat angiography to assess the result in the SB. If angiography shows an adequate result in the SB (>TIMI 3 flow in the SB, absence of a major SB dissection, no severe ostial narrowing and no evidence of ischemia by clinical symptoms or by pressure wire measurements), move to 10a; if inadequate, move to 10b

10)

   a. The SB safety wire can be removed and the case can be completed [16]

      NOTE: Routine treatment of the SB remains controversial. In the case of large side branches, re-access with simultaneous kissing balloon inflation to allow of re-access in the future is advocated by some experts.

   b. If angiography in the SB following POT inflation is found *not* to meet the above criteria then further SB treatment is indicated.

      i. Re-access the SB is then by introducing a new wire or by employing a “wire swap” also known as Do-Si-Do

      ii. Withdraw the MB wire into the deployed stent and is then used to cross into the SB, ideally into the most distal cell possible as bench top models indicate best results with this technique[20]

      iii. Once the side branch has been re-crossed, withdraw the trapped safety wire from the SB into the MV proximal to the stent and then advance into the distal MV.

      NOTE: The Do-Si-Do maneuver is preferred to ensure that the wire used to re-access the side branch enters the main branch stent via the central lumen and *not* via a side cell. The Do-Si-Do maneuver also saves the cost and added complexity of using an additional wire.

iv. Track a low profile, small diameter (1.5 mm) balloon into the SB to dilate the MB stent side cell. If the balloon does not easily cross, confirm that your guidewire has not woven through a stent strut prior to entering the SB. If still unable to advance a balloon through the side cell into a branch, **Table 1** describes several techniques that may be utilized

v. Advance a non-compliant balloon (sized to the side branch diameter) is used to address the ostial SB lesion

NOTE: Initial SB treatment strategy typically starts with kissing balloon inflation (KBI) of balloons in both the MV and SB.

vi. If this maneuver has not successfully treated the SB, (i.e, there is persistence of < TIMI3 flow, major dissection and/or high grade ostial lesion) then placement of a second stent in the side branch is indicated [16,21-25]

<u>Transitional Techniques for Provisional Stenting-Side Branch (Rescue/Bailout) Stenting</u>

Side branch (rescue/bailout) stenting is indicated for lesions that continue to have < TIMI 3 flow, significant narrowing or ongoing ischemia after side branch dilation.[12,16,26] The significance of discrete ostial narrowing following MB stenting can be difficult to assess. Koo and colleagues have utilized FFR (with a cutoff of ≤ 0.80) to determine a lesion associated with residual ischemia.[27] After deciding to pursue SB stenting, a number of different approaches have been employed, including– T stenting, TAP, culotte, or reverse crush. Technique selection is based on anatomic considerations (primarily bifurcation angle) as well as operator's familiarity with different techniques. The following transitional technique steps assume that the operator has performed MV stenting and opened a side cell into the SB using a provisional approach, as described above. While not explicitly described below, operators should ensure adequate expansion/apposition of stents deployed.

T Stent

The T stenting technique is favored due to its relative simplicity, but is typically reserved for wide angle (~90 degrees) bifurcation lesions. As with all bail out techniques, the first step is to prepare the segment to receive the second stent. It is important to balloon dilate the side cell of the previously deployed stent as well as the proximal SB with a ≥2.0 mm balloon to facilitate stent tracking. Primary stenting of the side branch, i.e., stent placement *without* pre-dilation, should be avoided due to fear of stripping the stent from the delivery balloon during advancement through the stent strut. The disadvantage of this technique is that it's likely to leave a small gap in stent coverage at the ostium of the SB, which is prone to vessel recoil, stent thrombosis and restenosis.

1. Perform provisional stenting of the bifurcation lesion
2. If the angiographic result after FKI is not satisfactory, remove both balloons while leaving the wires in place
3. Advance a stent down the SB wire and position it at the ostium of the SB, ensuring that it does not protrude into the MV at all. Real time IVUS positioned on the MV can be used to ensure perfect positioning
4. Deploy the SB stent and perform FKI

TAP

The T and protrusion (TAP) technique is more versatile, and can be used in narrower angle bifurcation lesions (70-90 degrees) and was developed to ensure complete stent coverage at the SB ostium. [16,19] The tradeoff is that this technique leads to the formation of a neocarina at the bifurcation, which can become a site of both ISR and ST. [19] Simultaneous inflation and deflation of both balloons is especially important with this technique to avoid carinal shift. [28]

1. Perform provisional stenting of the bifurcation lesion
2. If the angiographic result after FKI is not satisfactory, remove the SB balloon leaving the wires and MV balloon in place
3. Advance a stent down the SB wire and position it just across the ostium of the SB, ensuring that it protrudes into the MV minimally (1-2mm).
4. Deploy the SB stent and perform FKI

Reverse Crush Technique

The reverse crush technique is useful as the only transitional technique to deliver a final result that is similar to a crush. It is typically utilized after provisional stenting fails to achieve an adequate result after final kissing inflation. It also is a useful technique for treating patients brought back for intervention of a side branch that has previously been jailed.

1. Perform provisional stenting of the bifurcation lesion
2. If the angiographic result after FKI is not satisfactory, leave the MV balloon in place across the bifurcation lesion and remove the balloon that was in the side branch
3. Position a stent in the side branch lesion, protruding back several millimeters into the PMB ensuring the it does not extend proximally beyond the MV balloon or previously deployed MV stent
4. Deploy the SB stent and remove the SB balloon and withdraw the SB wire just proximal to the MV stent

5. Reinflate the balloon that was left in the MV, crushing the PMB portion of the SB stent into the wall of the vessel. Do not remove this balloon.
6. Advance the wire that was withdrawn from the SB in step 4 into the MV stent and across the SB ostium so that the distal wire tracks down the SB
7. Advance a fresh balloon down the SB wire and position it across the two layers of crushed stent covering the SB ostium
8. Inflate both the MV and SB balloon, opening up the SB ostium and performing a FKI

Transitional Culotte Stenting Technique

Culotte stenting is a moderate technical complexity two stent bifurcation technique that is useful in situations where the bifurcation angle is < 70 degrees and there is no significant size mismatch between the PMB and SB. Stent distortion is minimized compared to crush techniques and the risk of missing parts of the lesion are minimized as well. Culotte stenting does however commit the patient to two layers of stent in the PMB, potentially increasing the risk of ISR. Some operators report attempting to minimize the amount of overlap using techniques that have been described as “mini-culotte”, however these techniques have not been well studied.

1. Perform provisional stenting of the bifurcation lesion
2. If the angiographic result after FKI is unsatisfactory, remove both balloons and advance a stent down the SB wire, positioning it across the SB ostium protruding back generously (at least 5 mm) into the PMB
3. Withdraw the wire positioned in the DMB proximal to the MV stent to avoid sandwiching it between two layers of stent
4. Deploy the SB stent, jailing the DMB and leave the stent balloon in place

5. Advance the wire that is now parked in the proximal vessel into the MV stent, through the stent strut and into the DMB
6. Advance a balloon down the MV wire, position it across the bifurcation and inflate it simultaneously with the previously positioned stent balloon (performing a FKI)

Upfront Two-Stent Approaches

For complex "true" bifurcation lesions, deciding upon a two-stent approach upfront gives the operator increased options for treatment beyond the techniques discussed previously. There is marked variability in the literature regarding optimal two stent techniques, giving operators the freedom to select from a wide variety of approaches based on the patient characteristics, vessel anatomy, and lesion makeup. For example, Ferenc et al. found culotte stenting to be superior to traditional T-stenting in terms of re-stenosis rate. [29] A study by Erglis et al. found culotte stenting and crush technique (both classic and mini) to be comparable [30]. Finally, the aptly named DK Crush III trial revealed culotte technique to be inferior to DK crush technique. [31] Ultimately, the primary objective for bifurcation stenting is to minimize the amount of unapposed stent while balancing the complexity of the procedure. The more complex two-stent techniques (such as culotte and the crush variations) require re-crossing through side cells multiple times, leading to a higher chance of technical failure. T stenting and TAP are simpler techniques with a lower chance of immediate technical failure, and in this setting, it is reasonable to utilize T stenting and TAP over culotte or crush variations when possible. Overall, in our experience, the determination of specific two-stent approach be based on the individual patient's risk of ST and ISR, vessel angulation, lesion anatomy and the experience of the interventional cardiologist.

Once an upfront two-stent approach has been selected, examination of the angle between the DMB and SB is imperative for selection of the optimal approach. The major drawback to T stenting is the lack of ostial SB coverage, which can be associated with ISR. As such, bifurcation angles of 90 degrees are ideal for T stenting, as this angulation minimizes this gap, thereby lowering the risk of restenosis. While TAP eliminates this gap in coverage, it results in the formation of a neocarina, increasing the risk of ST. The length of the neocarina is minimized when the bifurcation angle is closest to 90 degrees. Based on these considerations, it is reasonable to consider TAP stenting for bifurcation angles as acute as 70 degrees. In general, for bifurcations with angles of < 70 degrees, DK crush, culotte and TAP stenting techniques are more favorable. For angles of 90 degrees or greater, T stenting is preferable, or alternatively mini-crush.[19]

After selection of a specific technique, choosing an appropriately sized guide catheter is necessary. For Traditional T stenting, culotte, TAP and DK crush, a 6Fr catheter is generally sufficient. Simultaneous kissing stents (SKS) – as used in V stenting, modified T, mini-crush and classic crush require a 7-8 Fr guide catheter.

A final kissing inflation (FKI) is indicated in all two stent techniques for bifurcation lesions. The FKI corrects stent distortion and expansion, and provides better scaffolding of the side branch ostium, which facilitates future access to the side branch. [17] A reduction in late restenosis has been shown with using FKI, as has lower MACE rate when complex stenting is performed and better angiographic results. [8,32,33] Many will opt for sequential inflations using a noncompliant balloon in the side branch, followed by a KBI at higher pressure. [19]

Currently, popular 2 stent techniques include T-stenting, TAP, classic crush, DK crush and culotte, which we will detail in this section. A summary of these techniques along with their respective advantages and disadvantages is included in **Table 2.**

T-stenting

1. Wire the MV and SB with two separate wires.
2. Angioplasty the MB and SB lesion to achieve adequate predilation.
3. Stent the SB initially, ensuring that the proximal stent edge does not protrude into the MV.
4. Withdraw the SB wire proximal to the PMB lesion in order to avoid sandwiching the wire between two layers of stent, which increases the risk of wire fracture.
5. Stent the MV, jailing the SB.
    a. If planning to use the stent balloon for FKI, advance it distal to the bifurcation
6. Using the wire that is now proximal to the bifurcation, re-wire the SB through a side cell of the MV stent.
7. Advance a noncompliant balloon into the SB, positioning the middle of the balloon at the ostium of the SB. POT may be performed at this time with additional inflations in the PMB.
8. Advance a new noncompliant balloon down the MV wire (or withdraw the stent balloon from the distal vessel if it was left there) and perform a FKI at the level of the bifurcation [16,19]

TAP / Inverted TAP

TAP avoids the problem with the gap at the ostium of the SB seen with the traditional T stenting technique. When planning a two-stent approach some operators will choose to reverse the order previously described with transition from PS to TAP, known as an inverted TAP. This involves deploying the stent from the PMB into the side branch first. By wiring the more challenging, angulated branch first, these operators argue that the risk of wire wrap may be reduced. It is important to note that this comes at the cost of potentially failing to recross the stent strut into the DMB, leaving the DMB jailed.[16,19]

TAP

1. Wire the MV and SB with two separate wires.
2. Angioplasty the MB lesion to achieve adequate predilation.
3. Stent the PMB into the DMB initially, effectively jailing the SB
4. Perform a wire swap, withdrawing the wire in the DMB and advancing it through the most distal side cell possible into the SB. Pull the jailed wire in the SB, then advance it through the stent into the DMB
5. Position a noncompliant angioplasty balloon across the stent strut and inflate to open a side cell into the DMB
6. Remove this balloon and deploy a stent in the SB, protruding minimally (1-3mm) into the PMB
7. Withdraw the stent balloon slightly into the PMB stent and advance an NC balloon on the MV wire, so that it spans the bifurcation
8. Perform a FKI

Inverted TAP

1. Wire the MV and SB with two separate wires.
2. Angioplasty the SB lesion to achieve adequate predilation.
3. Stent the PMB into the SB initially, effectively jailing the DMB
4. Perform a wire swap, withdrawing the wire in the SB and advancing it through the most distal side cell possible into the DMB. Pull the jailed wire in the DMB, then advance it through the stent into the SB
5. Position a noncompliant angioplasty balloon across the stent strut and inflate to open a side cell into the DMB
6. Remove this balloon and deploy a stent in the DMB, protruding minimally (1-3mm) into the PMB

7. Withdraw the stent balloon slightly into the PMB stent and advance an NC balloon on the SB wire, spanning the bifurcation
8. Perform a FKI

Modified T-stenting

The modified T stenting technique is an alternative that seeks to combat the problem of the gap in coverage at the ostium of the SB by producing a final result that is similar to a TAP. This technique requires simultaneous positioning of two stents, and therefore requires a 7F or 8F guide catheter. The advantage of this technique is its relative simplicity, however it is limited to bifurcations with roughly 90 degree angles. Additionally, this strategy requires perfect stent positioning and runs the risk of geographic miss of the SB ostium.[16,19]

1. Wire the MV and SB with two separate wires.
2. Angioplasty both the MV and SB lesions to achieve adequate predilation.
3. Position a stent in the MV spanning the bifurcation lesion and position a stent in the side branch, ensuring coverage of the SB ostium with no or negligible (<1mm) protrusion of the stent into the MV
4. Deploy the SB stent
5. Deploy the MB stent, effectively jailing the SB.
6. Perform a wire swap, withdrawing the wire in the DMB into the proximal portion of the MV stent and then readvancing it into the SB through a side cell of the MV stent. Pull the wire in the SB back into the MV stent and advance it into the DMB
7. Advance a NC balloon down the SB wire and inflate it across the ostium of the SB, effectively opening a side cell into the SB

8. Advance an NC balloon down the DMB wire and position it to span the bifurcation
9. Perform a FKI

Planned Culotte Stenting

Culotte stenting (**Figure 4A-T**) as a transition from a provisional approach is described above. One of the main problems with transitional culotte stenting is that it requires removal of the wire from the DMB prior to jailing the DMB.[16,19] As recrossing stent struts and opening a stent side cell can be the most technically challenging portions of bifurcation stenting procedures, transitional culotte stenting can lead to the unfavorable situation where the DMB becomes jailed and the operator is unable to restore the normal vessel architecture of the DMB. [34] For this reason, many operators will stent the SB first when culotte stenting is planned. While the DMB will become jailed initially, with this approach once the SB stent is initially deployed, a wire remains in the DMB during this step, allowing the operator to bail out by converting to one of the crush techniques. Additionally, should the operator fail to recross a strut or open a side cell following MV stent deployment, it is the smaller SB rather than the DMB that will be compromised. This technique of stenting the SB first is sometimes referred to as an inverted culotte technique, and is described below:

1. Advance two wires into both the DMB and into the SB
2. Predilate the SB lesion
3. Using the SB wire, position a stent across the bifurcation lesion, such that is spans the PMB into the SB
4. Perform a wire swap
    a. Withdraw the SB wire into the PMB portion of the stent and subsequently advance it into the DMB through a stent strut

b. Withdraw the jailed wire residing in the DMB so that the tip is proximal to the stent (some operators will advance this wire through the stent into the SB, however this will lead to sandwiching this wire between two layers of stent in subsequent steps)

5. Position a balloon on the wire that is now in the DMB across a stent strut in the MV and inflate, opening up a side cell into the DMB
6. Deploy the second stent spanning the MV lesion segment so that it protrudes generously (at least 5mm) back into the PMB
7. Advance the wire that was left proximal to the stent into the PMB portion of the stent and cross into the side branch through the stent struts
8. Advance a balloon down the SB wire and position it across the SB stent struts, then inflate the balloon to open a side cell into the SB
9. Advance a second balloon down the MV wire and position it at the level of the bifurcation. Align the balloons and perform FKI

Classic and Mini Crush

The classic and mini crush techniques are similar 2-stent approaches requiring a 7Fr or 8Fr guide catheter to permit simultaneous placement of two stents. A schematic of this is shown in **Figure 5A-5F.** As the name implies, both of these techniques require crushing the entire proximal portion of the SB stent into the side of PMB prior to covering it with an additional layer of stent. This will result in three layers of stent covering roughly 100-180 degrees of the circumference of the PMB (with one layer of stent covering the remainder of the PMB). The only difference between the classic crush and mini crush techniques is the length of stent protruding from the SB into the PMB that is then crushed into the side wall (1-2mm for mini crush and 3-5mm for classic crush). Mini-crush compared with the classic crush is associated with a lesser potential for stent thrombosis as the length of the PMB that becomes covered in three layers of stent is minimized. [16,19,35]

1. Wire the MV and SB with two separate wires and angioplasty both the MV and SB lesions to achieve adequate predilation.
2. Position a stent in the MV spanning the lesion and a stent in the SB spanning the bifurcation lesion and protruding back into the PMB (1-2mm for mini crush, 3-5mm for classic crush). The MV stent must extend further back proximally than the SB stent.
3. Deploy the SB stent and then carefully remove the stent balloon and withdraw the SB wire proximal to the MV stent , ensuring that the MV stent is not moved.
4. Deploy the MV stent, which will crush the proximal portion of the SB stent into the PMB wall
5. Advance the wire that is now proximal to the MV stent through the crushed stent struts into the SB
6. Advance a NC balloon across the ostium of the SB and inflate it to open a side cell in the stent
7. Advance an NC balloon down the DMB wire and position it to span the bifurcation
8. Perform a FKI

DK crush

The DK crush technique (**Figure 6A-H**) represents a modification with regards to the classic crush technique. While it is a technically complex strategy, it is useful in its versatility. This technique can be used in any bifurcation lesion regardless of bifurcation angle and can be performed through a 6F guide catheter, as it does not require positioning of two stents simultaneously. The DK crush technique was developed to improve upon the main weakness of other crush techniques, which is the challenge of recrossing through multiple layers of crushed stent. [16,19] Classic crush failure rates of roughly 20-25% have been attributed to the technical difficulty of recrossing into the side branch. By performing an initial kissing inflation after deployment of the SB stent as described in the DK crush technique, operators are never required to cross more than a single layer of stent, making the DK crush technique appealing for treatment of select complex bifurcation lesions. [35]

1. Position wires into both the DMB and SB
2. Advance a balloon to the level of the bifurcation on the DMB wire and advance a stent in the SB, protruding minimally (1-2mm) into the PMB
3. Deploy the SB stent
4. Inflate the MV balloon, crushing the proximal portion of the SB stent
5. Perform a kissing balloon inflation (typically using the stent balloon and previously used MV balloon)
6. Remove the balloons and withdraw the SB wire into the PMB proximal to the stent
7. Advance a stent over the DMB wire that spans the entire bifurcation lesion (also ensuring that it covers well proximal to the crushed SB stent)
8. Deploy this MV stent, jailing the SB
9. Withdraw the stent balloon just proximal to the bifurcation lesion
10. Advance the wire that has been pulled back proximal to the bifurcation through the struts of the MV stent into the SB
11. Advance a new balloon down the SB wire across the stent struts into the SB. Advance the balloon on the MV wire so that it is aligned with the SB balloon.
12. Perform a FKI

V stenting

V stenting is another two stent approach that is not commonly utilized in contemporary practice as it can only be considered in Medina 0,1,1 bifurcation lesions. This technique requires simultaneous positioning and deployment of two stents, so a 7F or 8F guide catheter is required. The two stents are placed with a small amount of overlapping of their proximal stent portions. This presents an attractive, simple and quick approach to treatment of a bifurcation lesion, however there are several disadvantages that come with V stenting. As proximal stent protrusion can vary and disease immediately proximal to the bifurcation can be missed (especially with wider angle bifurcations), V stenting can lead to an undesirable result and lacks the reliability of many of the previously discussed techniques. [16,19]

1. Position wires into both the DMB and SB
2. Simultaneously position stents in the DMB and SB, both protruding minimally (<1mm) into the PMB
3. Deploy the stents simultaneously

Simultaneous kissing stents (SKS) or Double barrel technique

Double barrel stenting is the fastest and simplest of the two stent techniques. It is typically reserved for either salvage situations, emergencies or for interventions where hemodynamic collapse is likely with more complex techniques. This approach requires a 7 or 8F guide catheter as it involves simultaneous deployment of two stents spanning the entire bifurcation. This creates a long segment in the PMB with two side-by-side stents that are unlikely to ever endothelialize, usually leading to the recommendation for lifelong dual antiplatelet therapy in these patients. [16,19]

1. Advance wires across the lesion and down the DMB and SB
2. Position stents across the entire bifurcation, protruding at least 5mm into the PMB with proximal edges aligned, and covering the lesion into the DMB/SB
3. Deploy the stents simultaneously

Dedicated Bifurcation Stents

More recently, industries have developed a number of dedicated bifurcation stents, BiOSS, STENTYS, Axxess and Tryton. The Tryton was designed for true bifurcation lesions that would require a 2-stent technique allowing for coverage of the side branch and then for placement of a DES into the main branch. [16] BiOSS dedicated bifurcation stents have evolved over the past decade, initially with a BMS, now with DES design, has shown promising results. [36] The STENTYS stents have adopted a self-apposing technology that's become of interest for treatment of left main bifurcation lesions. The stents have undergone modifications, but have shown acceptable results in treatment of non-LM bifurcation lesions [37] and in LM bifurcations among patients presenting with stable angina. [38] Axxess is a self expanding DES that has shown safety in use for bifurcation lesions. [39] Overall, a detailed review of the clinical data is beyond the scope of this chapter, but further studies are emerging to help define their role in bifurcation stenting.

LM bifurcation

Treatment of LM coronary disease by PCI has always been a challenge for operators, in part due to the size of the vessel and in that it braches into main coronary arteries, the left anterior descending (LAD) and circumflex (LCx), supplying large territories of myocardium. Treatment of left main bifurcation lesions is detailed in Chapter 7.

Adjunctive Imaging

Intravascular ultrasound (IVUS) and optical coherence tomography (OCT) imaging may be useful adjunctive resources for the optimization of PCI for bifurcation anatomy. Both can be employed pre and post stent deployment. The advantages for intravascular imaging include: 1. identifying concentric disease for appropriate stent sizing (particularly in the LM); 2. understanding the anatomy and disease burden at the bifurcation; 3. characterizing ostial side branch disease (as it can be difficult to discern carinal shift from plaque shift);[19] 4. Facilitation of re-wiring through stent struts at the appropriate location; 5. Evaluation of stent apposition and expansion post-deployment; and 6. inspection for dissection.

Currently available evidence supports routine use of IVUS after complex stenting procedures, which includes bifurcation interventions. Patel and colleagues looked at long term outcomes using IVUS for bifurcation lesions and showed that the use of IVUS was associated with significantly lower rates of death or MI, death, peri-procedure MI, TVR and TLR compared to no IVUS, concluding that an IVUS guided technique was associated with lower rates of cardiac events at late follow up.[40] This has also been shown when comparing unprotected left main bifurcation with guidance of IVUS vs without (reduction in long term mortality rate). [41]

Conclusion

The approach and best treatment strategy for bifurcation lesions remains an ongoing challenge in the setting of PCI. Overall, a provisional stenting technique is recommend and generally sufficient for a majority of coronary bifurcations. However, an upfront two stent approach should be considered for more complex lesions, and the best approach should be individualized to the patient's anatomy, bleeding risk on dual antiplatelet therapy, potential for stent thrombosis, and operator experience.

dsadsadsadsa

Tables & Figures

Chapter 10:

Table 1: Techniques for crossing difficult side cell balloon

Step	Technique	Details
First Line	Increased POT	Utilize a larger balloon to further expand the proximal stent
Second Line	Beveled Balloon	Utilize a Glider balloon with a beveled tip and rotate
Third Line	Distal anchor	Inflate a balloon inside the stent distal to the side branch and pull traction to stabilize the guide catheter while advancing the second balloon through the side cell

Table 2: Advantages and disadvantages of bifurcation techniques

1 stent approach	**Technique**	**Advantage**	**Disadvantages**	**Comments**
	Provisional stenting	Can convert to a familiar 2 stent technique if needed (T-stenting, TAP or culotte)	No side branch coverage	Default approach for bifurcation stenting Stent the MV and consider angioplasty or stent to side branch only in cases of significant flow limitation
2 stent approach	Double Kissing (DK) crush	Compared with the classic crush, DK has additional KBI after side branch stent is implanted, leaving only 1 layer of metal struts at the ostium of the side branch with minimal distortion More complete endothelialization Less stent distortion, improved stent apposition	Stent fractures can lead to side branch ostial restenosis Rewiring the SB from the proximal MV needs to be done with caution; if rewired too distally, MV stent can increase the possibility of the wire going between the stent and vessel wall leaving a cap at the ostium after stent crushing Advancing the balloon over the wire after re-wiring the side branch can be difficult	Often considered in left main bifurcation techniques
	Classic crush	Immediate patency of both branches is assured and should be applied in condition of instability or where the anatomy appears complex Excellent coverage of the ostium of the side branch	Requires a 7 or 8Fr guide catheter Should be avoided in wide angled bifurcations 2 stents are advanced and deployed together Movement of the MV stent while the SB balloon and wire are being removed Multiple layers for endothelialization	“mini” crush and classic crush are distinguished by the amount of side branch stent that protrudes into the MV; mini 1-2 mm and classic 3-5 mm
	T	Easily converted from a provisional 1 stent technique Less laborious than crush or culotte	Risk of leaving a small gap between the stent implanted in the main branch and the one in the side branch which could lead to incomplete drug coverage and the possibility of developing ostial restenosis at the side branch	Preferred for T shaped angulation (90 degree angle)
	TAP	Easily converted form a provisional 1 stent strategy and usually the preferred approach Complete coverage of the side branch without gaps	Single layer neocarina is created by the side branch stent struts protruding into the main vessel at the level of the carina – this is short in TAP but is created	When converting from a PS strategy, MV stent will be placed first, when attempting with a known 2 step strategy, stent the SB first Preferred for Y shaped angulation

				Limit protrusion while implanting side branch stent
	Culotte	Near perfect coverage of the carina and side branch ostium Very good angiographic result May guarantee a more homogenous distribution of struts and drugs at the site of bifurcation Can be used in almost all bifurcations regardless of angle	Excess metal covering the proximal end in the MV Complexity in re-wiring both branches through the stent strut is required	Technically challenging procedure Not advised for MV and SB with significantly different diameters

Figure 1A-D: (A) Medina Classification of bifurcation lesions [1] (B) example of a Medina class 1, 1, 0 lesion; (C) example of a medina class 1, 0, 0 lesion; (D) Medina class 0, 1, 0

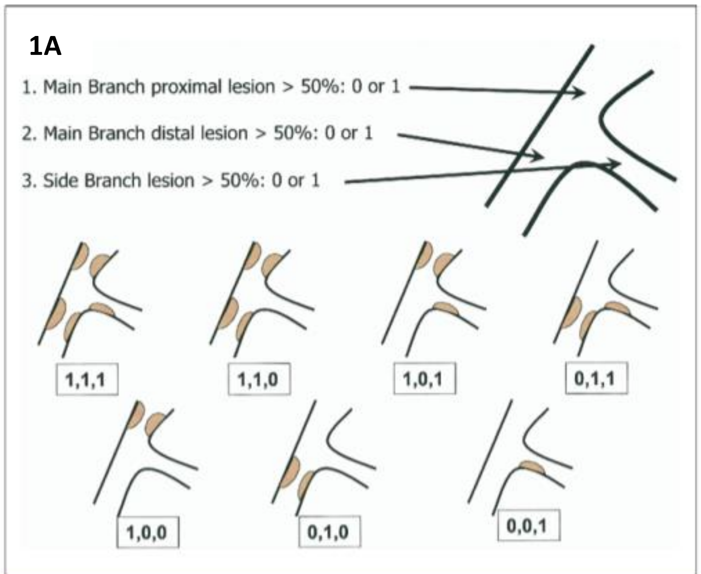
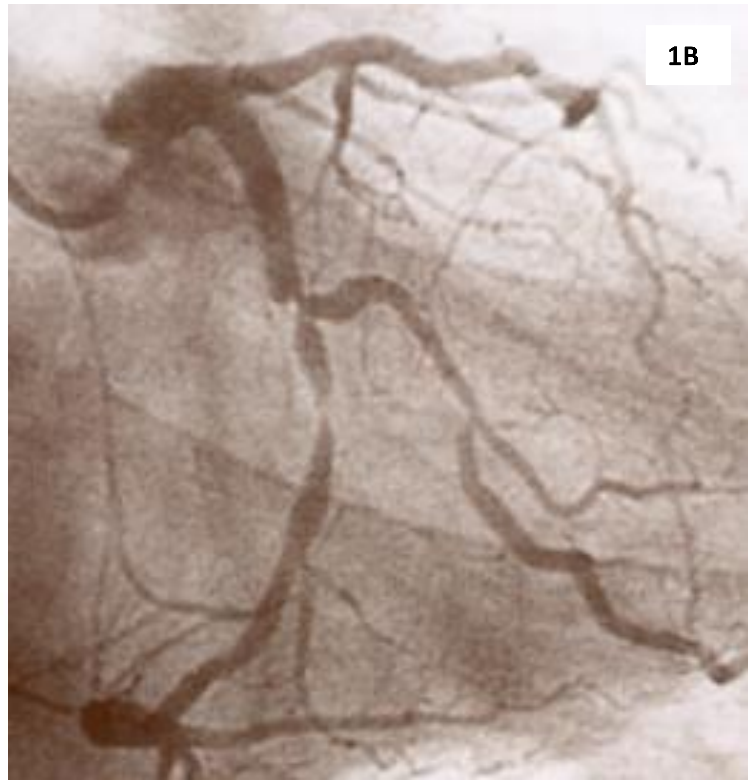
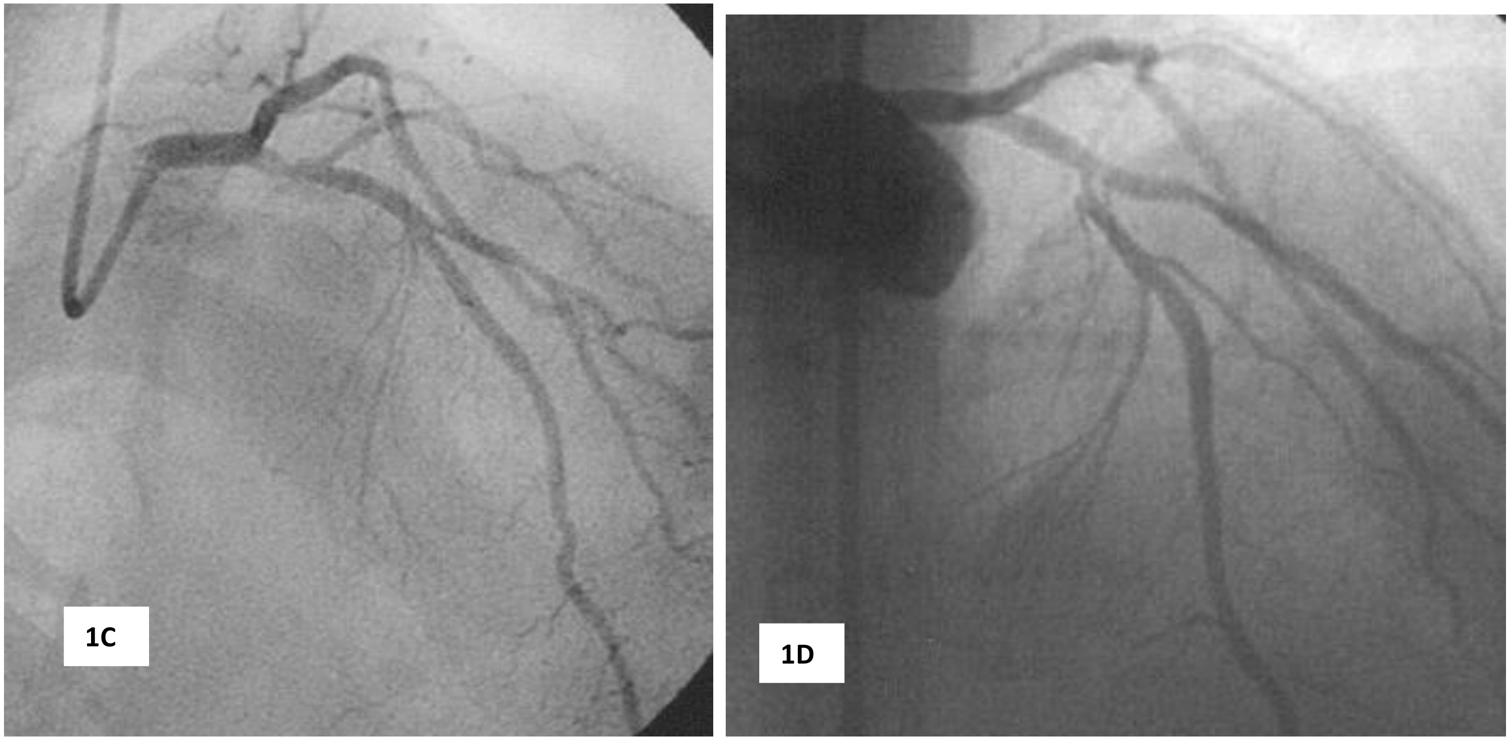


Figure 1. Medina Classification of Bifurcation Lesions

In the Medina classification (25), a binary value (1,0) is given to each of the 3 components of a bifurcation (main branch proximal, main branch distal, and the side branch) according to whether each of these segments is compromised (1) or not (0).





Reference:

[1] Latib A, Colombo A. Bifurcation disease: what do we know, what should we do? *JACC Cardiovasc Interv.* 2008;1(3):218-226.

Figures 2A & 2B: Definition criteria of complex bifurcation lesions [2]

2A

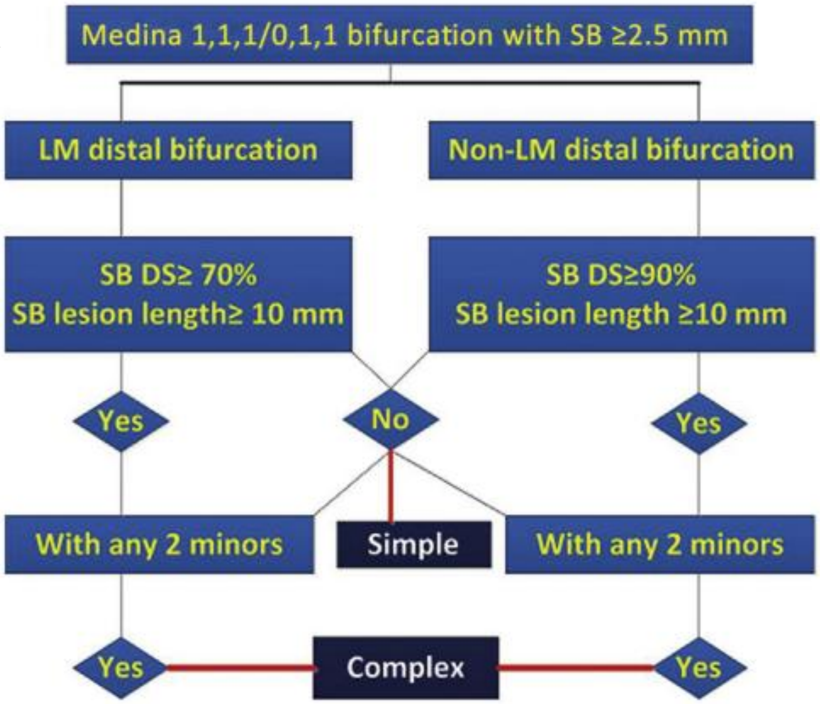


FIGURE 1 **Description of Complex Bifurcation Lesion Definitions**

For bifurcation lesions (Medina 1,1,1/0,1,1 with side branch diameter minimally 2.5 mm, major criteria (SB DS and SB lesion length) plus any 2 minor criteria are defined as complex bifurcation lesions. DS = diameter stenosis; LM = left main; SB = side branch.

2B

TABLE 3 Independent Factors of Major Adverse Cardiac Events at 1 Year After Stenting by Regression Analysis of 1,500 Patients in the Training Group

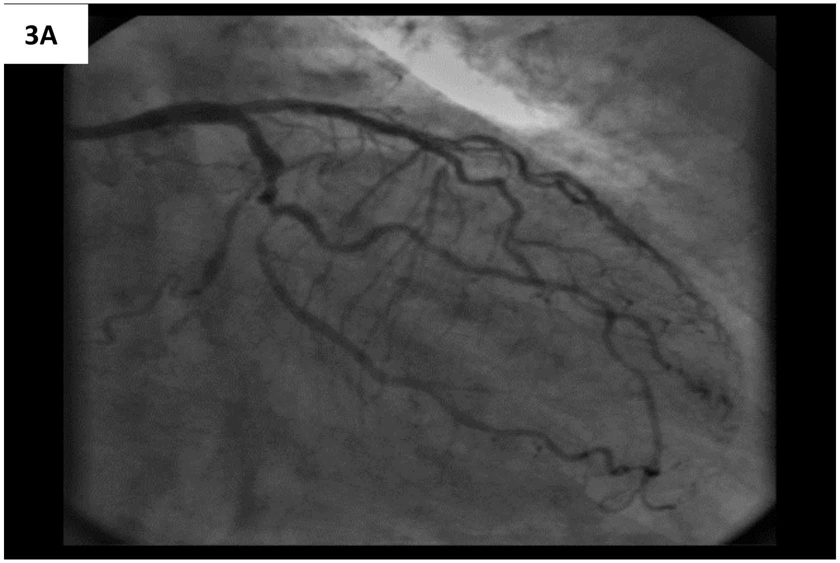
	p Value	HR (95% CI)	Sensitivity, %	Specificity, %
Major 1: Distal LM bifurcation: SB-DS ≥70% and SB lesion length ≥10 mm	<0.001	55.2 (21.005-79.437)	80	72
Major 2: Non-LM bifurcation: SB-DS ≥90% and SB lesion length ≥10 mm	<0.001	66.3 (12.708-98.184)	80	74
Minor 1: Moderate to severe calcification	0.002	38.7 (24.516-72.695)	64	65
Minor 2: Multiple lesions	0.007	26.8 (4.322-57.004)	68	60
Minor 3: Bifurcation angle <45°	0.004	14.1 (9.245-18.018)	64	53
Minor 4: Main vessel RVD <2.5 mm	0.010	9.4 (7.556-14.814)	69	58
Minor 5: Thrombus-containing lesions	0.002	27.2 (4.662-78.301)	66	64
Minor 6: MV lesion length ≥25 mm	0.010	6.9 (3.879-12.398)	57	66
Major 1 + any 2 minor 1-6 = complex			87	83
Major 2 + any 2 minor 1-6 = complex			88	83

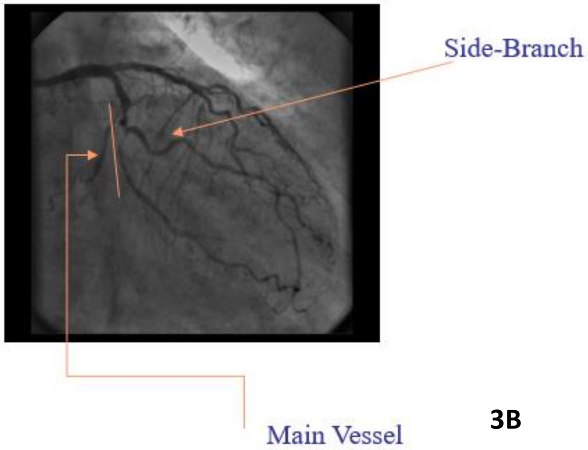
CI = confidence interval; DS = diameter stenosis; HR = hazard ratio; LM = left main; MV = multivessel; RVD = reference vessel diameter; SB = side branch.

[2] Chen SL, Sheiban I, Xu B, et al. Impact of the complexity of bifurcation lesions treated with drug-eluting stents: the DEFINITION study (Definitions and impact of complEx biFurcation lesIons on clinical outcomes after percutaNeous coronary IntervenTIOn using drug-eluting steNts). *JACC Cardiovasc Interv.* 2014;7(11):1266-1276.

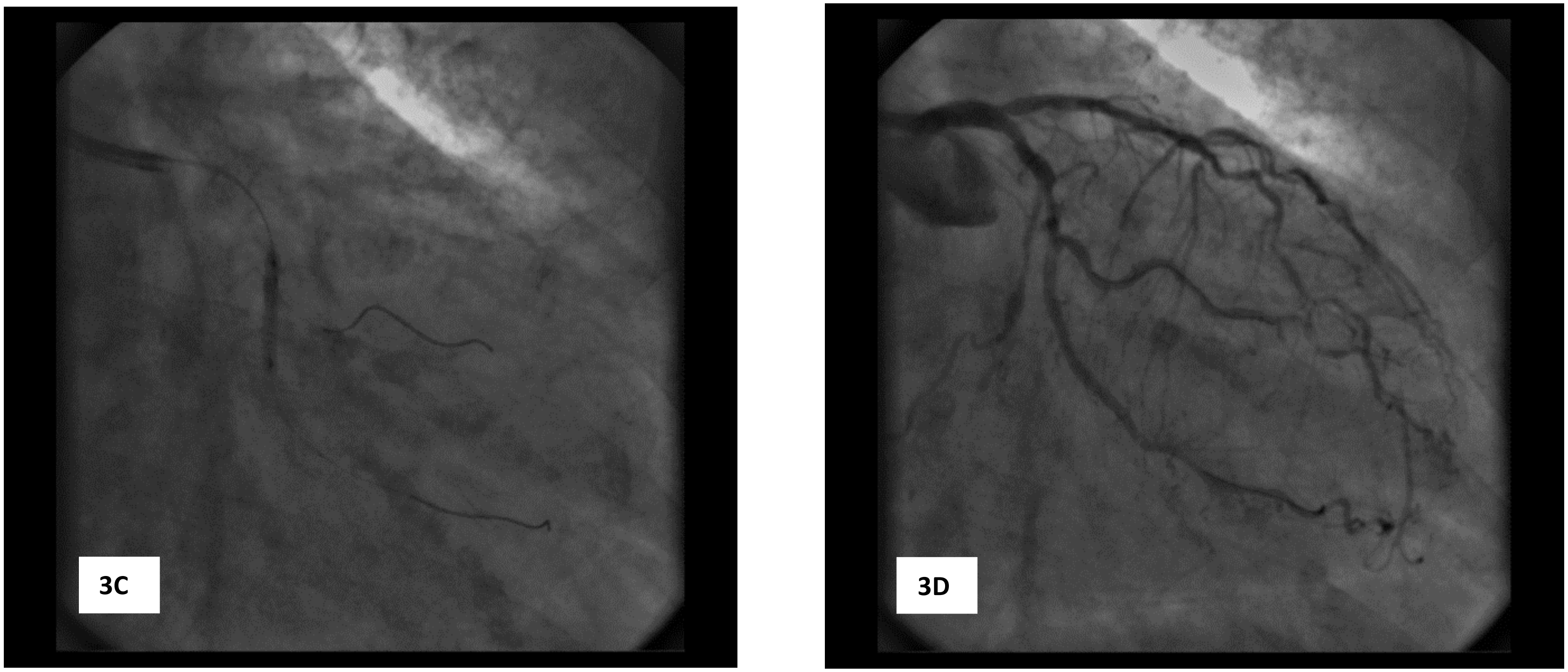
Figure 3A-G: (A) angiographic example of medina class 1, 1, 0 bifurcation OM lesion treated with provisional stenting approach; (B) selected guide with EBU 4.0, wire the main vessel with pilot 50 and side branch with BMW wire; (C) pre-dilate the main vessel with a voyager 2.5 mm; (D) evaluate for plaque shift or side branch dissection; (E): deploy stent, trapping the side branch guidewire. Review angiography then exchange guidewires “Do-Si-Do”; (F): Final kissing inflation, in this example the main vessel has a 3.0 non-compliant balloon and the side branch has a 2.0 non-compliant balloon; (G): final angiographic review

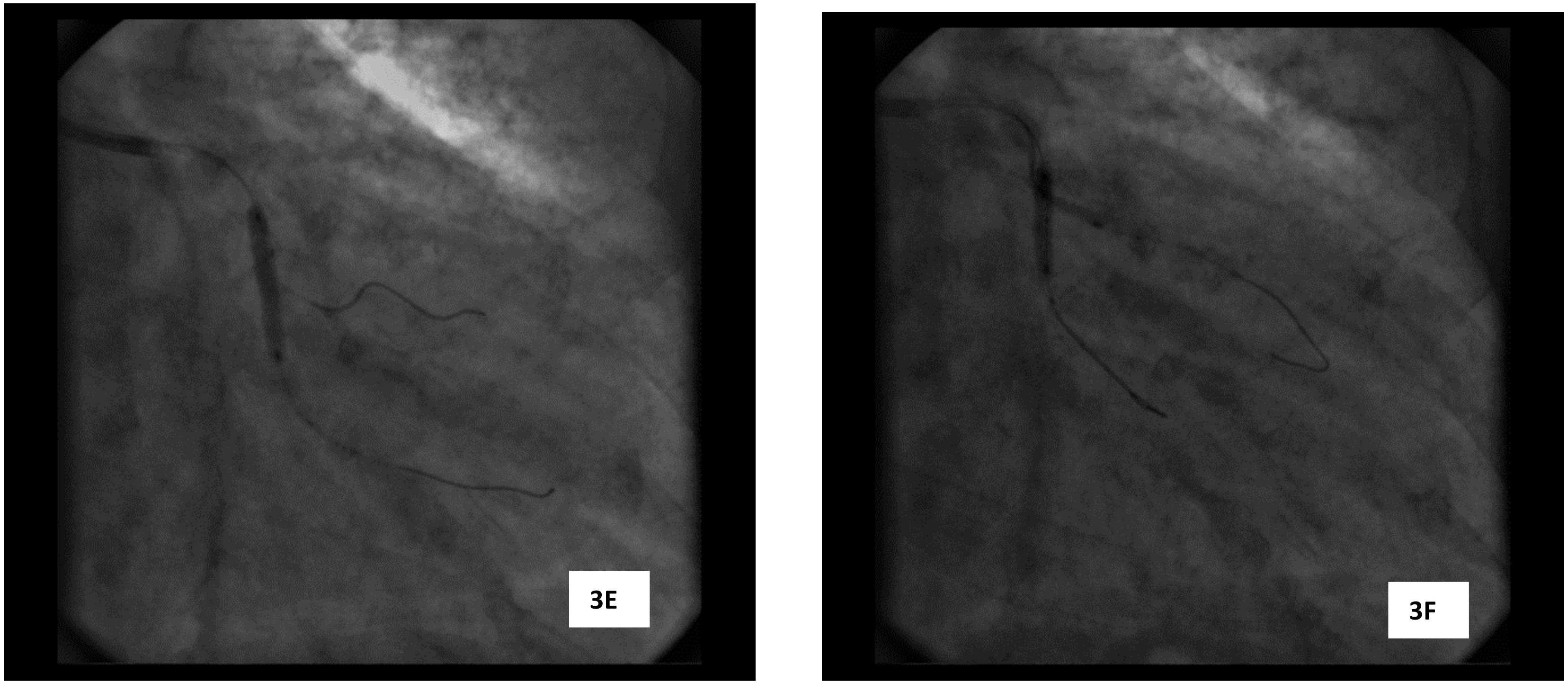
3A

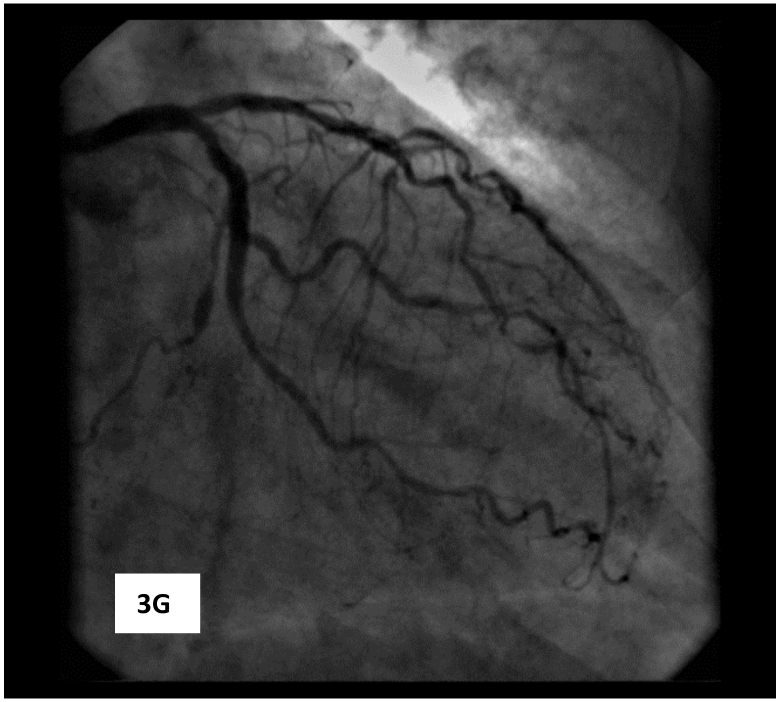




3B

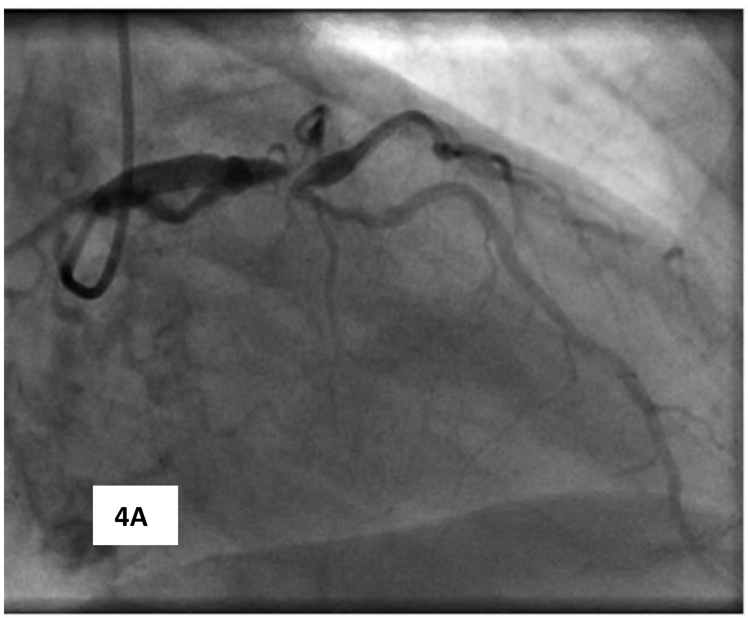

3C
3D

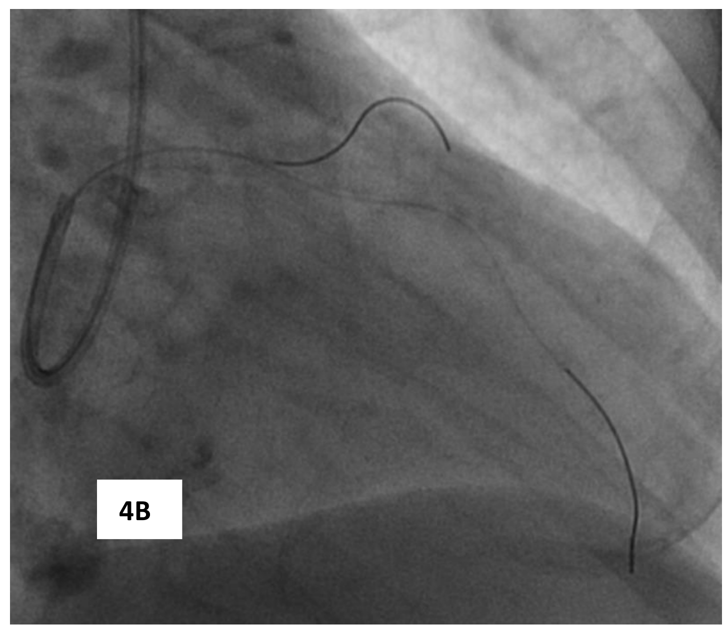

3E
3F

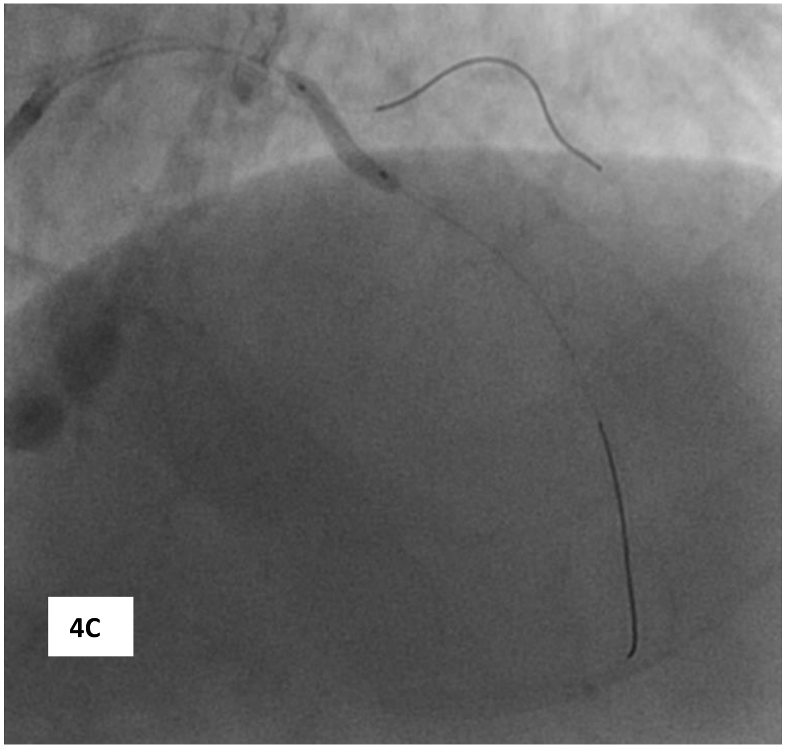


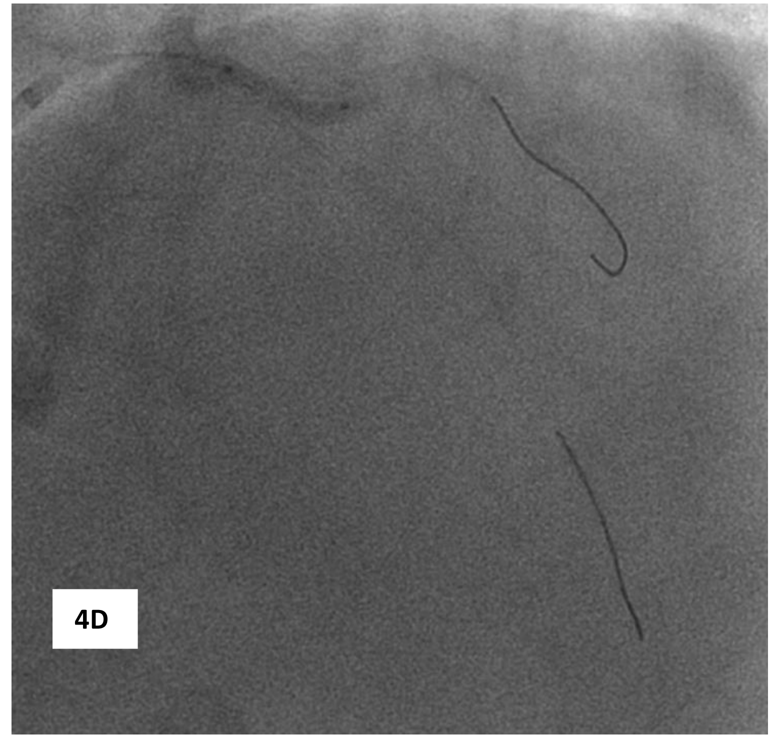
3G

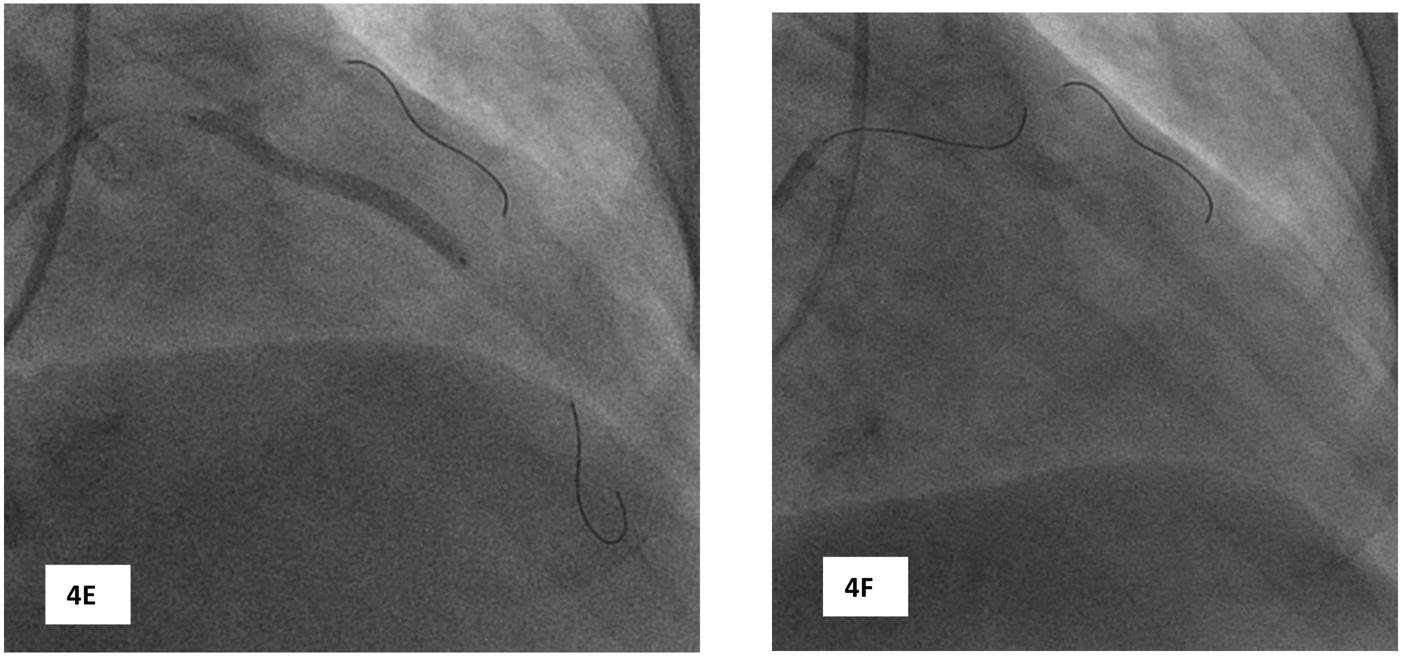
Figure 4A-T: culotte technique step by step approach; (A) angiography of complex bifurcation lesion of the LAD and first diagonal branch (D1); (B) wire down both the LAD and the D1 lesion after engagement of the left main with a 6F EBU 3.5 guide catheter (C) balloon into MB; (D) balloon into SB; (E) drug eluting stent into the MB; (F) pull back LAD wire and recross into the SB; (G & H) retracted original D1 wire and redirected into the distal LAD, completing the first recrossing; (I) balloon to dilate struts; (J) stent advanced into the SB; (K) LAD wire removed and pulled back into the guide; (L) drug eluting stent deployed in side branch, extending back into main branch and overlapped proximally with first stent; (M) recrossed stent struts of side branch stent back into distal main branch vessel, second recrossing complete; (N) balloon to dilate side branch stent struts; (O) balloon to optimize LAD stent, to high pressure, and repeated more distal to length of the LAD stent; (P) simultaneous kissing balloon inflation; (Q) balloon inflation in the main branch; (R) balloon inflation into the side branch; (S & T) final angiographic results

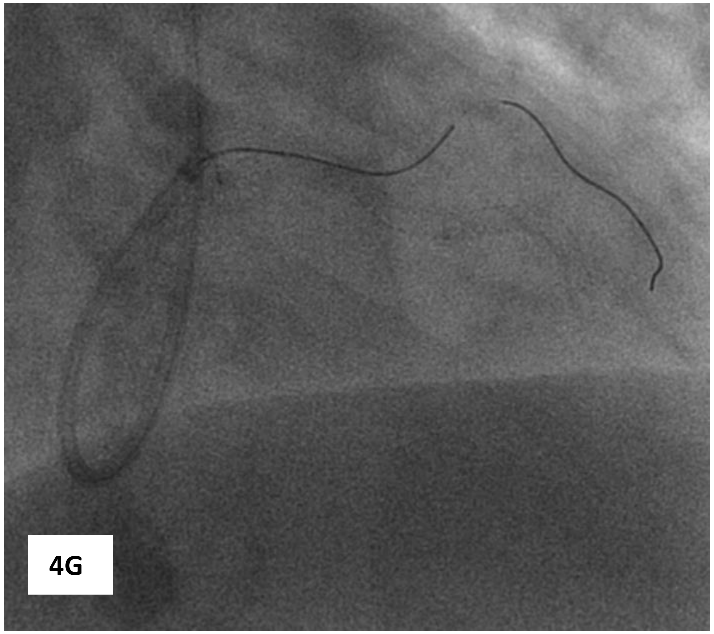


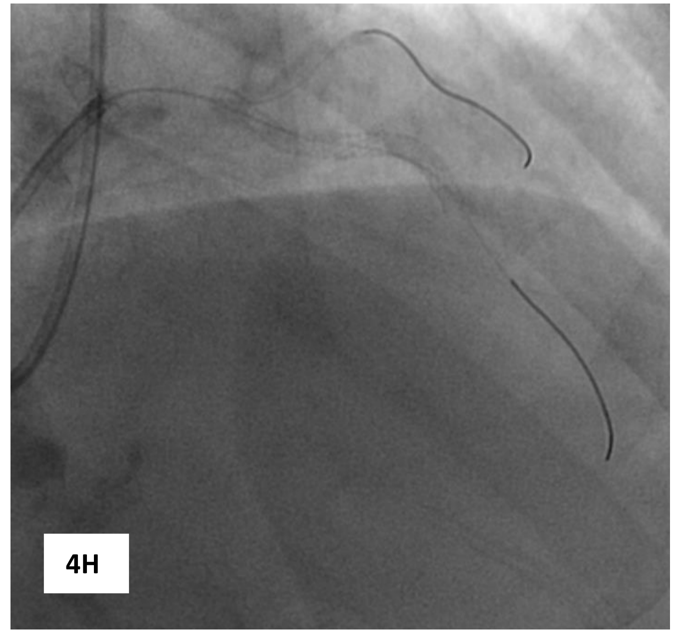


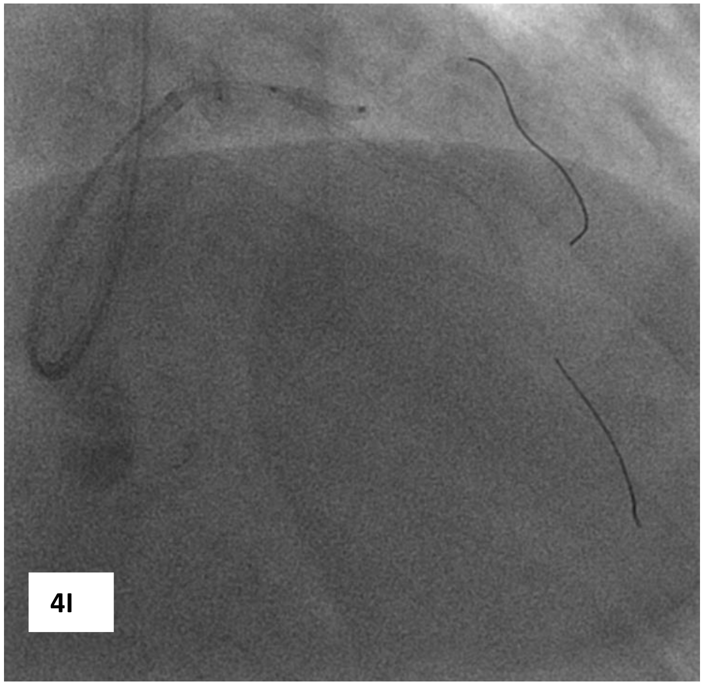
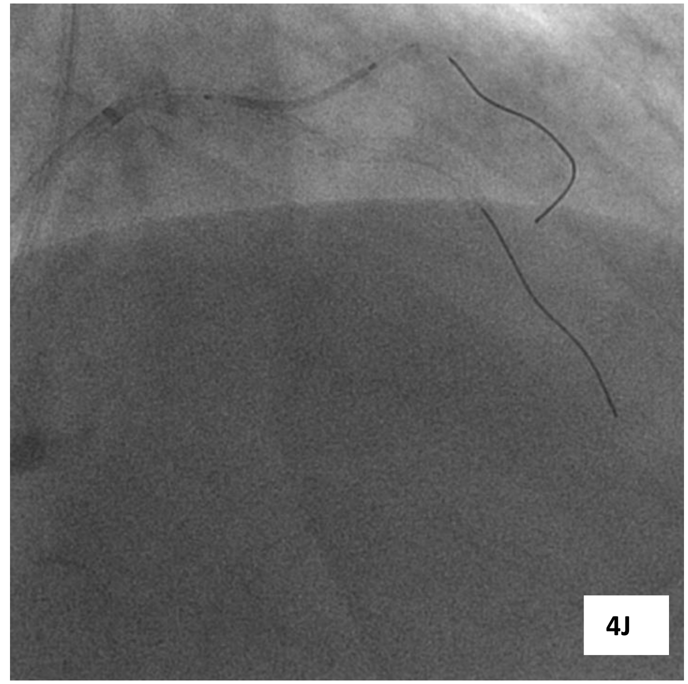

4C

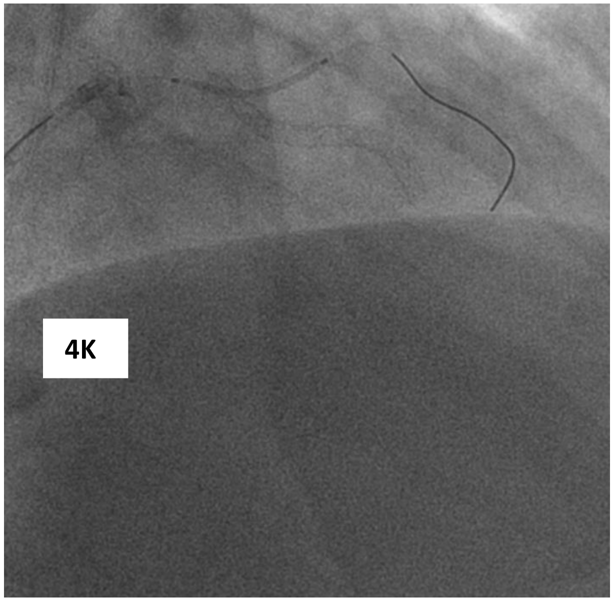

4D

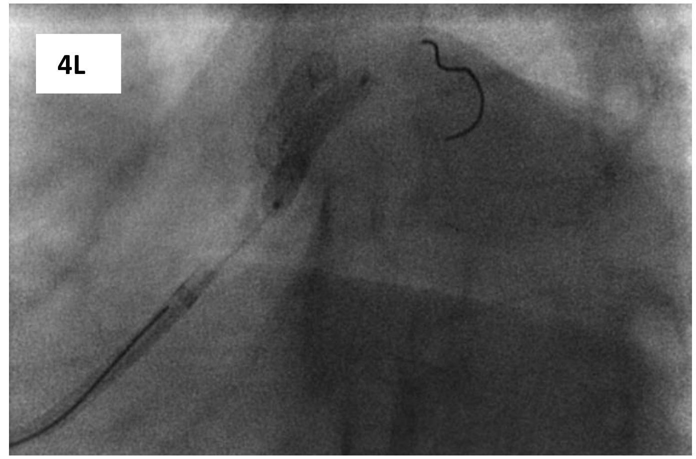

4E
4F

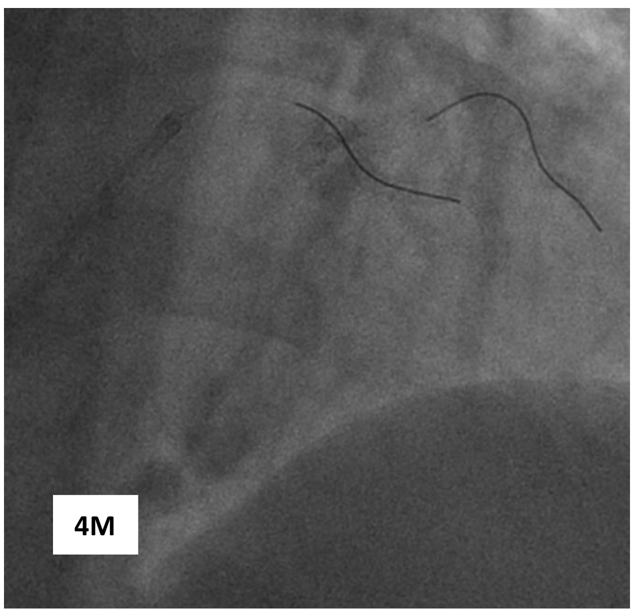

4G

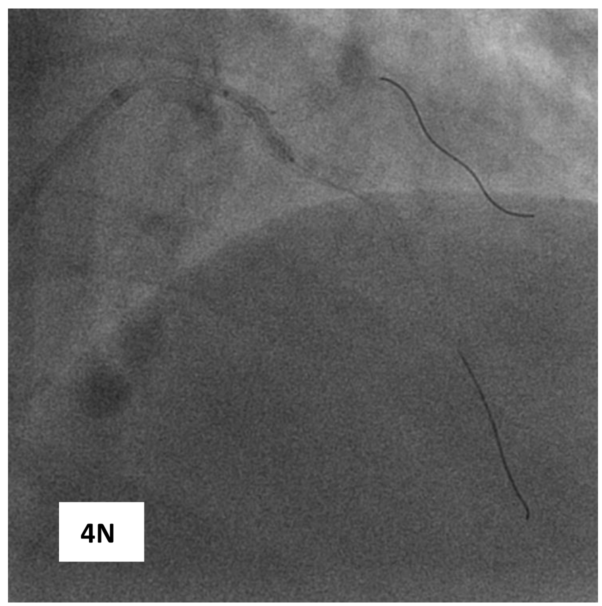

4H

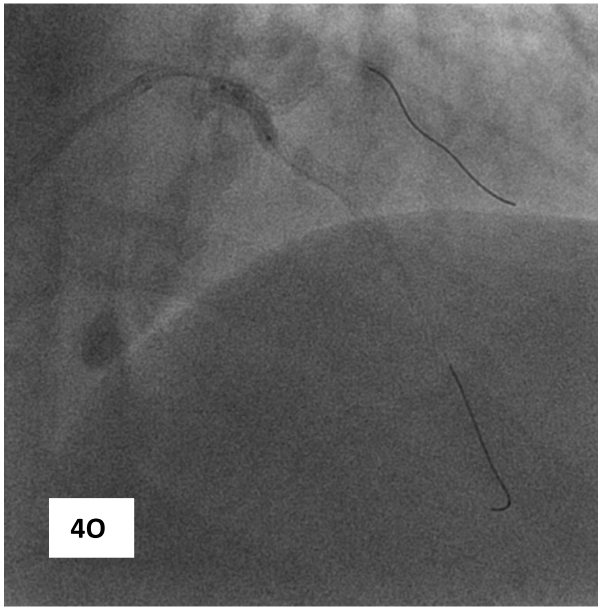

4I

4J

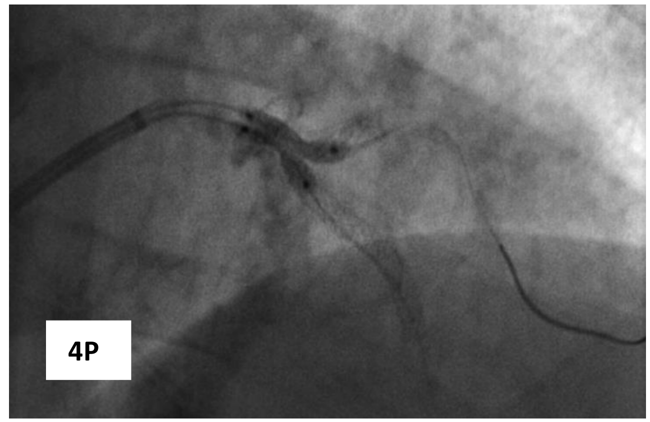

4K

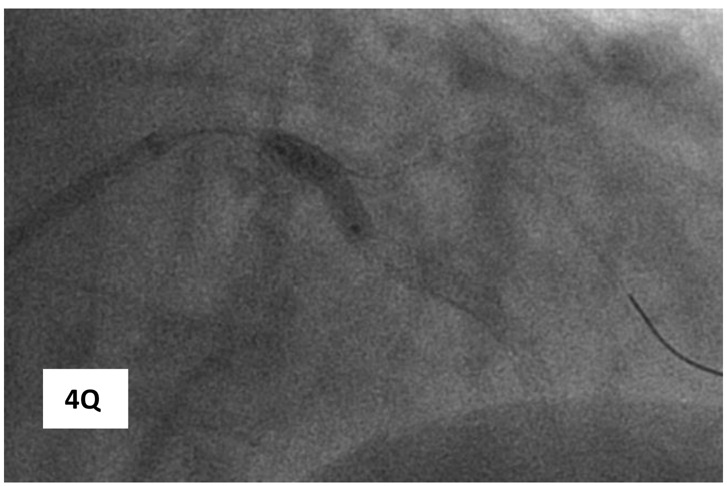

4L

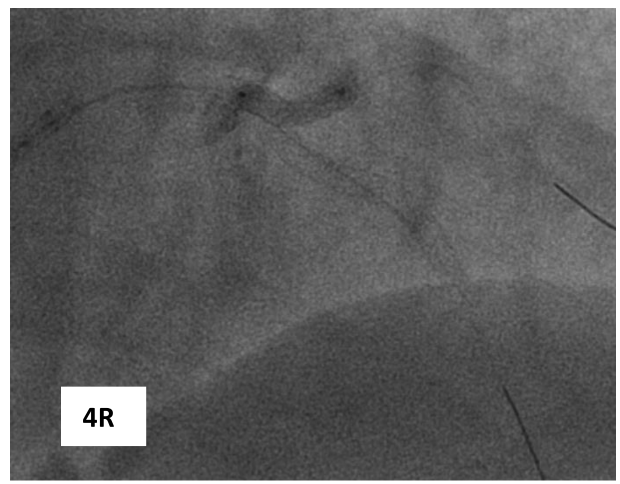

4M

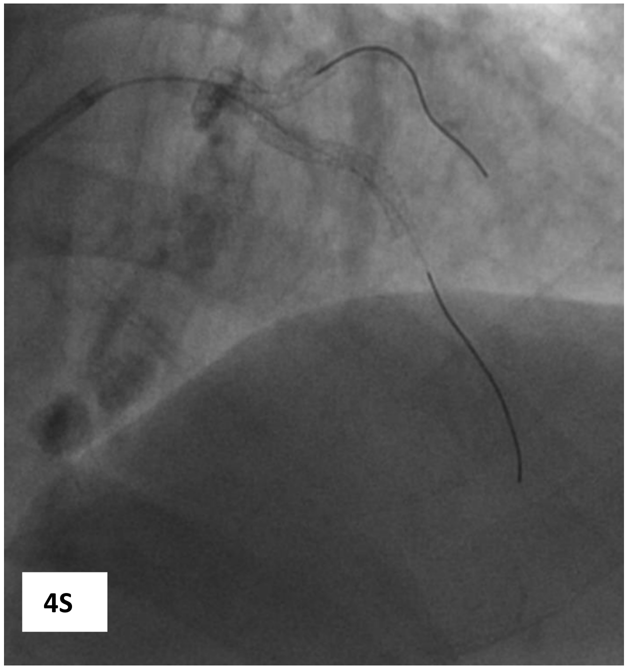

4N


4O


4P


4Q


4R


4S

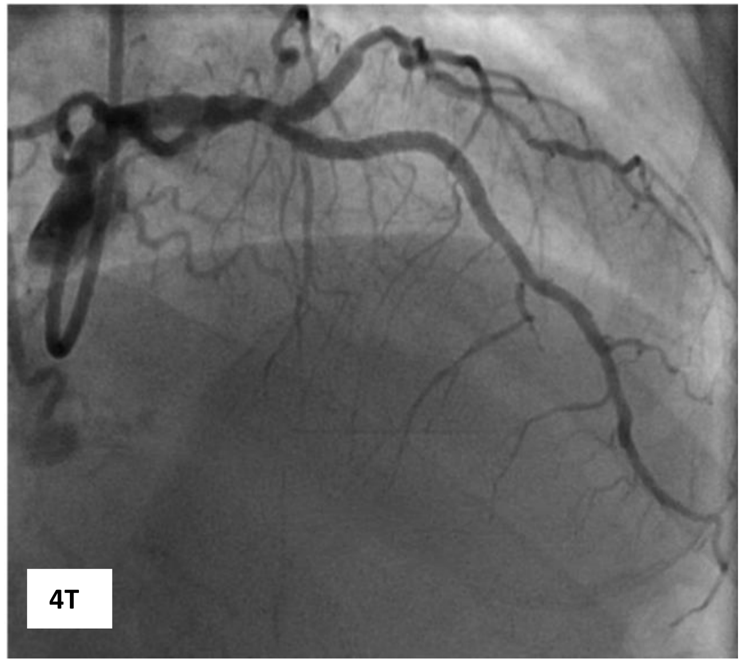
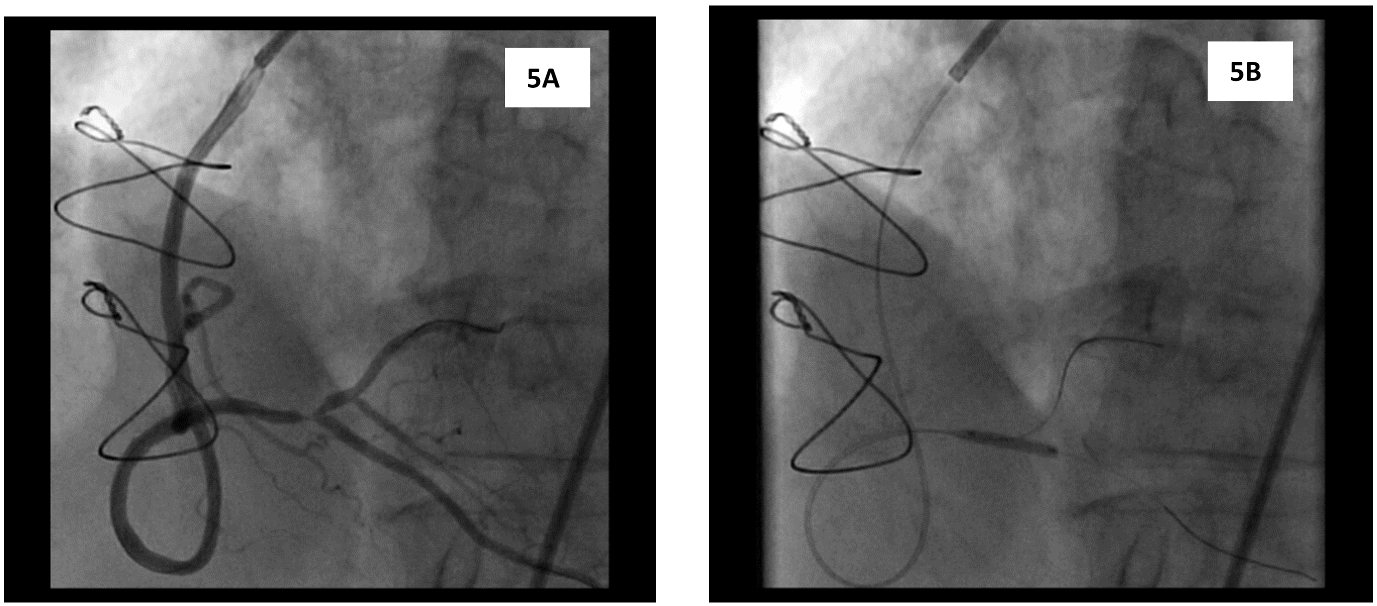

4T

Figure 5A-F: example of classic crush stenting in patient with remote CABG and angina (A): high grade focal lesion; choice of an 8 Fr MP 1 guide catheter; (B) Main vessel and side branch both wired with BMW wires, pre-dilate; (C) position stents; (D) deploy side branch stent, then follow up with angiography to evaluate for distal edge dissection; (E) deploy main vessel stent; (F) final kissing inflations



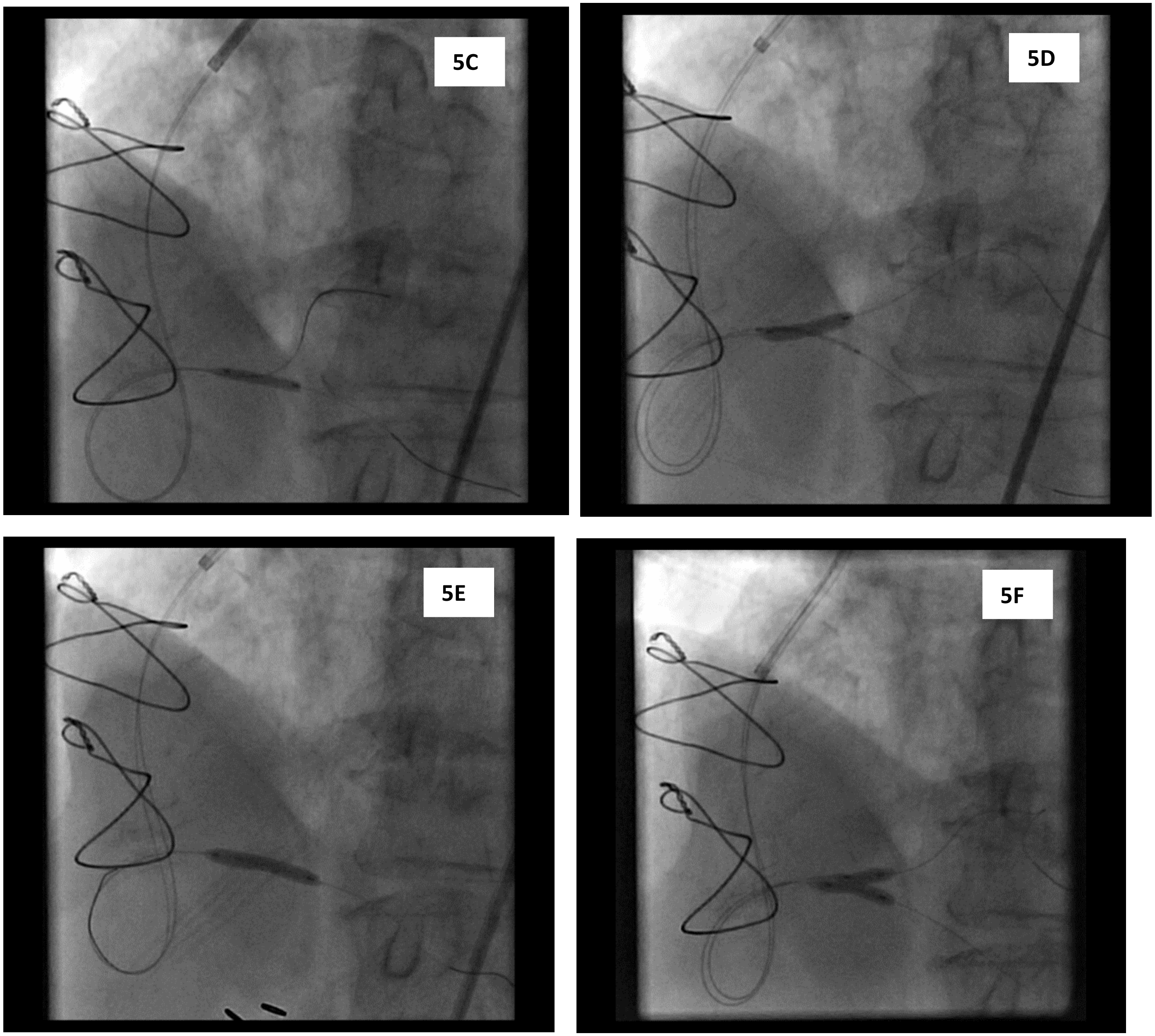
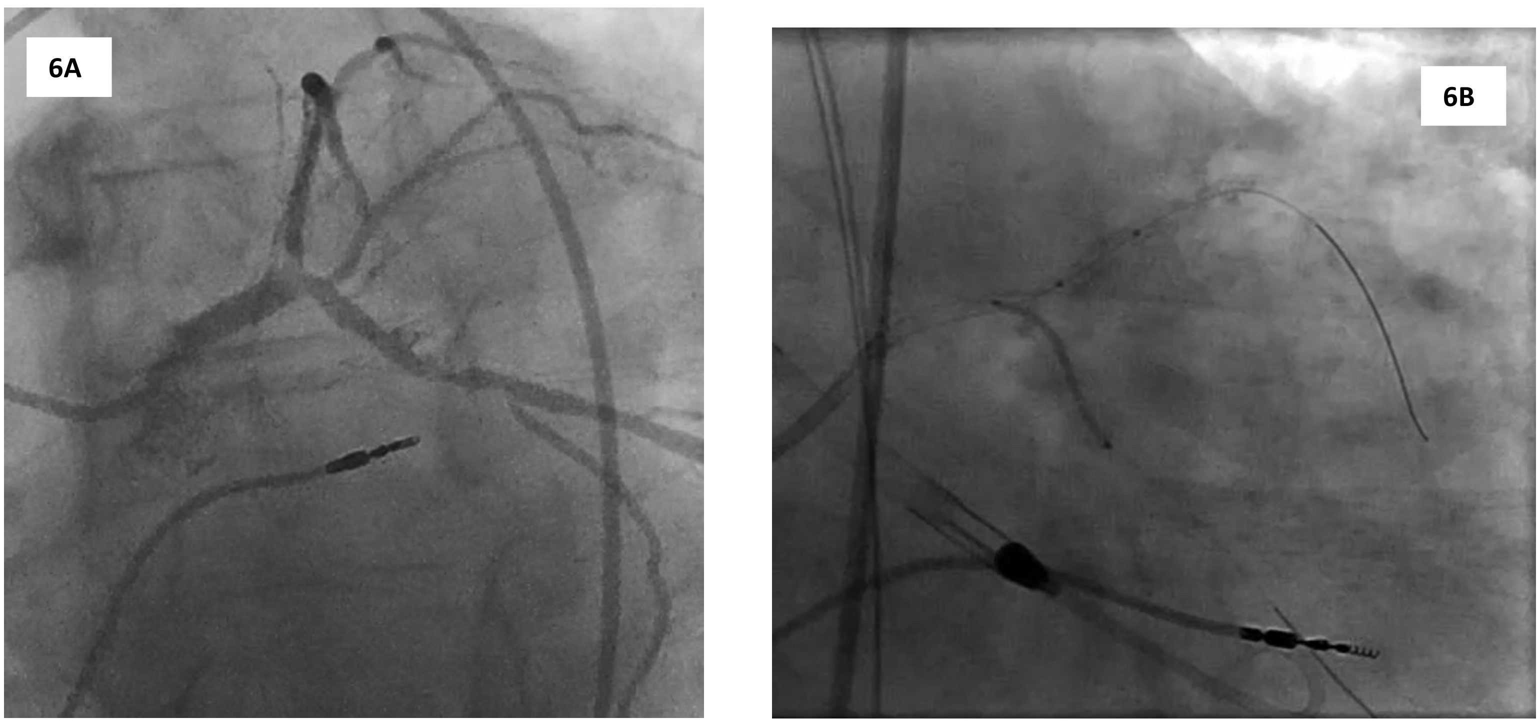
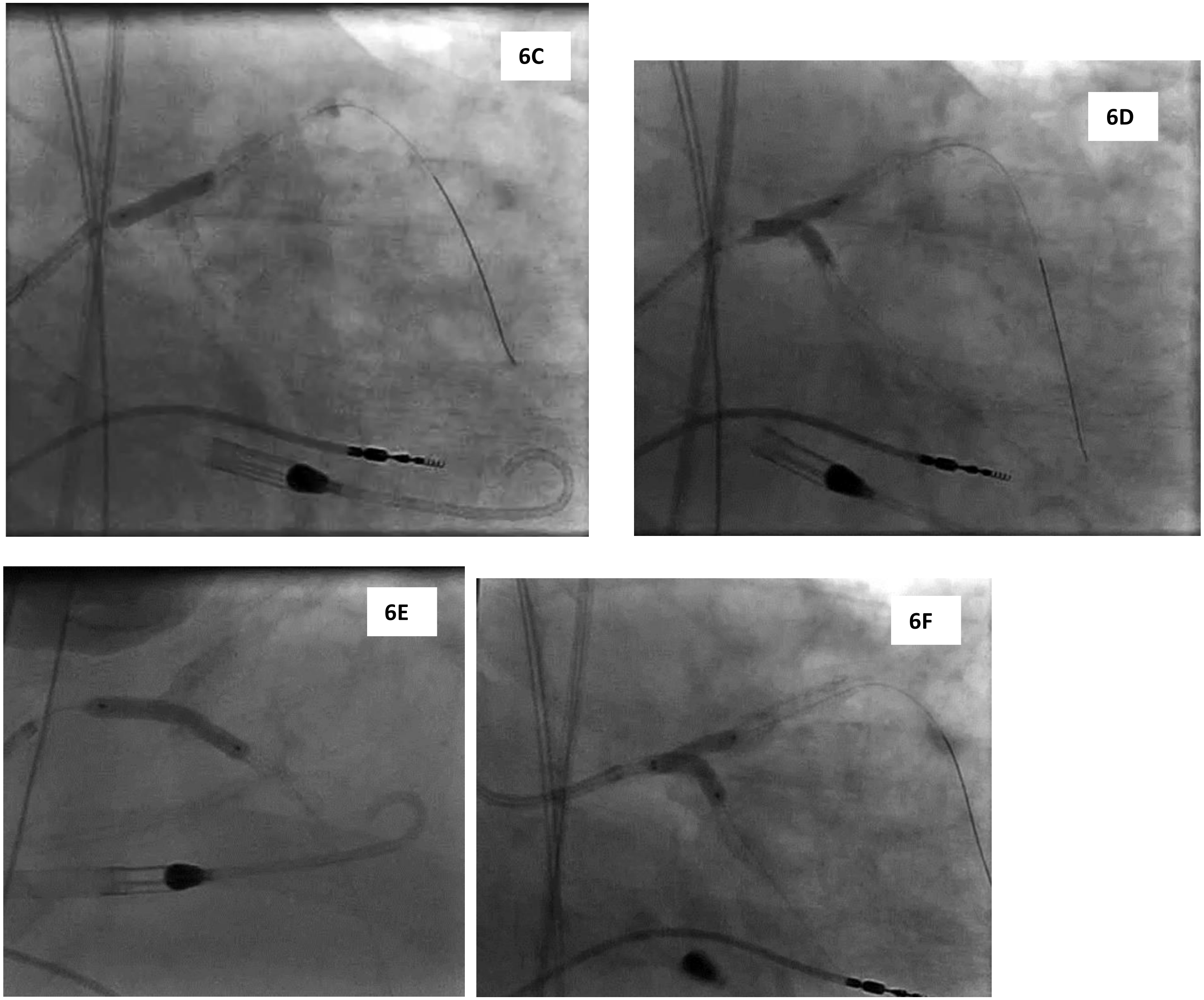
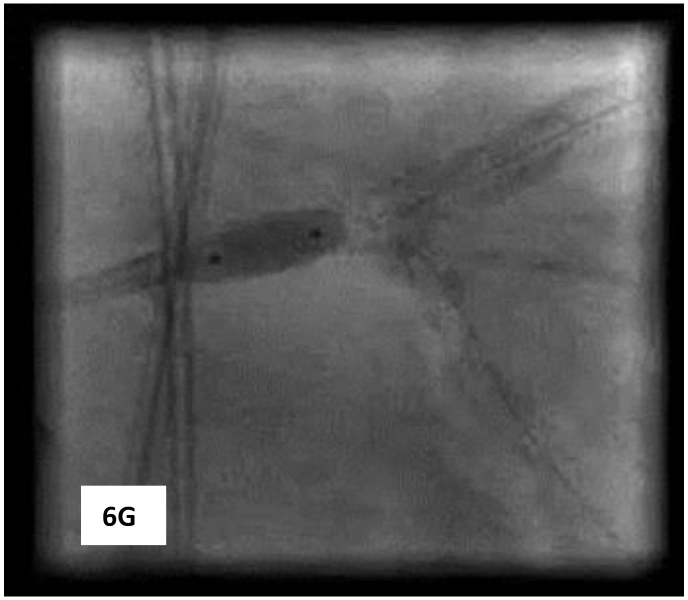
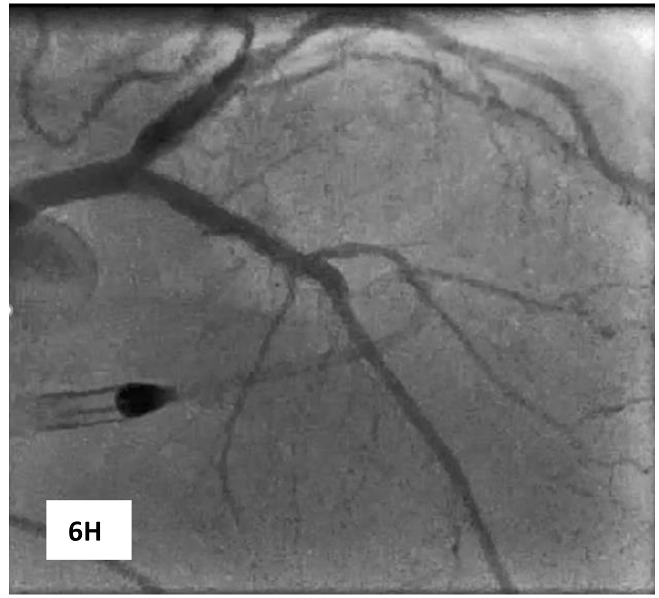

5C
5D
5E
5F

Figure 6A-H: Step by step DK crush technique; (A) diagnostic angiography of bifurcation distal left main into the left anterior descending artery (LAD) and left circumflex (LCx) lesion; (B) after engaging the left main with a 7F XB 4.0 guide and placing Impella for hemodynamic support, both the LAD (main branch) and the LCx (side branch) were wired and predilated; a 3.00 x 28 mm drug eluting stent was then advanced into the SB while the balloon remained in the MB; the SB stent was then deployed (C) the balloon in the main branch was then inflated to crush the side branch stent; (D) the SB is then re-wired and the first kissing balloon inflation is performed; (E) stent deployed in the LAD (MB) extending into the left main; (F) the side branch is then re-wired, and then final kissing balloon inflations are pursued; (G) proximal optimization technique to the proximal main vessel; (H) final angiographic result




6C
6D
6E
6F


6G


6H

References

1. Louvard Y, Thomas M, Dzavik V, et al. Classification of coronary artery bifurcation lesions and treatments: time for a consensus! *Catheter Cardiovasc Interv.* 2008;71(2):175-183.

2. Lassen JF, Holm NR, Stankovic G, Lefevre T, Chieffo A, Hildick-Smith D, Pan M, Darremont O, Albiero R, Ferenc M, Louvard Y. Percutaneous coronary intervention for coronary bifurcation disease: consensus from the first 10 years of the European Bifurcation Club meetings. *EuroIntervention.* 2014;10(5):545-560.

3. Nakazawa G, Yazdani SK, Finn AV, Vorpahl M, Kolodgie FD, Virmani R. Pathological findings at bifurcation lesions: the impact of flow distribution on atherosclerosis and arterial healing after stent implantation. *J Am Coll Cardiol.* 2010;55(16):1679-1687.

4. Colombo A, Moses JW, Morice MC, et al. Randomized study to evaluate sirolimus-eluting stents implanted at coronary bifurcation lesions. *Circulation.* 2004;109(10):1244-1249.

5. Palmerini T, Sangiorgi D, Marzocchi A, et al. Ostial and midshaft lesions vs. bifurcation lesions in 1111 patients with unprotected left main coronary artery stenosis treated with drug-eluting stents: results of the survey from the Italian Society of Invasive Cardiology. *Eur Heart J.* 2009;30(17):2087-2094.

6. Medina A, Suarez de Lezo J, Pan M. [A new classification of coronary bifurcation lesions]. *Rev Esp Cardiol.* 2006;59(2):183.

7. Chen SL, Sheiban I, Xu B, et al. Impact of the complexity of bifurcation lesions treated with drug-eluting stents: the DEFINITION study (Definitions and impact of complEx biFurcation lesIons on clinical outcomes after percutaNeous coronary IntervenTIOn using drug-eluting steNts). *JACC Cardiovasc Interv.* 2014;7(11):1266-1276.

8. Colombo A, Bramucci E, Sacca S, et al. Randomized study of the crush technique versus provisional side-branch stenting in true coronary bifurcations: the CACTUS (Coronary

Bifurcations: Application of the Crushing Technique Using Sirolimus-Eluting Stents) Study. *Circulation.* 2009;119(1):71-78.

9. Ferenc M, Gick M, Kienzle RP, et al. Randomized trial on routine vs. provisional T-stenting in the treatment of de novo coronary bifurcation lesions. *Eur Heart J.* 2008;29(23):2859-2867.

10. Pan M, de Lezo JS, Medina A, et al. Rapamycin-eluting stents for the treatment of bifurcated coronary lesions: a randomized comparison of a simple versus complex strategy. *Am Heart J.* 2004;148(5):857-864.

11. Steigen TK, Maeng M, Wiseth R, et al. Randomized study on simple versus complex stenting of coronary artery bifurcation lesions: the Nordic bifurcation study. *Circulation.* 2006;114(18):1955-1961.

12. Hildick-Smith D, de Belder AJ, Cooter N, et al. Randomized trial of simple versus complex drug-eluting stenting for bifurcation lesions: the British Bifurcation Coronary Study: old, new, and evolving strategies. *Circulation.* 2010;121(10):1235-1243.

13. Ford TJ, McCartney P, Corcoran D, et al. Single- Versus 2-Stent Strategies for Coronary Bifurcation Lesions: A Systematic Review and Meta-Analysis of Randomized Trials With Long-Term Follow-up. *J Am Heart Assoc.* 2018;7(11).

14. Latib A, Chieffo A, Colombo A. Elective Double Stenting for Left Main Coronary Artery Bifurcation Lesions: Patient Selection and Technique. *Tips and Tricks in Interventional Therapy of Coronary Bifurcation Lesions*: CRC Press; 2010:169-212.

15. Chen SL, Santoso T, Zhang JJ, et al. Clinical Outcome of Double Kissing Crush Versus Provisional Stenting of Coronary Artery Bifurcation Lesions: The 5-Year Follow-Up Results From a Randomized and Multicenter DKCRUSH-II Study (Randomized Study on Double Kissing Crush Technique Versus Provisional Stenting Technique for Coronary Artery Bifurcation Lesions). *Circ Cardiovasc Interv.* 2017;10(2).

16. Sawaya FJ, Lefevre T, Chevalier B, et al. Contemporary Approach to Coronary Bifurcation Lesion Treatment. *JACC Cardiovasc Interv.* 2016;9(18):1861-1878.

17. Latib A MI, Sheiban I, Colombo A. When are two stents needed? Which technique is the best? How to perform? *EuroIntervention.* 2010;6:J81-J87.

18. Singh JDJPY. Bifurcation Lesions. 2019.

19. Nguyen T, Hu D, Chen SL, et al. Practical Handbook of Advanced Interventional Cardiology, Fourth Edition. 2013.

20. Lefevre T, Darremont O, Albiero R. Provisional side branch stenting for the treatment of bifurcation lesions. *EuroIntervention.* 2010;6 Suppl J:J65-71.

21. Murasato Y FG, Foin N. Final kissing balloon inflation: the whole story. *EuroIntervention.* 2015;11:V81-V85.

22. Niemela M, Kervinen K, Erglis A, et al. Randomized comparison of final kissing balloon dilatation versus no final kissing balloon dilatation in patients with coronary bifurcation lesions treated with main vessel stenting: the Nordic-Baltic Bifurcation Study III. *Circulation.* 2011;123(1):79-86.

23. Gwon HC, Hahn JY, Koo BK, et al. Final kissing ballooning and long-term clinical outcomes in coronary bifurcation lesions treated with 1-stent technique: results from the COBIS registry. *Heart.* 2012;98(3):225-231.

24. Yu CW, Yang JH, Song YB, et al. Long-Term Clinical Outcomes of Final Kissing Ballooning in Coronary Bifurcation Lesions Treated With the 1-Stent Technique: Results From the COBIS II Registry (Korean Coronary Bifurcation Stenting Registry). *JACC Cardiovasc Interv.* 2015;8(10):1297-1307.

25. Song YB, Park TK, Hahn JY, et al. Optimal Strategy for Provisional Side Branch Intervention in Coronary Bifurcation Lesions: 3-Year Outcomes of the SMART-STRATEGY Randomized Trial. *JACC Cardiovasc Interv.* 2016;9(6):517-526.

26. Kumsars I, Narbute I, Thuesen L, et al. Side branch fractional flow reserve measurements after main vessel stenting: a Nordic-Baltic Bifurcation Study III substudy. *EuroIntervention.* 2012;7(10):1155-1161.

27. Koo BK, Kang HJ, Youn TJ, et al. Physiologic assessment of jailed side branch lesions using fractional flow reserve. *J Am Coll Cardiol.* 2005;46(4):633-637.

28. Mortier P, Hikichi Y, Foin N, et al. Provisional stenting of coronary bifurcations: insights into final kissing balloon post-dilation and stent design by computational modeling. *JACC Cardiovasc Interv.* 2014;7(3):325-333.

29. Ferenc M, Gick M, Comberg T, et al. Culotte stenting vs. TAP stenting for treatment of de-novo coronary bifurcation lesions with the need for side-branch stenting: the Bifurcations Bad Krozingen (BBK) II angiographic trial. *Eur Heart J.* 2016;37(45):3399-3405.

30. Erglis A, Kumsars I, Niemela M, et al. Randomized comparison of coronary bifurcation stenting with the crush versus the culotte technique using sirolimus eluting stents: the Nordic stent technique study. *Circ Cardiovasc Interv.* 2009;2(1):27-34.

31. Chen SL, Xu B, Han YL, et al. Comparison of double kissing crush versus Culotte stenting for unprotected distal left main bifurcation lesions: results from a multicenter, randomized, prospective DKCRUSH-III study. *J Am Coll Cardiol.* 2013;61(14):1482-1488.

32. Hoye A, Iakovou I, Ge L, et al. Long-term outcomes after stenting of bifurcation lesions with the "crush" technique: predictors of an adverse outcome. *J Am Coll Cardiol.* 2006;47(10):1949-1958.

33. Adriaenssens T, Byrne RA, Dibra A, et al. Culotte stenting technique in coronary bifurcation disease: angiographic follow-up using dedicated quantitative coronary angiographic analysis and 12-month clinical outcomes. *Eur Heart J.* 2008;29(23):2868-2876.

34. Erglis A, Lassen JF, Di Mario C. Technical aspects of the culotte technique. *EuroIntervention.* 2015;11 Suppl V:V99-101.

35. Zhang JJ, Chen SL. Classic crush and DK crush stenting techniques. *EuroIntervention.* 2015;11 Suppl V:V102-105.

36. Gil RJ, Bil J, Kern A, et al. Comparison of dedicated BIOSS bifurcation stents with regular drug-eluting stents for coronary artery bifurcated lesions: Pooled analysis from two randomized studies. *Cardiol J.* 2018;25(3):308-316.

37. Naber CK, Pyxaras SA, Nef H, et al. Final results of a self-apposing paclitaxel-eluting stent fOr the PErcutaNeous treatment of de novo lesions in native bifurcated coronary arteries study. *EuroIntervention.* 2016;12(3):356-358.

38. Wanha W, Mielczarek M, Smolka G, et al. Safety and efficacy of self-apposing Stentys drug-eluting stent in left main coronary artery PCI: Multicentre LM-STENTYS registry. *Catheter Cardiovasc Interv.* 2019;93(4):574-582.

39. Verheye S, Agostoni P, Dubois CL, et al. 9-month clinical, angiographic, and intravascular ultrasound results of a prospective evaluation of the Axxess self-expanding biolimus A9-eluting stent in coronary bifurcation lesions: the DIVERGE (Drug-Eluting Stent Intervention for Treating Side Branches Effectively) study. *J Am Coll Cardiol.* 2009;53(12):1031-1039.

40. Patel Y, Depta JP, Novak E, et al. Long-term outcomes with use of intravascular ultrasound for the treatment of coronary bifurcation lesions. *Am J Cardiol.* 2012;109(7):960-965.

41. Park SJ, Kim YH, Park DW, et al. Impact of intravascular ultrasound guidance on long-term mortality in stenting for unprotected left main coronary artery stenosis. *Circ Cardiovasc Interv.* 2009;2(3):167-177.