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

Rigatelli G *et al*. Left main double stenting

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**Abstract**

Complex bifurcations have been suggested to be better approached by a planned double stent technique, 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. In left main (LM) bifurcations, DK-Crush has provided evidences of 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 became part of the repertoire of double stenting techniques, providing evidences 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 carena. Finally last generation ultrathin strut stents are gaining a reputation of 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 a minimal crushing obtained using ultra-thin stents is on the good way to obtain surgical-like outcomes in the treatment of complex LM bifurcation disease.

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

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**Core tip:** The modern crush techniques such as DK-Crush and Nano-Crush, are providing excellent results on mid and long-term follow up, suggesting that a minimal crushing obtained using ultra-thin stents is on the 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 important issues to achieve favorable short- and long-term outcomes.

Left main (LM) bifurcation disease is probably the only real important bifurcation in human vascular tree. Then 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 been already identified as a predictor of complex LM bifurcation probably requiring a double stenting strategy.

To achieve post procedural results similar, or even better, from a rheolytic point of view, to those guarantee by surgical treatment, the use of intravenous ultrasound is mandatory[8] in order to assess properly 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 technique (Table 1)[9]. Recently DK-Crush has provided evidences of its superiority over Culotte[10] and provisional-T[11] in terms of restenosis and stent thrombosis, gaining respect as one of the most performant techniques for bifurcations stenting.

Even more recently the Nano-Crush technique[12-13] became part of therepertoire of double stenting techniques, providing evidences 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. Leading to a lower rate of thrombosis and restenosis at both side branch (SB) and true carena[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 a wiring and pre-dilation of both branches and in both SB stenting before the main branch (MB) stenting. One of different strands 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.

The length of protrusion if the SB stent explains why a kissing, the first one, is required when DK-Crush is adopted. In the classical DK-Crush, after the MB stenting, while until recently rewiring of the SB generally represented the next step, now the use of proximal optimization technique (POT) has been recommended, as in Nano-Crush, where POT facilitates the LCx rewiring. Subsequently, both techniques included akind 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 final step, as in Nano-Crush (Figure 1).

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

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

TAP or standard T usually leave SB stent strut floating into the MB: that cause a non-physiologic flowwhich 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, also in the “Mini” version, two or three metal layers into the carena for a length ranging from 5 to 15 mm.

**AMOUNT OF METAL INTO THE CARENA: IT REALLY MATTERS?**

The lack or excess of the amount of metal layers at the carena has been suggested a potential cause of stent restenosis and thrombosis, respectively[17]. As recently suggested by our group, using computed fluid dynamic, Culotte and in general all the techniques which leaves a huge amount of metal at the carena, impacted unfavorably on the bifurcation rheology, causing an increase in the lower wall shear stress (WSS) also in the SB. Indeed, as well known, low WSS are potential substrate for restenosis and thrombosis (Figure 2).

Ideally, to achieve the more physiological flow profile, there should be less metal coverage in the carina side and full metal coverage in the area opposite to 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 carena by the struts strictly depends on the angles: Sharp angles tend to increase the amount of metal at the carena specially 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 shorterand 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 any other techniques, would potentially improve both safety and long-term outcomes.

**STENT ENGINEERING CONSIDERATIONS**

The Orsiro (Biotronic AG, BÜlach, Switzerland) stent is considered thestent with 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 overcoming the major intrinsic structural limitation to the stent’s design such as the 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 the real-world scenario but promise to maintain the line of predecessor or even do better in terms of strut neointima coverage.

Nowadays stent size working in most LM should be not inferior to 4.5 mm and all modern techniques imply the use of POT at high pressure: all these issues might have an impact of stent deformation, polimer rupture which all can influence the thrombosis and restenosis rates. The availability of thin struts and sizes 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 alternative to surgical treatment[22-24] but the treatment of complex LM disease distal/bifurcation disease remains the real obstacle to overcome to really achieve satisfactory results. In such disease double stenting technique would provide a more reliable strategy as supported by the numerous evidences coming from both clinical and virtual studies about the benefits provided by the 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 a minimal crushing obtained using ultra-thin stents is on the good way to obtain surgical-like outcomesin the treatment of complex LM bifurcation disease.

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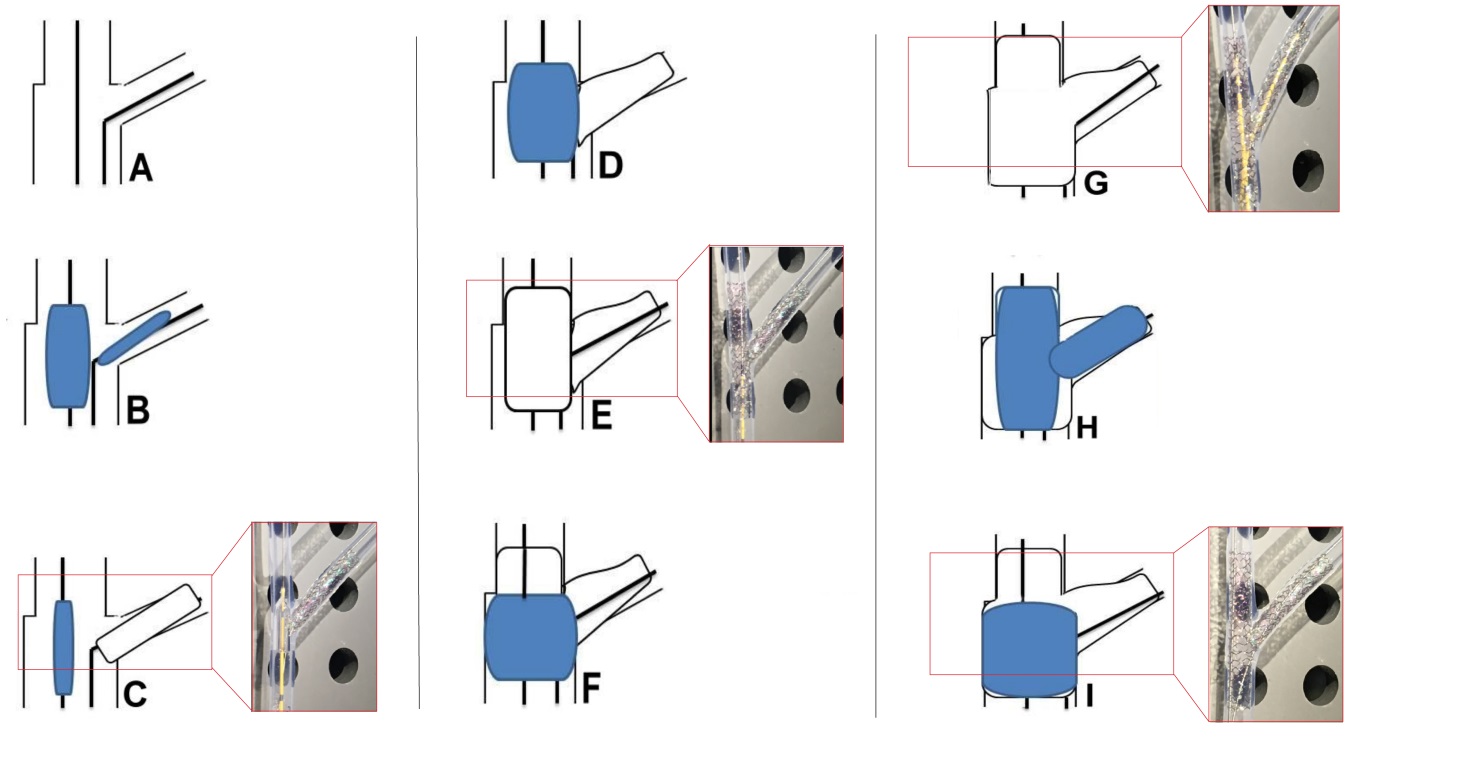
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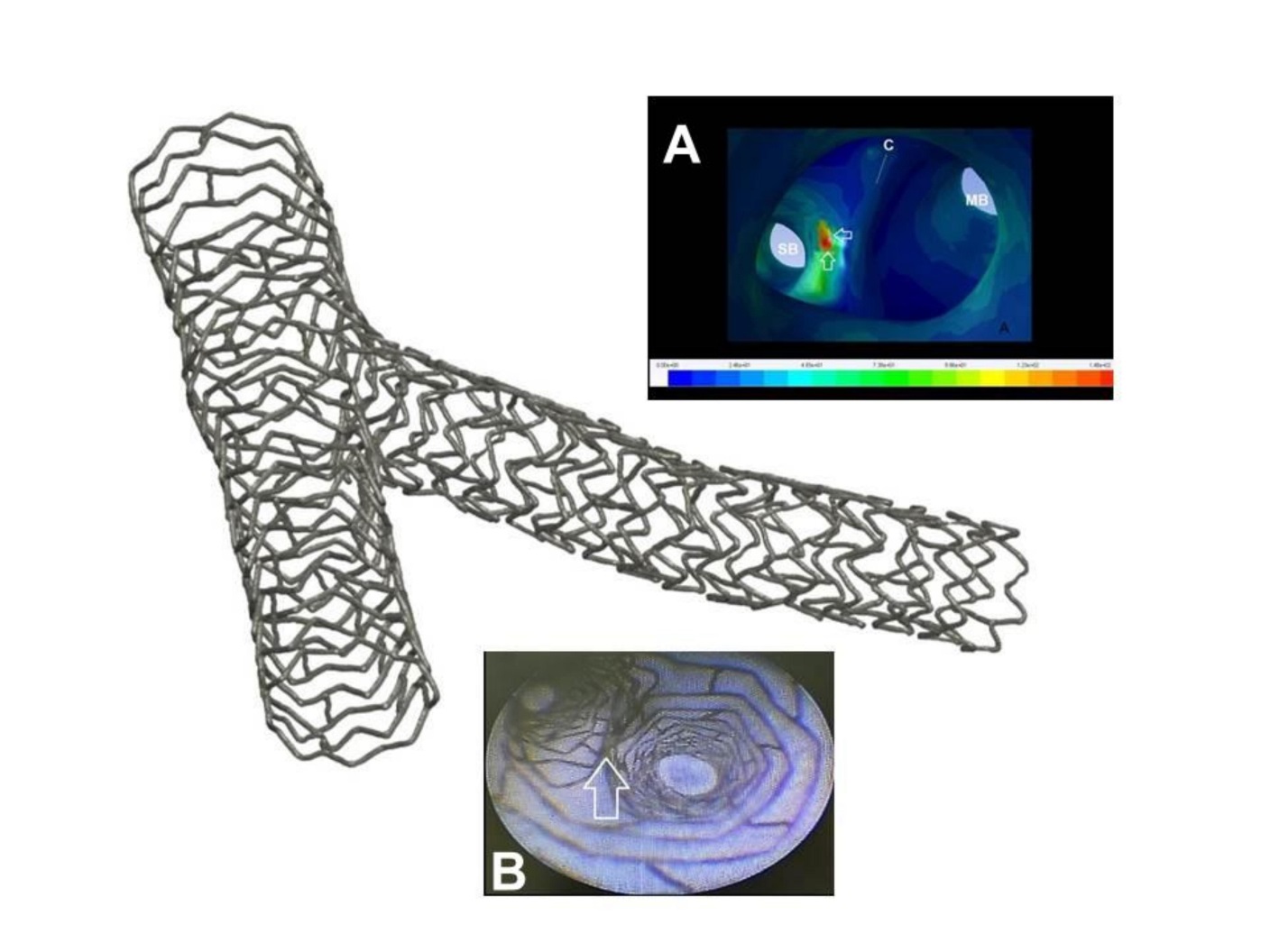
Grade B (Very good): B

Grade C (Good): C, C

Grade D (Fair): 0

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**Figure 1 Key steps of the Nano-Crush stenting technique.** As both branches are wired (A), both branches are predicated with non-compliant balloons (B) and the stent at side branch is deployed (C: bench test correlate image). Then the balloon of the deployed stent is withdrawn and the main branch balloon is inflated in the 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 then after rewiring of the side branch (G: bench test correlate image), a snuggle kissing 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).

**Figure 2 Micro computed tomography picture of a bifurcation treated by Nano-Crush technique.** A: Region of the carena investigated by computed fluid dynamic showing from inside of the vessel a region of high wall shear stress (red zone, white arrows) located at the side branch (SB) portion of the carena which potentially should 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 bifurcatyion with a very minimal (Nano) apposition of two stent layer.

**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 |

**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, US | 70 | 6 (4.0 stent) |
| Ultimaster Terumo, Japan | 80 | 5.8 (3.5 stent) |
| Biomime Meril | 65 | 5.3 (4.5 stent)\* |
| Synergy Boston Scientific, US | 74 | 5.7 (4.0 stent) |

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