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Original Research

The Balloon-Assisted Double-Kissing T-Stenting Technique: Concept, In Vitro Model, and Case Examples

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ABSTRACT

Background: In complex bifurcation percutaneous coronary intervention, 2-stent strategies are often required. Commonly used 2-stent techniques can lead to suboptimal results due to their complexity. We developed the balloon-assisted double-kissing T-stenting (DKT) technique, which uses balloons to optimize stent placement, delivery, and final architecture.

Methods: With the balloon-assisted DKT technique, a balloon is inflated into the main branch (MB) to identify the best position of the side-branch (SB) stent instead of relying on angiography. DKT aims at supporting the SB ostium with stent crowns instead of distorted open cell(s), by achieving a longitudinal deformation with minimal crush of the SB stent upon implantation of the MB stent. This hypothesis was tested on a bench model. We report how the technique was performed in 2 cases and provide intracoronary imaging of the results.

Results: As hypothesized, DKT resulted in a longitudinal accordion-like deformation and minimal crush effect on bench. The SB ostium was supported by stent crowns. The SB wall opposed to the carina was well covered with crowns from the MB stent after proximal optimization technique and final kissing. The technique was successfully used in 2 complex left main cases with perfect coverage of the SB ostium as assessed with intracoronary imaging.

Conclusions: The balloon-assisted DKT is a simple technique that combines strengths of double-kissing crush and culotte techniques, results in appropriate SB ostium coverage, and deserves further investigation.

Introduction

For complex bifurcation lesions with longer side-branch (SB) disease, a planned 2-stent strategy is often required.[1–4] Among 2-stents techniques, double-kissing (DK) crush, culotte, T-stenting, and T-and-protrusion (TAP) techniques have proved their utility.[1,2,4,5] Classical T-stenting is prone to geographical miss and lack of carina coverage, whereas TAP results in the creation of a neo-carina.[1] Moreover, DK crush and culotte techniques are quite difficult to execute.[1]

Stents are designed to scaffold the arterial wall through expansion of linked stent crowns, which provide the radial force to support the artery at the nominal stent diameter.[6] Individual stent crowns are attached with metal links or laser fused, enabling access to the SB between the crowns (stent cells). In bifurcation stenting involving SB treatment, the balloon pushes the crowns apart to create an open cell. From a biomechanical standpoint, SB ballooning and/or use of 2 stents may lead to (1) metal, polymer, and drug overlap (with culotte and crush techniques), potentially impairing arterial healing; (2) stent distortion, leading to a combination of crowns and links supporting the SB ostium (seen in all crush techniques) rather than only crowns; or (3) creation of a neocarina (with TAP), with nonapposed struts that can increase thrombogenicity. In addition, in DK crush, if the SB wire crosses too distal prior to the first kissing balloon inflation (KBI), ballooning can result in collapse of full crowns away from carina, resulting in geographic miss.

We propose a simpler and effective 2-stent bifurcation technique that is suitable for most anatomies, largely preserves the original architecture of the MB and SB stents, and minimizes the amount of crushed stent material in the bifurcation while avoiding geographic miss.

The balloon-assisted double-kissing T-stenting technique

Bifurcation stenting should be performed in a view that minimizes overlap between branches.[7] As for any percutaneous coronary intervention (PCI), adequate lesion preparation should be done. Furthermore,

Abbreviations: DKT, balloon-assisted T-stenting; IVUS, intravascular ultrasound; KBI, kissing balloon inflation; MB, main branch; PCI, percutaneous coronary intervention; POT, proximal optimization technique; SB, side-branch; TAP, T-and-protrusion.

Keywords: bifurcation; coronary artery disease; percutaneous coronary intervention.

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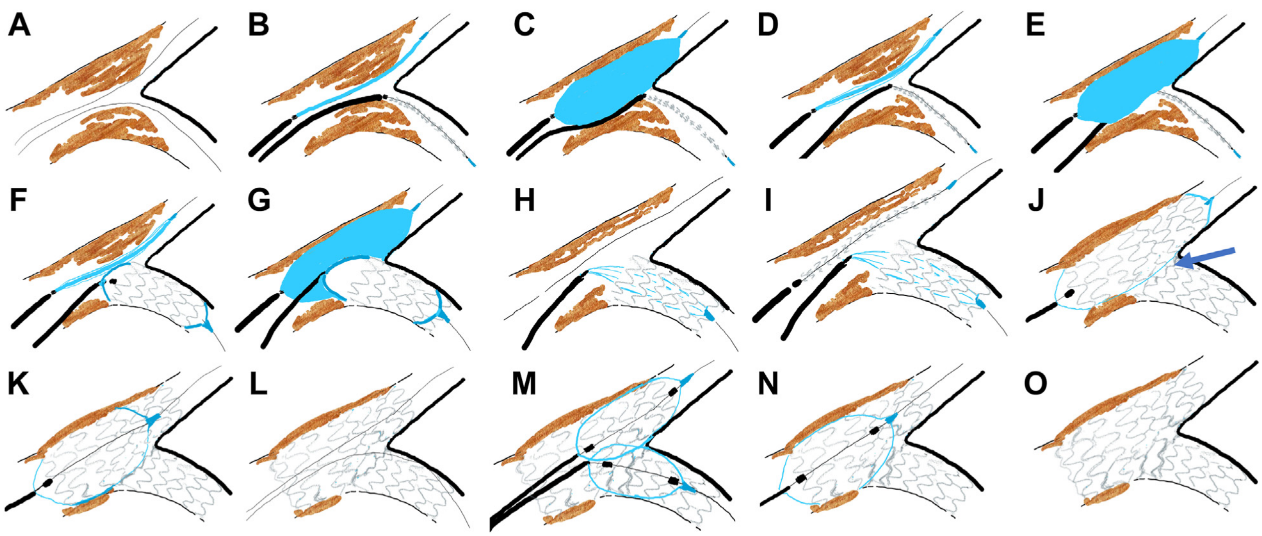


Figure 1.

The balloon-assisted double-kissing T-stenting technique (DKT) with a more open angle. (**A**) Dilation of both branches. (**B**) Stent in SB, balloon in MB (sized to distal MB). (**C**) Stent is too deep into the SB because there is no contact between the balloon and the SB stent proximal edge. (**D**) Stent pulled, for minimal protrusion proximal to carina. (**E**) Inflation of balloon, confirming optimal position, with good contact of the proximal SB stent edge with the balloon, without too much tilt or contact of the undeployed stent with the MB balloon inflated. This ensures that the stent is not too deep into the SB (good contact with the balloon) and not too proximal (only minimal contact). (**F**) SB stent deployed. (**G**) Stent delivery balloon pulled few millimeters and first KBI performed. (**H**) Deflated delivery balloon left in place (bumper effect), preventing the MB stent delivery system to catch on the SB stent struts. (**I**) MB stent delivered. (**J**) After removal of SB balloon and wire, MB stent deployed, causing an intentional longitudinal deformation effect of the SB stent (arrow). (**K**) First POT optimizing apposition of struts proximal to the bifurcation and further intentional longitudinal deformation of the SB stent crowns. (**L**) Wire crossed through distal MB stent struts. (**M**) Second KBI pushing main stent crowns struts toward SB. (**N**) Second POT. (**O**) Final T-stenting result. KBI, kissing balloon inflation; MB, main branch; POT, proximal optimization technique; SB, side branch.

intracoronary imaging is strongly recommended to assess plaque morphology, vessel sizing, and results. After satisfactory lesion preparation, the balloon-assisted double-kissing T-stenting (DKT) technique is performed as outlined below (Figure 1 for a broad angle bifurcation and Figure 2 a narrow angle bifurcation, both with same steps):

1. SB stent is advanced into the SB (Figures 1B and 2B). A balloon sized 1:1 to the distal MB is delivered into the MB. The MB balloon is inflated across the SB ostium to enable optimal positioning of the SB stent, which should minimally protrude into the MB (about 1 crown or 1 mm) on the carina side. If repositioning of the SB stent is required, the MB balloon is deflated to allow easy movements of the stent and to avoid building up tension in the system that could result in further stent movement upon MB balloon deflation. As such, sequential MB balloon inflations at nominal pressure and deflations may be required to finally obtain the optimal SB stent

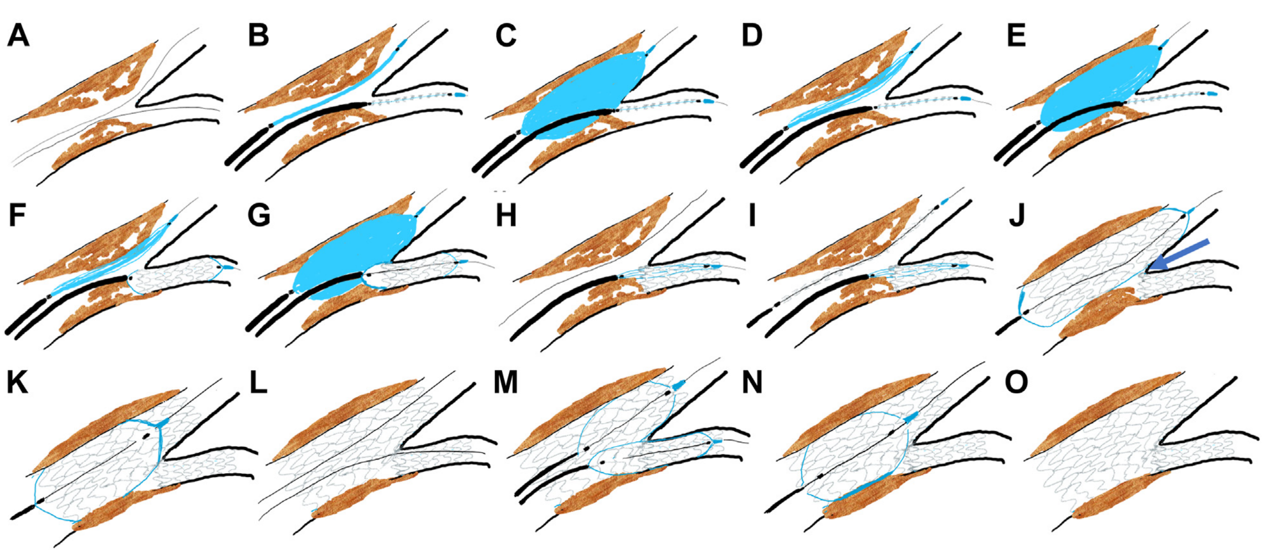


Figure 2.

The balloon-assisted double-kissing T-stenting technique (DKT) with a narrow angle. (**A**) Dilation of both branches. (**B**) Stent in SB, balloon in MB (sized to distal MB). (**C**) Inflation of the positioning balloon, to assess position of SB stent. Here, the stent in too deep into the SB because there is no contact between the balloon and the SB stent proximal edge. (**D**) Stent pulled back, for minimal protrusion proximal to carina. (**E**) Inflation of balloon, confirming optimal position, with good contact of the proximal SB stent edge with the balloon, without too much tilt or contact of the undeployed stent with the MB balloon inflated. (**F**) SB stent deployed. (**G**) Stent delivery balloon pulled few millimeters and first KBI. (**H**) Deflated delivery balloon left in place (bumper effect), preventing the MB stent delivery system to catch on the SB stent struts. (**I**) MB stent delivered. (**J**) After removal of SB balloon and wire, MB stent deployed, causing an intentional minimal longitudinal deformation with or without minimal carina-side crushing effect of SB stent (arrow). (**K**) First POT optimizing apposition of struts proximal to the bifurcation and causing further intentional minimal longitudinal deformation of the SB stent. (**L**) Wire crossed through distal MB stent cells. (**M**) Second KBI pushing main stent crowns struts toward SB (coverage of proximal SB with MB stent crowns). (**N**) Second POT. (**O**) Final T-stenting result. KBI, kissing balloon inflation; MB, main branch; POT, proximal optimization technique; SB, side branch.

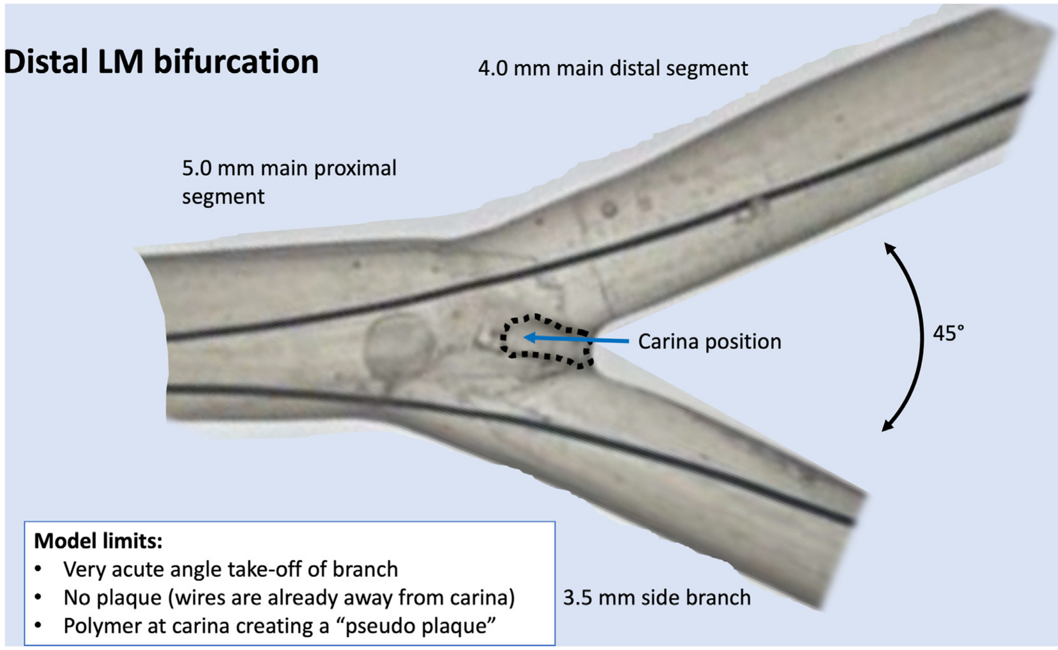
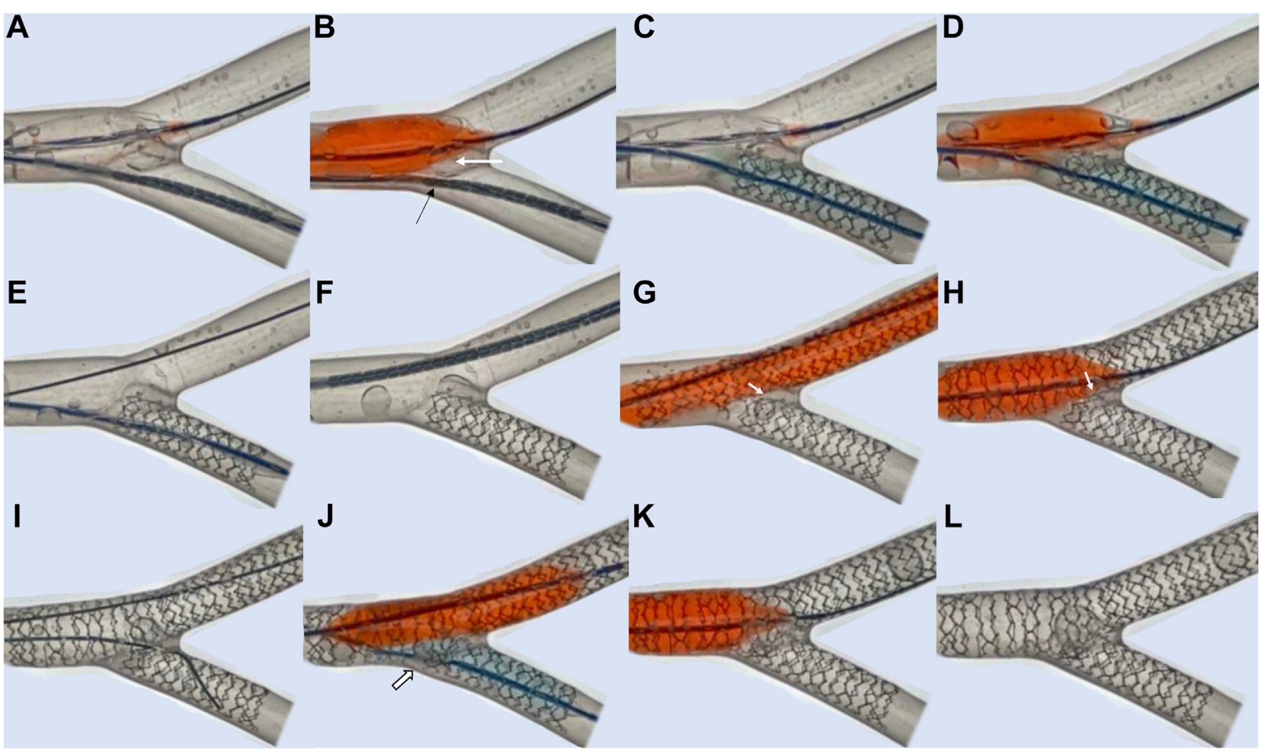


Figure 3.
In vitro bifurcation model with transparent polymer tubes (a narrow angle). LM, left main.

position (Figures 1C-1E and 2C-2E). Use of the MB positioning balloon instead of angiography ensures that the SB stent does not protrude too much into the MB lumen, which will be evidenced by a long contact between the MB balloon and the SB stent and that the SB stent is also not too deep, evidenced as a gap between the outer edge of the balloon (where the future MB stent will be) and



Central Illustration.
In vitro model of the balloon-assisted double-kissing T-stenting (DKT) technique. (**A**) Stent in SB, balloon in MB (sized to distal MB). (**B**) Inflation of balloon, to assess position of SB stent. It is optimal when the proximal edge of SB stent (black arrow) extends few struts proximal to the carina (white arrow). (**C**) SB stent deployed with proximal struts extending slightly proximal to the carina (white arrow). (**D**) First KBI. (**E**) Deflated delivery balloon left in place (bumper effect) preventing the MB stent to catch on the SB stent struts. (**F**) MB stent delivered, then removal of SB stent delivery balloon and wire. (**G**) MB stent deployed, causing minimal intentional longitudinal deformation with some compaction of SB stent (arrow). (**H**) First POT, causing further intentional longitudinal deformation of SB stent (arrow). (**I**) Wire crossed through distal MB stent struts. (**J**) Second KBI with opening of the main stent crowns toward the SB (arrow). (**K**) Second POT. (**L**) Final T-stenting result. KBI, kissing balloon inflation; MB, main branch; POT, proximal optimization technique; SB, side branch.

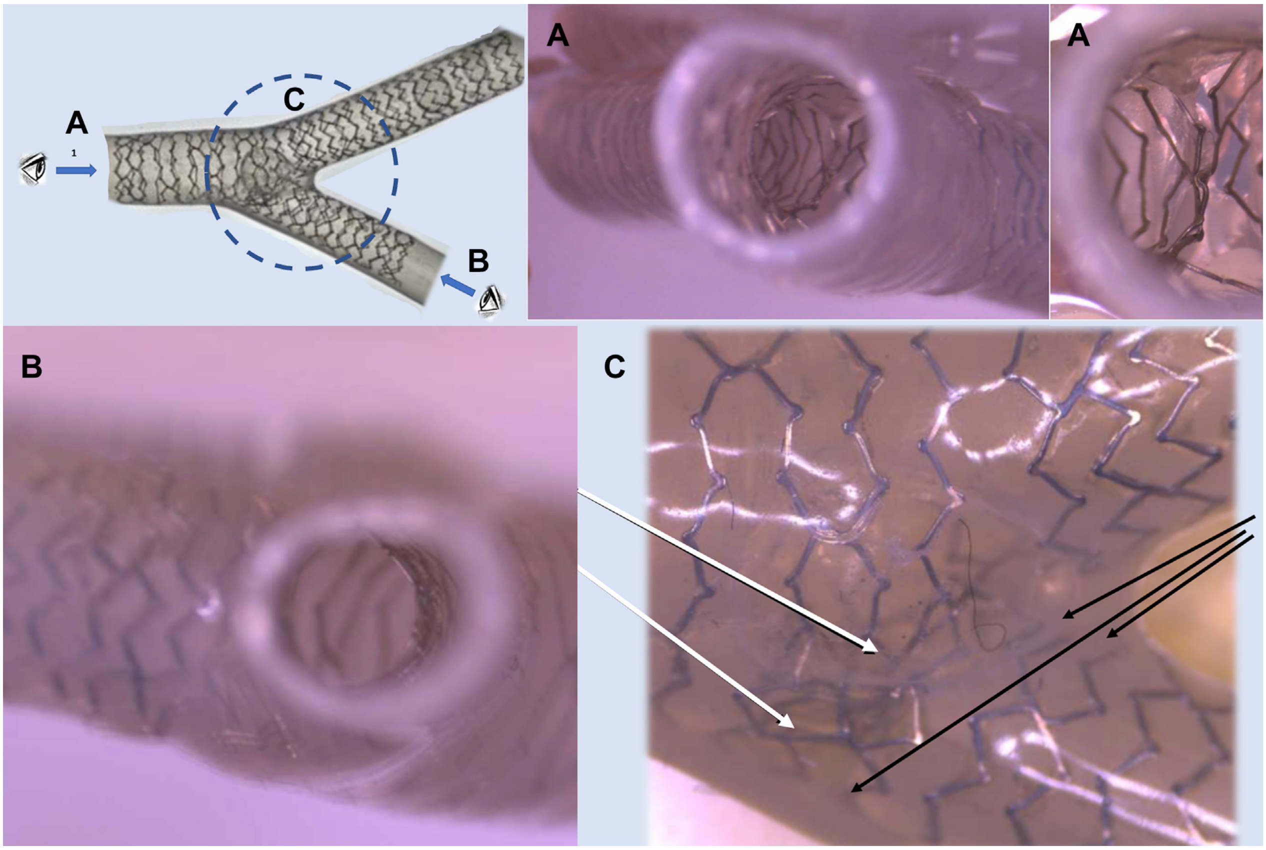


Figure 4.
In vitro inside and outside views of post–balloon-assisted double-kissing T-stenting struts architecture. (**A**) View from the proximal MB stent lumen showing good coverage of carina and crowns supporting the SB ostium. (**B**) View from the SB stent lumen showing good opening of MB stent cells toward the branch. (**C**) Outside view showing "accordioned" crowns supporting the SB ostium (black arrows) and partial stenting of the branch for opening of the MB stent proximal crowns toward the SB (white arrows). MB, main branch; POT, proximal optimization technique; SB, side branch.

the proximal edge of the stent. No angiography is needed at this stage, saving contrast. In cases when the takeoff of the SB remains unclear due to foreshortening or other factors, operators should protrude the SB stent slightly more into the MB so that the worst-case scenario result will be a minicrush instead of incomplete SB coverage. After confirming optimal SB stent position, the MB balloon is deflated, and the SB stent is deployed (Figures 1F and 2F).

2. After SB stent deployment, the deflated SB stent delivery balloon (SDB) is pulled back by 1 or 2 mm to perform the first KBI with the MB balloon still in place (Figures 1G and 2G). This KBI ensures that the MB plaque is adequately prepared to accommodate the MB stent, and patency of the SB stent entry to the stent from its proximal edge.
3. The MB balloon (Figures 1H and 2H) is removed while leaving the SDB in place. The deflated SDB ensures easier delivery of the MB stent by acting as a "bumper" to deflect the MB stent delivery system away from the SB stent struts that may be minimally protruding into the MB lumen close to the carina (Figures 1I and 2I).
4. The MB stent is delivered to the correct position, followed by removal of the SB SDB and guide wire. The MB stent is then deployed, causing longitudinal displacement of the proximal SB stent struts that were protruding into the MB at the carina level (Figure 1J). The proximal crowns move closer together but maintain patency of the SB stent lumen because of the limited extension of the SB stent proximal to the carina. With deployment of the MB stent, struts are pushed against the proximal SB stent crowns. Those metallic structures are interacting, resulting in longitudinal compression of the proximal SB stent cells in an accordion-like effect as opposed to tilting or crushing, which would be expected from the inflation of a hydrophilic balloon over the proximal SB struts. In case of broader bifurcation angles (60°-90°), very minimal compression of the SB stent struts near the carina may result because the broad angle limits the amount of SB stent protrusion at the carina (Figure 1J). In narrower angles (<60°), longitudinal SB stent compression will be more pronounced and will involve partial compaction (minicrush).
5. An initial proximal optimization technique (POT) is performed in the proximal MB to optimize MB stent apposition and expansion and further compress the proximal SB stent crowns (Figures 1K and 2K).
6. The SB is then rewired through a distal MB stent cell to ensure that the MB stents crowns will further open toward the SB wall opposite to the carina with SB ballooning, providing adequate strut coverage in this region and avoiding creation of a long metallic neocarina (Figures 1L and 2L).
7. A second and final KBI (Figures 1M and 2M) is performed, again with balloons sized to the SB and distal MB diameters.
8. A final POT is performed to complete the procedure (Figures 1N-1O and 2N-2O).

The DKT technique can be done readily with ≥7F guide wire. Moreover, 6F guide wires may prevent the use of the SDB as a bumper balloon during the MB stent delivery step because of limited guide space. Replacing the SDB by a new balloon, inflated and deflated in the branch and pulled 2 mm to serve as bumper, will usually allow the delivery of the MB stent in 6F guide wires.

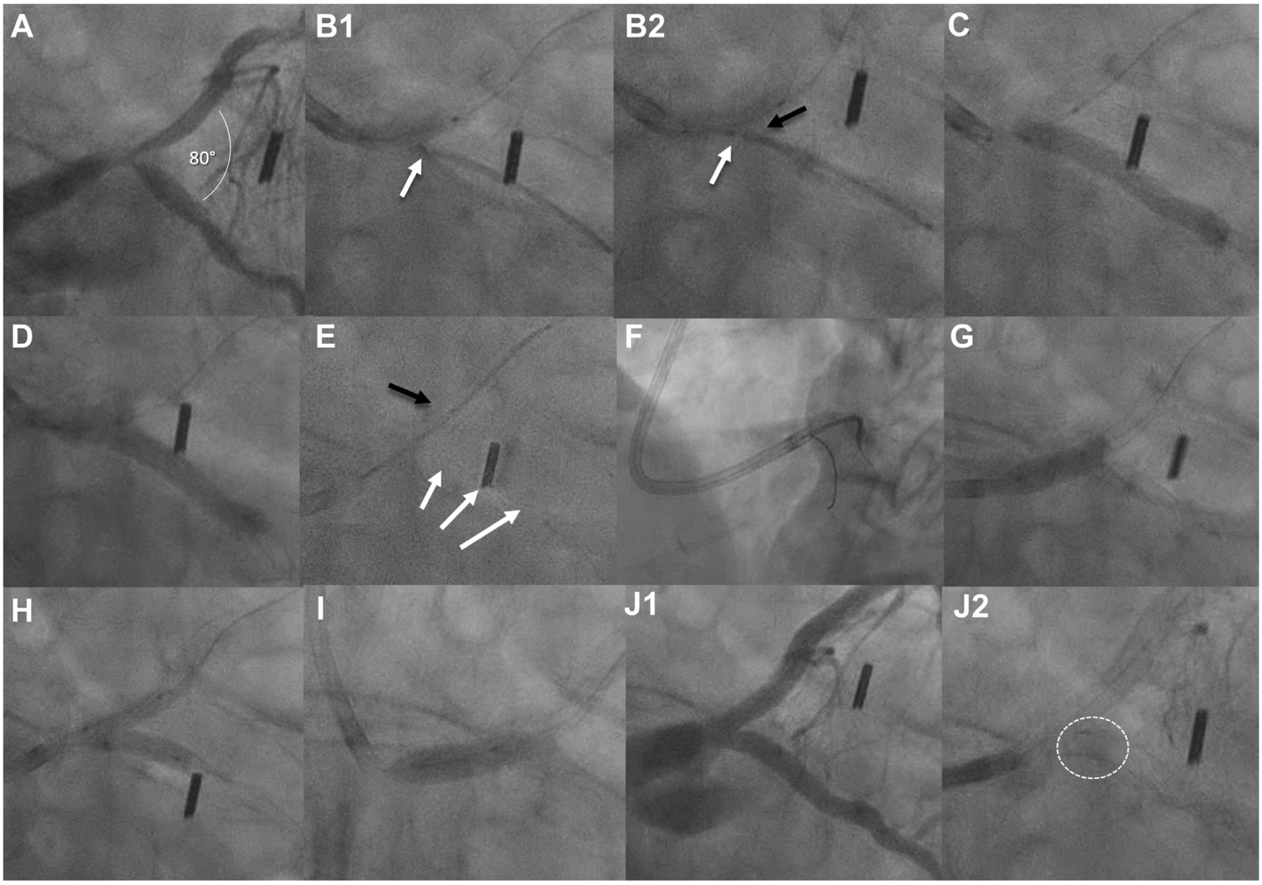


Figure 5.
Case 1. Detailed stepwise angiographic imaging of the balloon-assisted double-kissing T-stenting technique. (**A**) Severe distal LM Medina 1.1.1 bifurcation, with an 80° angle between branches. (**B1-B2**) Balloon-assisted positioning of the SB stent with balloon in MB sized to LAD: stent too distal in **B1** and optimal in **B2**, with minimal protrusion of proximal stent struts (white arrow) proximal to the carina (black arrow). (**C**) SB stent deployed. (**D**) First KBI, keeping proximal opening of the stent crowns. (**E**) Delivery of MB stent (black arrow) with stent delivery balloon left in SB (white arrows), helping stent to track away from protruding struts (bumper effect). (**F**) MB stent placement and deployment (here with wire in sinus for optimal proximal positioning). (**G**) First POT. (**H**) Second KBI. (**I**) Re-POT. (**J**) Final result with increased density of the ostium of the proximal SB on the carina and opposite sites (white circle) believed to be the result of the intentional accordion-like collapse of the proximal SB stent crowns. KBI, kissing balloon inflation; MB, main branch; POT, proximal optimization technique; SB, side branch.

Bench model testing experiment

Method

Bench model testing was performed at the Boston Scientific Customer Interaction Centre (Galway, Ireland) based on the sequence proposed in Figures 1 and 2. The model was built of polymer (proprietary of Boston Scientific) and allowed for sequential photography of stent deployment (Figure 3). The MB diameter was 5.0 mm, the distal MB diameter 4.0 mm, and the SB diameter 3.5 mm, with a shallow bifurcation angle. For the experiment, 2 Synergy stents were used. Balloons were filled with colored saline. Stents were delivered in water. The aim of the experiment was to understand the behavior of the stent crowns and links with DKT. We hypothesized that the SB stent crowns would support the SB and the MB stent crowns would displace during SB inflation and KBI to cover the proximal segment of the SB opposite (upstream) from the carina.

Results

MB stent deployment caused a small amount of intentional longitudinal deformation of SB stent (Central Illustration). The first POT led to further longitudinal deformation of the SB stent. However, after crossing through the distal cell of the MB stent prior to the second KBI, the MB stent crowns opened into the SB, compensating for the initial lack of SB stent coverage upstream from the carina. The view from the MB showed good coverage of the carina, and minimal overlap of struts or neocarina (Figure 4). As opposed to a DK crush architecture, stent crowns were supporting the SB ostium rather than stent cells. When viewing the artery lumen from the SB stent lumen, the cells of the main stents were well opened and apposed. The outside view of the stents demonstrated that accordioning of the SB crowns enabled support the SB ostium (black arrows) along with displacement of struts from the MB stent struts to the SB during KBI.

Case examples

Case 1—Distal left main true bifurcation lesion with an open angle. A 69-year-old patient with diabetes and prior stroke was admitted for non–ST-elevation myocardial infarction. A coronary angiography showed a severe left main (LM) bifurcation lesion, and a transthoracic echocardiogram showed a mildly reduced left ventricular ejection fraction at 45%. An intra-aortic balloon pump was placed for refractory chest pain. PCI was judged preferable by the heart team. This complex Medina 1.1.1 bifurcation was believed to require an upfront 2-stent strategy (Figure 5A), and we treated it with the balloon-assisted

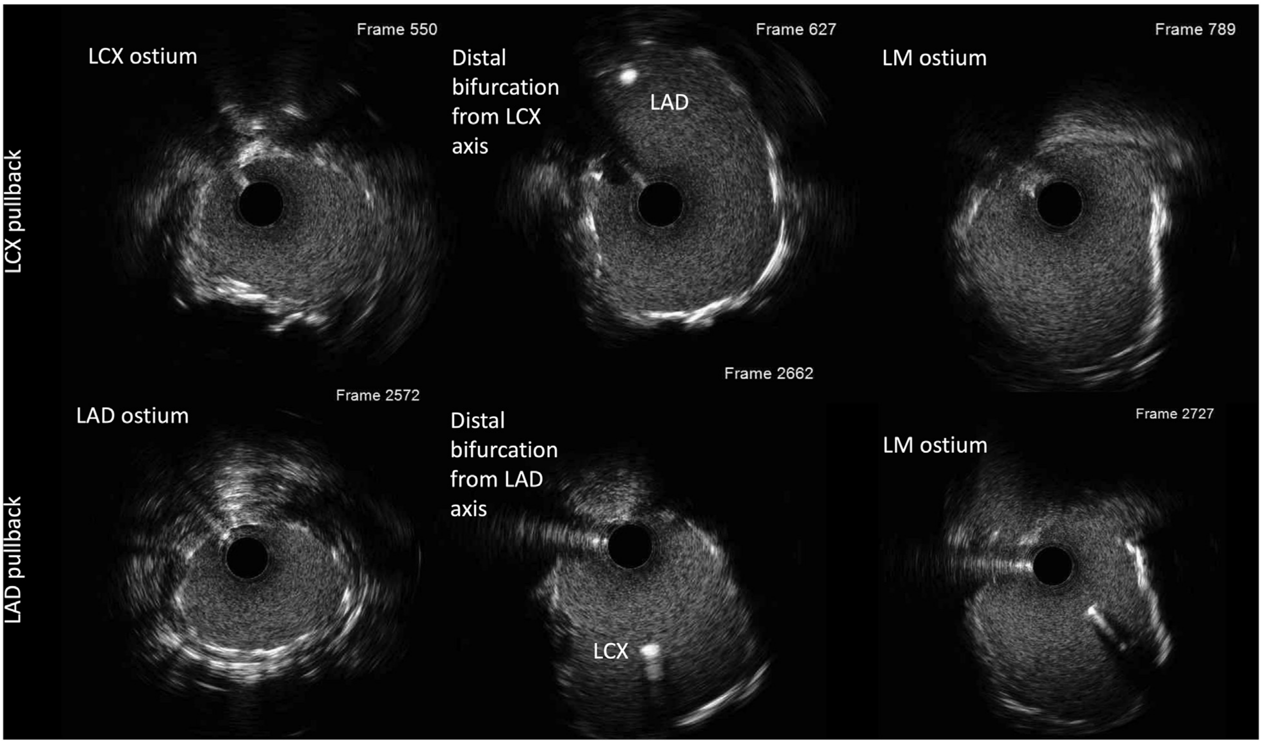


Figure 6.
Case 1. IVUS still frames of pullback images from the LAD and the LCX showing optimal opening of SB stent struts and coverage. IVUS, intravascular ultrasound; LAD, left anterior descending; LCX, left circumflex.

DKT technique, with the circumflex as the SB. A 7F XB 3.5 guide wire was used. After wiring and predilation of both branches, a 3.5- × 26-mm^2 Onyx Frontier stent (Medtronic, Ireland) was optimally positioned in the SB with repeat inflations and deflations of a 3.0- × 15-mm^2 balloon in the MB (Figure 5B1, B2). Once optimal position was selected, the SB stent was deployed, minimally protruding into the MB (Figure 5C). The first KBI was performed with the SDB pulled 1 mm back and the MB balloon in place (Figure 5D). A 3.5- × 38-mm^2 Onyx Frontier stent was then delivered into the MB with the SDB acting as a bumper (Figure 5E). The SB gear was removed, and the MB stent was positioned from the LM ostium to the left anterior descending (LAD; here with a wire in the aortic sinus for optimal positioning) artery (Figure 5F). The MB stent was deployed, and a first POT performed with a 5.0- × 12-mm^2 balloon (Figure 5G). The SB was rewired from a distal cell, and a final KBI was completed with 2 3.5- × 15-mm^2 balloons (Figure 5H). A final POT was done with the 5.0- × 12-mm^2 balloon (Figure 5I), leading to an excellent result angiographically (5J1). A dry (no contrast) cineangiography showed increased density of the struts at the SB ostium on not only the carina side but also the opposite side, suggesting an accordion-like effect of the SB stent crowns (Figure 5J2). Post-PCI intravascular ultrasound (IVUS) showed excellent coverage of the SB ostium (Figure 6). The patient was discharged on day 3 after PCI. At 1-year follow-up, the patient was angina and ischemia free.

Case 2—Distal LM true bifurcation lesion with a narrower angle between branches (similar to bench model). A 69-year-old patient with diabetes and hepatic cirrhosis presented with non–ST-elevation myocardial infarction and was found to have severe perfusion defects involving the LAD and circumflex territories. A coronary angiography showed multivessel coronary artery disease combined with a severe distal LM bifurcation lesion. Left ventricular ejection fraction was at normal levels. An intra-aortic balloon pump was inserted owing to refractory angina. Following a heart team discussion, PCI was preferred. The right coronary artery was stented first, and the LM bifurcation was treated in a staged procedure. A 7F XB 3.5 guide wire was used. The complex Medina 1.1.1 lesion requiring a 2-stent strategy with the circumflex being the SB (Figure 7A). We used the DKT technique. Severe calcification of the LM into LAD required rotational atherectomy with a 2.0-mm burr. LAD and circumflex were wired and predilated (Figure 7B1-B3) with good balloon expansion. A 2.5- × 12-mm^2 Synergy stent (Boston Scientific) was deployed into the SB after optimal positioning with multiple inflations/deflations of a 3.5- × 15-mm balloon in the MB (Figure 7C1-D). A first KBI was performed (Figure 7E). After removal of the MB predilation balloon, leaving the SDB as a bumper, a 3.5- × 28-mm Xience Skypoint (Abbott) was advanced into the MB. After removing the SB gear, the MB stent was deployed (Figure 7F). A first POT with a 5.0- × 8-mm^2 balloon was done with the distal marker at the carina (Figure 7G). The SB was rewired through a distal MB stent cell, and a final KBI was performed with a 2.5- × 15-mm^2 balloon in the SB and a 3.5- × 15-mm^2 balloon in the MB (Figure 7H). A final re-POT was done with the 5.0- × 8-mm^2 balloon (Figure 7I). The final angiographic result was excellent with an accordion-like effect of the proximal crowns of the SB stent (Figure 7J1, J2). Post-PCI IVUS showed optimal stent expansion and coverage of the SB ostium seen on the MB IVUS pullback (Figure 8).

Discussion

We described an improved T-stenting technique, the balloon-assisted DKT, for complex bifurcations requiring an upfront 2-stent strategy. DKT technique offered good coverage of the SB ostium with minimal metal overlap in bench testing and in case examples that utilized intravascular imaging. DKT can readily be applied to complex bifurcations that range from broad to narrower bifurcation angles. Relying on balloon inflation in the MB rather than on contrast injection reduces its use. The simplicity of the DKT technique makes it reproducible and easy to teach.

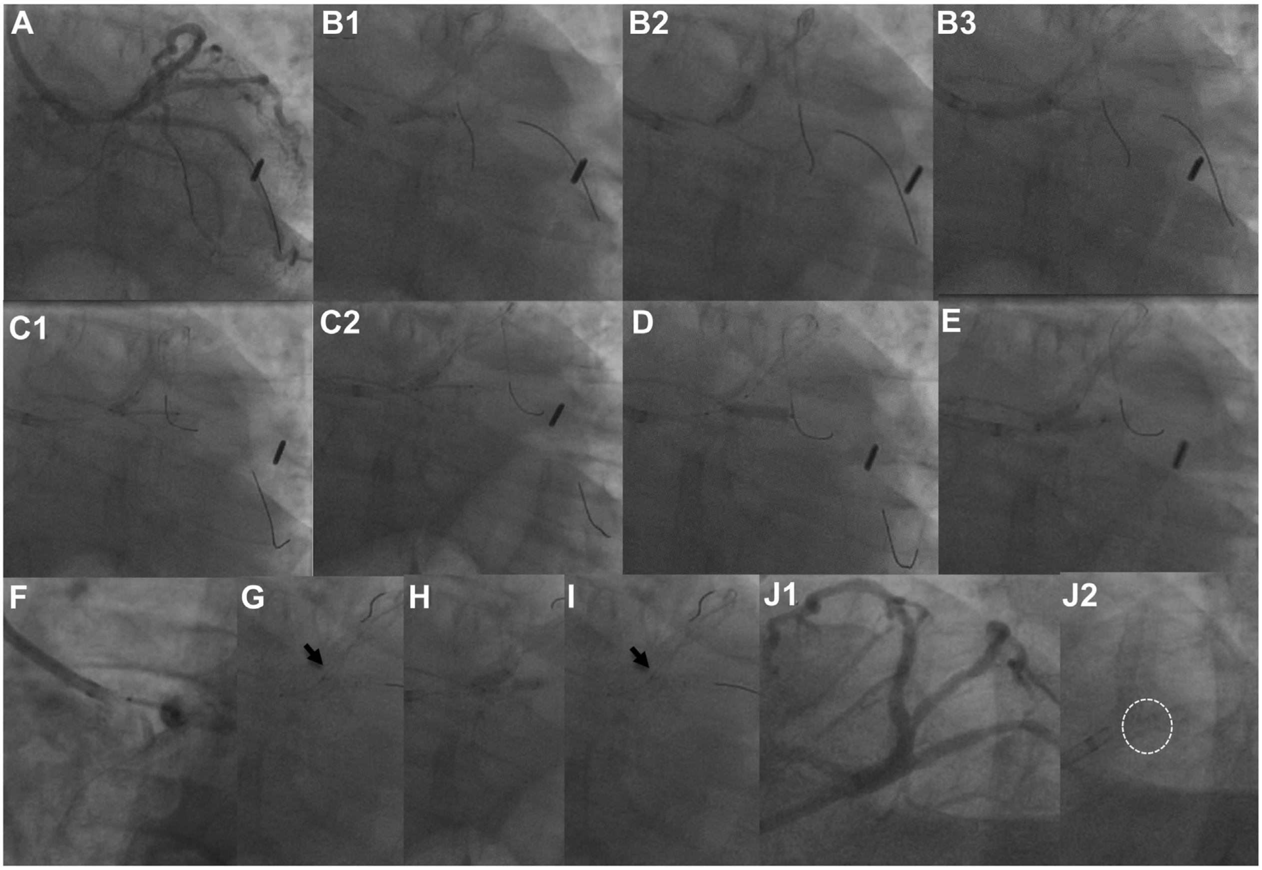


Figure 7.
Case 2. Detailed stepwise angiographic imaging of the balloon-assisted double-kissing T-stenting technique. (**A**) Severe and calcified distal LM Medina 1.1.1 bifurcation, with a nondisease diagonal branch. The angle between the LAD and the LCX is shallow (lower than 60°). (**B1-B3**) Sequential ballooning of the LCX, LAD, and LM with good balloon expansion. (**C1-C2**) Balloon-assisted positioning of the SB stent with balloon in MB sized to LAD: stent too distal in **C1** and optimal in **C2**, with minimal protrusion of proximal stent struts proximal to the carina. (**D**) SB stent deployed. (**E**) First KBI, keeping proximal opening of the stent crowns. (**F**) Delivery and deployment of MB stent. (**G**) After MB stent delivery with the LCX stent delivery balloon left in place (bumper effect) (not shown here), LCX gear removed and MB stent deployed. (**G**) First POT (showing deflated balloon with marker just proximal to carina (black arrow). (**H**) Second KBI. (**I**) Re-POT. (**J**) Final result with increased density of the ostium of the proximal SB on the carina and opposite sites (white circle) believed to be the result of the intentional accordion-like collapse of the proximal SB stent crowns. KBI, kissing balloon inflation; LAD, left anterior descending; LM, left main; LCX, left circumflex; MB, main branch; POT, proximal optimization technique; SB, side branch.

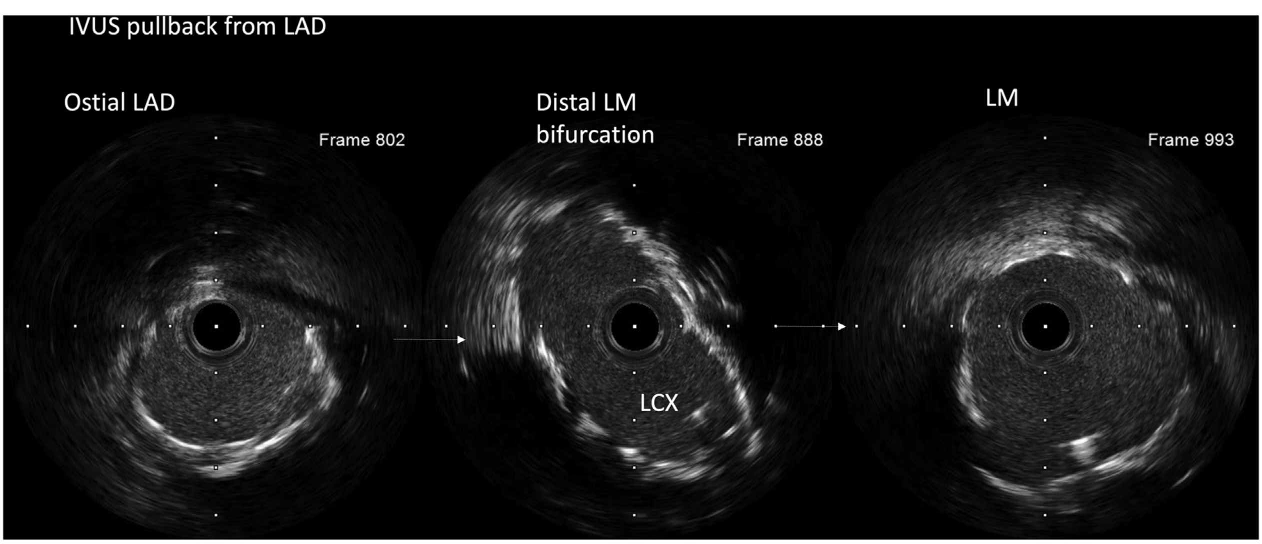


Figure 8.
Case 2. IVUS still frames of pullback images from the LAD and the LCX showing optimal opening of SB stent struts and coverage. IVUS, intravascular ultrasound; LAD, left anterior descending; LCX, left circumflex.

Table 1. Biomechanical and technical advantages of the balloon-assisted double-kissing T-stenting (DKT) stenting technique compared with other 2 stent techniques.

	DKT	DK crush	Culotte	Minicrush	Nanocrush	DK nanocrush	TAP	Provisional T-stenting	Classical T-stenting
SB stenting first technique	Yes	Yes	Not always	Yes	Yes	Yes	No	No	Yes
Suitable for all MB to SB angles	Most	No[a]	Yes	Yes	Yes	Yes	No[b]	No	Yes
Allow use of all stent diameters	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Balloon-assisted optimal positioning of SB stent and delivery of MB stent	Yes	No	No	No	No	No	Yes	Possible	No
Proximal SB crowns pushed inward by the stent deployed in MB (intentional accordion-like effect)	Yes	No	No	No	No	No	No	No	Not always
Crush of the SB proximal crowns closing the opening of the stent	Unlikely	Yes	No	Yes	Minimal	Minimal	No	No	Unlikely
SB stent crowns supporting the ostium (as opposed to opened stent cell)	Yes	No	Yes	Not always	Not always	Yes	Yes	Yes	Not always
Recrossing with wire through side struts	1 time	2 times	2 times	1 time	1 time	1 time	1 time	1 time	1 time
Risk of rewiring subintimal in a dissected SB ostium	No	Yes[c]	Yes[d]	No	No	No	Yes	Yes	No
Partial stenting of proximal SB with main stent crowns	Yes[e]	Possible	No	Possible	Possible	No	No	Yes	Yes
Risk of noncoverage of SB ostium next to the carina	Minimal	Yes	No	Yes	Yes	No	No	No	Yes
Risk of metallic neocarina	Minimal	Minimal	No	Minimal	Minimal	Yes	Yes	Minimal	Minimal
Overlap of metal and drug	Minimal	+	+++	+	Minimal	++	+	Minimal	Minimal
Risk of deformation with final POT	Minimal	Minimal	Minimal	Minimal	Minimal	Yes[f]	Yes[f]	Minimal	Minimal
Risk of deformation with final IVUS assessment	No	No	No	No	No	Yes[g]	Yes[g]	No	No

IVUS, intravascular ultrasound; MB, main branch; POT, proximal optimization technique; SB, side branch; TAP, T-and-protrusion.
[a] Higher risk of noncoverage of carina with open angles. [b] Risk of long neocarina with narrow angles. [c] If first wire recross is performed too distal in the branch. [d] After first stent delivery. [e] If narrow angle between branches, main stent struts compensate for lack of coverage proximal by SB stent. [f] May convert neocarina into an internal crush if performed too distal. [g] May deform the metal at the carina by the IVUS catheter in the MB.

We believe balloon-assisted DKT offers several advantages over commonly used 2-stent techniques. DK crush was designed to improve success of SB access and final KBI, steps that are more difficult with single final KBI crush techniques. DK crush gained popularity following trials that showed its superiority over classical crush and provisional stenting.[8,9] DK crush was also associated with better outcomes compared with culotte technique in LM bifurcations.[10,11] The favorable results with DK crush may be due to higher rates of final KBI with DK crush compared with other techniques (99% vs 80%-85%).[12,13] However, DK crush has limitations related to the time and complexity of executing all the steps required.[1] In addition, DK crush requires 2 distinct SB wiring techniques. The first wire recross needs to be performed proximally to avoid crushing metal away from the carina, a course unfortunately difficult to predict. The final wire recross prior to the final KBI however needs to be done from a distal cell, to open the MB stent crowns away from the carina. Failure to understand these nuances may lead to an excess in metal overlap or to asymmetrical stent distribution at ostium and decreased drug or metal support at the carina level. Moreover, despite a perfectly executed DK crush, the SB ostium remains supported by some SB stent cells instead of complete crowns. SB stent cells versus crown scaffolding of the SB ostium in DK crush may reduce radial strength, increasing risk of recoil and restenosis.[14]

New crush techniques, such as the nanocrush and DK nanocrush are not adequate for all anatomies and may result in the same final 2-stent architecture as the DK crush or with a long neocarina after DK nanocrush.[15,16] The culotte technique is also commonly used[17] but harbor limitations of less favorable outcomes compared with those of DK crush, with a double layer of stents in the MB. DK culotte is considered the bailout technique of choice when a provisional stenting approach must be converted to a 2-stent strategy[1] but can only be considered when the MB and SB have similar diameters. Moreover, animal models suggest that culotte techniques have high rates of malapposition and thrombogenicity in the proximal MB, attributable to implanting 2 layers of metal, drug, and polymer.[18,19] The classical T-stenting and TAP techniques are MB stent-first techniques, and both can be easily completed by most operators. Although the principal advantage of T-stenting and TAP is the support of the SB ostium by full stent crowns instead of opened stent cells, both techniques are prone to either geographical miss (classical T-stenting) or creation of a long neocarina from the SB stent in the MB (TAP). If POT is performed, it must be meticulously done following TAP to avoid crushing the SB stent extending into the MB stent. Even intracoronary imaging post-TAP, especially on the MB wire, can theoretically distort the neocarina. These technical pitfalls may have contributed to worse outcomes of T-stenting and TAP compared with those of DK crush or culotte in recent trials.[2,4,12]

The balloon-assisted DKT offers the advantage of minimal stent overlap, potentially reducing the risk of stent thrombosis.[18–20] The technique is also simpler to execute, involving only 1 recross into the SB. As opposed to DK crush, the SB ostium is supported by full stent crowns (potentially reinforced with crowns intentionally accordioned together) instead of an open cell, preserving the axial force of the SB stent. Risk of noncoverage of the SB at the carina level is minimal compared with that of crush techniques. Compared with that of classical T-stenting, the risk of geographical miss is minimized with DKT with the use of the MB balloon for positioning instead of contrast guidance. Bifurcation PCI characteristics of commonly used techniques are compared in Table 1.

The DKT bifurcation strategy also has limitations. The first is a risk of missing coverage of the ostium with a too deep positioning of the SB stent, especially when enough contact is seen between the proximal edge of the stent and the balloon, but the view foreshortens the carina. The second is the risk of a too proximal implant of the SB stent, leading to minicrush, full crush, or creation of a neocarina. Whether the advantages of DKT over other 2-stent techniques are enough to offset the potential risk of incomplete SB coverage remains to be demonstrated clinically. To reduce the risk of incomplete SB coverage, proper understanding of best angles to assess bifurcations is key.[7] Confirmation on angiography of the absence of branch overlap or Mach effect is also critical. In cases where the actual position of the ostium of the SB remains unclear despite several sequential MB balloon inflations and change of views, operators should allow the SB stent to protrude more generously into the MB, resulting in a minicrush instead of incomplete SB coverage.

Although we showed feasibility in narrow angles, the technique performed in bifurcation with sharper angles may be more challenging. Despite achieving an intentional concertina effect at the SB ostium during bench tests and in vivo cases, more classic crushing of the SB stent will occur in some cases despite optimal viewing. Moreover, depending on the position of the wire through the main stent struts to the SB prior to the final KBI, a short neocarina can be formed, especially when the wire recrosses too proximal. It did not occur in our bench model and the 2 cases, but a longitudinal view of the IVUS runs would have been more convincing. Nevertheless, the architecture can still be optimized with a final KBI. We only report acute outcomes of 2 LM cases, and balloon-assisted DKT applicability to non-LM bifurcation needs to be assessed. Although high-definition IVUS provides good assessment of stent interaction and vessel coverage, optical coherence tomography would have provided better understanding of the final architecture. Further research is needed to confirm what we noticed about the metal interaction between the 2 stents with this technique and to establish the clinical efficacy of the DKT technique compared with other commonly used bifurcation stenting methods.

Conclusion

The DKT bifurcation technique is an evolution of the SB first T-stenting technique that combines strengths of DK crush and culotte techniques. It relies mostly on balloon assistance for positioning and delivering stents rather than angiography and is easy to execute. In vitro testing and early clinical experience suggest that DKT produces effective MB and SB stent coverage and scaffolding. Clinical studies are needed to compare the efficacy of DKT with other popular 2-stent bifurcation techniques in selected higher-complexity bifurcation lesions.

Declaration of competing interest

Louis Verreault-Julien has no relationship with industry. Stéphane Rinfret reports being a consultant for Medtronic and Teleflex. Kevin Croce reports being a consultant for Boston Scientific, Abbott, Teleflex, CSI, Abiomed, Takeda, and Philips. Boston Scientific only provided images of the stents from the model used by the authors for this publication. Boston Scientific does not endorse any specific techniques used in bifurcation stenting.

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Ethics statement and patient consent

Institutional review board approval was not required because there is no identifiable information in this article.

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