Bifurcation lesions

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The introduction of drug-eluting stents has significantly improved the immediate and long-term results following treatment of bifurcation coronary lesions. Despite these improvements, few questions are still without a clear answer. Among them the most important one is the need to use two stents vs provisional side branch stenting in true bifurcations. At present time the approach most frequently applied is to stent the main branch stenting to the side branch only for suboptimal results. In situations when the operator needs two stents as intention to treat we suggest the usage of the "Crush" or "V" technique. These two approaches have been utilized with good immediate and long-term results with sirolimus-eluting stents and with polymer-based paclitaxel-eluting stents. The usage of the "Crush" technique followed by final dilation of the side branch and with kissing balloon inflation has decreased. We recently evaluated results with this technique in 70 patients treated with sirolimus-eluting stents. The 6-month angiographic follow-up was available in 83% of the lesions and restenosis rate was 33% (7% main and side branches and 26% only side branch). No difference was observed in the restenosis rate on the main branch between lesions treated with final kissing balloon inflation and lesions without final kissing inflation (4% in the final kissing group vs 8% in the no final kissing group, p = 1.00). The restenosis rate on the side branch was lower in the final kissing group (17%) in comparison to the no final kissing group (42%) (p = 0.046). Similar results are achieved with polymer-based paclitaxel-eluting stents.

The introduction of drug-eluting stents with selective usage of stenting the main and side branches applying the "Crush" or "V" techniques has significantly improved the results compared to bare metal stents in bifurcation lesions.

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Progress in coronary interventions has left few areas in need for major improvements: bifurcation lesions, chronic total occlusions, and unprotected left main disease remain the three fields in search for a major advance.

The all field of bifurcation lesions is so different in its inside that most attempts to compare different studies are almost futile. Attempts to classify bifurcation lesions[1-4] are very commendable but suffer all limitations of coronary angiography (different plaque distribution and extent of disease when evaluated by intravascular ultrasound)[5]. The lesion itself (the plaque characteristics) acquires, in the context of a bifurcation, a unique value. For example, a soft plaque distributed toward the origin of the side branch is more prone to shift toward the side branch upon main branch dilation than a fibrous plaque. Some of these factors are unrecognizable at the time of angiography and therefore cannot be quantified. The lack of possibility of quantifying a number of important factors makes the all field open to more weakness and increases the difficulties to evaluate and compare results. This lack of information is introducing very important unanswered questions:
- How will behave the side branch following main branch stenting?
- Will this behavior be influenced by the presence of disease at the origin and inside the side branch?
- How will the plaque composition in the main and side branches affect the final result and influence the immediate and long-term results following a specific approach?
- Is the angle between the main and side branches important in affecting the immediate results and the fluid dynamics to act on the long-term results?

Nothing more needs to be added to support the concept that bifurcation lesions are by their constitutions a tremendously variable entity. They are perhaps a rare subset of lesions in which we notice a unique "lesion-to-lesion interaction": the two branches affect each other. In addition, the therapeutic strategy adopted on one branch will affect the other branch.

All these considerations are very important because they give to us an overview of the field and of the knowledge we need to acquire in order to make statements and more importantly to plan studies with the attempt to evaluate the behavior of all possible important variables.

What is available

A small randomized study utilizing sirolimus-eluting stents in bifurcations has given us some important initial direction to structure our approach for treatment of bifurcation lesions[6]. The conclusions are:
- compared to historical studies utilizing bare metal stents[1,7-10], a remarkable improvement has been achieved in the treatment of bifurcation lesions when one (main branch) or two stents (main branch and side branch) are implanted;
- the side branch seems the weak ring in the chain in terms of higher risk of angiographic restenosis (still around 20%) and a slight higher risk of thrombosis;
- when possible, placement of one single stent on the main branch gives a similar result of placement of two stents;
- suboptimal coverage with struts and drugs at the ostium of the side branch are possible contributing factors to side branch restenosis.

In addition to this study a number of reports (at this time still personal communications or in the context of presentations on the topic of bifurcation lesions) are stressing the issue of possible stent recoil at the ostium of the side branch.

When do we need to stent the side branch?

This question is complex and like many complex questions they need a simple answer.
- Intention to treat: when the side branch has the size suitable for stenting and there is ≥ 50% stenosis at the ostium or near the ostium.
- Provisional: when following placement of a stent in the main branch and following kissing balloon inflation the side branch has > 50% stenosis or a dissection and has suitable size for stenting.

A more comprehensive way to answer the question. *The size and the territory of distribution of the side branch.* One element which is not sufficiently clear in this question is "side branch". As intuitive can be the term "side branch" there is a misleading connotation associated with it. The term "side branch" may convey a vessel of less importance compared to the main branch. While this statement may be true in many cases, there are a number of situations in which the side branch is as important as the main branch regarding the size and territory of distribution. The left main with the left anterior descending and the circumflex, the presence of a large intermediate branch, a large and long diagonal branch, a right coronary artery which bifurcates in a posterior descending artery and a number of posterolateral branches, a dominant circumflex which bifurcates into a distal circumflex and a large obtuse marginal branch are all examples in which the side branch is quite different from a standard diagonal branch which is commonly used to define a side branch and feel comfortable with this attribute. Before attempting to answer the above questions we first need to reformulate the question:
- Are we dealing with a bifurcation giving origin to a side branch from the main branch or are we evaluating an anatomical situation in which there are two branches (a condition in which the term "side branch" may not appear so appropriate)?

The more the side branch is functionally and anatomically similar to the main branch, the more likely we may use the two stents.

If the side branch is really a side branch this fact will influence more the approach to use only one stent in the main branch and perform a balloon angioplasty for the side branch. The other condition will make us more likely to use two stents. This first answer to our original question is still quite preliminary because, as we will see later, other factors will affect the very final conduct.

Angle between the main and the side branch and the amount of disease at the ostium of the side branch. The other two elements to be taken into account are what is the angle between the main and the side branch and the presence of disease (plaque) at the origin of the side branch.

The angle of origin of the branch (side branch most of the times) can be: an acute angle, a right angle or an obtuse angle. This angle will influence how the side branch ostium will "react" upon positioning a stent on the main branch. The more the angle between the two branches is acute, the more likely we will notice a narrowing at the ostium of the side branch following stenting of the main branch. Another element to consider when looking at the angle between the two branches is the difficulty to recross into the side branch following stenting of the main branch. We can say that this difficulty goes into the opposite direction from the one causing the plaque shift. This statement means that an acute angle causes more plaque shift or compromise the ostium of the side branch but should facilitate recrossing with a wire into the side branch, while an obtuse angle will be less likely associated with plaque shift but make wire recrossing more difficult.

The more acute is the angle between the two branches, the more likely we will use the two stents. The more difficult we assume will be recrossing into the side branch, the more likely we will use two stents.

The amount of plaque and the degree of stenosis at the origin of the side branch are also very important in our decision-making process. This variable should be better evaluated knowing other information, such as the type of atherosclerotic plaque both in the main vessel and in the side branch and its distribution. Unfortunately, angiography gives only a limited insight into these data and intravascular ultrasound cannot be proposed in the routine evaluation of bifurcations. We are putting into play the type of the plaque at the origin of the side branch in addition to its amount because this parameter should be taken into account when choosing whether to predilate and how to dilate the side branch. Before entering into the issue of placing two stents or one stent, a fibrotic side branch if properly predilated with a cutting balloon may then not need a stent after stenting of the main branch. For this reason besides the degree of stenosis at the origin of the side branch another operational variable to be considered is the extent of improvement in the side branch sustained upon initial dilation. Along the same concept it is important to take into account how the side branch deteriorated following dilation of the main branch. The results achieved following mentioned maneuvers will affect our decisions.

The more severe is the stenosis at the ostium of the side branch, the more likely we will use two stents. The less improvement we obtained (sometimes a dissection) on side branch dilation, the more likely we will use two stents. The more deterioration at the ostium of the side branch we had, the more likely we will use two stents.

The final decision

The decision to use one or two stents or sometimes even three (in case of a trifurcation) should be taken as early as possible. An appropriate and timely taken decision will affect the result and help save time and cost and lower the risk of complications.

What it is important to know is that if we take the decision to use one stent (on the main branch) there is almost always the possibility of placing a second stent on the side branch in case the result is not evaluated as optimal or adequate. This condition is defined "provisional stenting"[11,12]. While provisional stenting allows to defer a decision most of the times after having stented the main branch and having done a balloon dilation of the side branch and a kissing balloon dilation of both branches what does not allow is performance of some techniques such as "V" stenting or sometimes may make recrossing with a stent into the side branch a difficult, if not an impossible task.

All these considerations need to be taken into account while making the initial decision regarding implantation of two stents or implantation of one stent with provisional side branch stenting.

The side branch needs to stay open. With few exceptions most of the side branches of a bifurcation lesion need to maintain patency during and by the end of the procedure. This statement does not mean that each side branch needs to be treated with balloon inflation or with stenting.

Occasionally some small side branches (usually ≤ 1.5 mm in diameter), typically in the context of a trifurcation or a second subdivision of a diagonal branch, especially if diffusely diseased and with a small distribution area, do need protection and their closure can be accepted to minimize the complexity of the procedure.

The strategy to protect a minor side branch is to place a wire which can be left until the stenting procedure on the main branch has been completed. These temporary jailed wires can be retrieved without problems.

Difficult access to the side branch. There are some circumstances in which, due to the location of the plaque in the main branch and due to the angulation of the side branch, a guide wire cannot be advanced in the side branch. After having attempted different types of wires with all sorts of curves and all personal tricks the operator may be left with the impossibility of advancing a wire in the side branch. As rare as this condition can be it will happen. At this point few options are available: 1) abort the procedure because the risk to loose the side branch will be too high considering also the size and distribution of the branch (typically an angulated circumflex artery), 2) perform directional atherectomy on the main branch with the intent to remove the plaque which prevents entry toward the side branch (Fig. 1), 3) dilating the main branch with a balloon with the rationale that the plaque modification and hopefully a favorable plaque shift will facilitate access toward the side branch.

Each of the three options has its rationale and the specific anatomical condition and clinical scenario may direct the operator to choose one vs the other.

Role of atherectomy debulking. Directional coronary atherectomy has been considered ideal for bifurcation lesions. The rationale for plaque removal in this setting is various and there are a number of positive anecdotal experiences[13-16]. In the time of the SOLD Registry (Stenting after Optimal Lesion Debulking)[17] bifurcation lesions were included in this registry and the results were very encouraging to launch the AMIGO trial (Atherectomy before Multi-Link Improves Lumen Gain and Clinical Outcomes). Unfortunately this study failed to support the original findings and hypothesis even in the subgroup of lesions involving a bifurcation[6]. The main problem of directional atherectomy which may also have affected the results of the AMIGO trial is that the technique is very operator-dependent and the amount of tissue removal quite variable depending on the commitment to perform extensive debulking. In addition, except for the very recent introduction of the Silver Hawk device (Fox Hollow Technologies, Redwood City, CA, USA), no further development in the devices available were done for a long time period.

Recently a new study named COMBAT which utilizes the Silver Hawk device has been launched in the

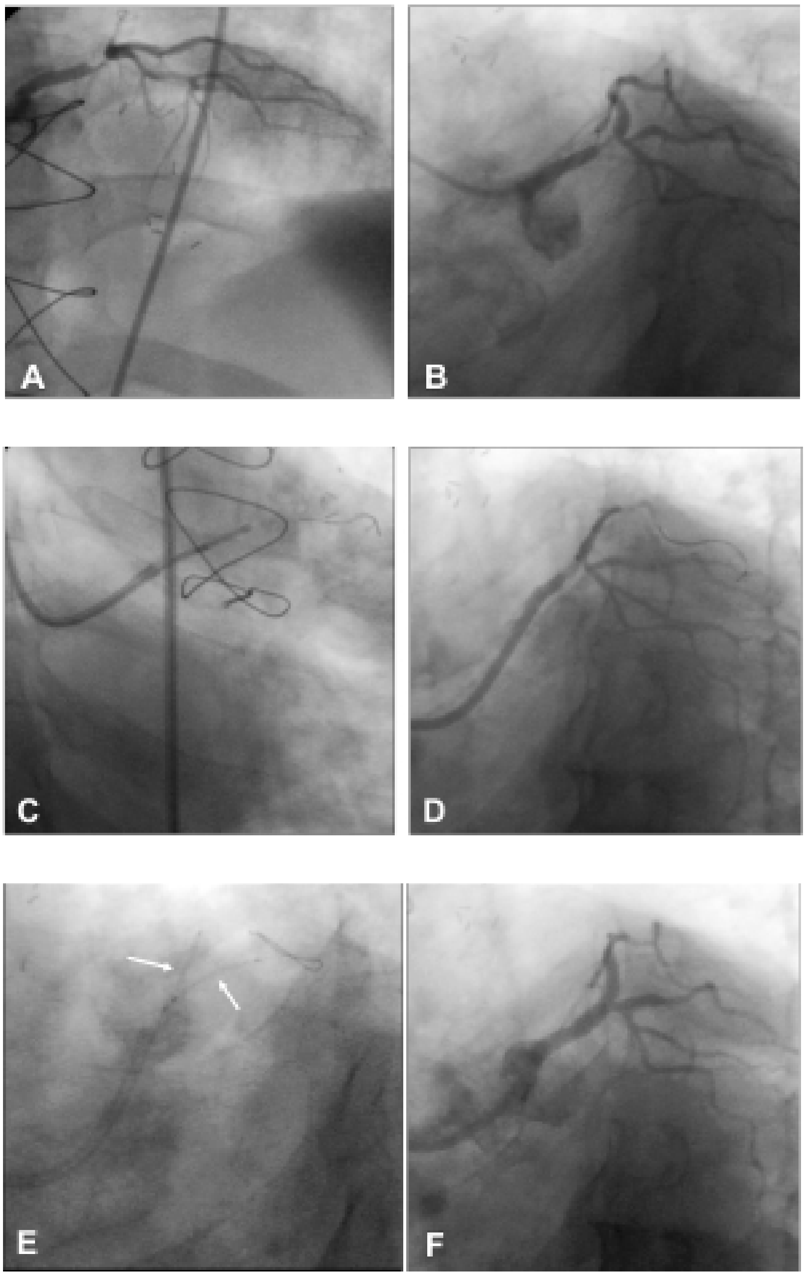

Figure 1. Panels A *and* B *show baseline angiogram of a lesion involving the distal segment of the left main, with a sharp angulation of the circumflex artery which did not allow wire negotiation at this level. After directional atherectomy was performed in the left anterior descending coronary artery* (panels C *and* D)*, wire was advanced and crushing stenting was performed (*panel E, arrows *point stents positioned in the left anterior descending and circumflex coronary arteries). Final result is presented in* panel F.

United States. Whatever the results will be we suspect that the competition from the introduction of drug-eluting stents will narrow significantly the area of application of this atherectomy.

Despite this concerns and the lack of strong scientific evidence which supports the advantage of plaque debulking in bifurcation lesions, our experience in this setting has been favorable and we still occasionally combine atherectomy and drug-eluting stents when the anatomical setting is appropriate, such as a left main stenosis with a large plaque burden demonstrated by intravascular ultrasound.

Role of rotational atherectomy. Rotational atherectomy is a procedure which in the last few years has been used less and less. In most cardiac catheterization laboratories the use of this procedure is nil or < 5% of all interventions. Early reports stated and advantage to facilitate stent delivery and expansion with a suggestion for clinical benefit when employed in lesions which demanded the usage of this technology[18]. The SPORT (Stenting POst RoTational atherectomy)[2] randomized study utilizing rotational atherectomy and stenting failed to support any advantage of this technology over standard stenting. Our interpretation is that a niche technology cannot demonstrate its advantage when used outside the area where should work at its best. Unfortunately due to the randomized design of the SPORT trial heavily calcified lesions were not included.

All these considerations make us suggest that rotational atherectomy is most probably beneficial and sometimes essential in heavily calcified bifurcation lesions. Most of the times rotablation is simply performed only on the main branch but occasionally (very rare) also the side branch or only the side branch can be treated (only one wire is left in place). We think that especially with usage of drug-eluting stents the lesion preparation with compliance change of a very calcified lesion can substantially facilitate stent delivery and symmetrical stent expansion with more homogeneous drug delivery[18-20].

Role of cutting balloon. A number of single center studies reported the beneficial combination of stenting preceded by cutting balloon dilation[21-24]. Bifurcation lesions where there is a large plaque mass and frequently fibrotic on the ostium of the side branch seem an ideal setting for this device[25]. The REDUCE III (Restenosis Reduction by Cutting Balloon Evaluation) evaluated the role of cutting balloon dilation before stenting vs standard balloon dilation in a variety of lesions[26]. This trial reported a lower restenosis rate (11.8 vs 18.8%, $p = 0.04$) when lesions were predilated with the cutting balloon. The fact that the final lumen diameter post-procedure was larger in the cutting balloon arm and that the late loss was 0.74 mm for both strategies may make us assume that the main advantage was toward better stent expansion.

What is the take home message? As we said for rotational atherectomy, it is difficult to demonstrate that a niche device has an advantage in every lesion. For this reason we suggest the usage of cutting balloon in moderately calcific and fibrotic lesions, especially the ones which involve the origin of the side branch. In heavily calcified lesions the cutting balloon could be the second step following small burr rotablation. This strategy will minimize distal embolization and maximize lumen again thanks to the access to large size cutting balloons.

The major limitation of this statement is the fact that it is very difficult to establish *a priori* the lesion characteristics to an extent such to suggest that a particular lesion will be better prepared with the cutting balloon rather than with the standard balloon.

Symmetric stent expansion, avoidance of side branch recoil and stent compression are all attractive hypotheses which need proper evaluation.

Guiding catheter. Treatment of bifurcation lesions requires frequently simultaneous insertion of two balloons or of two stents, therefore some specific considerations regarding the selection of an appropriate guiding catheter are important. With current available very low-profile balloons (Maverick, Boston Scientific-Scimed, Minneapolis, MN, USA) it is possible to insert two balloons inside a large lumen 6F guiding catheter. If two stents are needed some limitations have to be known. The two stents can only be inserted one following the other but not simultaneously. The standard "Crush" technique and the "V" or "Kissing" stent technique cannot be performed unless a guiding catheter of at least 8F is utilized (7F with Taxus but with some difficulties). A 6F guiding catheter can be utilized if the operator performs a provisional stenting technique with a second stent (for the side branch) which is advanced following positioning of the first stent in the main branch. Techniques such as the "T" technique, the reverse Crush technique, the step Crush technique (see below for a description of each technique) can all be used with a 6F guiding catheter.

Two stents by intention to treat. If the operator evaluates that a particular bifurcation will need implantation of two stents, one on the main and the other on the side branch, the techniques we consider suitable in the era of drug-eluting stenting are the ones we are describing below[6,27-29].

The "V" (Kissing stent) technique

The "V" technique consists of delivery and implantation of two stents together[29,30]. One stent is advanced in the side branch, the other one in the main branch distally from the origin of the side branch. The main advantage of the "V" technique is that the interventional cardiologist will never loose access to any of the two branches. In addition when a final kissing inflation is performed there is no need to recross any stent. Figure 2 shows how this procedure is performed. An 8F guiding catheter is needed, when using Taxus stents a 7F catheter can be utilized if the operator accepts high friction and very poor visualization.

- Step 1. Both branches are wired and fully predilated. It is important to perform an adequate predilation in order to allow stent expansion in the most symmetrical fashion.
- Step 2. The two stents are positioned into the branches with a slight protrusion in the main proximal branch. Different operators allow a variable amount of protrusion creating sometimes a rather long (≥ 5 mm) double barrel in the proximal main branch. While we recognize that it is impossible to be so accurate to position the stent exactly at the ostium of each branch we generally try to limit the length of the new carina to < 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 maneuver is essential when the Kissing stent technique is used to stent a trifurcation using three kissing stents (9F guiding catheter). Following accurate stent positioning, always verified in two projections, each balloon is first inflated individually at high pressure (≥ 12 atm).

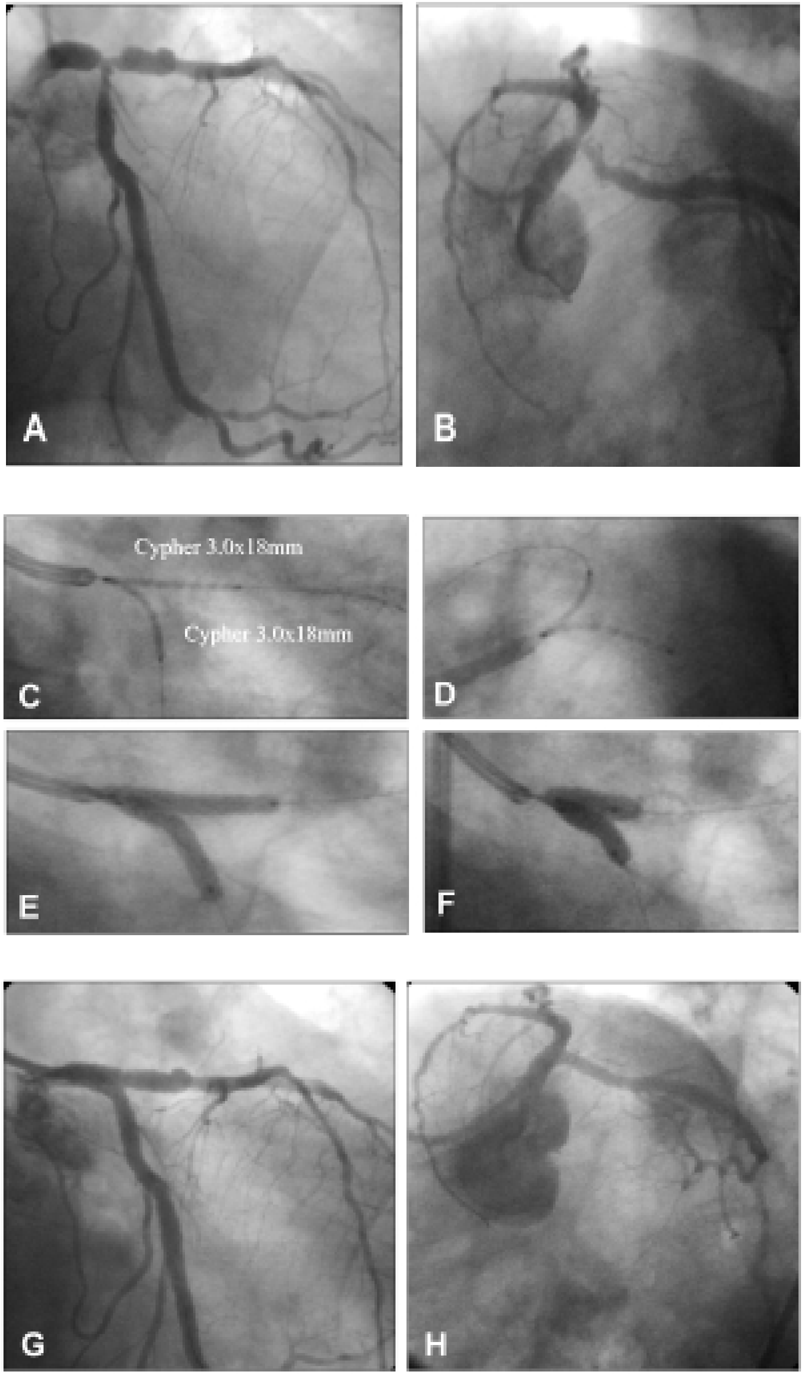

Figure 2. *Baseline angiogram of the left main coronary artery bifurcation lesion, with two large branches, the left anterior descending and circumflex coronary arteries, is presented in* panels A *and* B. *The V-stenting was used due to the fact that the disease was mainly at the level of the very distal left main and the angle of the two branches was very favorable for a V-technique. Stent positioning in two projections is shown in* panels C *and* D *and stent deployment and post-dilation with the 4 mm balloons is shown in* panels E *and* F. *Final result is presented in* panels G *and* H.

• Step 3. The next step is to inflate both balloons simultaneously at 8 atm.

Using the "V" technique a metallic neocarina is created within the vessel proximal to the bifurcation. Theoretical concerns about the risk of thrombosis related to this new carina have not been confirmed in our and other operators' experience. The technique has been successfully applied with bare metal stents and with drug-eluting stents (Cypher and Taxus). The type of lesions we consider most suitable for this technique are very proximal lesions such as bifurcation left main lesions with a left main artery which is short or free of disease. Ideally, the angle between the two branches should be < 90°. The "V" technique is also suitable for other bifurcations provided the portion of the vessel proximal to the bifurcation is free of disease and there is no need to deploy a stent more proximally. It is quite intuitive how problematic may result positioning a stent proximally to the double barrel with an inevitable bias toward one of the two branches and the high likelihood to leave a gap.

The Crush technique (side branch stent crushed by the main branch stent)

The Crush technique was born together with drug-eluting stents[27]. The sirolimus bifurcation study brought to the attention the emerging new problem of side branch focal restenosis despite utilization of two Cypher stents (one in the main branch and the other in the side branch)[6]. At that time the "T" technique was the default approach when two stents were implanted. The need to guarantee for full coverage of the ostium of the side branch prompted the idea to allow some protrusion of the side branch stent and then with the stent in the main branch the protruding segment of the side branch stent was flattened against the wall of the main branch between the vessel wall and the main branch stent, hence the denomination "crushing" or "crush". The angiographic results following the initial application of this technique, which was at that time solely utilized with the Cypher stent, were quite optimal and we felt no need for recrossing into the side branch to perform a final kissing inflation[27]. Despite a good clinical outcome without any event of stent thrombosis, which was a quite feared complication due to the triple stent layer in the main branch, there was a 25% incidence of focal restenosis at the ostium of the side branch. Despite the positive fact that almost half of these patients were asymptomatic and did not show any evidence of ischemia we were still seeing what we noticed during follow-up of the Cypher bifurcation trial.

Since then routine recrossing into the side branch and inflation of a balloon in the side branch and then kissing balloon inflation was performed[6]. The implementation of final kissing balloon inflation was done in order to allow better strut contact against the ostium of the side branch and therefore better drug delivery. The Crush technique became therefore a sort of simplified Culottes technique[31,32], since performance of the final kissing inflation restenosis at the ostium of the side branch seems to be declining (follow-up still in progress)[6]. The positive aspect is that whenever restenosis occurs this narrowing is very focal (< 5 mm in length) and most of the times not associated with symptoms or ischemia.

The main advantage of the Crush technique is that immediate patency of both branches is assured. This gain is of no little importance especially when the side branch is functionally relevant or difficult to be wired. The main disadvantage is that the performance of the final kissing makes the procedure more laborious due to the need to recross multiple struts with a wire and a balloon.

Webster et al.[33] reported bench-testing with three different stent platforms (BX Velocity, Cordis J&J Company, Express II, Boston Scientific, and Driver, Medtronic) utilizing the Crush technique. The authors stressed the importance of final kissing balloon inflation and concluded that appropriate side branch and main vessel post-dilation is needed to expand the stent at the ostium fully, to widen gaps between stent struts overlying the side branch (facilitating subsequent access), and to prevent stent distortion.

An 8F guiding catheter is needed; when using Taxus stents a 7F catheter can be utilized if the operator accepts high friction and very poor visualization.

Below we will describe some modification of the Crush technique, which allow provisional side branch stenting and permit performing the same or similar approach utilizing a 6F guiding catheter.

An example of the Crush stenting is presented in figure 3.

- Step 1. Both branches are wired and fully dilated. Particular attention is paid to dilate the side branch and we frequently utilize a 6 mm long cutting balloon if there is evidence that the predilating regular balloon does not fully expand at the ostium of the side branch or upon deflation of the predilating regular balloon there is marked recoil of the side branch ostium.
- Step 2. The stent for the side branch is advanced in the side branch and then the stent for the main branch is advanced in its branch.
- Step 3. The stents are positioned by pulling the side branch stent into the main branch for about 5 mm. This step is verified in at least two projections. It is important that the stent in the main branch should always end more proximally than the stent in the side branch and protruding in the main branch.
- Step 4. The stent in the side branch is deployed at lest at 12 atm. The balloon is deflated and removed from the guiding catheter. An angiogram is taken to verify that the side branch has a good lumen, normal flow and no distal dissection or residual lesions. If an additional stent may need to be implanted in the side branch this is the time to do it. Following this verification the wire is removed from the side branch and the stent in the main branch is fully deployed at high pressure, usually > 12 atm. Angiogram is taken following removal of the balloon in the main branch.
- Step 5. A wire is advanced in the side branch. This maneuver may be time-consuming in the initial experience with this technique. Lately an average of 2 min of fluoroscopy was used to complete wire advancement. Besides trying with the initial wire (Balance Universal, Guidant, Temecula, CA, USA), the most efficient wire to cross the struts of the stent toward the side branch is the Rinato wire (Asahi Intech, Japan). We frequently try first to cross through the stent struts into the side branch with the smallest balloon we have on the cath table, then, if this balloon fails, we use a Maverick 1.5 mm diameter. If the 1.5 mm balloon fails to cross we consider reposing the wire by recrossing the stent struts

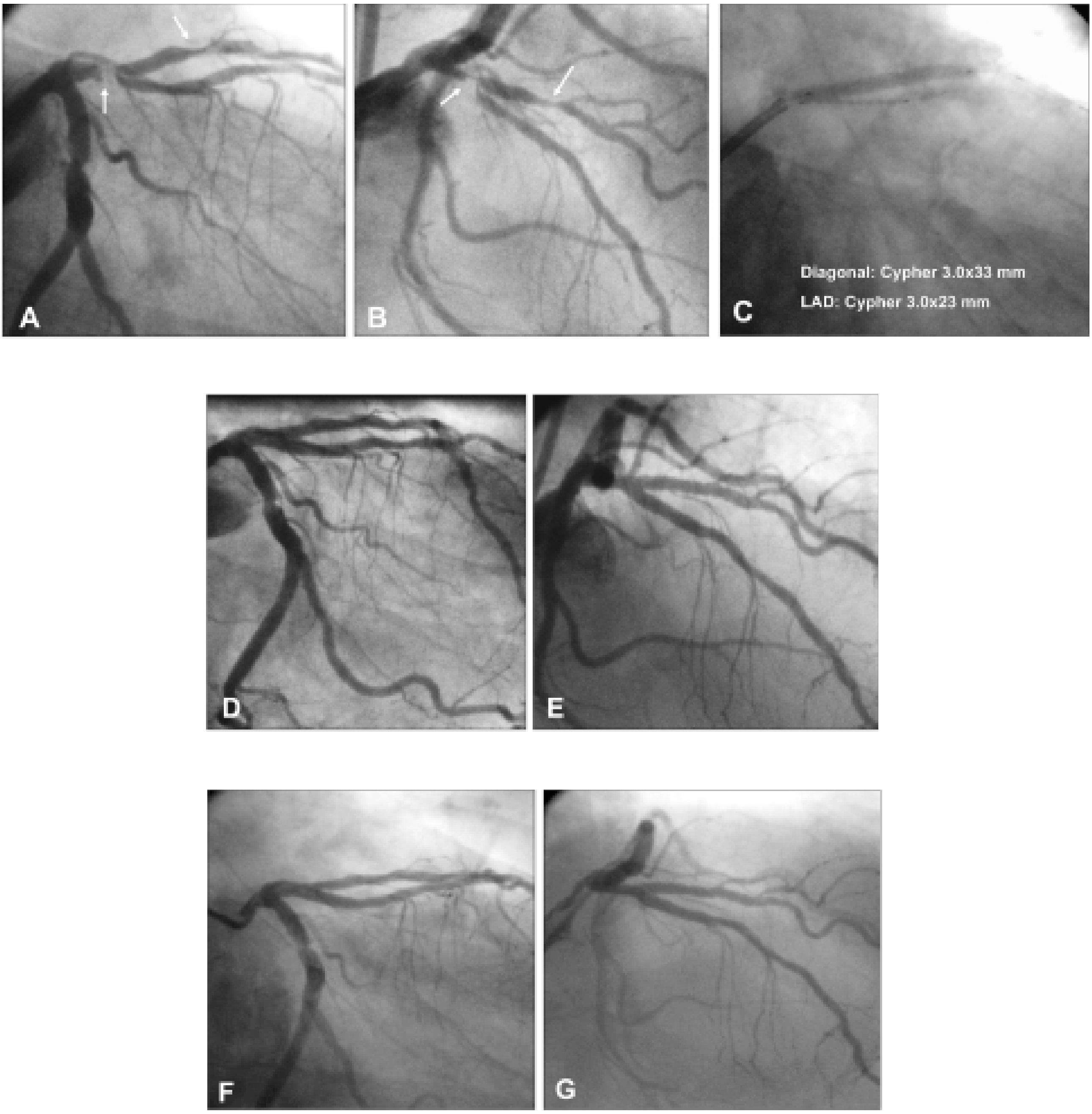

Figure 3. *Baseline angiogram of a bifurcation lesion, involving the left anterior descending coronary artery (LAD) and a large diagonal branch is presented in panels* A *and* B (arrows *point to the site of stenosis*). *Following lesion predilation two stents are positioned with the stent in the LAD more proximally than the stent in the diagonal branch* (panel C). *Side branch stent is inflated first (diagonal branch). Note that a long stent was chosen for diagonal branch in order to cover also a lesion distal to the bifurcation site* (arrow). *Optimal final result* (panels D *and* E) *was maintained at 10-month angiographic follow-up* (panels F *and* G).

in another spot. If the problem presents again we then try a fixed wire balloon, such as an ACE or a PIVOT (Guidant, Temecula, CA, USA). It is important to perform a final dilation on the stent toward the side branch with a balloon appropriately sized to the diameter of this branch and inflated at high pressure (usually ≥ 12 atm).

• Step 6. A second balloon is advanced over the wire which was left in place in the main branch and kissing balloon inflation is performed at 8 atm.

Variations of the Crush technique. *Reverse Crush (side branch stent crushed by a balloon).* The main purpose to perform the reverse Crush is to allow an opportunity for provisional side branch stenting. The reverse Crush can be performed utilizing a 6F guiding catheter. An example is shown in figure 4.

• Step 1. A stent is deployed in the main branch and balloon dilation with kissing inflation toward the side branch is performed. It is assumed that the result at the ostium or at the proximal segment of the side branch is

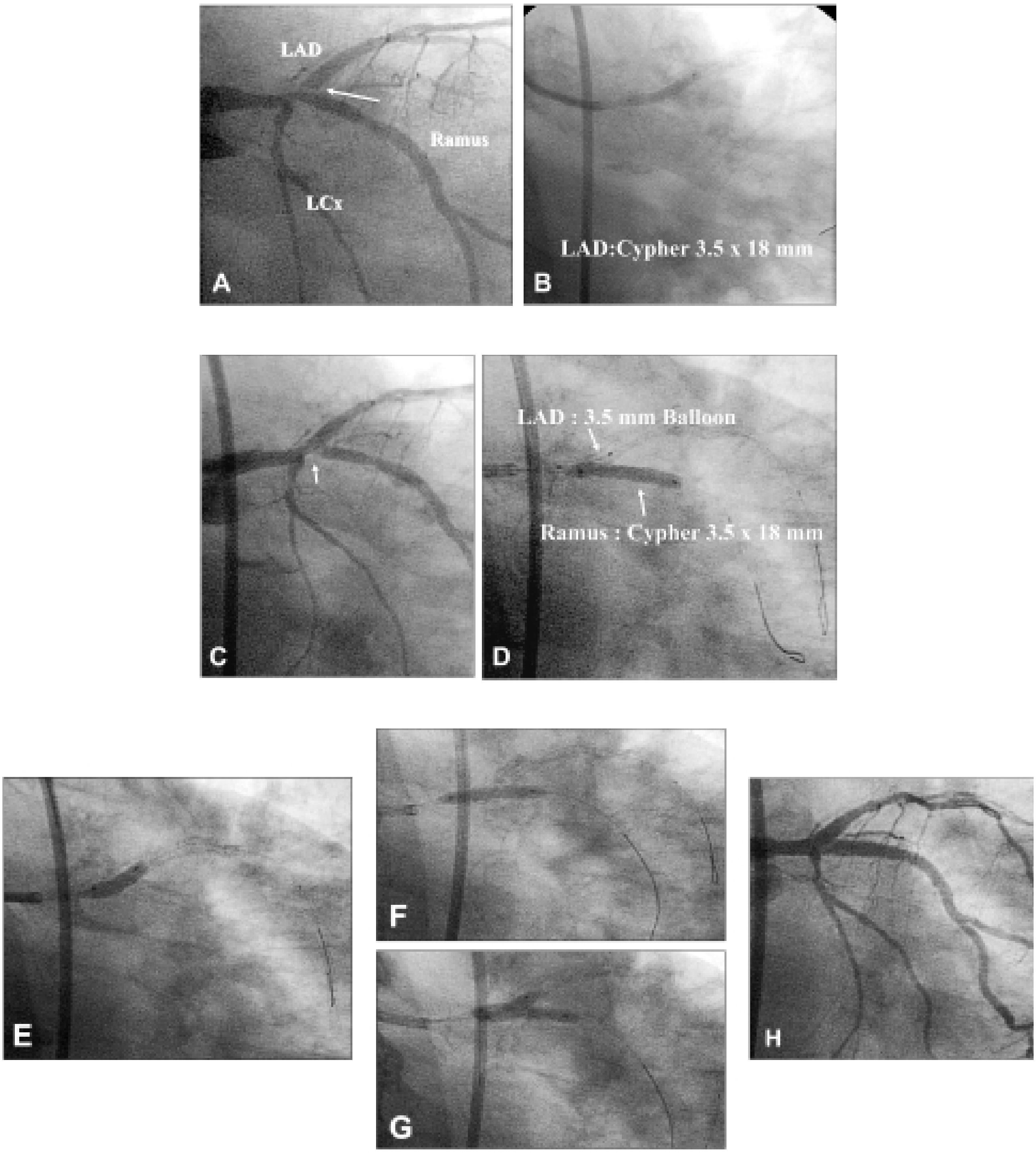

Figure 4. *An example of an ostial lesion of the left anterior descending coronary artery (LAD), with some distal disease in the left main coronary artery is presented in* panel A (arrow *points to the site of stenosis). The distal left main trifurcates, with the large intermediate branch and the smaller circumflex branch (LCx). A single 3.5 × 18 mm Cypher stent is implanted in the LAD* (panel B) *causing compromise of the intermediate branch* (panel C, arrow *points to the site of stenosis). Due to the fact that a stent is already in place in the LAD, the reverse Crush technique was utilized for intermediate branch stenting* (panel D, arrows *point to the site of stenosis). A stand-by balloon in the LAD is used to crush the protruding part of the stent from the intermediate branch into the LAD* (panel E)*. The next step is to recross into the intermediate branch and perform kissing inflation* (panels F *and* G)*. Final result is presented in* panel H.

suboptimal in order for the operator to decide to deploy a stent at this site.

• Step 2. A second stent is advanced into the side branch and left in position without being deployed.

• Step 3. A balloon sized according to the diameter of the main branch is advanced in the main branch and positioned at the level of the bifurcation paying attention to stay inside the stent previously deployed in the main branch.

• Step 4. The stent in the side branch is retracted about

3 to 5 mm into the main branch and deployed, the deploying balloon is removed and an angiogram is obtained to verify no distal dissection or distal stent is needed. If such is the case the wire from the side branch is removed and the balloon in the main branch is inflated at high pressure (≥ 12 atm).

The other steps are similar to the ones described for the Crush technique and involve recrossing into the side branch performing side branch dilation and final kissing.

Step Crush (side branch stent crushed by the main branch stent) (Fig. 5). The main reason to utilize this technique is to perform the standard "Crush" technique utilizing a 6F guiding catheter. Operators who perform the radial approach may be particularly interested in this technique. The final result is basically similar to the one obtained with the standard Crush technique with the only difference that each stent is advanced and deployed separately in order to use a 6F

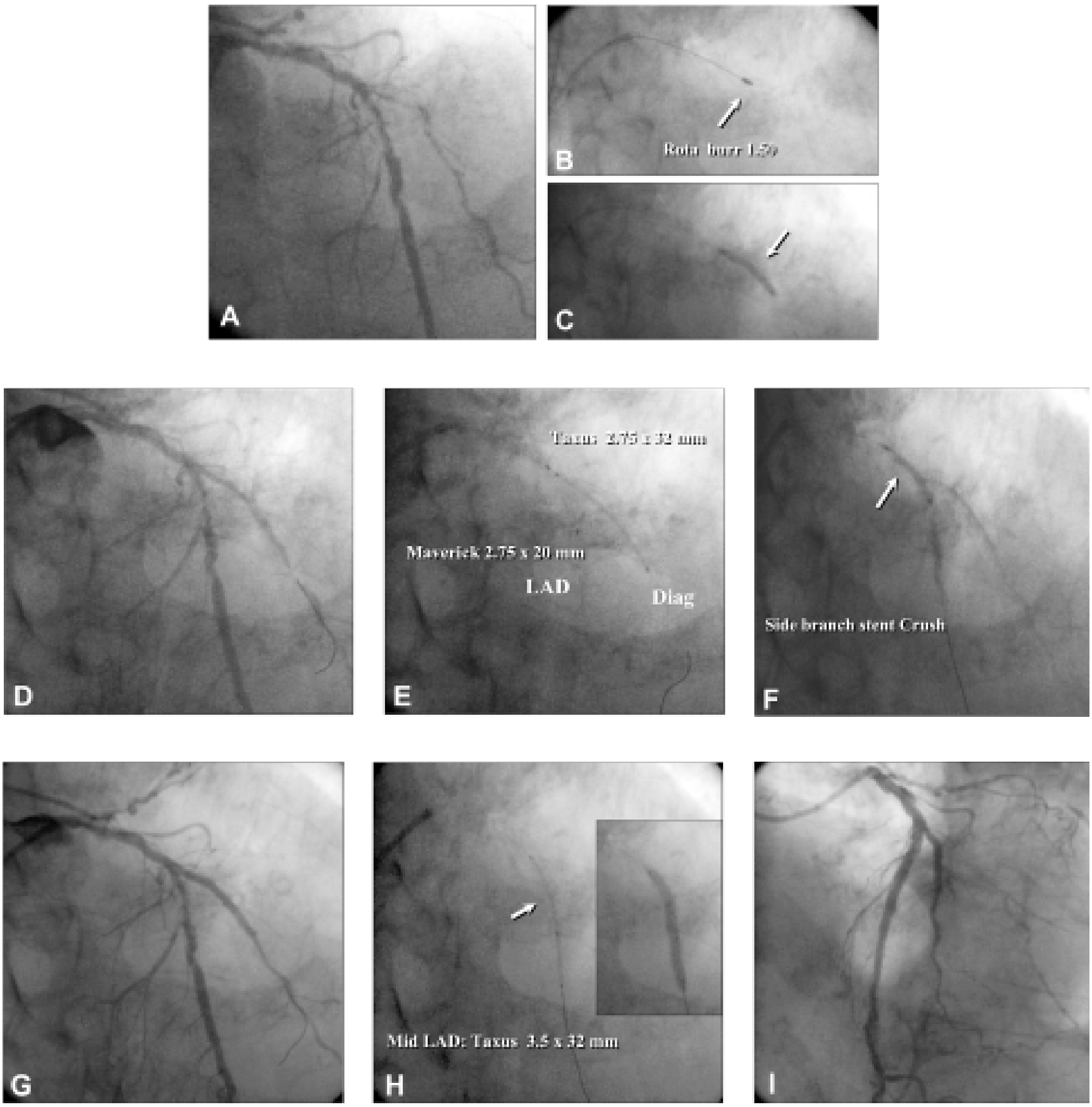

Figure 5. *Baseline angiogram of a bifurcation lesion in the left anterior descending coronary artery (LAD)-diagonal branch (Diag) is presented in* panel A. *Rotational atherectomy (Rota) was performed with subsequent complete expansion of the balloon as demonstrated in* panels B, C *and* D. *The next step was to implant a stent in the diagonal branch with the idea not to stent the LAD* (panel E). *The stent was made protruding in the LAD and the protruding part was crushed with a 2.75 Maverick balloon* (panels F *and* G). *The LAD was then stented* (panel H) *and this procedure became a classic Crush technique but now performed in a step fashion with the side branch stented first and the main branch stented second. The final result is demonstrated in* panel I.

guide. The need for a 6F guide is the only reason to utilize this technique.

• Step 1. Is the same as the standard Crush technique.
• Step 2. A stent is advanced in the side branch protruding into the main branch a few millimeters. A balloon (Maverick) is advanced in the main branch over the bifurcation.
• Step 3. The stent in the side branch is deployed, the balloon removed, an angiography is performed: if the result is adequate the wire is also removed. The main branch balloon is then inflated to crush the protruding side branch stent and removed.
• Step 4. A stent is advanced in the main branch and deployed (usually at ≥ 12 atm).

The next steps are similar to the Crush technique and involve recrossing into the side branch, performing side branch stent dilation and kissing balloon dilation. The size of the balloon and of the stents is chosen accordingly to the diameter of the vessels to be stented. In the event the segment of the vessel proximal to the bifurcation is relatively small and the operator may fear the risk that the two balloons inflated simultaneously may be oversized the kissing inflation is performed at low pressure (4 atm).

Results following utilization of the Crush technique. We recently reported[6,27] the immediate and 8-month clinical outcome of a Crush stenting technique in the first 120 consecutive bifurcation lesions using drug-eluting stents (sirolimus-eluting stents, n = 74; paclitaxel-eluting stents, n = 46).

The Cypher experience. The angiographic results following the initial application of this technique, which was at that time solely utilized with the Cypher stent, were quite optimal and we felt no need for recrossing into the side branch to perform a final kissing inflation. Despite a good clinical outcome with only two events of stent thrombosis at the side branch, a quite feared complication due to the triple stent layer in the main branch, there was a 25% incidence of focal restenosis at the ostium of the side branch. Recently we reported short and intermediate outcome of 73 consecutive bifurcations from 70 patients treated with the Crush technique with sirolimus-eluting stents[34]. Angiographic success was reached in all lesions. Final kissing inflation was performed in 28 lesions (38%), due to the initial perception that this maneuver was not important. During hospital stay no patient died; 4 (5.7%) patients had myocardial infarction unrelated to stent thrombosis. At 6-month follow-up no patients died and the target lesion revascularization rate was 23%. The 6-month angiographic follow-up was available in 83% of the lesions and the restenosis rate was 33% (7% main and side branches and 26% only side branch). No difference was observed in the restenosis rate on the main branch between lesions treated with final kissing balloon inflation and lesions without final kissing inflation (4% in the final kissing group vs 8% in the no final kissing group, p = 1.00). The restenosis rate on the side branch was lower in the final kissing group (17%) in comparison to the no final kissing group (42%, p = 0.046). Wire recrossing and inflation of a balloon at the side branch with a balloon with at least equal diameter with the stent[33], and then kissing balloon inflation are recommended. The implementation of final kissing balloon inflation was done in order to allow better strut contact against the ostium of the side branch and therefore better drug delivery[33,34]. The Crush technique became therefore a sort of simplified Culottes technique. After the implementation of the final kissing inflation as part of the refinement of the technique, restenosis at the ostium of the side branch seems to decline. The positive aspect is that whenever restenosis occurs this narrowing is very focal (< 5 mm in length) and most of the times not associated with symptoms or ischemia.

The Taxus experience. Forty-six patients with 46 bifurcations were treated. Kissing inflation was performed in 41 of them (87%). Hospital outcome: Q-wave myocardial infarction none, non-Q wave myocardial infarction 2 patients. Only 11 patients were eligible for 8-month follow-up and the events were quite low, with 1 target vessel revascularization and 1 target lesion revascularization. Angiographic follow-up has only been performed in 10 patients, with 1 restenosis out of the 8 patients treated with kissing (12%) and 2 restenosis out of 2 patients treated without kissing.

Conclusions. Even if these results should be considered preliminary we can say that the adverse events, excluding the need of revascularization, are very low with both stents and even without kissing. Final kissing inflation, even if it does not eliminate restenosis at the ostium of the side branch seems to reduce this event by ≥ 50%. When restenosis occurs it is most of the times located at the ostium of the side branch, it is focal and frequently occurs without symptoms.

The "T" stenting technique

The usage of the "T" technique is mainly as a tool to shift from provisional stenting to stenting the side branch[35,36]. We completely replaced the usage of the "T" technique with the reverse Crush technique. Some operators still prefer the usage of this classical approach when two stents are needed following placement of a stent in the main branch. There are some operators who prefer not to use the Crush technique at all because of the concerns of the triple stent layer in the main branch and because of the difficulties to cross into the side branch. These operators will use the "T" technique also as a default technique when they plan to implant two stents.

In our view the "T" technique almost always will create a small gap between the stent implanted in the main branch and the one implanted in the side branch. When drug-eluting stents are used, this gap may be a factor contributing to uneven distribution of the drug and hence ostial restenosis at the side branch. We believe that this was a possible concurrent cause for the restenosis we noticed at the ostium of the side branch when two stents were implanted in the sirolimus bifurcation study, as in that study the "T" technique was used when two stents were implanted[6].

"T" technique as part of provisional stenting. When the operator performs this technique a stent is first fully deployed in the main branch then, following dilation of the side branch and kissing balloon inflation (main and side branch), the operator realizes that the result on the side branch is suboptimal. At this point a stent is advanced into the side branch and carefully positioned at the ostium of the branch. A final kissing inflation is performed. A 6F guiding catheter is sufficient.

Standard "T" technique. This technique is rarely used any more. The main area of application is when the operator is treating an ostial lesion of the side branch. In this specific condition only one stent is placed at the ostium of the side branch and a balloon is at times parked in the main branch and sometimes inflated at low pressure following the deployment of the stent in the side branch.

In a classical description the standard "T" technique consists in positioning a stent first at the ostium of the side branch being careful not to have the stent protruding in the main branch. Some operators leave a balloon in the main branch to help to further locate the main branch. Following deployment of the stent in the side branch and removal of the balloon and of the wire from the side branch, a second stent is advanced in the main branch. A wire is then readvanced into the side branch and final kissing balloon inflation is performed.

In the event the stent positioned in the side branch will protrude too much into the main branch making the other stent impossible to be advanced, the inflation of a balloon in the main branch (sometimes starting with a 1.5 mm balloon) will convert this technique into a Crush or partial Crush technique and allow advancement of a stent in the main branch. When performing this maneuver it is always important to remove first the wire from the side branch.

Like the other "T" technique, a 6F guiding catheter is sufficient.

Modified "T" technique. This technique has completely been replaced, in our laboratory, by the Crush technique.

The performance of the modified "T" technique commits always to stenting the main and side branches and almost always will leave a small gap between the struts of the stent in the main and side branch.

Compared to the other "T" techniques which can be performed with a 6F guiding catheter, the modified "T" technique will require at least a 7F guiding catheter.

Following predilation, the performance of this technique demands advancement of a stent into the side branch first (without deployment of the stent), then a second stent is advanced and positioned across the bifurcation in the main branch. The stent in the side branch is deployed and following verification of adequate result the balloon and the wire are removed from the side branch. Then the stent in the main branch is deployed usually at ≥ 12 atm. A wire is then readvanced into the side branch and a kissing balloon dilation is performed (usually at 8 atm).

Associated pharmacological treatment

When performing bifurcation stenting with one or two stents we do not usually change our protocol of periprocedural heparin administration (100 U/kg without elective IIb/IIIa and 70 U/kg with elective IIb/IIIa). Usage of IIb/IIIa is reserved to thrombus containing lesions, patients with unstable angina or acute myocardial infarction and it is not associated with the simple presence of a bifurcation lesion. IIb/IIIa inhibitors are sometimes administered when the final result at the side branch appears suboptimal and for various clinical or anatomical reasons the operator feels not necessary to implant another stent.

We pay a lot of attention to periprocedural preparation with thienopyridines and in doubt we administer a 600 mg loading dose of clopidogrel in the catheterization laboratory[37].

The duration of combined thienopyridine and aspirin treatment following stent implantation varies according to the length of the stent implanted, the type of stent used, and the clinical conditions of the patient (acute coronary syndrome at the time of stenting or diabetes mellitus).

In the sirolimus bifurcation study clopidogrel was continued for 3 months and no late thrombosis was observed[6]. All cases of thrombosis occurred during treatment with clopidogrel and some of them were associated with an angiographic suboptimal result. The only case of sudden death (4.5 months post-procedure) occurred while still taking clopidogrel. Unfortunately, the small number of patients enrolled in this trial does not allow us to draw any conclusion regarding the safety of 3-month clopidogrel administration in bifurcation lesions, especially when two stents are used. Our current practice is to administer combined antiplatelet therapy for at least 3 months for bifurcations treated with one Cypher stent, 6 months for bifurcations treated with 2 Cypher or Taxus stents (any length), and 1 year for more complex cases including patients with acute coronary syndrome at the time of stenting and diabetics.

Conclusions

The introduction of drug-eluting stents has made a remarkable improvement in the treatment of bifurcation lesions. The sirolimus bifurcation study, with all the limitations of being the very first study utilizing a drug-eluting stent, has demonstrated almost suppression of restenosis in the main branch. As for restenosis in the side branch which occurred in about 1 out of 5 lesions treated, we cannot dismiss the fact that this restenosis was almost always focal and therefore quite simple in its treatment. There has been some concern regarding the numerically high thrombosis rate (3.5%). We think that the learning curve with this new device (especially when implanting two stents) may have contributed to these adverse events. We should not also forget that the relative low number of patients enrolled in this study could have contributed, as frequently happens with a small number of patients in a study, to magnify complications.

The current appropriate application of provisional stenting and refinement of stent techniques when implanting two stents will further improve the results. Finally the introduction of drug-eluting dedicated stents for different types of bifurcations may further facilitate the conquest of one of the most challenging areas in interventional cardiology.

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