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When are two stents needed? Which technique is the best? How to perform?

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Six randomised trials have been performed comparing a provisional stenting approach of implanting one DES on only the main branch (MB) vs. an elective double stenting approach of implanting a DES on both the MB and side branch (SB) of the bifurcation.[1-6] None of these studies showed a clear advantage for routine double stenting over a provisional strategy of MB stenting with only balloon angioplasty of the SB, as regards to restenosis in the main or side branches or in repeat bifurcation revascularisation. One may thus ask if we still need to learn and teach double stenting techniques which are certainly more complex, time-consuming and expensive than provisional stenting. On the other hand, it may be justified to question the generalisation of these randomised trials to all patients with bifurcation disease. In these trials, operators randomised bifurcations that had a high likelihood of having an acceptable result with the provisional technique. Indeed, patients with complex bifurcation anatomy such as large SBs with severe disease extending more than a few mm from the ostium were not well represented in these trials.[7] While we strongly agree that the provisional approach of implanting one stent on the MB should be the default approach in most bifurcations lesions; we do believe that there is still a need for an individualised approach to bifurcation PCI and that two stents are still needed in 20-30% of true bifurcations unless located on the left main coronary artery where this percentage may be higher.[8,9] In addition we do not know how many patients did not enter the randomised trials because they had a bifurcation disease more suitable for two stents: this number needs to be considered as well. In this review we describe which bifurcations require two stents, the most commonly used bifurcation techniques in order of our preference, their anatomic indications as well as the advantages and disadvantages, and a practical description of technique execution.

When are two stents needed?

Correct patient selection for elective double stenting requires accurate assessment of lesion severity, distribution, extension, and presence of concomitant disease.[7] The decision to perform double stenting depends predominantly on the SB and should generally be reserved for true bifurcations with SBs that (Figure 1):

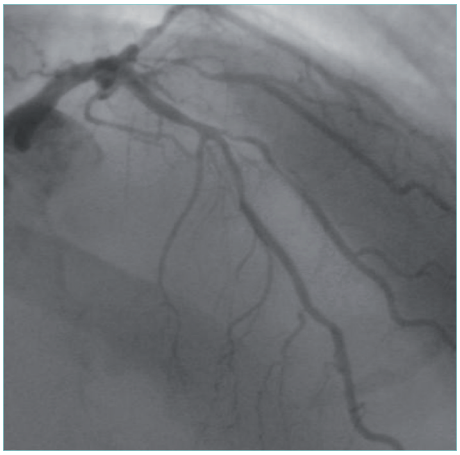

Figure 1. An angiographic example of a true bifurcation (Medina 1,1,1 with a SB >2.5 mm and disease extending more than 10 mm from the ostium) which we believe requires elective double stenting and that has not been well represented in the randomised bifurcation trials.

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– are relatively large in diameter (>2.5 mm) and territory of distribution
– have severe disease that extends well beyond the ostium (10-20 mm or more)
– have an unfavourable angle for re-crossing after MB stent implantation.

We do not consider these variables in isolation, but there is usually a combination of these factors present that dictates the decision to electively perform double stenting. The only situation, in which we would perform double stenting as intention-to-treat for a non-true bifurcation with a non-diseased ostium, is if there is distal disease close to the ostium that can be covered by a long stent from the MB. We should emphasise that the decision to implant a second stent may also be made at an intermediate time, such as after wire insertion that may favourably modify the bifurcation angle or following predilatation of the MB and SB. However, a timely taken action will affect the result, help save time and cost, and lower the risks of complications.

Which technique is the best?

There are limited data comparing different double stenting bifurcation techniques and there is no unequivocal evidence demonstrating the superiority of one technique over others. The Nordic Stent Technique Study is the only randomised trial comparing two different double stent techniques that result in complete coverage of the SB ostium. In this study, 424 patients were randomised to either crush or culotte stenting utilising sirolimus-eluting stents (77% of which were true bifurcation lesions).[10] At 6-months clinical follow-up, there were no significant differences between the two groups in terms of death, myocardial infarction or revascularisation (crush 4.3% vs. culotte 3.7%, p=0.87). Procedure and fluoroscopy times and contrast volumes were also similar in the two groups. However, there was a trend for higher incidence of periprocedural MI (crush 15.5% vs. culotte 8.8%, p=0.08). Angiographically, there was a trend toward less in-segment restenosis (6.6% vs. 12.1%; p=0.10) and significantly reduced in-stent restenosis following culotte stenting (4.5% vs. 10.5%; p=0.046). The relevance of this angiographic finding is unclear and may be explained by the lower rate of final kissing inflation (FKI) in the crush group (85% vs. 92%; p=0.03) as well as the lack of the 2-step FKI when performing crush stenting.

Thus, in the absence of strong evidence demonstrating the superiority of a specific technique in improving clinical outcomes, the selection of double stenting technique is based on the stability of the patient, the anatomy of the bifurcation and the familiarity and competence of the operator with a specific technique. Important anatomical factors that need to be considered include the diameter of the two branches (similar or discrepant), bifurcation angle, extent of disease in the MB proximal to the carina, severity of the ostial SB stenosis (does it require aggressive pre-dilatation), presence of dissection in MB or SB after predilatation. We strongly believe that optimal performance of a double stenting technique and optimisation of the final result is more important than which technique is selected, and this is what determines clinical outcomes. An example is the importance of FKI in reducing late loss and restenosis, especially at the SB ostium, which has been repeatedly demonstrated and has now become standard in the performance of all two stent techniques[11,12]. There are other important technical factors that may contribute to optimising outcomes when performing two stent techniques such as high pressure SB inflation, the use of non-compliant balloons, selection of correct balloon size for FKI and the use of intravascular ultrasound (IVUS).[9]

How to perform?

In this section, we will describe how to perform and select patients for all the currently utilised techniques for elective double stenting. We would once again stress that it is not only the specific technique used but rather the meticulous attention to performing the procedure that is important in ensuring success and improving long-term results.

The culotte technique

The culotte technique provides near-perfect coverage of the carina and SB ostium at the expense of an excess of metal covering the proximal end.[13] It will give the best immediate angiographic result and theoretically it may guarantee a more homogeneous distribution of struts and drug at the site of the bifurcation. This technique can be used in almost all true bifurcation lesions irrespective of the bifurcation angle. The only anatomic limitation to the culotte technique is when there is a large mismatch between the proximal MB and SB diameters due to the risk of incomplete SB stent apposition to the proximal MB. Open-cell stents are preferred when the SB diameter is >3 mm because with some closed-cell stents such as the Cypher (Cordis Corp., Johnson & Johnson, Warren, NJ, USA), the intra-strut opening toward the branches may only reach a maximum diameter of 3 mm. The main disadvantage of the technique is its complexity in that rewiring of both branches through the stent struts is required, which can be technically demanding and time-consuming and thus we do not suggest this technique if both branches are dissected after pre-dilatation.

Technique description – Can be performed with a 6 Fr guiding catheter (Figure 2)

a) Both branches are wired and pre-dilated.
b) A stent is deployed across the most angulated branch, usually the SB.
c) The non-stented branch is rewired through the stent struts and dilated.
d) A second stent is advanced and expanded into the non-stented branch, usually the MB.
e) Finally, kissing balloon inflation is performed. When performing the kissing inflation, we prefer using non-compliant balloons and dilating each limb of the culotte at high pressure (≥16 atm) individually before simultaneously inflating both balloons at 8-12 atm.

Although the culotte technique may be technically more challenging than other techniques, there are a number of factors that can facilitate its successful performance. When rewiring the other branch after stent placement, we always first place the guidewire distal into the stented branch to be sure that we have not passed under the stent struts before re-crossing into the branch. In performing the culotte technique, we recommend stenting the branch with the sharpest angle first. This has the advantage that re-crossing stent struts into the less angulated branch will be easier as will passing the

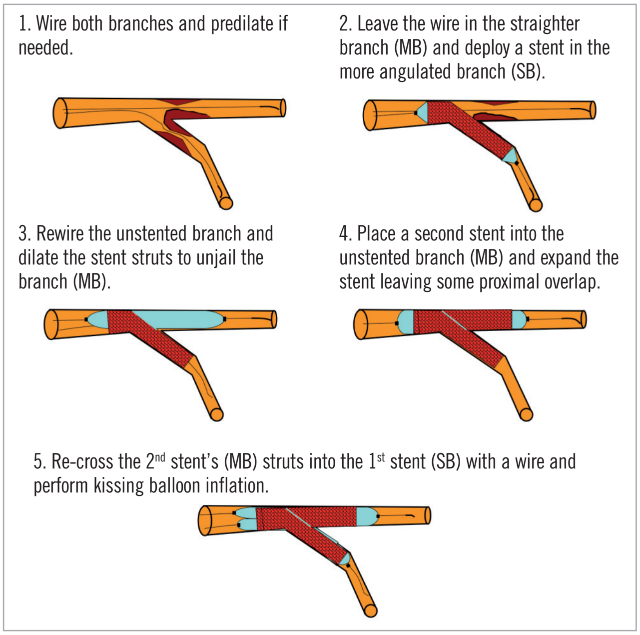

Figure 2. A schematic representation of the culotte technique.

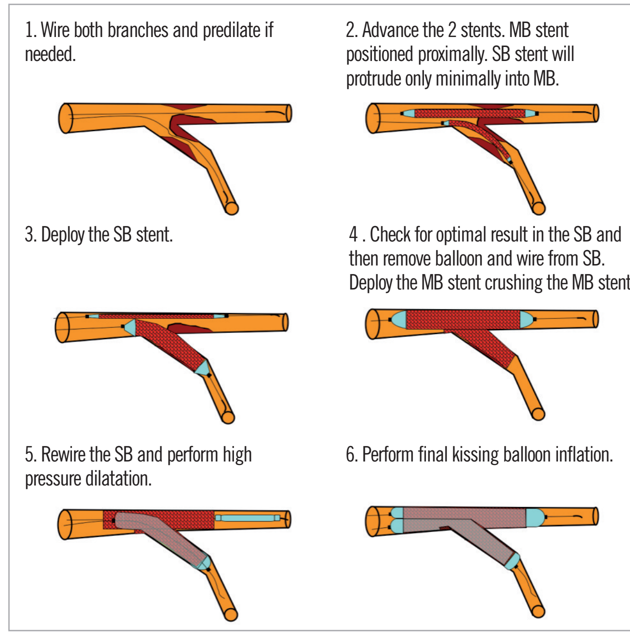

Figure 3. A schematic representation of the mini-crush technique.

second stent through stent struts into a less angulated branch. However, this conventional practice has recently been challenged in the Nordic Stent Technique Study, where the authors recommended stenting of the MB first to avoid acute closure of the MB.[10] This approach guarantees patency of the MB and may avoid one of the potential problems of performing the culotte technique where we always need to remove the wire from one of the two branches and patency of this branch is not guaranteed. It is for this reason we prefer not to perform the culotte technique if there is a dissection in both branches after pre-dilatation.

The mini-crush technique (SB stent crushed by the MB stent)

The main advantage of the crush technique is that immediate patency of both branches is assured and therefore it should be applied in conditions of instability or when the anatomy appears complex.[1] This objective is notably important when the SB is functionally relevant or difficult to wire. In addition, this technique provides excellent coverage of the ostium of the SB. This technique can be used in almost all true bifurcation lesions but should be avoided in wide angle bifurcations. The main disadvantage is that in order to perform FKI, there is the need to re-cross multiple struts with a wire and a balloon. However, only the SB has to be re-wired and not both branches as in the culotte technique. The crush technique has evolved and is nowadays performed with less stent protrusion into the MB (i.e., mini-crush) and mandatory 2-step FKI.[14,15]

Technique description – Requires a 7 or 8 Fr guiding catheter (Figure 3)

a) Both branches are wired and fully dilated.
b) The SB stent is positioned in the SB and then the MB stent is advanced.
c) The SB stent is pulled back into the MB about 1-2 mm and is verified in at least two projections.
d) The SB stent is deployed at least at 12 atm. The balloon is deflated and removed from the guiding catheter. An angiogram is taken to verify that the SB has an appropriate lumen, normal flow and that no distal dissection or residual lesions are present. If an additional stent is needed in the SB, this is the time to implant it. Following this check, the stent in the MB is fully deployed at high pressure, usually above 12 atm. An angiogram is taken following removal of the balloon from the MB. When we use this technique we keep only a single indeflator on the table which is connected to the SB stent. This will prevent inadvertent deployment of the MB stent first, thereby crushing the undeployed SB stent.
e) Re-wire SB. It is important to perform a two-step FKI. First we suggest a dilatation of the stent towards the SB with a balloon appropriately sized to the diameter of this branch and inflated at high pressure (16 atm or more), then FKI with a second balloon in the MB with an inflation pressure about 8-14 atm in both balloons.

Step crush

When there is the need to perform the mini-crush technique and a 6 Fr guiding catheter is the only available approach (radial approach), the “step crush” or “the modified balloon crush” techniques can be used. The final result is basically similar to that obtained with the standard crush technique, with the only difference that each stent is advanced and deployed separately. Another modification of the step crush is when reverse crush stenting needs to be performed as a crossover from provisional SB stenting. The need for a 6 Fr guiding catheter is the only reason to utilise this technique.

Technique description

a) Both branches are wired and fully dilated.
b) Stent is advanced in the SB protruding a few millimetres into the MB. A balloon is advanced in the MB over the bifurcation.

c) Stent in SB is deployed, the balloon removed, an angiogram is performed, and if the result is adequate the wire is also removed.
d) MB balloon is then inflated (to crush the protruding SB stent) and removed.
e) A second stent is advanced in the MB and deployed (usually at 12 atm or more).
f) The next steps are similar to those of the classical crush technique and involve re-crossing into the SB, SB stent dilatation and 2-step final kissing balloon inflation.

An important change in the classical crush technique is that we now try to limit the area of crush stenting and multiple layering of stent struts by performing a mini-crush. The mini-crush may be associated with more complete endothelialisation (and theoretically less stent thrombosis) and easier re-crossing of the crushed stent. Finally, the bifurcation angle may be an important factor to be considered when performing the crush technique. When the angle between the MB and SB is closed to 90°, it is possible to minimise the gap even without crushing the SB stent and utilising the modified T technique. Furthermore, a bifurcation angle B ≥50° between the two branches has been suggested as an independent predictor of MACE after crush stenting.[16] There have been many modifications of the crush technique and one worth mentioning is the double kissing (DK) crush technique. This technique is a modification of the step crush where balloon kissing inflation is performed twice: firstly after the SB stent is crushed by the MB balloon and then the routine FKI at the end of the procedure. DK crush may result in less stent distortion, improved stent apposition, and facilitate FKI. This technique may be superior to the classic crush technique in optimising acute procedural results and possibly also improves clinical outcomes by facilitating FKI in all patients.[17] It has also recently been studied in the DK-CRUSH-II trial which randomly assigned 370 true bifurcations to treatment with either the DK crush or provisional stenting.[18] Interestingly, this is the first and only randomised trial to suggest that double stenting may be superior to provisional stenting and associated with a lower rate of restenosis and repeat revascularisation.

T- and modified T-techniques

The T-technique is the most frequently utilised to crossover from provisional stenting to stenting the SB and is most suited to bifurcations where the angle between the branches is close to 90°. This technique is less laborious than the crush or culotte technique. In our view the T-technique is associated with the risk of leaving a small gap between the stent implanted in the MB and the one implanted in the SB. This gap may be a factor contributing to an uneven distribution of the drug, hence leading to ostial restenosis at the SB. For this reason, this technique has largely been replaced by the modified T-stenting technique. Currently, we rarely perform the classical T-technique in our practice, and in our opinion there are two reasons to perform the classical T-technique: 1) to place a stent at the ostium of a SB after placement of a stent in the MB because the result at the SB ostium was unsatisfactory (provisional SB stenting). In this situation we have replaced the classical T-technique with the TAP (T and Protrusion), and 2) to perform stenting at the ostium of the SB when there is isolated SB ostial stenosis (e.g., T-balloon stenting).

Classical T-technique description

a) Position a stent first at the ostium of the SB, being careful to avoid stent protrusion into the MB while at the same time trying to minimise any possible gap.
b) Deploy the stent and remove the balloon from the SB (keep the wire in the SB).
c) Advance and deploy the MB stent.
d) Re-wire the SB and then remove the jailed wire.
e) SB balloon dilatation and FKI.

The above description of T-stenting describes the situation in which the operator decides to stent the SB first. However, in majority of cases, the T-stenting technique is performed after MB and provisional SB stenting for a suboptimal result or flow-limiting dissection in the SB.

Modified T-technique (Figure 4)

Modified T-stenting is a variation performed by simultaneously positioning stents at the SB and MB with the SB stent minimally protruding into the MB, when the angle between the branches is close to 90°. The SB stent is deployed first, and then after wire and balloon removal from the SB, the MB stent is deployed. The procedure is completed with FKI.

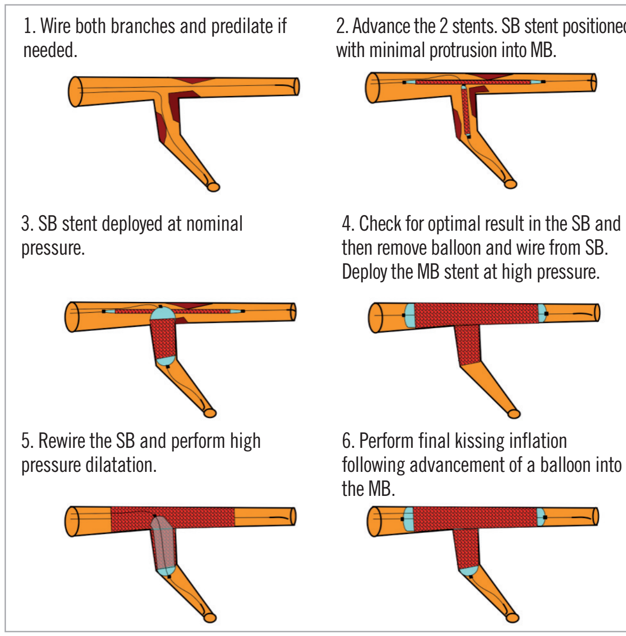

Figure 4. A schematic representation of the modified T-stenting technique.

The V and the simultaneous kissing stent (SKS) techniques

The V and the SKS techniques are performed by delivering and implanting two stents together.[19,20] One stent is advanced into the SB and the other into the MB. Both stents are pulled back to create a new carina as close as possible to the original one. When the two stents protrude into the MB with the creation of a double barrel and a very proximal carina, the technique is called SKS.[20] The main advantage of these techniques is that access to both branches is always preserved during the procedure with no need for rewiring any of the branches. V-stenting is relatively easy and fast and thus ideal in emergencies. In addition when FKI is performed there is no need to re-cross the SB stent. V-stenting is ideal for Medina 0,1,1 bifurcations with a large proximal MB that is relatively free from disease and with a <90° angle between both branches. We reserve this technique for patients with a short left main coronary artery (LMCA) free from disease and critical disease of both the LAD and LCX ostia. There are several limitations for this technique that need to be considered: a) the possibility of balloon barotrauma to the proximal MB during stent deployment or post-dilatation which can lead to dissection, progression of disease, or proximal edge restenosis; b) if a proximal stent becomes necessary to treat a proximal dissection there is almost always the risk of leaving a small gap and the stent needs to be directed towards one of the two arms of the V; c) if restenosis occurs in the neo carina or at the proximal stent edge it would require converting to the crush technique for treatment which would make re-crossing into the branch covered by the crushed stent potentially challenging as four layers of stent struts will need to be traversed; d) if disease distal to the V-stenting or SKS site needs to be treated at follow-up, rewiring the stented vessels may be complicated by wire passage behind stent struts. Interestingly, a modified V-technique with two stents deployed together on the SB and distal MB and a stent (manually crimped onto two balloons) placed in the proximal MB was the first double stenting technique utilised for coronary bifurcations.[21]

Technique description – requires an 8 Fr guiding catheter (Figure 5).

a) Both branches are wired and fully pre-dilated.

b) Two stents are positioned into the branches with a slight protrusion of both stents into the proximal MB. Different operators allow a variable amount of protrusion creating sometimes a rather long (5 or more mm) double barrel in the proximal MB (SKS). While we recognise that it is impossible to be so accurate in positioning the stents exactly at the ostium of each branch we generally try to limit the length of the new carina to less than 5 mm. Sometimes it is necessary to advance the first stent more distally into the vessel to facilitate the advancement of the second stent. This manoeuvre is essential when the kissing stent technique is used to stent a trifurcation using three kissing stents (need of a 9 Fr guiding catheter). Following accurate stent positioning it is important to verify their correct placement in two projections before deploying the stents.

c) Each stent is deployed individually at high pressure of 12 atm or more. Some operators prefer deploying the stents simultaneously. When the stents are deployed simultaneously the operator needs to be aware of the risk of proximal MB dissection. This can be avoided by using lower deployment pressure.

d) Perform high pressure sequential single stent post-dilatation followed by medium-pressure FKI with short and noncompliant balloons. Balloon sizes are chosen according to the diameter of the treated vessels. In the event that the reference vessel size proximal to the bifurcation is relatively small, FKI should be performed using low pressure inflation to avoid proximal dissection.

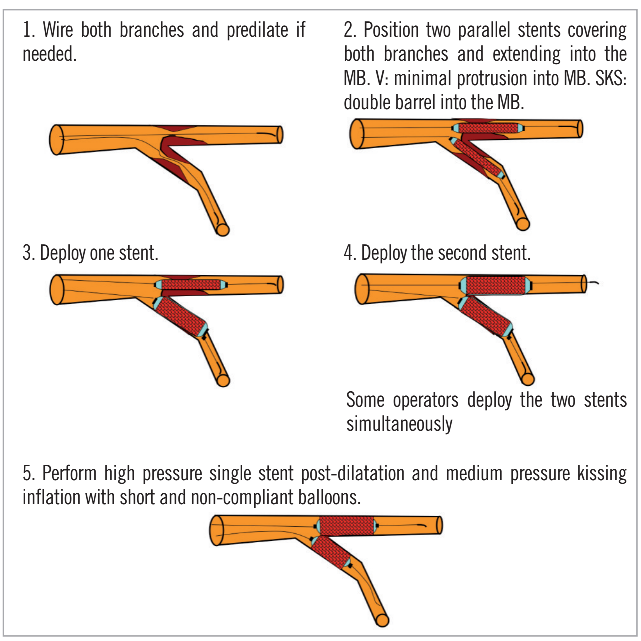

Figure 5. A schematic representation of the V-stenting technique.

Proponents of the SKS technique assert that this technique can be performed even if the LMCA is long and has significant disease that extends into the bifurcation. They also suggest that the SKS is preferred when the LMCA is very large resulting in a significant diameter mismatch with the LAD and LCX, as this technique will ensure apposition and full coverage of the large LMCA with drug. In our experience, we have found that we have not had difficulty in performing the other 2-stent techniques in large LMCA and ensuring good stent apposition with IVUS guidance and FKI. The SKS technique results in a new metallic carina quite proximally into the LMCA. We do not know at present what the long-term outcome risks are of leaving this exposed double stent layer in a vessel when utilising DES. There have been case reports describing a thin diaphragmatic membranous structure at the new carina (at the level of the kissing struts) resulting in an angiographic filling defect. Other than producing a very distressing angiographic appearance, the exact long-term significance and relation to adverse advents of this membrane is not known.[8]

Difficult access to the SB or MB after stenting

Access to the SB is one of the greatest challenges in bifurcation PCI. Difficult access to the SB or MB can occur either at the start of the procedure or after SB or MB stenting. Difficulty may occur in re-crossing the stent struts with a guidewire or advancing a balloon through the stent struts. We would like to address the problem of rewiring and advancing balloons into one of the branches after having stented the other branch (MB or SB), which is often the greatest difficulty with double stenting techniques such as the mini-crush or even culotte. In our experience, re-crossing into the SB through the MB stent struts or vice versa is usually possible using the Rinato-Prowater wire (Asahi Intecc Co Ltd, Nagoya, Japan/Abbott Vascular Devices, Redwood City, CA, USA). In difficult situations, we have also successfully used the Pilot 50 and 150, (Abbott Vascular Devices, Redwood City, CA, USA/Guidant Corporation, Santa Clara, CA, USA), Fielder FC or Miracle 3/4.5 gm (Asahi Intecc Co Ltd, Nagoya, Japan/Abbott

Vascular Devices, Redwood City, CA, USA) wires. However, we are very cautious about using hydrophilic guidewires when re-crossing into the SB due to the risk of wire induced dissection and perforation. The jailed wire in the branch should always be left in place as a marker until complete re-crossing has been done. After having re-crossed into the branch with a guidewire, there may subsequently be great difficulty advancing a balloon through the struts in order to dilate them. We frequently try first to cross through the stent struts with the smallest balloon we have on the table. If this balloon fails, we then use a Maverick (Boston Scientific, MA, USA) 1.5 mm diameter balloon to separate struts and allow a larger balloon to pass. If the 1.5 mm balloon cannot cross we consider re-crossing with a second wire while the first wire remains in place to traverse the stent struts in another spot. If balloon insertion through the strut still proves impossible, the stent should be further dilated. Another attempt should be made with a 1.5 mm coaxial balloon. Another tip that sometimes works is to advance the balloon as close as is possible to the stent struts, inflating the balloon to at least 12-14 atm for 20 seconds, and while deflating the balloon to attempt advancing it further. Repeating this manoeuvre can often result in the balloon being slowly advanced through the stent struts.[8,9] If it still proves impossible to re-cross into the branch, another technique that we have used is to try to pass a 1.5 mm balloon over the jailed wire behind the stent struts, in order to either: a) re-dilate a sub totally occluded or dissected branch ostium and then try again to pass the stent struts with a guidewire; or b) to convert the procedure into a reverse crush.

Final kissing inflation (FKI) after double stenting

A special mention needs to be made of the importance of FKI when implanting two stents in a bifurcation. FKI is important to correct stent distortion and expansion[22] especially in fully expanding the stent in the proximal MB where the diameter is usually much larger, providing better scaffolding of the SB ostium, and facilitating future access to the SB. FKI has been repeatedly demonstrated to reduce late loss and restenosis, especially at the SB and has now become standard in the performance of all double stenting techniques.[1,11,12,23] Indeed, a sub analysis of the CACTUS trial showed that FKI was associated with a better angiographic result and lower MACE rate when complex stenting was performed, and similar results were observed when using a more simple provisional SB stenting technique.[1]

It is very important to perform the so called “two-step kissing inflation” which consists of high pressure balloon inflation in the SB before performing the true FKI at medium pressures. Ormiston et al have recently demonstrated through imaging of bench deployments that a) traditional one-step kissing post-dilation leaves considerable residual metallic stenosis that may not be visible on angiography and may predispose to thrombosis because of eddy currents, stasis, altered shear stress, and foreign body presence; b) SB ostial coverage and residual stenosis by metal struts is significantly reduced by 2-step kissing inflation.[24] In performing FKI, it is critical to choose post-dilatation balloons of appropriate size; i.e., the kissing balloons should be the same size or larger than the deploying balloons to prevent stent distortion.[22] When performing FKI we inflate both balloons simultaneously and slowly which makes “melon seeding” less likely. We also deflate the balloons simultaneously to avoid distortion.

Conclusions

Although provisional SB stenting is the default strategy in majority of coronary bifurcations, elective double stenting is still required in about 20-30% of lesions. The decision to stent both branches is primarily dictated by the SB anatomy, i.e., severity and distribution of disease, angle, diameter and area of distribution. There is no conclusive evidence showing the superiority of one technique in all lesions and across all ranges of operator experience. The decision as to which technique to use should be based on bifurcation morphology and operator experience. Optimal performance of the technique and optimisation of the final result is compulsory to avoid complications and ensure favourable long-term results. In particular, FKI with appropriately sized noncompliant balloons is mandatory with all double stenting techniques. Finally, although not addressed in this review, the introduction of dedicated bifurcation stents may significantly change elective double stenting by facilitating certain techniques and thus making the procedure safer and shorter.

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