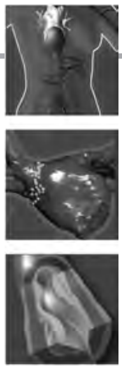

# Seeing double: the double kissing crush stenting technique for coronary bifurcation lesions

*"In the drug-eluting stent era, interventionalists continue to face the traditional problems: stent one or both branches? Which technique is better?"*

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The percutaneous approach for coronary bifurcation lesions is technically challenging, mainly secondary to worse postprocedural clinical outcomes, including higher rate of restenosis and target-lesion revascularization (TLR), which lead to unacceptable major adverse cardiac event (MACE) rates [1,2].

The introduction of drug-eluting stents (DES) fundamentally changed the concept of percutaneous treatment for coronary bifurcation lesions, mainly because of the reduced postprocedural restenotic rate compared with that of bare-metal stents [2,3]. In one previous study by Colombo *et al.*, sirolimus-eluting stents were implanted in both the main vessel and side branch (SB) [1]. Angiographic results demonstrated restenosis rates as high as 27%, especially at the orifice of the SB. Further study elucidated that the gap between vessel wall and stent struts was the main reason contributing to the repeat occurrence of stenosis. Therefore, effective coverage of the SB would potentially result in a reduction of the incidence of restenosis, particularly at the SB ostium [4]. Simultaneously, these previous studies implied that DES does not work well in the setting of bifurcation lesions, especially when a two-stent technique is used [5–8]. Based on the classical stenting techniques available in the bare-metal stent era, new stenting techniques were innovated in the DES era.

The controversy regarding one- versus two-stent technique has been longstanding. This is the issue on the intention-to-treat – the one-stent technique entails stenting the main vessel only, with or without balloon inflation of the SB; in the two-stent technique, SB stenting is scheduled without waiting for the results after ballooning. From this analysis, one-stent technique does not answer the question of whether to stent the SB if the result of balloon angioplasty is suboptimal (including flow-limiting dissection, acute closure and so on). In fact, no real one-stent technique is in clinical practice, and instead provisional stenting is becoming the mainstream technique in the current century – some individuals undergoing treatment with the one-stent approach would be transferred to the double-stent arm [9]. Upon consideration, it becomes apparent that the choice of the two-stent technique is limited if the initial intention was to only place one stent because the side stent had to be advanced into the SB through the stent struts of the main vessel. If this is the case, the only choices of the two-stent technique include inner crush, modified T stenting and the culotte technique. Therefore, provisional stenting, especially the provisional optimization stenting technique, indicates the possibility of stenting the SB. In the DES era, interventionalists continue to face the traditional problems: stent one or both branches? Which technique is better? This conundrum was further made apparent by a larger prospective, multicenter, randomized NORDIC study with DES [4]. In this study, the second stent for the SB was implanted only if there was impaired flow (TIMI 0–1). Both subgroups (one- and two-stent) had very low rates of MACE at 12 months of clinical follow-up. Further analysis demonstrated that a higher MACE rate was observed in patients treated by classical crush stenting, compared with the culotte group. Assali *et al.* reported that when treating bifurcation lesions with sirolimus-eluting stents, restenosis following a single stent procedure is comparable to stenting both parent and SB vessels [10]. Thus, stenting the main branch lesion coupled with balloon angioplasty in the SB produces a high success rate and good clinical outcomes at 6 months.

## Classical crush stenting

The classical crush technique was developed to improve ostial SB coverage without compromising access to the SB during DES implantation [11]; it comprises several modified techniques including reverse crush, balloon crush and inner crush. This technique involves the simultaneous advancement of two stents into the main vessel and the SB, respectively, with 3–5 mm of the side stent protruding into the main vessel; the technique requires relatively larger guiding catheters. In their study of 231 patients who were treated with classical crush stenting, Hoye *et al.* reported a survival-free TLR rate of 90.3%, a survival-free MACE rate of 83.5%, a possible stent thrombosis rate of 4.3%, and a SB restenosis rate of 25.3% at 9 months [12]. Another prospective registry by Moussa *et al.* revealed a 6-month TLR rate of 11.3% postclassical stenting with sirolimus-eluting stents; however, final kissing balloon inflation (FKBI) was performed in 87.5% of patients [13]. One study reported that a narrow distal left main artery bifurcation angle was associated with less ostial left circumflex (LCx) stent expansion [14]. Dzavik *et al.* concluded that a bifurcation angle ≥50° was an independent predictor of MACE after classical crush [15]. In this study, FKBIs were performed at the same rate in different angle groups, and there was a significant association between bifurcation angle, FKBIs and MACE even though there was no attempt to perform FKBIs in 11 out of 16 patients with a wide angle. Ormiston *et al.* demonstrated that kissing balloon inflation did not achieve full expansion of the SB stent in a bifurcation angle of 80° [16]. Studies reported that FKBI after classical crush was mandatory to improve outcomes [17]. Most importantly, failure of FKBI after crush stenting was associated with a higher incidence of stent thrombosis, as reported by Ge *et al.* [18]. These observations indicated that the classical crush stenting technique needed to be modified.

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Despite the fact that short-term outcomes were encouraging, the mid- or long-term outcomes remained not fully satisfactory. The main drawback was the high restenosis rate especially observed on the SB, and the higher incidence of postprocedural stent thrombosis as compared with more simple lesions. Colombo's team proposed the new modified crush technique, mini-crush stenting in 2006 [19]. The mini-crush approach consisted of a minor retraction of the SB stent into the main branch so that the proximal marker of the SB stent is situated in the main branch at a distance of 1–2 mm proximal to the carina of the bifurcation. Another difference consisted of 'crushing' the SB stent with a balloon instead of the main-branch stent as in the standard approach; this is accomplished by loading the balloon in the main vessel, covering the protruding SB stent segment, and crushing it against the main vessel wall. The procedure is then completed as in the standard crush with a kissing balloon. In a series of 45 consecutive patients treated by mini-crush stenting, at 72 days postprocedure there was one case of SB stent thrombosis (2.2%), which resulted in a non-Q-wave myocardial infarction. Angiographic follow-up was obtained in 100% of patients at 7.5 ± 1.3 months. Target lesion revascularization was 12.2%; no death and Q-wave myocardial infarction were observed. Restenosis rate in the main branch was 12.2%, while in the SB it was 2.0%. As reported in this study, FKBI was achieved in 94.2%. In fact, there was no technical difference between classical versus mini-crush stenting. The only minor 'difference' was the length of side stent protruding into the main vessel. From our *in vivo* intravascular ultrasound (IVUS) study, the average length of the side stent protruding into the main vessel was approximately 3–3.5 mm by the classical crush approach, compared with 1–2 mm by mini-crush. The shortened length of side stent in the main vessel raised concerns about fully covering the SB ostium, especially in the setting of angulation and severe overlapping of both branches. The key question we should answer is what is the success rate associated with FKBI.

## Double kissing crush

As analyzed previously, the success rate of FKBI by classical crush stenting is approximately 70–80% in an entire cohort of patients with bifurcation lesions. This rate would be increased to >90% in patients with distal left main bifurcation lesions [20]. Which factors correlate with the failure of FKBI in the context of classical crush stenting?

Distorted side stent geometry and irregularity in overlapped stent strut layers at the carina of the bifurcation are two common geographic characteristics immediately after the classical crush technique [21]. In addition to technical pitfalls, for example, the guidewire is commonly advanced under the SB stent, rather than into the true stent lumen, therefore, less expanded SB stents with irregular and small stent cells after classical crush do not allow for easy advancement of postdilation balloons [22,23]. Similarly, previous studies demonstrate that the post-stent minimal lumen diameter (MLD) is commonly seen at the ostial SB [17]. A larger post-percutaneous coronary intervention (PCI) SB MLD would indicate a relatively larger cell dimension. Metal mass, irregular overlapping of struts at the carina and a distorted side stent were the main factors influencing the performance of FKBIs. The main difference between classical and double kissing (DK) crush was the introduction of a first kissing balloon inflation prior to implanting the second stent. This suggests that the first kissing inflation not only repaired the distorted geometry, but also enlarged the cells of the SB stent, allowing easier performance of FKBIs. The finding that left main bifurcation lesions had the highest rate of FKBIs supports this concept. Restenosis is highest at the SB ostium after bifurcation stenting; however, its mechanism is incompletely understood. Ge *et al.* proposed that polymer rupture and uneven distribution of stent struts were two possible factors contributing to this phenomenon [21]. Murasato *et al.* reported that FKBIs improved the apposition of the stent to the vessel wall [24]; however, the SB stent was narrowed at the overlapping site, and the overlapped stent in the main vessel created a metal mass limiting the complete SB balloon expansion resulting in severe stent strut malapposition. This was confirmed by an IVUS study immediately after classical crush stenting [17]. As a result, there is room left for the modification, and we proposed the (DK) crush technique.

## ■ Description of DK crush stenting

Two wires are positioned distal to lesions in both the main vessel and SB. The stent in the SB is inflated first with another balloon positioned in the main vessel. The guidewire and stenting balloon are then removed from the SB simultaneously. The previously positioned balloon in the main vessel is inflated, and it crushes the stent from the ostial SB to the proximal portion. First, kissing balloon angioplasty is performed after successful rewiring and re-ballooning of the SB. This is the first kissing angioplasty to expand the orifice of the SB. Re-removal of the wire and balloon from the SB is repeated. Then, the stent in the main vessel is inflated to further crush the side stent. Second kissing angioplasty is repeated after the second rewiring and re-ballooning of the SB is successful. The proximal segment of the side stent becomes distorted and unexpanded severely after the balloon is positioned as described previously in the main vessel. The first kissing balloon angioplasty repairs the distorted proximal segment and fully expands the orifice of the side stent. The inflated stent in the main vessel nearly does not touch or only touches the less SB stent protrotuded into the main vessel; therefore, recrossing the side stent and the second kissing balloon angioplasty becomes much easier. Notably, not only do rewiring and re-ballooning become difficult or impossible, but they also put more damage on the distorted side stent if the wire ends up partially or completely under stent. The main reasons that contribute to these suboptimal immediate- and long-term results lie in the large metal coverage gap. As a result, kissing balloon angioplasty is a key step to repair stent distortion and cover the origin of the SB. However, no reports have provided real success rates for kissing balloon angioplasty. With the worldwide use of the transradial approach with 6F guiding catheters for percutaneous coronary interventions [25], it is commonly difficult to deliver two stents simultaneously. Lim *et al.* made the first modification that a balloon rather than stent was positioned in the main vessel during balloon inflation in the SB, and this balloon when inflated would crush the proximal portion of the inflated stent [26]. Then, another stent would be advanced along the wire in the main vessel. The authors reported that final kissing balloon angioplasty was successful in five out of seven patients (70%). However, this modified balloon crush technique has no major differences with classical crush technique.

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Our team proposed the DK crush technique in 2005 [27], and compared it with the classical crush technique in two pilot studies in consecutive patients with true bifurcation lesions [27,28]. The results showed that FKBI by DK crush was successful in 100% of cases, significantly higher than that achieved by classical crush.

Since then, we conducted the DKCRUSH-1 study, a randomized, multicenter, prospective trial from 12 high-volume centers, to assess potential differences in MACE rates between the

DK and classical crush techniques [23]. A total of 313 patients were studied. More diabetic patients were randomized to the DK crush group. FKBI was used in 76% in the classical crush and 100% in the DK crush group ($p < 0.001$). MLD and acute gain in both pre-main vessel and post-main vessel segments post-PCI in the without-FKBI subgroup were smaller. Restenosis mostly occured in the body of the stent in the main vessel in the subgroup not receiving FKBI. More TLRs were seen in the classical crush groups. Post-PCI side stent diameter and lack of DK crush were two independent predictors of TLR. Independent factors of FKBI, unsatisfactory kissing (KUS) and TLR were: post-PCI side stent diameter, main stent length, lesion location and bifurcation angle; post-PCI SB MLD and current smoker status; and KUS and DK crush technique, respectively. FKBI was the only independent factor of late stent thrombosis. Significantly, the incidence of stent thrombosis was 3.2% in the classical crush group (5.1% without and 1.7% with FKBIs) and 1.3% in the DK crush group. Cumulative 8-month MACE rate was 24.4% in the classical crush group (35.9% in patients without FKBI and 19.7% in patients with FKBI), significantly greater than that in the DK crush group (11.4%; $p = 0.02$).

From April 2007 to June 2009, the DKCRUSH-II study consisted of 370 unselected patients with coronary bifurcation lesions from seven Asian centers, randomly assigned to either DK or provisional stenting (PS) groups [29]. Additional SB stent in PS was required if final results were suboptimal. The primary end point was the occurrence of MACE at 12 months, including cardiac death, myocardial infarction, or target-vessel revascularization. The secondary end point was angiographic restenosis at 8 months. There were three procedural occlusions of SB in the provisional stenting group. At 8 months, angiographic restenosis rates in the main vessel and SB were significantly different between the DK (3.8 and 4.9%; $p = 0.036$) and PS groups (9.7 and 22.2% $p < 0.001$; respectively). Additional SB stent in the PS group was required in 28.6% of lesions. Target-vessel revascularization occured in 6.5% in the DK group, significantly less often than in the PS group (14.6%; $p = 0.017$). Nonsignificant differences in MACE and definite stent thrombosis were observed between the DK (10.3 and 2.2%; $p = 0.070$) and PS groups (17.3 and 0.5%; $p = 0.372$).

## Financial & competing interests disclosure

*The author has no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.*

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