Stenting Techniques for Patients With Bifurcation Coronary Artery Disease

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Atherosclerotic lesions at the bifurcation of coronary arteries are associated with higher rates of restenosis following stenting, and can be technically challenging when performing percutaneous coronary intervention (PCI). Many techniques have arisen for PCI of these lesions, often incorporating the use of multiple balloons and the placement of two or more stents. A technique commonly used for bifurcations is kissing balloon angioplasty, in which two balloons are inflated simultaneously to prevent the shifting of plaque into the side branch. Provisional side branch stenting is the technique of using a stent for the main branch, and stenting the side branch only if necessary. Multiple-stent techniques include T-stenting, crush technique, culotte, simultaneous kissing stents, V-stenting, and Y-stenting; the goal of these techniques is to provide maximal apposition to the vessel wall with effective drug delivery in the case of drug-eluting stents. Additionally, dedicated bifurcation stents also exist, with apertures that allow placement of additional stents. Debulking techniques such as atherectomy can be employed as stand-alone procedures or to debulk lesions prior to bifurcation stenting. Despite these many options for PCI of bifurcation lesions, there are currently inadequate data to indicate which of these techniques is superior, and many trials have found that complex stenting techniques provide no additional benefits when compared with provisional side branch stenting. Additional, well-designed randomized trials evaluating specific stenting techniques are necessary to determine the best practice for bifurcation lesions.
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Coronary bifurcations may develop atherosclerotic lesions due to turbulent blood flow and high shear stress. Approximately 8% to 15% of percutaneous coronary intervention (PCI) involves bifurcation lesions.[1] PCI of the bifurcation can lead to a “snow plowing” effect, which can cause plaque shifting into the opposite branch, compromising its patency. Atherosclerotic lesions at the bifurcation of coronary arteries commonly are complex lesions, pose a technical challenge to PCI, are associated with an increased risk of angiographic restenosis, myocardial infarction (MI), and thrombosis, as well as higher cost and resource utilization.[1,2] There are multiple interventional options for coronary bifurcation lesions, which vary in technical difficulty. However, there is no clear consensus on which technique is associated with the best outcome. We discuss the management of a patient with severe disease in the left anterior descending artery (LAD) and first diagonal branch (D1) treated successfully with PCI and review the current treatment strategies for bifurcation lesions.

Case Report

A 69-year-old man with a past medical history of diabetes mellitus and hypercholesterolemia underwent cardiac catheterization due to angina pectoris and an abnormal stress test result with ischemia in the anteroseptal wall. The coronary angiogram demonstrated a severe diffuse stenosis of the proximal LAD and D1 ostium (Figures 1 and 2). Left ventricular angiography demonstrated an ejection fraction of 60%.

The decision was made to perform PCI. The patient was given clopidogrel, 600 mg, and aspirin, 325 mg. After predilatation of the LAD and D1 with kissing balloons (Figure 3), simultaneous kissing stents were placed in the LAD (3.0 × 28 mm Taxus stent [Boston Scientific, Natick, MA]) and D1 (2.5 × 16 Taxus stent) (Figure 4) and inflated simultaneously at 16 atmospheres (Figure 5). The stents were postdilated simultaneously with noncompliant kissing balloon inflations (Figure 6). Final angiographic images demonstrated excellent angiographic results (Figure 7). Intravascular ultrasound (IVUS) was performed, which

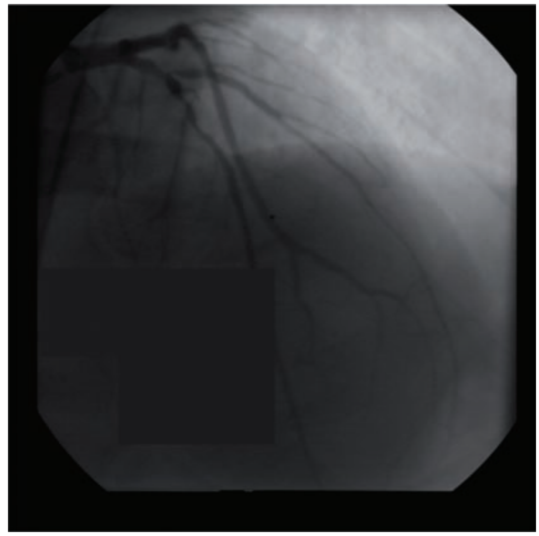

Figure 1. *Coronary angiography demonstrates severe disease at the left anterior descending artery/first diagonal branch in the anteroposterior-cranial view.*

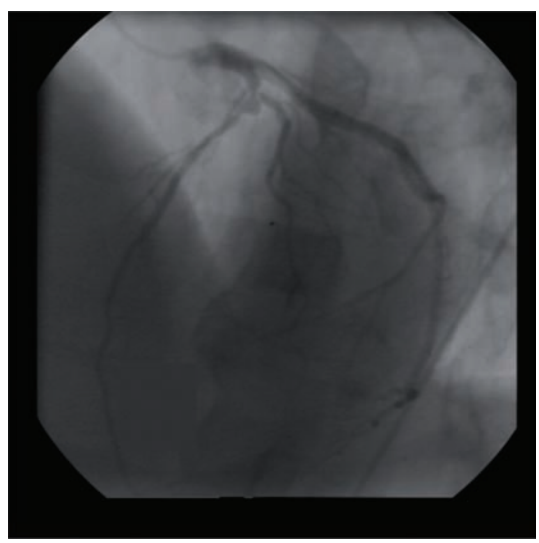

Figure 2. *Coronary angiography demonstrates severe left anterior descending artery/first diagonal branch in the left anterior oblique-cranial view.*

Figure 3. *Prestenting kissing balloon inflation.*

Figure 4. *Stent placement in the left anterior descending artery/first diagonal branch in preparation for simultaneous kissing stents. The proximal markers of each stent are aligned juxtaposed to one other.*

Figure 5. *Simultaneous kissing stents. Both stents are inflated simultaneously.*

Figure 6. *Postdilatation with kissing balloon inflations in the left anterior descending artery and first diagonal branch.*

demonstrated excellent stent apposition, expansion, and no dissection. At 3-year follow-up, the patient continues to do well with no angina, MI, and target vessel revascularization; a recent nuclear stress test demonstrated no ischemia.

Discussion

Ideally, the one-stent approach should be used whenever possible when treating bifurcation lesions. The disadvantage of using a single stent in the main vessel is that, after PCI at the bifurcation, the plaque can shift to compromise the side branch. If this does occur, kissing balloon angioplasty can be performed. If the angiographic result after balloon angioplasty in the side branch is suboptimal (that is, if the residual stenosis is $>$ 50%, the fractional flow reserve is $<$ 0.75, dissection is present, or there is $<$ Thrombolysis In Myocardial Infarction grade 3 flow),[1] stenting of the side branch should be performed.[3] This practice of only stenting a side branch in higher risk patients is termed provisional stenting.

Final kissing balloon inflation should be routinely performed after bifurcation stenting involving two stents. The most effective method involves two steps, rather than inflating both balloons simultaneously in one step.[1] The first step is inflating a balloon in the side branch only at high pressure. This is followed by simultaneous kissing balloon inflation. By using final kissing balloon dilation, (re)stenosis of the side branch is reduced.[4]

The options for multiple stents include T-stenting, T and protrusion (TAP), which is a modified version of T-stenting, crush technique, modified T-stenting, culotte, V-stenting, simultaneous kissing stents, and Y-stenting.[3,5] Kissing balloon angioplasty, or simultaneous inflation of balloons in both branches, is used to

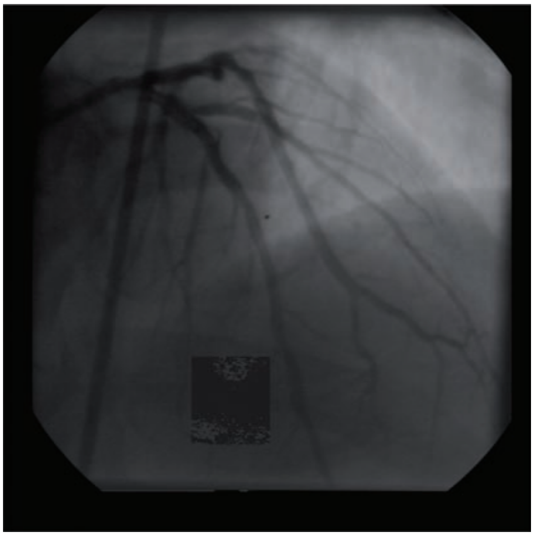

Figure 7. *Final coronary angiography demonstrates widely patent stents in the left anterior descending artery and first diagonal branch. At 3-year follow-up, the patient is asymptomatic and has not experienced myocardial infarction or target vessel revascularization.*

avoid shifting of plaque to the side branch and acute ischemia.[6] However, one randomized trial found that, as long as flow reduction was not observed in the side branch after main branch angioplasty, there was no negative effect due to omitting side branch PCI.[7]

T-stenting involves first expanding a stent in the main vessel of a bifurcation, followed by extending a stent through the struts of the first stent into the side branch. The main weakness of this method is that the ostium of the side branch is not covered by stent. Two variations on T-stenting are modified T-stenting and the TAP technique. In modified T-stenting, a stent is placed first in the side branch, and then into the main branch, covering the ostium of the side branch.[5] The TAP technique involves the same initial step as T-stenting: placement of the main vessel stent. Next, a stent is deployed in the side branch, with the struts of the side branch stent protruding into the main vessel. A final kissing balloon inflation is performed.[8]

In the crush technique, after stents are placed in both branches, the side branch stent is expanded first followed by the removal of the stent delivery system and wire.[9] Then, the main branch stent is expanded, crushing the portion of the side branch stent that extends into the main vessel. This is similar to T-stenting, with the exception that the side branch stent extends into the main vessel by 4 to 5 mm. A "mini-crush" technique is different in that there is only minimal extension (≤ 2 mm) of the side branch stent into the main vessel. The crush technique ameliorates the possibility of incomplete coverage of the side branch ostium that may occur with T-stenting and lead to a greater risk of restenosis.

The culotte technique is another two-stent method to ensure complete coverage of the ostium of the side branch. The first stent is advanced down the side branch and expanded.[5] Next, a balloon is moved into the main branch through the first stent, and is then dilated, providing an opening in the stent. A second stent is then advanced into the main branch through this aperture, and expanded. This second stent overlaps with the portion of the first stent in the main vessel.

V-stenting and simultaneous kissing stents (SKS) also use stents in both branches of the bifurcation.[5] In V-stenting, stents are expanded in both branches of the bifurcation, but they do not extend into the main vessel.[10] The SKS technique is similar to V-stenting but the stents extend into the main vessel. Because the stents are expanded simultaneously, neither stent is crushed, and they overlap in the main vessel.[11] In this patient, the SKS technique was chosen because it was thought that a one-stent approach would result in inadequate results of the ostial D1. Furthermore, the vessel proximal to the LAD/D1 bifurcation was large enough to accommodate two stents inflated simultaneously. Y-stenting is similar to V-stenting, with the exception that a third stent is placed proximally in the main vessel.[12]

Dedicated bifurcation stents have been developed; they are either stents that extend into both branches, or stents with a built-in aperture for better access to the side branch.[13] Debulking techniques, including directional and rotational atherectomy, are another approach to treating bifurcation lesions. Both directional coronary atherectomy (DCA) and rotational atherectomy have been determined to be safe and effective for bifurcation lesions in feasibility studies.[14-16] The Coronary Angioplasty Versus Excisional Atherectomy Trial-I (CAVEAT I) study compared angioplasty to DCA, and a subgroup analysis examined patients with bifurcation lesions.[17]

Debulking techniques, including directional and rotational atherectomy, are another approach to treating bifurcation lesions.

In patients with bifurcation disease, DCA resulted in a greater reduction in stenosis immediately following the procedure; however, DCA was also associated with higher rates of side branch closure and non–Q-wave MI. Mortality and Q-wave MI were not affected. In a nonrandomized study, Dauerman and colleagues[18] compared percutaneous transluminal coronary angioplasty (PTCA) with PTCA plus DCA or rotational atherectomy. Mortality, MI, and target vessel revascularization were each lower in the PTCA/debulking group. Combined major adverse cardiac events (MACE) were 56% in the PTCA group compared with only 30% in the PTCA/debulking group. This study confirmed the CAVEAT I findings of higher side branch compromise with debulking. The authors postulated that more aggressive rescue of occluded side branches may explain the lower rate of periprocedural infarction observed when compared with CAVEAT I. IVUS guidance for atherectomy may be useful for achieving optimal debulking in bifurcations.[19] Randomized trials should be conducted comparing PTCA to PTCA/atherectomy to determine the effect of atherectomy on clinical outcomes.

Intravascular ultrasound guidance for atherectomy may be useful for achieving optimal debulking in bifurcations.

Several trials have been conducted to determine the best technique for treating bifurcation lesions (Table 1). The Stenting Coronary Arteries in Nonstress/Benestent Disease (SCANDSTENT) trial reported that in bifurcation stenting (as with stenting of simple lesions), sirolimus-eluting stents are associated with a lower rate of target lesion revascularization (TLR), and a lower rate of restenosis in the side branch when compared with bare-metal stents.[20] Additionally, sirolimus-eluting stents were superior to paclitaxel-eluting stents for bifurcation lesions.[21]

Several studies have been conducted comparing complex stenting (two stents) to simple stenting (one stent). In a retrospective study comparing complex stenting (either T-stenting, V-stenting, Y-stenting, or culotte technique) to simple stenting, TLR and MACE at 6-month follow-up were not significantly different between groups.[22] Additionally, MACE during and immediately following PCI occurred at a rate of 13% in complex stenting versus 0% with simple stenting, which may be due to the added difficulty of complex stenting. Several randomized trials comparing complex and simple stenting with angioplasty of the side branch also found no significant difference in outcomes.[2,23,24] The Nordic Bifurcation Study found statistically significantly higher levels of plasma troponin and creatine kinase-MB following complex stenting, along with longer fluoroscopy times and more contrast used.[2] The British Bifurcation Coronary Study found an increased rate of MACE at 9 months in the complex stenting group, which was due not only to increased periprocedural MI, but also increased rate of MI after leaving the hospital.[25] The Bifurcations Bad Krozingen randomized trial found no significant difference in MACE at 1 year.[26] Several meta-analyses of these randomized controlled trials and other studies in recent years have also found increased rates of MI with complex stenting, but no difference in long-term outcomes.[27-30]

In addition to comparisons of complex versus simple stenting techniques, there have also been studies comparing two different complex stenting techniques, or a specific complex stenting technique to provisional stenting. When the SKS technique was first introduced, it was associated with a 5% rate of TLR after 6 months compared with 18% with provisional side branch stenting.[10] However, there is still a need for a randomized trial to reproduce these results. The Coronary Bifurcations: Applications of the Crushing Technique Using Sirolimus-Eluting Stents (CACTUS) trial evaluated the effectiveness of the crush technique versus provisional stenting, and found no difference in outcomes between the two methods.[31] Another randomized trial compared the crush technique with the culotte technique, and whereas MACE were similar in both groups, the culotte technique was associated with a lower rate of in-stent restenosis.[32] A variant on the crush technique, the double kissing crush technique, was associated with decreased MACE and TLR rates at 8 and 24 months when compared with the crush technique. This technique is modified from the classic crush as follows: the side branch is stented, then the side branch is balloon crushed, then kissing balloon angioplasty is performed, then the main branch stent is placed, and finally a second kissing

The CACTUS trial evaluated the effectiveness of the crush technique versus provisional stenting, and found no difference in outcomes between the two methods.

Table 1
Results of Studies on Coronary Bifurcation

Study	Study Type	Comparison	Results	*P* Value
Sharma SK et al[11]	Observational	SKS vs PSB	TLR: 5% in SKS, and 18% in PSB	$P = .007$
Yamashita T et al[22]	Observational	MV + SB (multiple techniques used) vs MV alone	Procedural complications: 13% in MV + SB, 0% in MV alone	$P < .05$
			MACE at 6 mo: 51% in MV + SB, 0% in MV alone	$P =$ NS
Palmerini T et al[36]	Observational	MV + SB (mostly T-stenting, V-stenting, and crush) vs MV alone	MV only was associated with lower risk of MACE at 2 y; HR = 0.53	95% CI = 0.37- 0.76
Dauerman HL et al[18]	Observational	PTCA alone vs PTCA + atherectomy	MACE at 1 y: 56% in PTCA alone, 30% PTCA + atherectomy	$P = .05$
Colombo A et al[23]	Randomized trial	MV + SB (mostly T-stenting) vs PSB	No difference in MACE at 6 mo	$P =$ NS
Pan M et al[24]	Randomized trial	MV + SB vs MV alone	No difference in clinical outcome	$P =$ NS
Steigen TK et al[2]	Randomized trial	MV + SB (mostly crush, culotte, and T-stenting) vs PSB	In the MV + SB group there were significantly higher fluoroscopy times, contrast volumes, and procedure times	$P < .0001$
			MACE at 6 mo: 3.4% in MV + SB, 2.9% in PSB	$P =$ NS
Hildick-Smith D et al[25]	Randomized trial	MV + SB (culotte or crush) vs PSB	In hospital MACE: 2% in PSB, 8% in MV + SB	$P = .002$
			MACE at 9 mo: 8% in PSB, 15.2% in MV + SB	$P = .009$
Ferenc M et al[26]	Randomized trial	MV + SB (T-stenting) vs PSB	MACE at 1 y: 11.9% in MV + SB, 12.9% in PSB	$P =$ NS
Colombo A et al[31]	Randomized trial	crush vs PSB	MACE at 6 mo: 15.8% in crush, 15.0% in PSB	$P =$ NS

Table 1
Results of Studies on Coronary Bifurcation—(continued)

Study	Study Type	Comparison	Results	*P* Value
Erglis A et al[32]	Randomized trial	Crush vs culotte	MACE at 6 mo: 4.3% in crush, 3.7% in culotte	P = NS
Chen SL et al[33]	Randomized trial	DK vs crush	MACE at 8 mo: 24.4% in crush, 11.4% in DK	$P = .02$
Chen and Kwan[34]	Follow-up of Chen SL et al[33]	DK vs crush	MACE at 24 mo: 29.9% in crush, 18.1% in DK	$P = .044$
Cervinka P et al[35]	Randomized trial	Dedicated bifurcation stent vs PSB	MACE at 12 mo: 13.7% in dedicated stenting, 13.3% in PSB	P = NS
Brener SJ et al[17]	Subanalysis of randomized trial	PTCA vs DCA	Death or MI at 6 mo: 3% in PTCA, 9% in DCA	$P < .001$
Tsuchida K et al[37]	Subanalysis of randomized trial	MV + SB (T-stenting, V-stenting, culotte, or crush) vs MV alone	MACCE at 12 mo: 9.8% in MV + SB, 14.1% in MV alone	P = NS
Niccoli G et al[27]	Meta-analysis	MV + SB (mostly crush, culotte, T-stenting) vs PSB	No difference in MACE	P = NS
Hakeem A et al[28]	Meta-analysis	MV + SB vs PSB	MACE at 6-12 mo: 12.6% in MV + SB, 9.6% in PSB	P = NS
Zhang F et al[29]	Meta-analysis	MV + SB (mostly crush, culotte, T-stenting) vs PSB	MI at > 6 mo was significantly higher in MV + SB	$P = .001$
Katritsis D et al[30]	Meta-analysis	MV + SB (mostly crush, culotte, T-stenting) vs PSB	No difference in TLR at follow-up	P = NS

DCA, directional coronary atherectomy; DK, double kissing; HR, hazard ratio; MACCE, major adverse cardiac and cerebrovascular events; MACE, major adverse cardiac events; MV, main vessel; NS, not significant; PTCA, percutaneous transluminal coronary angioplasty; PSB, provisional side branch stenting; SB, side branch; SKS, simultaneous kissing stents; TLR, target lesion revascularization; TVR, target vessel revascularization.

balloon inflation is performed.[33,34] A randomized trial conducted to evaluate the use of the Twin-Rail™ (Invatec, Brescia, Italy) dedicated bifurcation stent reported no advantage over provisional stenting.[35] Randomized trials evaluating other dedicated bifurcation stents are currently being performed.[1]

Conclusions

The ideal stenting strategy for coronary bifurcation lesions has yet to be determined. When comparing complex stenting in general to provisional stenting, provisional appears to be superior due to the decreased rate of procedural complications and little difference in long-term outcomes. However, some complex stenting strategies may fare better than others. Debulking techniques may also play a role in the management of bifurcation lesions. ■

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Main Points

- Coronary bifurcation lesions involve a higher rate of myocardial infarction and restenosis, and performing percutaneous coronary intervention is technically complex.
- Many different stenting techniques exist to treat bifurcation lesions, including provisional side branch stenting (single-stent) and complex stenting (multiple-stent).
- Debulking techniques, including directional and rotational atherectomy, may be an alternative to angioplasty and stenting.
- Many randomized trials comparing provisional side branch stenting to complex stenting have found that complex stenting in general provides no benefits; however, additional trials would be useful to determine whether specific stenting techniques are superior to others.

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