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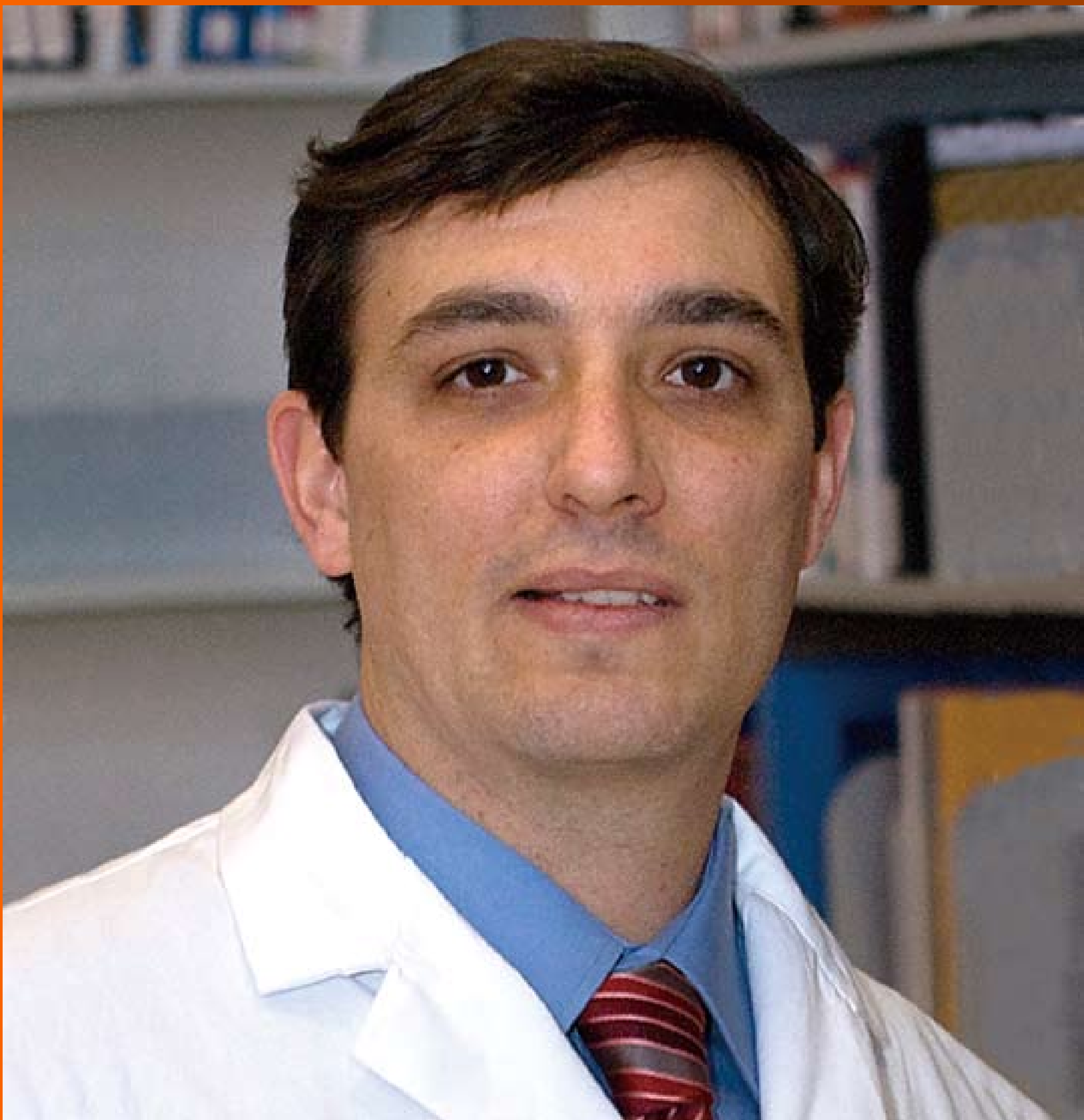

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EDITORIAL

Thin and crush: The new mantra in left main stenting?

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Abstract

Complex bifurcations have been suggested to be better approached by a planned double stent technique; however, recent randomized trials have shown better outcomes of provisional compared to planned two-stent strategy, in terms of both short-term efficacy and safety. In left main (LM) bifurcations, double kissing (DK)-Crush has demonstrated its superiority over Culotte and provisional-T in terms of restenosis and stent thrombosis, gaining respect as one of the most performant techniques for bifurcations stenting. On the other hand, the Nano-Crush technique has recently become part of the repertoire of double stenting techniques, providing evidence that the use of ultrathin strut stents and very minimal crush would be beneficial for both the physiological and rheological properties of the complex bifurcations, even in LM scenario, leading to a lower rate of thrombosis and restenosis at both side branch and true carina. Finally, the newest generation of ultrathin strut stents are gaining a reputation for its safe and effective use in LM treatment thanks to improved design with increased expansion rate capable of LM treatment up to 5-6 mm diameter. The modern crush techniques, such as DK-Crush and Nano-Crush, are providing excellent results on mid and long-term follow up, suggesting that minimal crushing obtained using ultra-thin stents is a good way to obtain surgical-like outcomes in the treatment of complex LM bifurcation disease.

Key words: Stent; Crush; Interventional cardiology; Percutaneous coronary intervention; Percutaneous coronary intervention; Coronary bifurcation

Core tip: Modern crush techniques such as DK-Crush and Nano-Crush are providing excellent results on mid and long-term follow-up, suggesting that minimal crushing obtained using ultra-thin stents is a good way to obtain surgical-like outcomes in the treatment of complex left main bifurcation disease.

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INTRODUCTION

Complex bifurcations have been suggested to be better approached by a planned double stent technique[1-2], although recent randomized trials have shown better outcomes of provisional compared to planned two-stent strategy in terms of both short-term efficacy and safety[3-4].The total amount of metal layers at both the carina and bifurcation angle after double stenting techniques[5-6] appeared to be important issues to achieve favorable short- and long-term outcomes.

Left main (LM) bifurcation disease is probably the only real important bifurcation in the human vascular tree. The DEFINITION trial[7] has given a practical definition of what is complex and what it is not in the treatment of coronary artery bifurcation disease. Indeed, a length of the left circumflex coronary artery (LCx) > 10 mm has already been identified as a predictor of complex LM bifurcation probably requiring a double stenting strategy.

To achieve similar or better post-procedural results guaranteed by surgical treatment from a rheolytic point of view, the use of intravenous ultrasound is mandatory[8] to properly assess the size and length of the disease in both branches and in the LM body, allowing an accurate selection of the most appropriate stenting technique and stents.

Culotte, mini-Culotte, DK-Crush, T-stent and Protrusion (TAP) are currently the most used double stenting techniques (Table 1)[9]. Recently, DK-Crush has demonstrated its superiority over Culotte[10] and provisional-T[11] techniques in terms of restenosis and stent thrombosis, gaining respect as one of the most performant techniques for bifurcation stenting.

Even more recently, the Nano-Crush technique[12-13] has become part of the repertoire of double stenting techniques, providing evidence that the use of ultrathin strut stents and very minimal crush is beneficial for both the physiological and rheological properties of the complex bifurcations, leading to a lower rate of thrombosis and restenosis at both side branch (SB) and true carina[14].

TECHNICAL COMPARISON AMONG NANO-CRUSH, DK-CRUSH AND OTHERS

Compared to the classical Crush technique introduced by Colombo *et al*[15], both the Nano- and DK–Crush represent a further modern development of the former. Both these latter techniques require wiring and pre-dilation of both branches and in both SB stenting before main branch (MB) stenting. A different strand is represented by the entity of the SB stent protrusion, which is minimal, with only one ring if possible, in the Nano-Crush, while it appears greater, with at least 3-4 mm of protrusion, in the DK-Crush technique.

Table 1 Available techniques for left main interventions

Single stent	Double stent
Cross over-provisional	T-stenting T and protrusion Mini-Crush Culotte and Mini-culotte DK crush Nano-Crush

Protrusion length of the SB stent explains why kissing is required when DK-Crush is adopted. In the classical DK-Crush, rewiring of the SB generally represented the next step after MB stenting. However, more recently, the use of proximal optimization technique (POT) has been recommended, as in Nano-Crush, where POT facilitates LCx rewiring. Subsequently, both techniques included a type of kissing balloon: Classical for the DK and with snuggle configuration in Nano-Crush. Moreover, the classical DK-Crush technique has been modified introducing a POT as the final step, as in Nano-Crush (Figure 1).

Different from DK-Crush, in which the ostium circumference is completely covered by the SB stent, in the Nano-Crush, the ostium is covered at the carina by the SB stent strut and at the opposite site of the carina by the MB struts opened by the POT into the SB ostium, providing complete circumferential coverage, especially in the case of tight angles, in which the ostium coverage might be incomplete at the carina.

Among these two stenting techniques, one significant difference is represented by the most appropriate stent to implant. In DK-Crush, virtually every kind of stent can be used, while the Nano-Crush has been created to fit with the concept of less metal in the carina, so the ideal stent should have the thinnest struts possible, at least 60 to 80 microns.

TAP or standard T usually leave the SB stent strut floating into the MB; this causes a non-physiologic flow, which may induce lower wall shear stress and turbulent flow, leading to thrombosis and in-stent restenosis[16]. On the other hand, the Culotte usually leaves two or three metal layers into the carina for a length ranging from 5 to 15 mm, even in the "Mini" version.

AMOUNT OF METAL INTO THE CARINA: DOES IT REALLY MATTER?

The lack or excess amount of metal layers at the carina has been suggested to be a potential cause of

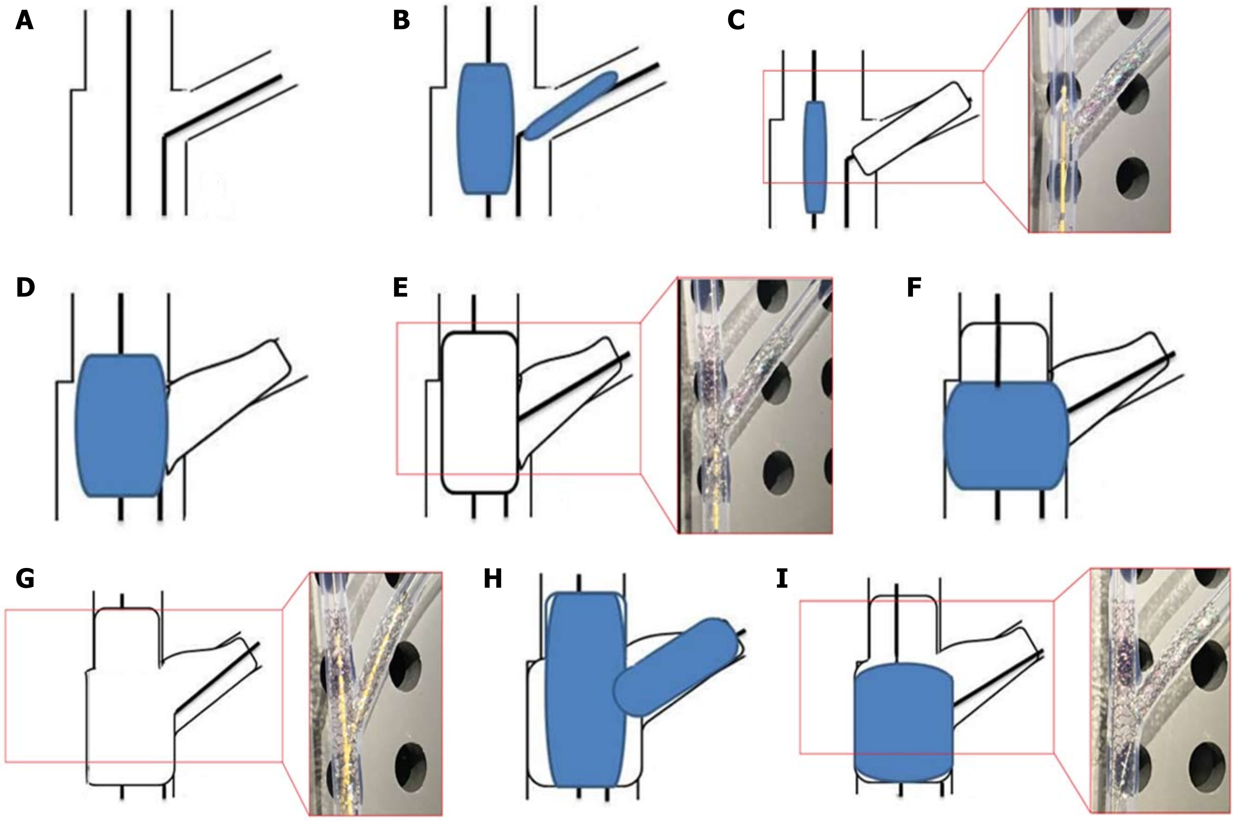

Figure 1 Key steps in the Nano-Crush stenting technique. As both branches are wired (A), both branches are predicated with non-compliant balloons (B) and the stent is deployed at the side branch (C: bench test correlate image). The balloon of the deployed stent is withdrawn and the main branch balloon is inflated in the main branch (MB) at high atmosphere (D); The MB stent of the diameter of the distal reference diameter (3.0 mm) is placed in position and deployed (E: bench test correlate image); Proximal optimization technique (POT) with non-compliant balloon of the same diameter of the MB is performed at high atmosphere (F) and after rewiring of the side branch (G: bench test correlate image), a snuggle kiss is performed with non-compliant balloons (H); Finally, a re-POT is performed with a non-compliant balloon at high atmosphere atm (I: bench test correlate image).

stent restenosis and thrombosis, respectively[17]. As recently suggested by our group, using computed fluid dynamics, the Culotte and other techniques that leave large amounts of metal at the carina unfavorably impacted the bifurcation rheology, causing an increase in lower wall shear stress (WSS) and in the SB. Indeed, low WSS is a potential substrate for restenosis and thrombosis (Figure 2).

To achieve a more physiological flow profile, there should ideally be less metal coverage in the carina side and full metal coverage in the area opposite of the carina and the ostium of the SB. DK-Crush and Nano-Crush are likely to work differently in terms of lowering WSS areas depending on the LM bifurcation. The distribution of metal and the coverage of the carina by the struts strictly depends on the angles: Sharp angles tend to increase the amount of metal at the carina, especially when a generous portion of the SB stent is protruding and should be crushed, whereas if the portion of the stent to be crushed is shorter and the angle is wider, the amount of the metal would be less and coverage might be even incomplete. Obviously, the use of ultra-thin stent struts in DK-Crush or other techniques would potentially improve both safety and long-term outcomes.

STENT ENGINEERING CONSIDERATIONS

The Orsiro (Biotronic AG, BÜlach, Switzerland) stent is considered to have the thinnest struts commercially available. In the most recent European randomized trials, this stent demonstrated a very good safety and efficacy profile. Indeed, its low rate of stent thrombosis reached the non-inferiority statistical significance compared to Xience Prime stent (Abbott Inc., United States)[18-19] with a faster strut endothelium coverage evaluated by optical coherence tomography in respect to the competitors[20]. These results could be achieved even after overcoming the major intrinsic structural limitation to the stent's design, such as longitudinal shortening[21]. Nowadays, other stents have been designed with similar ultra-thin struts, such as the Resolute Onyx stent by Medtronic Inc. or the Ultimaster by Terumo Inc., which are currently being evaluated in real-world scenarios but promise to maintain the line of their predecessor or do even better in terms of strut neointima coverage.

Nowadays, stent working size in most LMs should not be less than 4.5 mm, and all modern techniques imply the use of POT at high pressure. All of these issues

Table 2 Thinnest struts stents and their maximum expansion for left main interventions

Stent type	Strut thickness (μ)	Max size achievable (mm)
Orsiro Biotronik, Sui	60-80	5.3 (3.5 stent)
Onyx Medtronic, United States	70	6 (4.0 stent)
Ultimaster Terumo, Japan	80	5.8 (3.5 stent)
Biomime Meril	65	5.3 (4.5 stent)[1]
Synergy Boston Scientific, United States	74	5.7 (4.0 stent)

Data of maximum expansion retrieved from Sawaya FJ *et al*[24]. [1]Not verified in bench test.

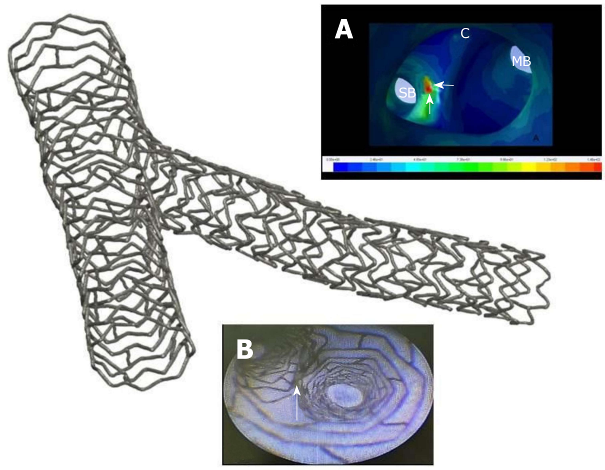

Figure 2 Microcomputed tomography picture of a bifurcation treated by the Nano-Crush technique. A: Region of the carina investigated by computed fluid dynamic showing from the inside of a vessel with high wall shear stress (red zone, white arrows) located at the side branch portion of the carina, which should potentially be in favor of less restenosis and thrombosis at that site; B: Angioscopic image of the same region showing a very smooth transition of the wall at the bifurcation with a very minimal (Nano) apposition of two stent layers. SB: Side branch; MB: Main branch.

could contribute to stent deformation and polymer rupture, both of which can influence thrombosis and restenosis rates. The availability of thin struts and different sized stents useful to treat LM bifurcation, maintaining a good radial force and minimal shortening will represent a mandatory goal to be accomplished by companies in the market in the near future (Table 2).

THE NEW MANTRA OF LM STENTING

Nowadays, LM stenting has gaining respect as an alternative to surgical treatment[22-24], but the treatment of complex LM disease distal/bifurcation disease remains a significant obstacle to overcome to achieve satisfactory results. In such disease, the double stenting technique would provide a more reliable strategy as supported by the evidence coming from both clinical and virtual studies about the benefits provided by thin strut stent technology.

The modern crush techniques such as DK-Crush and Nano-Crush are providing excellent results on mid and long-term follow up, suggesting that minimal crushing obtained using ultra-thin stents is a good way to obtain surgical-like outcomes in the treatment of complex LM bifurcation disease.

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