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# Provisional side branch stenting for the treatment of bifurcation lesions

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## Background

Since the advent of coronary angioplasty, treatment of bifurcation lesions has always proved a complex issue[1-4] resulting in lower angiographic success rates, higher complication rates and increased risk of restenosis. Therefore, the treatment of coronary bifurcation lesions is part of the history of coronary angioplasty and kissing balloon inflation for example was strongly recommended as early as the 80s.

Though the use of bare metal stents (BMS) and subsequently drug-eluting stents (DES) was instrumental in improving acute results, a number of difficulties still remained to be overcome. Many therapeutic strategies, techniques, tips and tricks have been proposed, some of them in contradiction with simple basic data; all this has made the topic of coronary bifurcation treatment one of the most debated issues in the field of interventional cardiology.

After the plain old balloon period and some unsuccessful attempts with atherectomy, the advent of stenting resulted in a high creativity by interventional cardiologists in the 90s[5]. However, among these strategies, the single-stent technique, i.e., stenting of the main branch (MB) with provisional side branch (SB) stenting, was associated with the most acceptable outcome[6-11].

The development of the DES brought about a very significant reduction in the risk of restenosis (Figure 1) and repeat intervention. As a result, surgery for patients with bifurcation lesions in large coronary vessels became obsolete. Therefore a lot of enthusiasm led certain teams to re-implement techniques which had been discredited in the BMS era and carry out new "very metallic" strategies[12-18].

Between 2000 and 2009, six randomised studies[19-24] as well as various meta-analyses[25-31] were performed, comparing complex techniques to provisional SB stenting approach. All have shown that there was no advantage in terms of SB efficacy to use complex techniques (Figure 2). On the other hand, the use of complex techniques was associated with an increased risk of myocardial infarction (mainly periprocedural), and a trend for a higher risk of

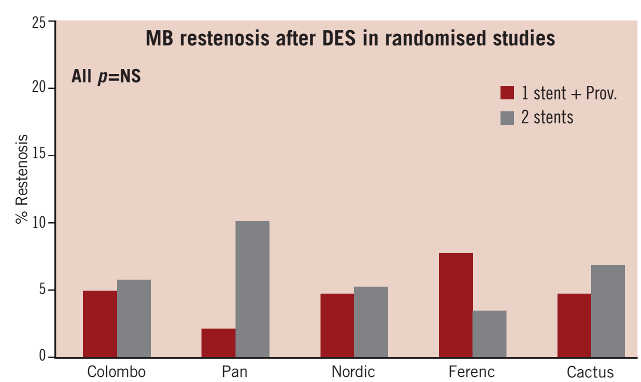


*Figure 1. Main branch restenosis rate in randomised studies were systematic angiographic follow-up was performed, comparing complex to provisional approach.*

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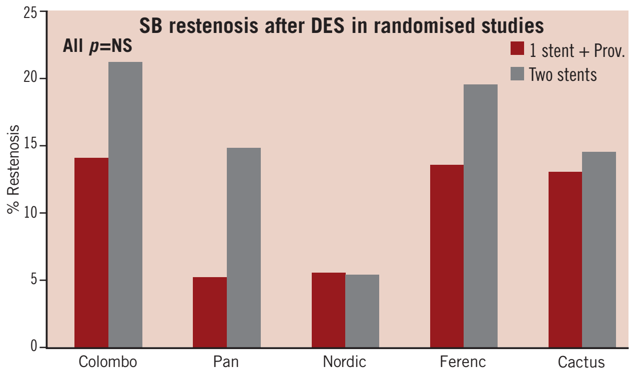


*Figure 2. Side branch restenosis rate in randomised studies were systematic angiographic follow-up was performed, comparing complex to provisional approach.*

stent thrombosis. This data applies to patients who were included in these randomised studies and it is interesting to see that the rate of cross-over from provisional to complex techniques varies from 5 to 30% in different studies suggesting that patients were probably not the same in all studies and confidence with the provisional approach was not the same in all centres.

Circumstances in which complex techniques are required as a primary option (SB stenting first), such as difficult SB access or long SB lesions are still a subject of controversy, as well as the choice of the optimal technique in such cases[32].

In all cases, it is important to keep in mind that the main objective is not only to achieve a good angiographic result, but also to avoid jeopardising the SB with potential non-Q AMI, or compromising the MB at long term by focusing on the achievement of a perfect result in the SB.

## Definition of provisional side branch stenting

Many techniques have been described in the literature. The MADS classification[5], adopted by the EBC in 2007 is an open classification based upon two principles: a definition of "generic" techniques according to the final positioning and aspect of stents at the end of the procedure, and strategic techniques, according to the position of the first stent deployed in the bifurcation.

Provisional SB stenting approach is an A technique (A for across the SB). This strategy was designed to meet the main objectives of bifurcation lesion treatment focusing on the MB whilst ensuring patency of the SB. This strategy consists in deploying a stent from the proximal segment to the distal segment of the MB. In some instances, due to technical (angles), or anatomical reasons (location of the tightest stenosis), or for reasons of myocardial viability, the stent is deployed from the proximal segment of the MB to the SB (inverted provisional).

The advantages of this strategy lie mainly in the "open" nature of this approach, the purpose of which is to perform an optimal treatment of the MB and coronary bifurcation with a single stent whenever possible. When necessary, a second stent can be deployed in the SB using the T or culotte implantation technique. This procedure can be easily carried out with a 6 Fr guiding catheter in the majority of cases.

The drawbacks of this technique are, on the one hand, the difficulty in ensuring permanent access to the SB, and on the other hand, potential problems in re-crossing the stent struts towards the SB or even in implanting a second stent in the SB after stenting the MB.

The relative simplicity of the provisional approach requiring a single stent in 80% to 90% of cases[33] and resulting in similar outcome compared with more complex strategies as demonstrated in randomised studies, has made this strategy the gold standard of bifurcation treatment even for the left main coronary artery as illustrated by the Syntax data[34].

## Basic principles

Considerable progress has been achieved recently in the understanding of fundamental aspects of coronary bifurcations in terms of flow pattern, shear stress, anatomopathology, physiology, bench testing and virtual bench testing. Knowledge of these aspects is fundamental to fully understand why provisional side branch stenting is the gold standard and how to do it easily.

### The 3-diameters

Ramifications of the coronary tree follow the rule of minimum energy cost in providing the underlying myocardium with the amount of blood required[35,37]. Therefore there are three segments in a bifurcation, each of which has its own reference diameter. The relation between the diameter of the proximal segment of the MB and the two distal segments is governed by the classical Murray's law ($Dprox^3=Ddist^3+Dside^3$). This complex formula[38] was recently simplified by Finet[39]: $Dprox=(Ddist+Dside)\times 0.678$. Consequently, the reference diameter of a coronary artery from its ostium to its distal segment does not taper following a linear pattern, but by steps, following the formation of a bifurcation.

### Carina is usually free of atheroma

Coronary bifurcation flow has specific characteristics. There is an acceleration of flow at the level of the flow divider with high shear stress (anti-atherogenic). Opposite to the carina, is an area of low shear stress were atheroma can grow-up[40,41]. This was confirmed by IVUS[42] and anatomopathologic studies. This may have an important impact on the strategy and technical approach when treating bifurcation lesions (Figure 3). For example, the risk of SB occlusion is mainly related to carina shifting (and not plaque shifting), when the MB stent size distal to the bifurcation is too large.

### Side branch lesions % stenosis are overestimated

As nicely shown by Koo et al[43], only 28% of SB stenosis >75% by QCA are physiologically significant (FFR <0.75). This information is very important, because the vast majority of lesions <75% by QCA does not need treatment, because they are not associated with ischaemia. The reasons for this poor angiographic performance are the non-circular shape of the SB ostium and the edge effect generated by angiography.

## Bench testing

The assessment of stents in bench tests has been essential in improving the comprehension of bifurcation stenting[44-48]. The first

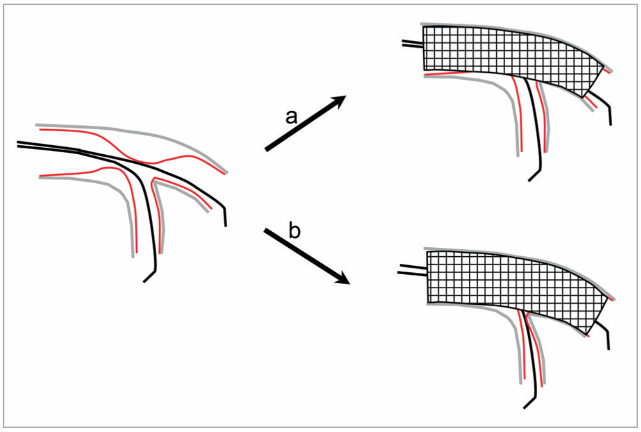


*Figure 3. Illustration of 1,1,0 left main bifurcation lesion. Option a, stent diameter selected according to distal MB reference. No carina shifting, but stent not fully apposed in the proximal MB. Option b, stent diameter selected according to proximal MB reference diameter. Severe carina shifting, but stent fully apposed in the proximal MB.*

benefit of bench testing was to show the distortion generated in the MB stent by the opening of a strut towards the SB, resulting in the projection of struts into the SB ostium and attraction of opposite struts in the main lumen. Various stenting techniques have been simulated in benches, allowing an accurate description of the inherent advantages and disadvantages of each technique. The second important information was the fact that opening a distal strut (close to the carina), gives better results in terms of SB ostial scaffolding than a proximal strut.

Currently, new available information shows that the flow is better when the struts are open toward the SB and also that kissing balloon inflation gives better results when it is done with short balloons, non-compliant balloon, that 30 second or more is better that 10 seconds and that it is better to inflate the MB first.

## What is a bifurcation lesion?

After years of fruitful discussion, the EBC finally reached a consensus: a bifurcation lesion is "a coronary artery narrowing occurring adjacent to, and/or involving the origin of a significant SB". A significant SB is a branch that you do not want to lose in the global context of a particular patient. The prognostic value of an SB occlusion depends on many factors such as size, length, viability of the myocardium perfused by the branch, the collateralising role of the SB, ventricular function and finally the threshold value defined by the interventional cardiologist himself.

Many bifurcation lesion classifications have been proposed, but today, the Medina classification[49] has become widely accepted. The three segments of a bifurcation generate also three angles: A (approach), between the proximal MB and SB; B (between), between the two distal branches, and C between the proximal and distal MB segments. Angle A defines the difficulty in accessing the SB. This angle, when >50°, can be significantly decreased by the insertion of a guidewire[50], which facilitate SB access after MB stenting. Angle B when small predicts independently the occurrence of SB occlusion after MB stenting[51].

## How to do the provisional approach?

### Optimal view is crucial during all the procedure

Coronary angiography provides the diameters and length of lesions located in the coronary bifurcation. Given the tri-dimensional structure of bifurcations, it is impossible to obtain a plane image of the three bifurcation segments without avoiding the foreshortening effect. Consequently, it is necessary to record several views from various angles in order to obtain a comprehensive picture of the lesion characteristics, to carry out the technical procedure appropriately and assess the procedural outcome.

The SB ostium poses the most frequent technical problems. It is rarely visualised adequately from two orthogonal views and may be explored from a single angle called "the working view". This view allows the visualisation of branch division as well as the measurement of angles and assessment of the degree of ostial SB stenosis. This is generally an RAO or LAO view with caudal inclination for the left main coronary artery, an anterior-posterior projection with marked cranial angulation for LAD-diagonal bifurcations, a slight RAO or LAO projection with caudal angulation for circumflex-proximal marginal bifurcations or cranial angulation for dominant distal circumflex coronary arteries and an antero-posterior projection with cranial angulation for distal right coronary arteries.

### One or two guidewires?

There are several advantages associated with the initial insertion of a guidewire in each branch. It may improve patency of the SB after MB stenting as suggested by Antonio Colombo. It is also a good marker of the SB origin in case of SB occlusion. In case of occlusion, it can also be used to reopen the SB by pushing a small balloon between the stent and the wall of the vessel.

The best way to avoid SB occlusion is too select the MB stent diameter according to the distal MB diameter in order to avoid carina shifting. Furthermore, the wire modifies angle A, thus facilitating guidewire exchange as well as balloon and stent advancement[50]. In the TULIP multicentre study[52], the use of only one wire when starting the procedure was a predictor of SB treatment failure and repeat intervention at six months.

### Should we pre-dilate the SB lesion or not?

Kissing balloon (KB) pre-dilatation is not recommended due to the risk of extensive dissection in unstented segments. Predilatation of the MB may be left to the discretion of the operator according to the type of lesion. Predilatation of the SB remains a subject of controversy. Our opinion is that it is preferable not to predilate the SB for two reasons. Firstly, the occurrence of dissection inherent in the enlargement of the lumen of the SB ostium may hinder or prevent access to the SB through the struts of the MB stent, and secondly, the enlargement of the SB lumen increases the likelihood that access to the SB may also be possible through a proximal strut, although access through a distal strut is the only possibility for projecting struts in the SB. SB predilatation should be used when SB access is difficult or in case of sever and calcified SB lesion. In case of SB predilatation, it is very important too carefully assess the angiographic result before MB stenting and be ready to switch to another strategy (Crush technique or culotte) in case of dissection.

## Main branch stenting

Stent selection should be made according to the maximal expansion ability of the stent, allowing stent apposition on the MB wall and on the SB ostium. The size of the stent struts is also an important criterion for the most proximal bifurcations (left main). Stents with closed cells should be avoided.

The choice of stent diameter for implantation in the MB is crucial. When too large, it may significantly increase the risk of SB occlusion by causing the carina to shift. Selection of the stent diameter should be made according to the diameter of the main distal segment in compliance with the fractal law. The drawback is the inadequate apposition of the stent on the proximal MB segment. This problem is easily solved by kissing balloon inflation and/or proximal optimisation technique (POT).

## Proximal optimisation technique (POT)

This technique provides a solution to the problem of under-deployment of the proximal part of the MB stent. It is carried out by inflating a short bigger balloon just proximal to the carina. As a result, the original anatomical configuration of the bifurcation is restored in compliance with the branching law. It changes also the orientation of the SB ostium, facilitating the insertion of a guide-wire, balloon and, if necessary, a stent in the SB, as well as the projection of struts in the SB ostium.

POT is especially useful in bifurcation lesions with a large SB because a marked difference in the diameter of the proximal and distal MB is observed (Figure 4).

## When should the SB be treated?

Angiographic assessment of the result in the SB ostium is not easy. The degree of angiographic stenosis is higher than when assessment by FFR[43]. Therefore, we should not over treat the SB with stents. The decision is easy when the SB lesions is <75 or better 50%, but difficult when >75%. It depends also on the SB lesion length and size. FFR could be helpful in this setting.

## Should kissing balloon inflation be performed after implantation of a single stent?

When POT has not been previously performed, balloon inflation in the SB ostium causes stent distortion in the MB and attraction of the struts opposite the SB in the MB lumen. KB inflation allows SB ostium treatment and apposition of the MB stent struts on the SB ostium. It also enables correction of stent distortion and correction of inadequate apposition in the MB. However, KB increases procedural complexity and may result in stent ovalisation, proximal dissection when balloons are inadequately positioned and even suboptimal deployment of the proximal stent segment. Although final KB is strongly recommended after a complex technique with two stents, it remains a controversial issue in the case of single stent implantation. The one-year follow-up results of the NORDIC III trial should provide an answer to this unresolved problem.

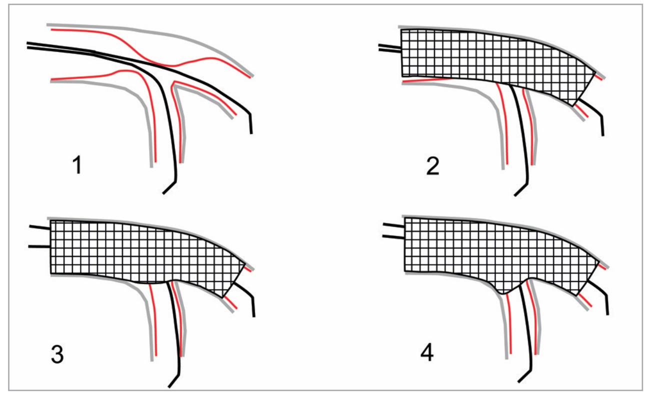


*Figure 4. 1. Illustration of 1,1,0 left main bifurcation lesion. 2. Optimal stent diameter (distal MB reference). 3. Proximal optimisation technique (POT) with a short larger balloon just proximal to the carina. Note that some metal is already pushed in the SB. 4. Result after kissing balloon inflation. Potentially adverse effects of SB predilatation. Top of the page: SB predilatation followed by stenting of the MB and result after kissing balloon inflation according to whether or not the proximal strut has been opened towards the SB. Bottom of the page: no SB predilatation.*

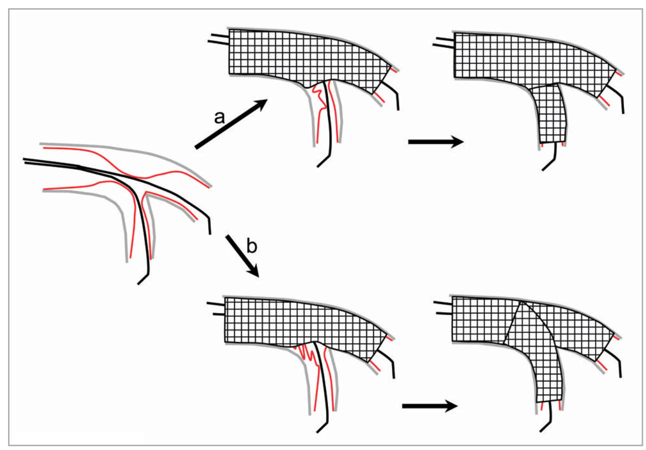


*Figure 5. Illustration of 1,0,1 left main bifurcation lesion. MB stent diameter selected according to distal MB reference. Option a. No SB predilatation. Distal strut opening toward the SB. If SB stenting is needed, T stenting can be used without any gap and no need for protrusion in the MB. Option b. SB predilatation. Proximal or mid strut opening. If SB stenting is needed, T stenting technique will not be optimal. Culotte technique will better scaffold the lesion.*

The pending issue is not whether KB is the right strategy, but when the SB should be treated at least by balloon dilatation. In cases of angiographic slow flow in the SB combined with EKG signs of ischaemia and chest pain, SB treatment is unanimously considered as necessary. In large SBs, a poor procedural outcome may result in the occurrence of symptoms and residual ischaemia. Absence of cell opening towards the SB may cause serious difficulties in treating restenosis or *de novo* distal disease.

## How to carry out kissing balloon inflation appropriately?

First of all, it is fundamental to insert a free wire in the SB through the struts of the MB stent and, if possible, in the strut closest to the carina. In order to achieve this, we exchange guidewires in most cases, although a third wire may also be used. The MB wire, pre-shaped into a long form and secured by the stent, is pulled towards the SB ostium. When guidewire advancement proves difficult, utilisation of POT, reshaping of the guidewire, use of a hydrophilic or a more rigid wire with improved torque, or even an orientable micro-catheter (Venture™; St. Jude Medical, St. Paul, MN, USA) may help overcome the technical issues.

In cases of persisting difficulties, advancement and subsequent inflation of a very small balloon over the jailed wire may restore flow in the SB and enable the crossing of MB stent struts.

Following insertion of a free wire in the SB, the SB jailed wire must be withdrawn proximal to the stent. During this manoeuvre, the guiding catheter must be closely controlled in order to avoid deep intubation which might cause proximal dissection. In rare occurrences where the guidewire cannot be easily withdrawn, the use and potential inflation of a small balloon may prove efficient.

Once released, the wire, having previously been made into a short and angulated form, should be advanced in the MB if possible with a loop whilst avoiding advancement outside the stent.

Selection of balloons for KB is crucial. The diameter must match that of the two distal branches. The balloons must be sufficiently short to avoid inflation outside the stent in the MB, and in disease-free areas in the SB. In cases where POT has not been performed, KB may optimise the proximal segment of the MB. When the SB lesion cannot be dilated at a reasonable pressure, which could be the result of inadequate stent expansion, increasing the pressure of semi-compliant balloon may enlarge the diameter of the unstented segment and cause dissection requiring stent deployment in the SB. The use of non-compliant balloons for KB allows improved stent expansion in the MB whilst reducing the risk of dissection in the SB. During KB, we inflate a balloon in the MB first and then the SB balloon in order to achieve strut projection in the ostium. The pressure applied depends on the persistence of a waist on the balloon.

Sequential balloon inflation (side, main, side) has been proposed as an alternative to kissing balloon inflation.

### When and how should the SB be stented?

As for balloon angioplasty treatment, the decision to stent the SB depends on the occurrence of complications as well as the angiographic result assessed from various projections, IVUS or FFR analysis and importance of the SB.

The beauty of the provisional SB stenting approach is that different techniques may be utilised for SB stenting. In our centre, we use mainly the provisional T stenting technique. Contrary to the systematic T stenting technique which starts with stent deployment in the SB, a second stent can be implanted without leaving any gap when the struts of the MB stent cover the SB ostium efficiently (Figure 5). In order to carry out accurate stent positioning, it is necessary to have a good angiographic "working view" and to know the relation between the proximal marker of the balloon and the proximal extremity of the stent which vary according to the type of stent used. Stent Boost or equivalent are very useful for SB stent positioning.

When the SB ostium is not well treated by the MB stent after the MB strut opening toward the SB, the operator should apply a different technique in order to scaffold the SB ostium adequately using the TAP technique (T and protrusion) or culotte stenting.

## Conclusion

Angioplasty of coronary bifurcations has posed many technical issues since the beginning of interventional cardiology. The advent of stenting generated the development of various techniques, and the management of coronary bifurcations gradually improved thanks to a better understanding of the fundamentals in this field. Technical strategies have now reached a certain maturity and it has become clear that the provisional side branch stenting strategy is the reference technique and the most commonly used worldwide. Though many aspects remain to be addressed, this simple and relatively flexible technique provides excellent short and mid-term results.


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