Journal of
Transcatheter Interventions
e-ISSN e-2595-4350

Double kissing crush: technical aspects and current considerations

Double kissing crush: aspectos técnicos e considerações atuais

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DOI: 10.31160/JOTCI202028A202008

ABSTRACT – Percutaneous treatment of coronary bifurcation lesions remains a challenge, even with all advances in technique and materials available, such as hydrophilic guidewires, lower profile balloons and drug-eluting stents with new materials, thinner struts and less thrombogenic polymers. Despite these advances, little progress has been made in dedicated bifurcation stenting. The degree of technical difficulty and the lack of dedicated material result in higher rates of restenosis and stent thrombosis, especially in true bifurcation lesions, in which the therapeutic strategy requires the implantation of, at least, two stents. Several double stent bifurcation techniques have been developed, such as kissing-stent, stent-crush, culotte, T-stenting, Y-stenting, and double kissing crush. The latter includes technical aspects whose primary objective is to facilitate crossing of the stent meshes, enabling a routinely execution of the final kissing balloon inflation, to reduce major adverse cardiovascular events (MACE). The double kissing crush technique has been improved since its conception, and has been extensively evaluated over several multicenter randomized studies comparing it with other techniques, which showed the superiority of the double kissing crush technique in true bifurcation lesions, including in the left main coronary artery, when analyzing the most commonly used techniques today.

Keywords: Percutaneous coronary intervention/methods; Stents

RESUMO – O tratamento percutâneo de lesões em bifurcações de artérias coronárias permanece um desafio, mesmo com todos os avanços em relação à técnica e aos materiais disponíveis, como cordas-guia hidrofílicas, balões de perfil mais baixo e stents farmacológicos com novos materiais, hastes mais finas e polímeros menos trombogênicos. Apesar desses avanços, pouco se evoluiu em relação a stents dedicados para bifurcações. O grau de dificuldade técnica e a carência de material dedicado resultam em taxas mais elevadas de reestenose e trombose de stent, especialmente em bifurcações verdadeiras, em que a estratégia terapêutica requer o implante de pelo menos dois stents. Diversas técnicas de bifurcação de duplo stent foram desenvolvidas, como *kissing-stent*, *stent-crush*, *culotte*, T-stent, Y-stent e *double kissing crush*. Esta última contempla aspectos técnicos, com o objetivo primordial de facilitar o cruzamento das malhas dos stents, para permitir a execução rotineira do *kissing-balloon* final, cuja importância reside na redução de eventos cardiovasculares adversos maiores (ECAM). A técnica *double kissing crush* foi aprimorada desde sua concepção e extensamente avaliada ao longo de vários estudos multicêntricos, randomizados e comparativos com outras técnicas, evidenciando a superioridade do *double kissing crush* em lesões de bifurcação verdadeira, inclusive de tronco de coronária esquerda, em comparação às demais técnicas mais utilizadas na atualidade.

Descritores: Intervenção coronária percutânea/métodos; Stents

How to cite this article:
Zago AC, Zago G, Beltrame RC, Zago AJ. Double kissing crush: technical aspects and current considerations. J Transcat Intervent. 2020;28:eA202008. https://doi.org/10.31160/JOTCI202028A202008

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Received on:
May 9, 2020

Accepted on:
Aug 17, 2020

INTRODUCTION

Percutaneous coronary intervention (PCI) and the results thereof have greatly evolved in recent years, especially after the advent of drug-eluting stents (DES) and the successive improvements to the platform, with new materials and thinner struts, and biocompatible polymers. However, despite the advances, little progress has been made in dedicated bifurcation stenting, which remains a challenge, for technical reasons and for the higher rates of restenosis and stent thrombosis.[1-6]

In true bifurcation lesions, when a double stent technique is required, proper coverage of the side branch ostium with the stent strut is essential, because this is the most frequent site of restenosis.[7-10] However, proper coverage of the side branch ostium by a second stent must not restrict blood flow and/or access to the side branch, to avoid ischemia and enable future PCI in the branch, if necessary. Therefore, several double-stent bifurcation techniques, such as the kissing-stent, stent-crush, culotte, T-stenting, Y-stenting techniques, and others have been developed.

In this article, we discuss the double kissing (DK) crush technique, and describe it detailing step-by-step, including some of the most recent advances and technical aspects, and also its indications and results, in comparison to other bifurcation lesion techniques.

INDICATIONS

Inadequate or suboptimal stent expansion is the main cause of the higher incidence of restenosis or stent thrombosis in bifurcation lesions with double-stent implantation. Therefore, postdilation of stents with the kissing-balloon technique, to fully expand the stent implanted in the side branch ostium and prevent the twisting of the stent struts implanted in the main vessel, is a crucial step in the technique of stent implantation in bifurcation lesions to ensure satisfactory short, medium and long-term results.[1,10] However, postdilation of stents with the kissing-balloon technique is always a major challenge for operators, due to the difficulty in crossing two layers of stent struts with the 0.014 guidewire or the balloon catheter to be used in postdilation. Consequently, the DK crush technique was developed, whose primary objective is to facilitate the crossing of the stent meshes, and to enable the routinely execution of this important step of the bifurcation technique.

In addition to facilitating the crossing of stent meshes, the DK crush technique also enables the implantation of the stent with a 6F arterial sheath, unlike the conventional crush technique, which requires a 7F arterial sheath, to better accommodate two stents, especially during the progression of the second stent inside the guide catheter. This advantage is currently very significant, since most procedures are now performed via radial artery, and many PCIs are performed ad hoc.

The relation between the anatomy of the coronary obstructions and the choice of bifurcation technique to be used is a very important aspect to be discussed. The DK crush technique is particularly indicated for true bifurcation lesions, i.e., with significant involvement of both the main vessel and the side branch, such as lesions with Medina classification 1,1,1, 1,0,1 and 0,1,1, which require the implantation of two stents for a satisfactory treatment of the obstructive lesions.

Another important criterion is the angle between the main vessel and the side branch. The use of the DK crush technique is especially recommended when the angle between the main vessel and the side branch is ≤70°. At angles ≤70°, the inflation of a balloon in the main vessel causes the crushing of the stent struts implanted in the side branch that are protruded into the main vessel (crush). However, at angles >70°, there is a risk of accidental displacement of the newly implanted stent in the side branch, when the main vessel balloon is inflated to crush the struts of the proximal portion of the stent implanted in the side branch; that is, the main vessel balloon, when crushing the struts, can distally move the stent properly positioned in the side branch, or even cause twisting of its proximal struts. This accidental displacement or deformation of the proximal stent struts previously implanted in the side branch can result in important complications, such as dissection of the branch, or even the main vessel, requiring the implantation of a third stent to cover the side branch segment in which there was displacement or deformation of the struts and/or impairment of flow with hemodynamic repercussions, mainly in the treatment of lesions in the left main coronary artery (LMCA).

Therefore, the correct execution of the DK crush technique, as well as its use in appropriate anatomical situations, is essential for procedural success.

TECHNIQUE

The planning of this procedure must be carried out thoroughly and in advance, because it requires greater amount of material than a conventional PCI. As in any procedure, especially high-complexity procedures, no material can be missing in its course, under the risk of hampering its execution and results.

Initially, the access route and the size of the arterial sheath must be defined. The DK crush procedure can be performed in most cases via radial artery with a 6F arterial sheath; however, the femoral access route is recommended in cases of excessive tortuosity of the arteries in the upper limb, which may hinder the progression of the material inside the guide catheter and coronary arteries. And this approach is also used in cases requiring greater support for the guide catheter, due to the use of very long stents or the presence of excessive tortuosity in the proximal segment or in the target lesion segment. Likewise, the use of a 7F arterial sheath provides greater support, as well as greater comfort for the operator during the contrast media injection and simultaneous insertion of materials, especially high-profile balloon catheters for postdilation and stents. Each case must be analyzed individually, to assess technical difficulties, when choosing the most appropriate access route and the size of the arterial introducer.

After selective cannulation of the coronary artery with an appropriate support guide catheter, 0.014 guidewires are inserted into the main vessel and the side branch. The decision to use a hydrophilic or a non-hydrophilic guidewire does not interfere with the technique, and is based on the experience of each operator in crossing the lesions. Next comes a controversial step, called predilation or preparation of the lesion (Figure 1). Some operators prefer to skip this step or even predilate only severely obstructed lesions. However, the authors believe that a single predilation or a predilation with a final kissing-balloon inflation, depending on the severity of the obstructive lesions, is of great importance.

This step provides the compression and initial accommodation of the atheromatous plaques, to prevent their displacement during the sequential implantation of the stents, which could obstruct the newly treated vessels and/or hinder the crossing and recrossing of the side branch stent struts with the guidewire, thus hampering the main purpose of this bifurcation technique, which is precisely to facilitate recrossing the side branch stent struts.

Then, the stent is positioned in the side branch, and the non-compliant balloon is positioned in the main vessel (Figure 2). According to the initial description of the technique,[11,12] the side branch stent should be positioned with a protrusion of approximately 3 to 5mm into the main vessel, and some considerations are needed here. There is a difference in the positioning of the side branch stent, when comparing different reference points; i.e., the proximal and distal edges of the proximal radiopaque mark of the balloon, or even the proximal edge of the stent, in relation to the distal edge of the proximal radiopaque mark of the balloon. It is noteworthy that the radiopaque mark is approximately 1-mm thick, and not all stents are accurately crimped next to the radiopaque mark, and the visualization of the stent varies according to the radiopacity of each brand, and depends on the quality of the fluoroscopy equipment available. Another important aspect in bifurcation lesions with side branch angulation ≤70°, a main indication for the use of DK crush technique, is that during the stent implantation, there is a gap between the two lateral and opposite points of the proximal edge of the stent and the main vessel wall axis, and this distance increases inversely proportional to the bifurcation angle. Finally, a longitudinal stent shortening (foreshortening), although very small in current stents, should also be considered as a relevant variable in the precise positioning of the side branch stent. Hence a minimal protrusion of the proximal edge of the side branch stent (approximately 2mm) into the main vessel is currently recommended, according to the most recent description of the technique,[10] for risk-benefit optimization. This way, lack of side branch ostial strut coverage is avoided (geographic missing), which considerably increases the rates of restenosis, minimizing strut protrusion into the main vessel, which can both hinder its distal access and result in a marked accumulation of metal, with a consequent increase in the risk of thrombosis and the rate of restenosis. After the correct and accurate positioning of the stent in the side branch, it is then implanted, with the non-compliant balloon catheter properly positioned in the main vessel. Next, the balloon and the 0.014 guidewire are removed from the side branch, after injecting the contrast media, to ensure the absence of dissection lines, and the balloon catheter is inflated in the main vessel to crush the proximal struts of the side branch stent (Figure 3).

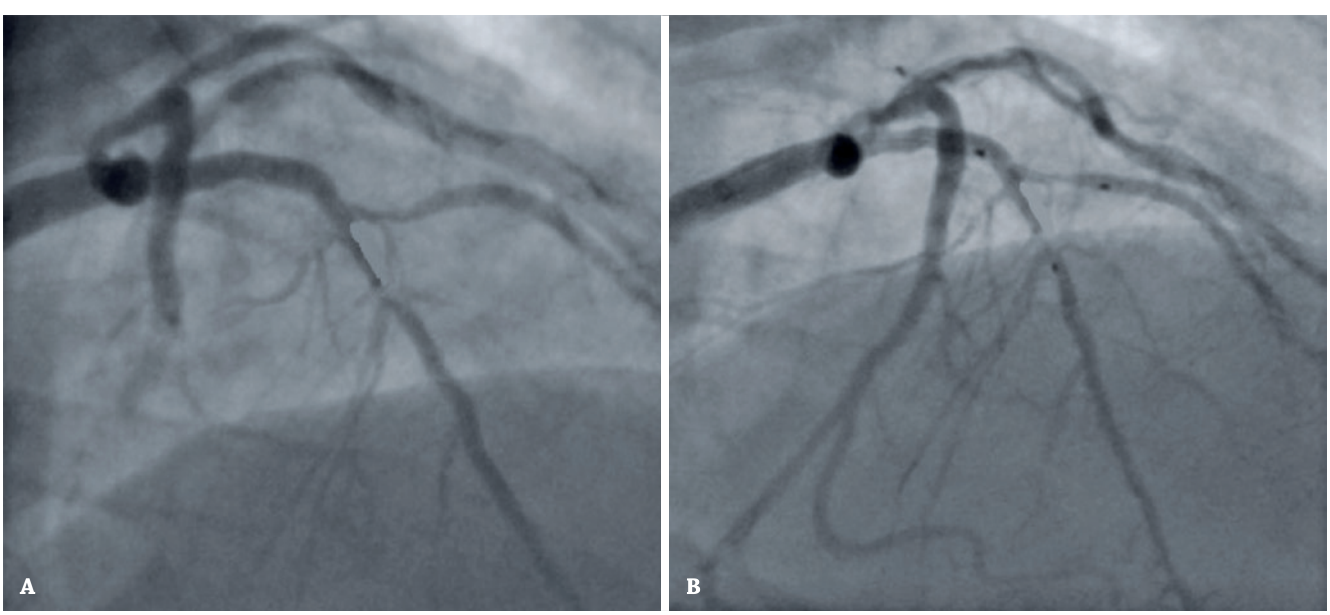


Figure 1. True bifurcation lesion in the left descending artery with the first diagonal branch. (A) Bifurcation lesion with Medina classification 1.1.1. (B) Predilation with kissing-balloon technique.

The next step in the procedure is recrossing the side branch with the 0.014 guidewire through the most proximal cell of the side branch stent mesh,[11] to avoid twisting of the stent struts or malapposition of the struts that are distal to the origin of the side branch (Figure 4). Next, an angioplasty with a non-compliant balloon inflated at high pressure (≥16atm) is performed to open an appropriately sized hole in the side branch stent meshes.[13] Then, an angioplasty is performed with the kissing-balloon technique (first kissing)[10,11,13,14] (Figure 5), using the same non-compliant balloon inflated in the side branch and the main vessel non-compliant balloon used for crushing the side branch stent struts, preferably maintaining a 1:1 ratio between the diameters of the coronary artery and the balloon catheter, both for the main vessel and for the side branch.

After the first kissing of the DK crush technique, the balloon catheter and the 0.014 guidewire must be removed from the side branch, and the main vessel balloon catheter has to be replaced by the stent, which must be selected and implanted according to the distal reference diameter of the main vessel. Subsequently, the main vessel stent should be postdilated in its proximal segment, including the

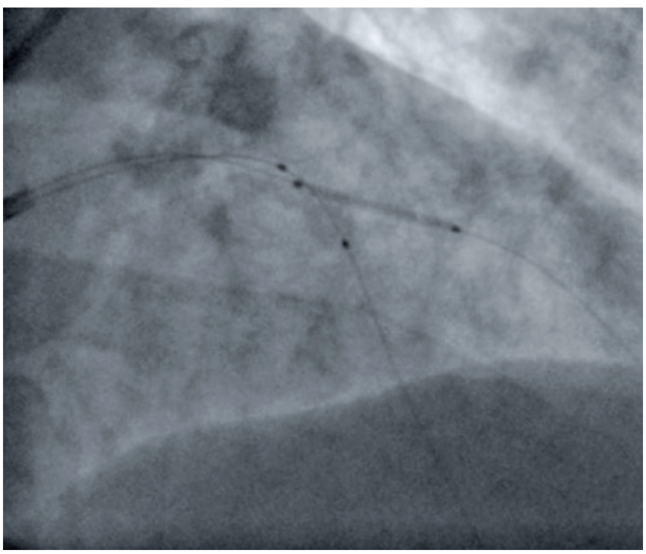
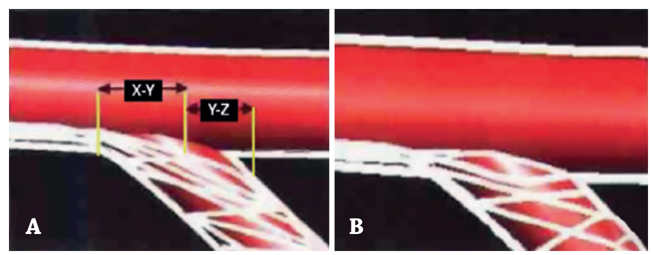


Figure 2. Stent positioning in the lateral branch and non-compliant balloon in the main vessel.



Source: adapted from Chen et al.[11]
Figure 4. Recrossing the side branch with guidewire. (A) The correct site for recrossing with the 0.014 guidewire in the side branch through the most proximal cell of the side branch stent mesh (segment X-Y). The incorrect site (segment Y-Z) results in distortion of stent struts and, consequently, in malapposition of struts that are distal to the origin of the side branch. (B) Appropriately sized hole in the side branch stent meshes after angioplasty with non-compliant balloon inflated at high pressure (≥16atm).

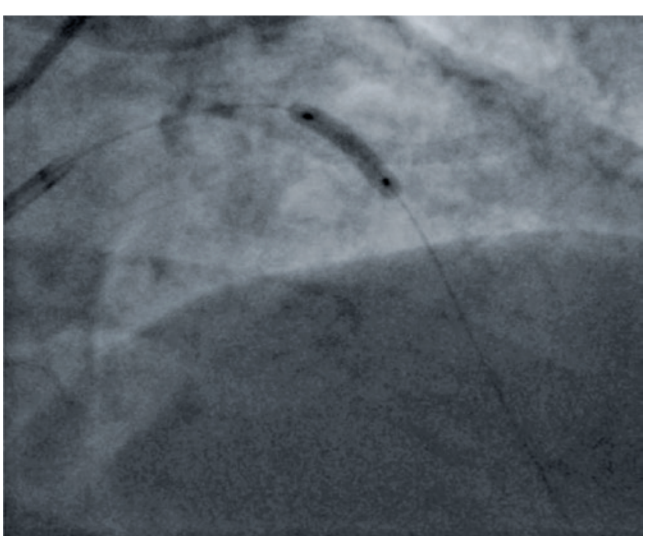


Figure 3. Crush: crushing of the proximal struts of the stent implanted in the lateral branch with the non-compliant balloon placed in the main vessel.

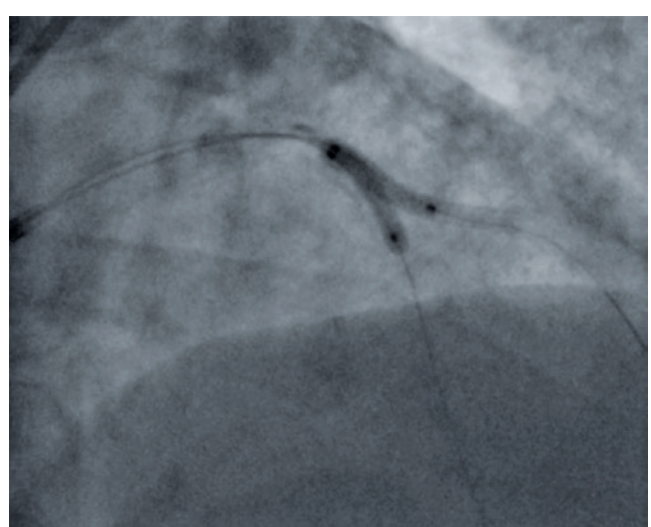
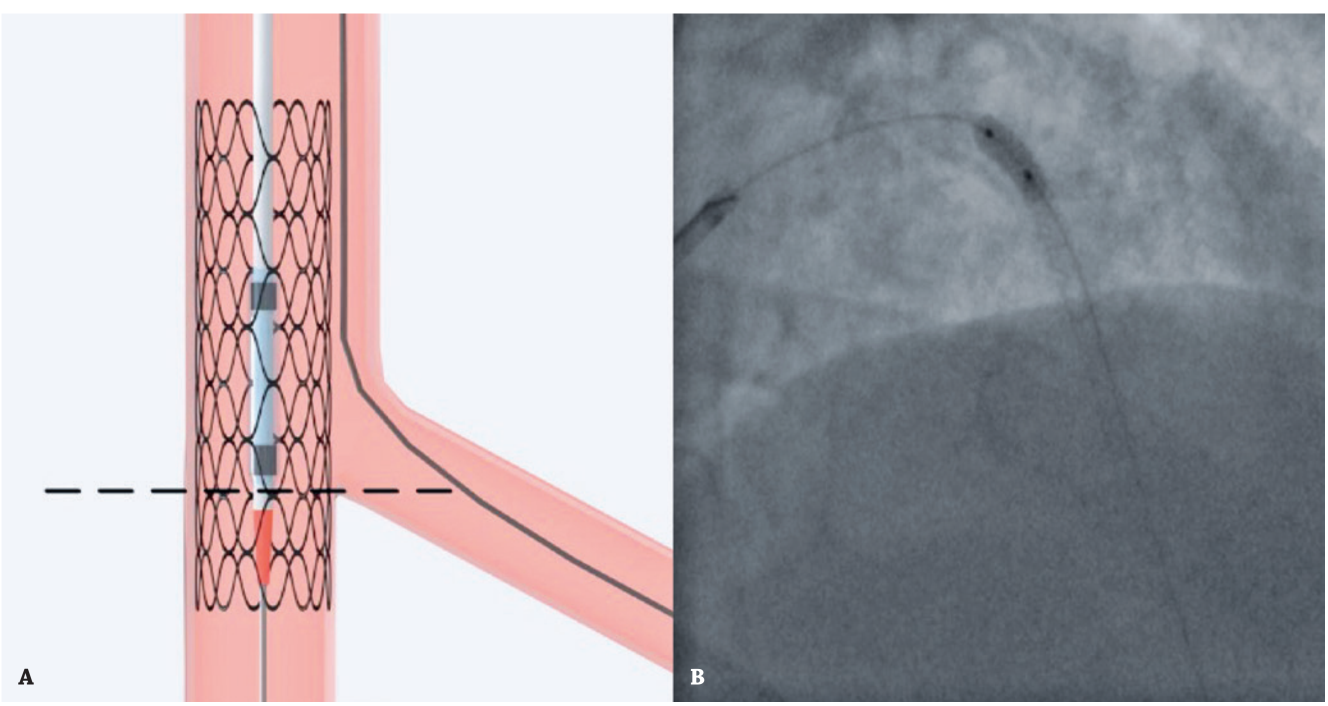


Figure 5. First kissing-balloon of the double kissing crush technique.

neocarina, with a non-compliant balloon catheter inflated at ≥18atm for proximal optimization (POT),[10,15] promoting additional crushing of the proximal struts of the stent implanted in the side branch (Figure 6). Then, the 0.014 guidewire is repositioned in the side branch through the double stent mesh, seeking to cross the side branch mesh through the hole opened in the first kissing balloon. The previous POT in the main vessel stent prevents an inadequate progression of the side branch 0.014 guidewire between the main vessel stent mesh and the vessel wall, whose subsequent postdilations would cause twisting or even fracture of struts with a consequent high risk of stent thrombosis and the serious clinical repercussions thereof. In addition, the POT also provides greater opening of the main vessel stent cells and creates an oblique angle in the stent mesh, towards the side branch ostium, both of which result in facilitating the recrossing of the stent from the main vessel into the side branch (Figure 7).

Subsequently, a new angioplasty with a non-compliant balloon catheter is performed at ≥16atm pressure in the side branch through the double stent mesh ostial coverage,[13] followed by a sequential dilation with a non-compliant balloon catheter at ≥16atm intra-stent pressure in the main vessel.[14] In most cases, a new balloon is required to cross the double mesh of stent struts that covers the side branch ostium, or even a low profile balloon just for opening an orifice to enable the passage of a non-compliant balloon of appropriate diameter, in a 1:1 ratio between the diameters of the side branch and the balloon catheter. Then, a second angioplasty is performed, with the kissing-balloon technique (second kissing), in the DK crush or final kissing-balloon (FKI) technique,[10-14,16] in which the use of balloon catheters is indicated in a 1:1 ratio between the diameters of the coronary artery and the balloon catheter for both the main vessel and the side branch. It is also suggested that a short overlap extension (<3mm) between the balloons is used, which provides a more spherical dilation of the main vessel stent and reduces the rate of restenosis[17,18] (Figure 8).

Finally, a routine angioplasty is recommended, with proximal in-stent optimization technique (Re-POT or final POT) in the main vessel, using a non-compliant balloon catheter with a diameter in a 1:1 ratio with the diameter of the main vessel proximal reference, extending between the proximal edge of the stent and the neocarina, inflated at ≥18atm[10,15] (Figure 9). The purpose of the angioplasty with a final POT is to correct the distortion of the metal struts in the proximal portion of the main vessel stent, caused by the simultaneous inflation of two balloon catheters inside



Source: Mehmedbegovic Z, Jelic D, Stankovic G. Why and how to perform Proximal Optimization Technique (POT) [Internet]. PCR Online [cited 2020 Jul 6]. Available from: https://www.pcronline.com/Cases-resources-images/Zoom-on/My-Toolkit/2020/performing-Proximal-Optimization-Technique

Figure 6. Balloon positioning for proximal optimization and reoptimization. (A) Correct positioning of the balloon catheter in relation to the neocarina for proximal optimization and reoptimization. (B) Non-compliant balloon inflated at 18atm in the main vessel for in-stent proximal optimization.

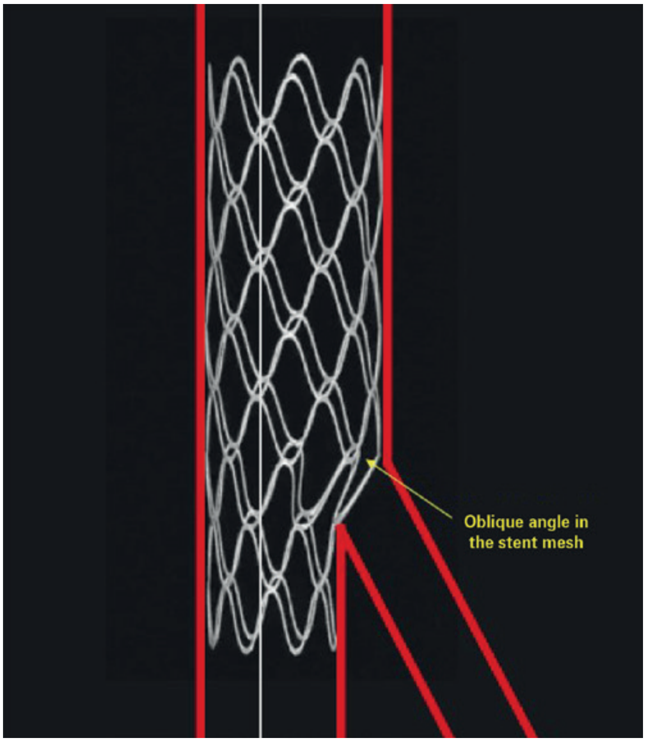
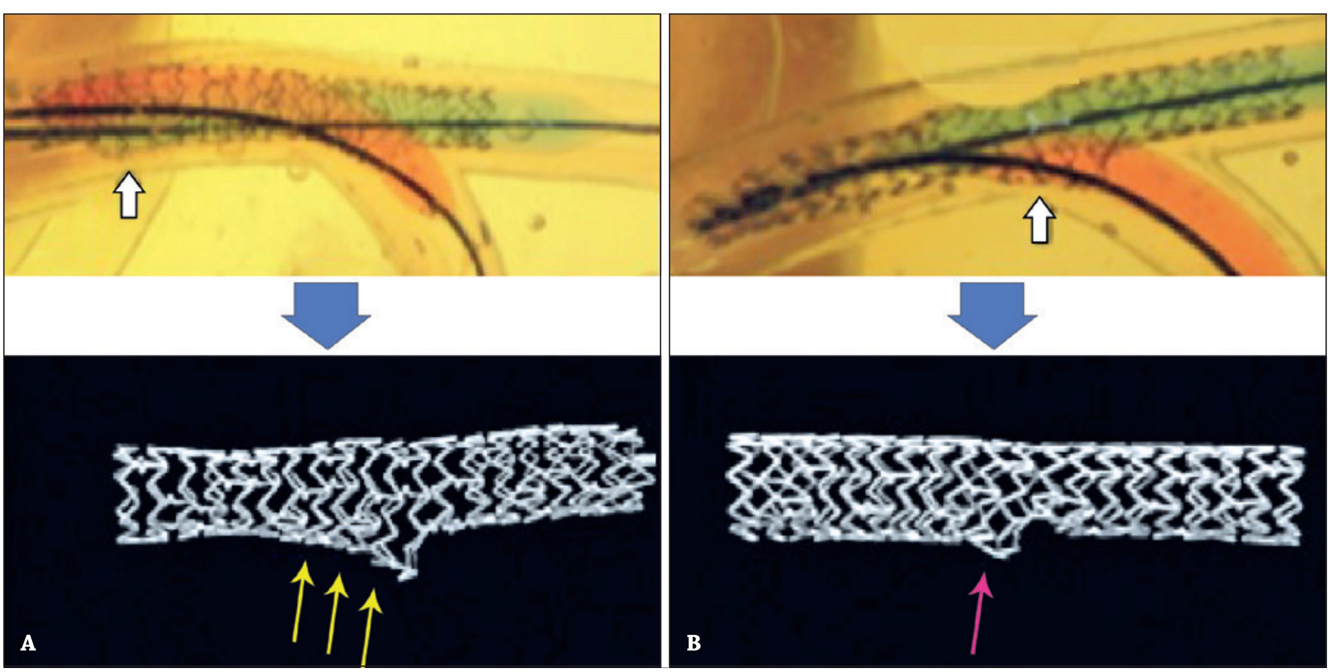


Figure 7. Result of proximal optimization: greater opening of the main vessel stent cells and oblique angle in the stent mesh, towards the side branch ostium, facilitating the recrossing of the stent from the main vessel into the side branch.

it, resulting in an asymmetric and oval shape of this portion of the stent, which often causes malapposition of the stent struts. Therefore, the final POT corrects the distortion in the circumference of the stent, minimizing the risk of stent thrombosis and restenosis due to malapposition of the struts. It is important that the distal portion of the balloon catheter in the final POT does not extend beyond the neocarina, to avoid oversizing the main vessel stent after the bifurcation in the postdilation, since an oversized stent may cause dissection, hematoma in the vessel wall or even its rupture. We also emphasize the importance of not leaving it shorter than 6 to 8mm proximal to the neocarina, or even smaller than the shortest balloon available for postdilation of the stent, to avoid direct contact of the postdilation balloon with the main vessel wall not covered by the stent mesh.

The DK crush technique has evolved to include new steps and technical modifications, since its initial description in an article published in 2005.[11] The first modification was proposed in the DK Crush II study,[13] with the inclusion of dilation of the side branch struts with a non-compliant balloon catheter at ≥16atm pressure, immediately after crushing the side branch stent struts and before the first kissing-balloon inflation, and also one more dilation of the side branch stent struts with the same balloon, and pressure after the implantation of the stent in the main vessel and



Source: adapted from Murasato et al.[18]

Figure 8. Positioning of balloons to perform the second kissing-balloon of the double kissing crush technique or the final kissing-balloon inflation. (A) Long overlapping of balloons, causing deformity of the proximal struts of the stent in relation to the neocarina. (B) Short overlapping (<3mm) of balloons, resulting in a more spherical geometry of the proximal struts of the stent in relation to the neocarina.

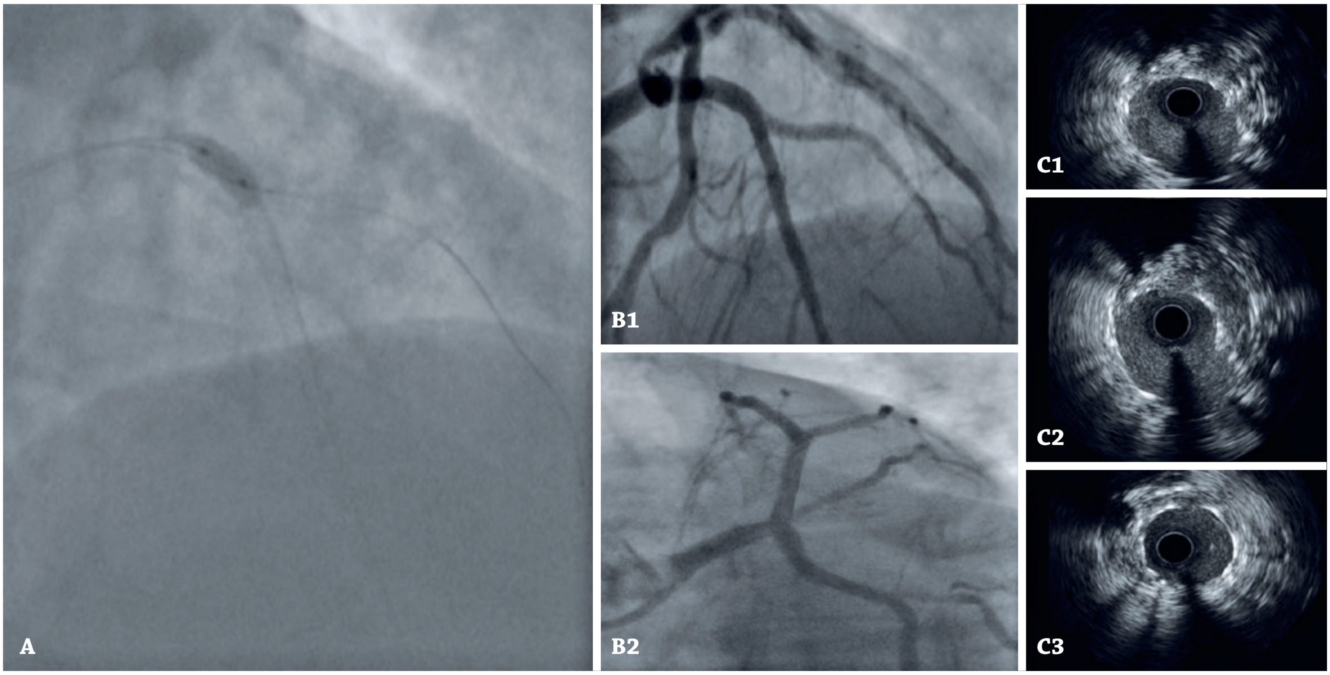
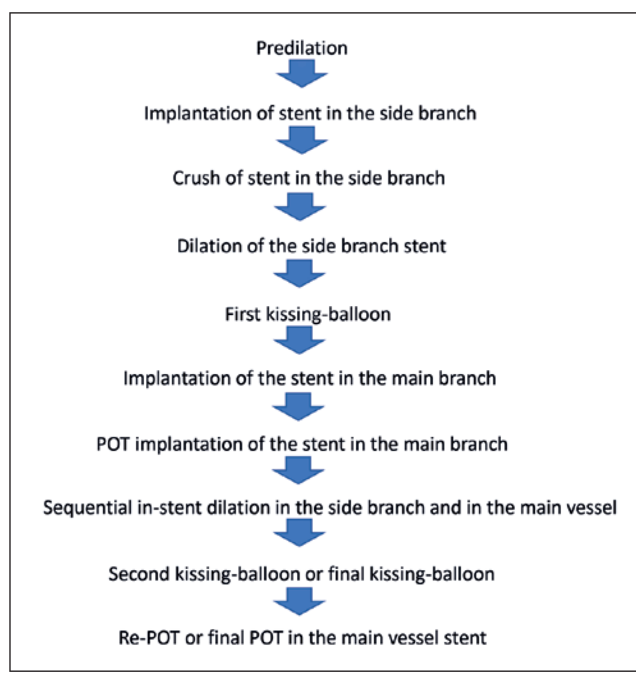


Figure 9. Reoptimization or final proximal optimization. (A) Non-compliant balloon inflated at 18atm in-stent in the main vessel. (B) Angiographic result of treatment of bifurcation of the left descending artery with the first diagonal branch, using the double kissing crush technique: (B1) cranial view; (B2) spider view. (C) Final ultrasonographic control: (C1) left descending artery proximal to the neocarina; (C2) neocarina of the left descending artery and first diagonal branch; (C3) left descending artery distal to neocarina.

before the second kissing-balloon inflation. The addition of the dilation of the main vessel stent with a non-compliant balloon catheter at ≥16atm pressure right after the dilation of the side branch stent proposed above in the DK Crush II study, that is, immediately before the FKI, was suggested in the DK study Crush III.[14] Finally, the DK Crush V[10] study introduced a minimal protrusion of approximately 2mm of the side branch stent into the main vessel, which originally was 3 to 5mm, as well as POT of the main vessel stent with a non-compliant balloon catheter at ≥18atm pressure, either shortly after the implantation of the stent in the main vessel, to perform additional crushing, or shortly after FKI, as the last step of the procedure (Figure 10).

Whenever possible, all complex procedures, such as double stent implantation in bifurcation lesions, should be guided by an imaging method, such as intracoronary ultrasound (IVUS) and/or optical coherence tomography, to enable a more adequate and detailed planning of the technique steps to be used, a careful choice of the size (diameter and length) of the materials—especially balloon catheters and stents—and a more accurate monitoring of the procedure results allowing the inclusion of additional steps to optimize the result. The set of possibilities provided by the use of an imaging method adds more quality to the procedure in the treatment of bifurcation lesions, resulting in clinical benefits, such as decreased mortality and short-, medium- and long-term major adverse event rates, as demonstrated in several studies.[19-23]



POT: proximal optimization; Re-POT: proximal reoptimization.
Figure 10. Step-by-step chart of the double kissing crush technique.

COMPARATIVE ANALYSIS OF DIFFERENT BIFURCATION TECHNIQUES

The DK crush technique was first described by Chen et al., in an article published in 2005.[10] The main difference between the DK crush technique and the conventional crush technique consists of performing an angioplasty with the kissing-balloon technique (first kissing) prior to the stent implantation in the main vessel. According to the authors, the first kissing provides both the repair of the geometry of the stent implanted in the side branch after twisting of its struts when the crush is performed, and promotes the enlargement of the stent cells of the side branch, facilitating the recrossing of its struts by the 0.014 guidewire and the balloon, for the second kissing-balloon inflation (FKI). The execution of FKI is part of the conventional crush technique; however, this step is a main challenge of the technique, due to the difficulty in crossing the 0.014 guidewire and the balloon through the double mesh of stent struts in the side branch ostium. Therefore, the DK crush technique aims to facilitate the performance of FKI, which is important to reduce major adverse cardiovascular events (MACE), as demonstrated in previous studies.[9,24,25]

The DK Crush-I[12] study was the first prospective, multicenter and randomized study to compare the two stent crush techniques, i.e., DK crush technique *versus* conventional crush technique, in patients with bifurcation lesions. A total of 311 patients were evaluated, 156 in the conventional crush group, and 155 in the DK crush group, with a significant increase in the FKI success rate in the DK crush group (100% in the DK crush group *versus* 76% in the conventional crush; p<0.001). There was a significant reduction in MACE, i.e., acute myocardial infarction (MI), death from cardiac origin, or target lesion revascularization (TLR), in the group treated with the DK crush technique (11.4% *versus* 24.4% in the conventional crush group; p=0.02), within 8 months. A higher TLR-free survival rate was also observed in the DK crush group (89.5% *versus* 75.4% in the conventional crush; p=0.002). When separately analyzing patients with (75%= 117/156 patients) and without (25%= 39/156 patients) FKI in the conventional crush group, the importance of this procedure step in reducing major adverse cardiac events (11.4% in DK crush technique *versus* 35.9% in conventional crush without FKI *versus* 19.7% in conventional crush with FKI, p<0.05, in the comparison between DK crush technique *versus* conventional crush with FKI; and p<0.01 in the comparison between conventional crush without FKI *versus* conventional crush with FKI and DK crush), TLR (9.0% in DK crush technique *versus* 22.6% in conventional crush without FKI *versus* 17.8% in conventional crush with FKI; p<0.01, in the comparison between conventional crush without FKI *versus* conventional crush with FKB and DK crush), and restenosis in the side branch (12.3% in DK crush technique *versus* 36.6% in conventional crush without FKI *versus* 20.9% in conventional crush with FKB; p=0.01, in the comparison between conventional crush with FKB *versus* DK crush).

The performance of FKI, regardless of the technique used, was essential for a significant decrease in MACE and TLR, whereas the significant reduction in restenosis in the side branch was only obtained with the use of the DK crush technique, suggesting a greater influence of the effects of the first kissing on the late result in the side branch. The DK Crush-I study also showed the absence of FKI as the only independent predictor of stent thrombosis (OR 1.60; 95%CI 1.63-4.76; p=0.035); and minimal luminal diameter in the side branch RR of 16.57; 95%CI 3.39-11.20; p=0.001) and not using the DK crush technique (RR 24.68; 95%CI 4.15-23.55; p=0.001) as independent predictors of MACE. Final unsatisfactory kissing-balloon (residual stenosis ≥20% in the side branch ostium; RR 12.21; 95%CI 0.01-0.34; p=0.002) and not using the DK crush technique (RR 16.05; 95%CI 1.01-4.83; p=0.001) were identified as independent predictors of TLR. The DK crush technique is characterized by the use of a greater amount of contrast media (p=0.04), the use of a greater number of balloons (p<0.01) and a longer procedure time (p<0.001). However, the clinical and angiographic benefits obtained minimize these small disadvantages. Routine imaging methods were not used in this study (Table 1).

The provisional stenting technique has been widely used and recommended for the treatment of bifurcation lesions, including true bifurcation lesions, in which there is significant involvement of the side branch.[7,8,26] Therefore, the DK crush II[13] study was performed to compare the DK crush and provisional stenting techniques in the treatment of 370 patients with true bifurcation lesions Medina type 1,1,1 or 0,1,1. In the provisional stenting group, the criteria of residual stenosis >50%, dissection type >B, and reduced Thrombolysis in Myocardial Infarction (TIMI) flow were adopted for the treatment of the side branch with stenting, which was performed in 28.6% of patients selected for the provisional stenting group. The DK crush group had lower rates of angiographic restenosis in 8 months, both in the main vessel (3.8% in DK crush technique *versus* 9.7% in provisional stenting; p=0.036) and in the side branch (4.9% in DK crush technique *versus* 22.2% in provisional stenting; p<0.001). There was no statistically significant difference in MACE, i.e., death from cardiovascular etiology, acute MI or TLR, between both groups (10.3% in DK crush technique *versus* 17.3% in provisional stenting; p=0.070). Moreover, there was not a significant difference in the outcome of stent thrombosis (2.7% in DK crush technique *versus* 1.1% in provisional stenting; p=0.449). The rates of TLR (4.3% in DK crush technique *versus* 13.0% in provisional stenting; p=0.005) and target vessel revascularization (6.5% in DK crush technique *versus* 14.6% in provisional stenting; p=0.017) at 12 months were significantly lower in the DK crush group when compared with the provisional stenting group. IVUS was used similarly in less than 50% of cases

Table 1. Results of studies comparing double kissing crush technique and other bifurcation techniques

	DK Crush I (n=311 patients)			DK Crush II (n=370 patients)			DK Crush III (n=419 patients)						DK Crush V (n= 482 patients)		
	8 months			12 months			12 months			3 years			12 months		
	DK Crush	Conventional	p-value	DK Crush	Provisional	p-value	DK Crush	Culotte	p-value	DK Crush	Culotte	p-value	DK Crush	Provisional	p-value
MACE	11.4	24.4	0.02	10.3	17.3	0.07	6.2	16.3	0.001	8.2	23.7	<0.001	5.0	10.7	0.02
TLRA	9.0	18.9	0.03	4.3	13.0	0.005	2.4	6.7	0.037	3.8	14.0	<0.001	3.8	7.9	0.06
Restenosis (side branch)	12.3	24.4	0.01	4.9*	22.2*	<0.001	6.8*	12.6*	0.037	-	-	-	5.0	12.0	0.09
Thrombosis (stent)	1.3	3.2	1.0	2.7	1.1	0.449	0.5	1.0	0.623	0.5	3.9	0.02	0.4	3.3	0.02
FKI	100	76.0	<0.001	100	79.5	0.001	99.5	99.5	1.0	-	-	-	99.6	78.9	<0.001
IVUS	-	-	-	45.9	47.6	0.655	69.0	73.7	0.331	-	-	-	42.9	40.5	0.37

Results expressed as %.
*Assessment carried out in 8 months.
MACE: major adverse cardiovascular events; TLRA: target lesion revascularization; FKI: final kissing-balloon; IVUS: intracoronary ultrasound.

in both groups. According to the results described, the DK Crush II study showed superiority of the DK crush technique compared to the provisional stenting technique in true bifurcations, by reducing the rates of restenosis, revascularization of the target lesion and revascularization of the target vessel (Table 1).

Another commonly used double stent technique for true bifurcations is the culotte, which also consists of stent implantation in the side branch prior to the stent implantation in the main vessel; however, there is greater stent mesh overlapping when compared to the DK crush technique. The DK Crush III study[14,16] was a multicenter, randomized and prospective study, and compared both techniques in 419 patients with unprotected left main trunk bifurcation lesions. The DK crush technique provided lower rates of MACE, i.e., death of cardiovascular etiology, acute MI and/or TLR in 1 year (6.2% in DK crush technique *versus* 16.3% in culotte technique; p=0.001) and 3 years (8.2% in DK crush technique *versus* 23.7% in culotte technique; p<0.001), as well as a significant reduction in TLR rates in 1 year (2.4% in DK crush technique *versus* 6.7% in culotte technique; p=0.037) and 3 years (3.8% in DK crush technique *versus* 14.0% in culotte technique; p<0.001). There was no statistically significant difference in the rates of acute MI and stent thrombosis in 1 year; however, from the second year on, there was a statistically significant difference between the outcomes, favoring the DK crush technique — a difference that remained in the evaluation of results in 3 years, both for acute MI (3.4% in DK crush technique *versus* 8.2% in culotte technique; p=0.037) and for stent thrombosis (0.5% in DK crush technique *versus* 3.9% in culotte technique; p=0.020). The DK Crush III study showed a high rate of MACE in 3 years when the culotte technique was used to treat complex LMCA bifurcation lesions (51.5% in culotte technique *versus* 15.1% in DK crush technique; p<0.001), mainly due to a high rate of TLR (36.4% in culotte technique *versus* 7.5% in DK crush technique; p<0.001). There was no statistically significant difference in the rates of stent thrombosis at 1 or 3 years between both techniques in the subgroup of patients with complex LMCA bifurcation lesions. Analyzing the two treatment groups, an interesting result of this study was that, without distinction of subgroup (simple or complex lesion), a significant increase in stent thrombosis was observed in patients treated with the culotte technique from the analysis of 2 years, considering the interruption of the use of clopidogrel after 1 year of procedure, which suggests a possible association between a long segment of double stent mesh, and the absence of double antiplatelet aggregation as a possible etiological factor for the increased incidence of stent thrombosis. IVUS was similarly used in approximately 70% of cases in both groups, whereas FKI was performed in almost all cases in both groups. According to the aforementioned results, the DK Crush III study suggests the superiority of the DK crush technique compared to the culotte technique in the treatment of unprotected LMCA bifurcation lesions, by reducing the rates of MACE, acute MI, TLR and stent thrombosis (Table 1).

The DK Crush V[10] study compared the DK crush and provisional stenting techniques in 482 patients with unprotected LMCA true bifurcation lesions (Medina 1,1,1 or 0,1,1). The DK crush technique provided a significant reduction in combined adverse events, e.g., death of cardiovascular etiology, acute MI in the target vessel or revascularization of the target vessel, in 1 year (5.0% in DK crush technique *versus* 10.7% in provisional stenting; p=0.02), as well as a significant reduction in target vessel-related acute MI rates (0.4% in DK crush technique *versus* 2.9% in provisional stenting; p=0.03) and stent thrombosis rates (0.4% in DK crush technique *versus* 3.3% in provisional stenting; p=0.02) in 1 year. There was also a tendency towards lower TLR rates (3.8% in DK crush technique *versus* 7.9% in provisional stenting; p=0.06) and restenosis (main vessel: 1.9% in DK crush technique *versus* 5.7% in provisional stenting, p=0.09; and side branch: 5.0% in DK crush technique *versus* 12.0% in provisional stenting, p=0.09) in patients treated with the DK crush technique in 1 year. This study also showed even greater superiority of the DK crush technique over the provisional stenting technique by reducing combined adverse events in complex lesions of unprotected LMCA bifurcation (simple lesions: 3.9% in DK crush technique *versus* 8.0% in provisional stenting; RR 0.68; 95%CI 0.31-1.49; and complex lesions: 7.0% in DK crush technique *versus* 18.2% in provisional stenting; RR 0.27; 95%CI 0.05-0.54). Stent implantation in the side branch was necessary in 47.1% of cases treated with provisional stenting technique, 38.8% in simple bifurcation lesions and 64.9% in complex bifurcation lesions; therefore, as expected, there was greater need for stent implantation in the side branch in complex bifurcation lesions. Nonetheless, the rate was higher than in other studies involving the provisional stenting technique, [7,8,26] which can be explained by the greater complexity of the lesions treated in the study. IVUS was similarly used in just over 40% of cases in both groups, whereas FKI was significantly more frequent in patients treated with the DK crush technique (99.6% in DK crush technique *versus* 78.9% in provisional stenting; $p<0.001$). According to the aforementioned results, the DK Crush V study suggests superiority of the DK crush technique compared to the provisional stenting technique also in the treatment of unprotected LMCA bifurcation lesions, by significantly reducing the rates of combined adverse events, target vessel-related myocardial infarction, and stent thrombosis, as well as a tendency to reduce TLR and restenosis, with the most evident benefits observed in unprotected LMCA bifurcation complex lesions (Table 1).

CONCLUSION

The DK crush technique has been improved since its conception and has been extensively evaluated over several multicenter and randomized studies comparing it with other techniques, showing the superiority of the DK crush technique in true bifurcation lesions, including in the left main coronary artery, when compared to the most commonly used techniques today.

SOURCE OF FINANCING

None.

DECLARATION OF CONFLICTS OF INTEREST

The authors declare there are no conflicts of interest.

CONTRIBUTION OF AUTHORS

Conception and design of the study: ACZ; data collection: GZ and RCFB; data interpretation: ACZ, GZ, RCFB and AJZ; writing of the text: ACZ; approval of the final version to be published: ACZ and AJZ.

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