JACC: CARDIOVASCULAR INTERVENTIONS VOL. 5, NO. 8, 2012

ISSN 1936-8798/$36.00
PUBLISHED BY ELSEVIER INC.
http://dx.doi.org/10.1016/j.jcin.2012.06.005

STATE-OF-THE-ART PAPER

Kissing Balloon Inflation in Percutaneous Coronary Interventions

Gregory A. Sgueglia, MD, PhD,* Bernard Chevalier, MD†

Latina, Italy; and Massy, France

Bifurcation lesions are the most frequently approached complex coronary lesions in everyday interventional practice. Bifurcations complexity relies essentially on their very specific anatomy that is imperfectly handled by current coronary devices and, despite dedicated techniques and drug-eluting stents, percutaneous coronary interventions directed toward the treatment of bifurcations are technically demanding and require proper execution. Kissing balloon (KB) inflation was the first specific bifurcation technique to have been developed for percutaneous bifurcation interventions and continues to currently play an important role. Indeed, KB has been proposed to optimize stent apposition, improve side branch access while correcting stent deformation or distortion. Over the years, the KB technique has been deeply investigated by many different methods, from bench testing and computer simulations to in vivo intravascular imaging and clinical studies, producing a large amount of data pointing out the benefits and limitations of the technique. We sought to provide here a comprehensive overview of all those aspects. (J Am Coll Cardiol Intv 2012;5:803–11) © 2012 by the American College of Cardiology Foundation

Among complex coronary lesions, bifurcations are those most frequently encountered by every interventional cardiologist. Bifurcation complexity essentially relies on their specific anatomic configuration, which is imperfectly handled by current coronary devices.

Until the advent of drug–eluting stents (DES) and dedicated techniques, percutaneous bifurcation interventions were associated with very high rates of unfavorable outcomes (1,2). Nevertheless, procedures directed to bifurcation treatment are often technically demanding and require proper execution. When implementing dedicated percutaneous bifurcation approaches, kissing balloon (KB) has been variably recommended to optimize stent apposition, correct stent deformation or distortion, and improve side branch (SB) access. Over the years, KB has been deeply investigated by many different methods, from bench testing and computer simulations to in vivo intravascular imaging and clinical studies that have produced a large amount of data.

We review the rationale of KB and findings from dedicated studies, aiming to provide an updated and comprehensive overview of this technique.

From *Interventional Cardiology, Ospedale Santa Maria Goretti, Latina, Italy; and †Interventional Cardiology, Institut Cardiovasculaire Paris Sud, Massy, France. Dr. Sgueglia has reported that he has no relationships relevant to the contents of this paper to disclose. Dr. Chevalier is a consultant for Abbott Vascular, Medtronic, and Terumo.

Manuscript received March 8, 2012; revised manuscript received May 8, 2012, accepted June 7, 2012.

Anatomy of Bifurcation Lesions

A coronary bifurcation is a branching artery constituted by a main vessel (MV) and a SB. The segment before the origin of the SB is referred as proximal MV, whereas the one that is distal to it is referred as distal MV (Fig. 1). The tissue membrane separating the origins of the 2 bifurcation arms is called the flow divider or carina.

Operative definitions of bifurcation lesions have been based on the SB diameter, either arbitrarily or in relation to potential blood supply. Actually, a bifurcation stenosis is defined as a coronary artery narrowing occurring adjacent to and/or involving the origin of a significant SB (3). To be significant, the SB has to be considered important in the individual patient according to symptoms, location of ischemia, vitality, collateral vessels, and left ventricular function.

Morphology classification is mainly based on plaque distribution. Indeed, plaque distribution can variably involve the proximal MV, the distal MV, or the SB. This has engendered at least 6 different classification schemes (4–9). Sometimes, branching arteries are called "true" rather than "false" bifurcations according to the mere presence or absence of significant SB stenosis. Pathological examination of coronary arteries reveals that the atherosclerotic plaques are mainly located in areas of low shear stress, such as the lateral walls of the MV and SB, whereas they are less common at the carina level, which is characterized by high shear stress.

The spatial relation between the 2 arms of the bifurcation can be defined by 3 angles (Fig. 1) that have been recently named A (the angle between the proximal MV and the SB), B (the angle between the SB and the distal MV), and C (the angle between the proximal and distal segment of the MV). At times, bifurcations are defined as V- or T-type according to angle B being <70° or >70°, respectively. Moreover, the proximal and distal branches of a bifurcation often do not lie on a single plane, thus posing significant challenges to quantitative coronary angiography software.

A recent ex vivo study of polymer casts of human coronary arteries has revealed a complex curvilinear transition zone between MV and SB, mainly characterized by an elliptical and asymmetrical configuration of the SB ostium and brief tapering of the SB origin (10). Moreover, it has been previously pointed out that SB ostium asymmetry increases with increasing bifurcation angles (11). In bifurcations, there is also an asymmetrical geometric reduction according to the law of conservation of energy (12).

The complex interaction among different factors makes every bifurcation lesion quite unique (Fig. 1), although certain lesion characteristics have been associated with treatment success when using currently accepted techniques and DES platforms (13).

Abbreviations and Acronyms

CI = confidence interval

DES = drug-eluting stent(s)

FFR = fractional flow reserve

IVUS = intravascular ultrasound

KB = kissing balloon(s)

MV = main vessel

OCT = optical coherence tomography

SB = side branch(es)

TIMI = Thrombolysis In Myocardial Infarction

TLR = target lesion revascularization

The Need for KB

Bifurcation lesions, by their anatomy, expose the patient to the risk of SB damage, defined as worsening of percent stenosis, and in some cases, SB occlusion (14). Different mechanisms have been suggested to explain SB damage, such as plaque or carina shift, refractory spasm, or dissection of the ostium. In the case of SB occlusion, myocardial necrosis could ensue, being associated with a worse short- and long-term clinical outcome with elevation of both creatine kinase–myocardial band isoform and cardiac troponin levels (15–17). Despite the fact that most acutely occluded SBs undergo late spontaneous reperfusion (18), temporary occlusion causes myocardial enzyme elevation.

In the case of SB stenosis, myocardial ischemia might ensue with persistence of symptoms or mechanical dysfunction. In a recent prospective study of patients with bifurcation lesions successfully treated by DES implantation according to the provisional approach, significant SB stenosis was present in about 20% of patients as assessed by 3-dimensional quantitative coronary angiography. These patients had a significantly increased rate of late inducible ischemia and minor adverse coronary events (19). Angiographic (20) and intravascular ultrasound (IVUS) (21) predictors of SB damage have been described, with further insights recently provided by 3-dimensional optical coherence tomography (OCT) (22).

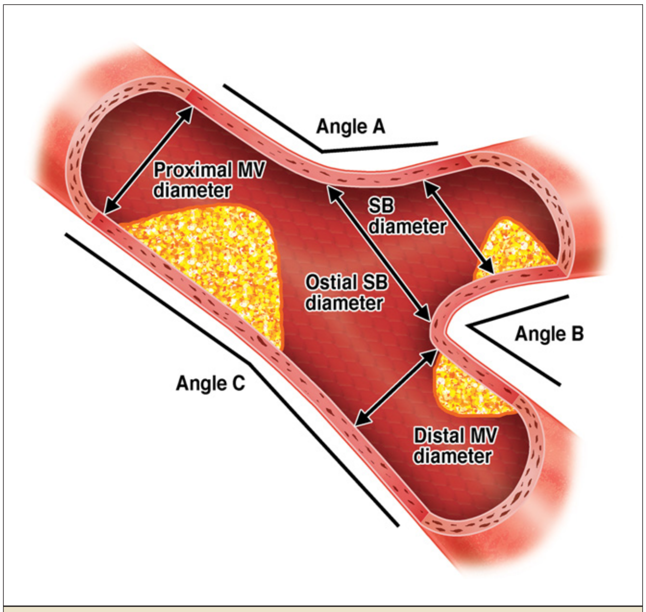

Figure 1. The Complexity of Bifurcation Lesions

Main aspects of anatomic complexity of bifurcation lesions include variable distribution of atherosclerosis, variable spatial relation between the branches defined by angles A, B, and C, the tapered nature of the side branch as reflected by a bigger ostial diameter, and the asymmetrical geometric reduction of the vessel diameter at the bifurcation site. MV = main vessel; SB = side branch.

History of KB

The term *kissing balloon* was first used by Gruentzig to describe the percutaneous treatment of an iliac bifurcation stenosis (23). In 1980, Velasquez et al. (24) published the first report of this technique for distal aorta angioplasty in a patient with Leriche syndrome. One year later, Gruentzig applied the KB technique to percutaneous coronary revascularization (25). At that time, 2 guiding catheters were required, each inserted through a single vascular access, and despite the name of the technique, the simultaneous inflation of the 2 balloons was not the routine: rather, repeated sequential inflation of the MV and SB balloons was deemed safer in regard to the risk of vessel dissection (26,27). Pioneering experiences were positively reported by Meier (25), Zack et al. (26), and Pinkerton et al. (28) in 3, 8, and 13 patients, respectively. In 1986, George et al. (29) reported their experience with KB through a brachiofemoral approach in 52 selected patients, with a procedural success obtained in 98% of them. To avoid a dual guiding catheter system, a single-guide, two-wire technique, sometimes called kissing wire, has been advocated as a simpler, but equally effective, approach to SB preservation (30). Advancing technology has rapidly made KB possible through a single guiding catheter using either 2 balloons with fixed wires (31), a balloon with a fixed wire and a balloon over the wire (23), 2 balloons over the wire (32), or 2 rapid exchange balloons (33). In 1996, Krikorian et al. (34) proposed a simplification of the technique with a single inflation device connected to the 2 balloons through a 3-way stopcock, allowing for single-operator interventions.

Following the introduction of coronary stents and refinement of the technology, the rate of KB progressively increased (6). Actually, KB can be performed with noncompliant balloons (35) and drug-eluting balloons (36) in a 6-F guiding catheter and with special equipment in a 5-F guiding catheter (37).

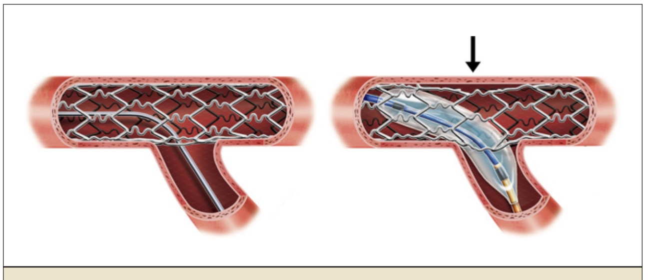

Figure 2. Main Vessel Stent Distortion Without Kissing Balloon

Bench testing has shown that balloon dilation through the side of the main vessel stent to open a cell toward the side branch determines marked distortion of the stent itself **(arrow)**.

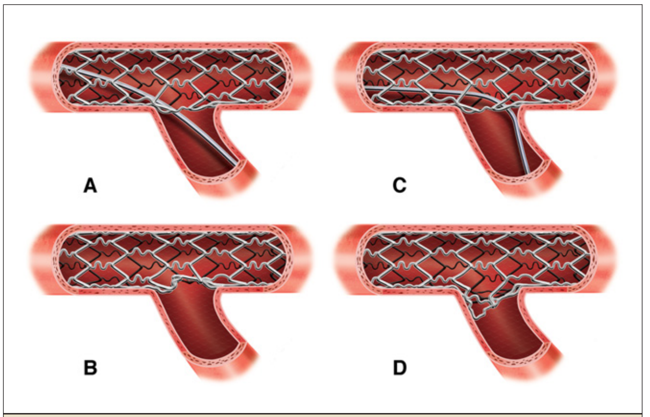

Figure 3. Influence of Main Vessel Stent Cell Rewiring on Stent Deformation Following Kissing Balloon

Access to the side branch through the strut of a stent is usually possible through 2 or 3 different cells. The cell choice affects stent deformation. Bench testing has shown that wire crossing through the strut closest to the carina **(C and D)** provides better scaffolding of the origin of the side branch than proximal crossing that pushes the struts inward towards the main vessel lumen **(A and B)**.

Gaining Insight Into KB

KB modifies the geometry of the implanted stent depending on many factors, including balloon size, inflation pressure, and deflation sequence.

Bench testing. One of the most important contributions of bench testing to the better understanding of bifurcation stenting is the demonstration by Ormiston et al. (38,39) that balloon dilation through the side of the MV stent to open a cell toward the SB results in marked distortion of the stent itself (Fig. 2). This important issue has been shown to be either prevented or corrected by KB. Accordingly, if the balloons chosen for the kissing inflation are too small, the MV stent will be distorted. Moreover, this finding underscores that the SB balloon should be deflated at the same time as the MV balloon to avoid MV stent deformation. However, the sensitivity to SB dilation in terms of MV stent distortion might vary according to specific designs (40,41).

KB can also provide optimal scaffolding of the SB ostium when care is taken to properly rewire the SB. In the provisional technique, bench testing has shown that wire crossing through the cell closest to the carina provides better scaffolding than proximal crossing (Fig. 3).

By contrast, when implementing the crush technique, it is highly advisable to cross the proximal cell. Indeed, bench tests have shown that when stents are crushed, there is a trough between the MV and SB stents on the side opposite to the crushed portion (42–45). If a wire recrosses the MV stent through a distal strut, it may pass outside the stents through the trough before entering the SB stent. If inflated, a post-dilation balloon would push the struts aside, producing a gap in coverage between the stents at the level of the carina. Moreover, a 2-step post-dilation involving a high-

JACC: CARDIOVASCULAR INTERVENTIONS, VOL. 5, NO. 8, 2012
AUGUST 2012:803–11

pressure post-dilation in the SB followed by final KB significantly reduced the ostial stenosis as compared with a 1-step post-dilation by KB. This is especially true for sharp SB angles (42–44).

Bench tests have also provided evidence on the limitations linked to a specific stent design (40) and to the KB technique itself. Indeed, it has been shown that KB determines coating damage to first-generation DES and elliptical deformation of the stent proximally to the SB (46) and that is corrected by final post-dilation of the proximal part of the MV stent (47). Overlapping configuration of the KB has also been shown to influence the stent deformation (45).

Finally, bench testing has recently been used to gain insight into the influence of flow patterns in stented coronary bifurcations with a silicone bifurcation model positioned within a closed-flow loop system mimicking the flow conditions of human arterial circulation (48). In this model, KB corrected the systolic flow disturbance induced by stent implantation.

Finite element analysis. Computer simulation allows assessment of physical structures through the building of geometric models incorporating realistic material behavior. Finite element analysis has recently provided valuable inside into percutaneous bifurcation interventions. Indeed, it has been shown that the relative position of the deployed MV stent strongly affects the occurring strut deformations, with optimal SB access being obtained only if a cell was centrally placed with respect to the SB ostium (49,50). Moreover, the stent cell design significantly affects strut apposition after SB dilation, pointing toward mandatory KB when dilating an open-cell stent (49).

Recently, a very elegant simulation by Mortier et al. (51) has highlighted that KB induces elliptical deformation of the proximal segment of the MV stent with consequent high vessel wall stress and possible direct vessel wall injury at the entry of the SB. However, KB simulations with a tapered balloon for the SB have shown a significant decrease in the MV stent overexpansion (52). Finally, it has been found that despite KB, a high proportion of struts at the proximal MV stent edge remained incompletely apposed as compared with simple MV stenting without opening the cell toward the SB (53).

Computational flow dynamics. Computers can also apply numerical methods and algorithms to analyze the interaction of fluid with definite surfaces.

In a computed model of a 90° bifurcation treated by T-stenting, flow features were characterized by flow stasis and recirculation areas downstream from the bifurcation, depending on the way the cell facing the SB was opened according to its variable position with respect to the SB itself. In absence of final KB, the stent struts protruding into the lumen of the MV induced high values of shear stress at the stent wall (54).

Recently, an innovative approach consisting in the development of a sequential model in which the structural simulations are used to build the fluid domains highlighted the advantages of final KB in terms of better flow pattern (52). Indeed, by removing the stent struts from the blood flow, final KB freed the access to the SB and lowered the hemodynamic disturbance that were present after the mere implantation of a stent on the MV. Of note, flow alteration in stented bifurcations has been shown to significantly influence the interaction between the eluted drug and the vessel wall (55).

Success and Safety of KB

The BBC ONE study (British Bifurcation Coronary Study: Old, New and Evolving Strategies) randomized 500 patients to either a simple stenting procedure with optional KB or a complex procedure (either crush or culotte) with mandatory KB (56). The reported rate of attempted and successful final KB is 31% and 29% in the provisional group and 90% and 76% in the crush group, respectively. Overall, KB success was 95% in the simple approach and 85% in the complex approach ($p = 0.01$).

So far, only 1 complication possibly related to the KB procedure has been described in the published reports. Indeed, an intramural hematoma was reported in a patient on warfarin therapy (international normalized ratio: 3.3) treated by KB after a stent implantation on the left main coronary artery across the left circumflex artery (57).

Imaging Assessment of KB

One-stent strategy. In a serial IVUS study on 23 patients treated by a 1-stent strategy followed by SB dilation and then final KB, dilation of the SB introduced geometric distortion of the distal MV stent and a 12% loss in stent area (58). After KB, stent geometry was not fully restored, and complete recovery of the stent area did not occur.

In the CORPAL (Cordoba & Las Palmas) Kiss trial, IVUS findings were assessed in 101 patients treated by a 1-stent technique for coronary bifurcation disease (59). Patients randomized to KB showed a larger proximal stent cross-sectional area than did the patients from the non-KB group, suggesting overexpansion of the proximal MV stent.

Recently, OCT has been used to point out the importance of KB after MV stenting (60) and to confirm in vivo the importance of recrossing the MV stent through the cell closest to the carina (61). Importantly, OCT has recently underlined a high rate of uncovered struts across the SB ostium when simple MV stenting is performed without final KB (62).

2-stent strategy. Twenty-five patients treated by crushing technique underwent IVUS analysis, and in 23 of them, final KB was performed. At IVUS, most SB lesions showed angiographically unsuspected stent underexpansion, with the smallest minimal stent area found at the SB ostium and frequent incomplete stent apposition in the crush area (63).

Another serial IVUS study compared the results of classical crush and double-crush technique at the end of the procedure and at 8-month follow-up (64). Incomplete crush was observed in 81.3% of the patients in the classical crush group compared with 38.5% in the double-crush group ($p = 0.004$). The post-procedure symmetry index was higher in the double-crush technique than in classical crush, both at the level of the MV stent and at the SB ostium.

A recent IVUS study has shown that the quality of the KB technique, in addition to its simple performance, significantly impacts the clinical outcome following crush stenting (65). Indeed, rewiring proximal rather than distal to the carina significantly predicted SB restenosis (hazard ratio: 2.34, 95% confidence interval [CI]: 1.78 to 4.32, $p < 0.001$).

Functional Assessment of KB

In patients treated by a 1-stent technique, fractional flow reserve (FFR) measured in the jailed SB was compared with quantitative coronary angiography results showing a negative correlation between percent stenosis and FFR ($r = -0.41$, $p < 0.001$). However, there was a wide variation of functional significance even among lesions with angiographically significant stenosis, with only 27% of lesions with ≥75% stenosis being functionally significant (66). In a subsequent study, KB has been performed in 26 lesions with FFR <0.75 showing achievement of FFR ≥0.75 in 92% of them (67). Notably, this functional gain was maintained at 6-month follow-up.

In a study of 60 patients treated by provisional stenting, lack of KB inflation was the only technical factor associated at univariate analysis with post-procedural inducible ischemia as assessed by exercise stress test (19).

Very recently, a FFR substudy of the Nordic-Baltic Bifurcation Study III showed that among 75 participating patients, FFR measured in the SB at the end of the procedure showed a significantly higher mean value in the final KB group as compared with the non-final KB group (0.92 vs. 0.85, respectively, $p = 0.011$) (68). Interestingly, the absence of final KB was a strong predictor of post-procedural FFR <0.75 ($p = 0.006$).

Clinical Assessment of KB

One-stent strategy. In the bare-metal stent era, KB has been shown to be associated with improved outcomes following provisional stenting (6). Moreover, in a small study on 59 patients undergoing MV stenting, SB compromise defined as Thrombolysis In Myocardial Infraction (TIMI) flow grade <3 was significantly higher using sequential balloon inflation than after KB (33% vs. 0%, respectively, $p = 0.003$), although the rate of target lesion revascularization (TLR) at 6-month follow-up was not different between the 2 groups (69).

THUEBIS (Thueringer Bifurcation Study) compared a strategy of percutaneous bifurcation intervention by provisional stenting and final KB with an approach consisting of provisional stenting, with SB dilation only in case of TIMI flow grade ≤2 in 110 patients (70). Paclitaxel-eluting stents were implanted in all patients, and dual antiplatelet therapy was prescribed for at least 6 months. At 6-month follow-up, no significant differences in the incidence of major adverse cardiac events was observed between the 2 groups (Table 1). Notably, in 10 patients randomized to final KB per protocol, SB could not be rewired, and in 7 of 54 patients randomized to final KB, balloon inflation was actually sequential rather than simultaneous. Overall, 31% of patients randomized to KB did not receive this treatment, thus impairing results interpretation.

In the Nordic-Baltic Bifurcation Study III, 477 patients with a bifurcation lesion were randomized to KB ($n = 238$) or non-KB ($n = 239$) after MV stenting with sirolimus-eluting stent (71). At 6-month follow-up, the rates of major adverse cardiac events were 2.1% and 2.5% ($p = 1.00$) in the KB and non-KB groups, respectively (Table 1). At 8-month angiographic follow-up in 326 patients, a trend was ob-

Table 1. Summary of Clinical Trials Assessing the Clinical Utility of KB Inflation in PCI

First Author/Study (Ref. #)	Stenting Strategy	n	Follow-Up Length	Cardiac Death (KB vs. Non-KB)	Myocardial Infarction (KB vs. Non-KB)	Target Lesion Revascularization (KB vs. Non-KB)	MACE (KB vs. Non-KB)	Definite/Probable Stent Thrombosis (KB vs. Non-KB)
Ge et al. (75)	Complex	KB (n = 116) vs. non-KB (n = 65)	9 months	1.7% vs. 0%	10.3% vs. 13.9%	9.5% vs. 24.6%*	19.8% vs. 38.5%*	2.6% vs. 3.1%
THUEBIS (70)	Simple	KB (n = 56) vs. non-KB (n = 54)	6 months	0% vs. 3.7%	3.6% vs. 1.9%	17.9% vs. 14.8%	23.2% vs. 24.1%	3.6% vs. 1.9%
Nordic III (71)	Simple	KB (n = 238) vs. non-KB (n = 239)	6 months	0.8% vs. 0%	0.4% vs. 1.3%	1.3% vs. 1.7%	2.1% vs. 2.5%	0.4% vs. 0.4%†
CORPAL Kiss (59)	Simple	KB (n = 124) vs. non-KB (n = 120)	12 months	0.8% vs. 1.7%	3.2% vs. 1.7%	4.0% vs. 1.7%	9% vs. 6%	0.8% vs. 0.8%

*p = 0.008; ††definite stent thrombosis.
KB = kissing balloon; MACE = major adverse cardiac events; PCI = percutaneous coronary intervention.

JACC: CARDIOVASCULAR INTERVENTIONS, VOL. 5, NO. 8, 2012
AUGUST 2012:803–11

served toward a lower rate of binary restenosis in the KB group (11% vs. 17.3% in the non-KB group, p = 0.11). Of note, KB significantly reduced angiographic SB restenosis (7.9% vs. 15.4%, p = 0.039), especially in true bifurcation lesions (7.6% vs. 20.0%, p = 0.024).

In a real-world registry assessing the incidence of target bifurcation failure in 187 patients treated by main mTOR inhibitor-eluting stents according to the provisional T-stenting and small protrusion (TAP) technique, lack of final KB was associated with a worse outcome (p = 0.045) at 12-month follow-up, with significant divergence of the Kaplan-Meier curves for event-free survival starting at the 6-month follow-up (72).

However, in the CORPAL Kiss Trial, patients with bifurcation lesions treated by a simple approach with sirolimus- or everolimus-eluting stents (50% each) were randomized to KB (n = 124) and non-KB (n = 120) with the MV stent cell opened toward the SB with single-balloon dilation in all patients of the non-KB group (59). The incidence of major adverse cardiac events was similar in both groups at 1-year follow-up (Table 1).

In the retrospective multicenter COBIS (COronary BIfurcation Stent) registry, among 1,065 patients treated by a 1-stent technique, 329 were treated by KB whereas 736 were not. At a median follow-up of 22 months, most TLRs were observed to occur in the MV rather than in the SB, whereas no significant differences were observed between groups in rates of cardiac death, myocardial infarction, or stent thrombosis (73).

In a recent meta-analysis, an increasing rate of final KB in the simple-strategy group significantly reduced the risk of SB restenosis (74).

2-stent strategy. Ge et al. (75) compared the 9-month outcome of 181 patients treated according to the crush technique, showing that the lack of final KB was a predictor of TLR at 9 months (hazard ratio: 1.79, 95% CI: 1.14 to 2.80, p = 0.01) (Table 1). In the SB, both late lumen loss and binary restenosis were lower among patients treated by final KB.

In 231 patients treated by crush technique with either sirolimus-eluting stents (n = 131) or paclitaxel-eluting stents (n = 101), final KB significantly improved angiographic results, leading to a larger post-procedural minimal lumen diameter in the MV and in the SB, which was maintained at follow-up (76).

In a study by Dzavik et al. (13), final KB was performed in 98 of 133 (74%) patients who were treated according to the crush technique. At a median follow-up of 386 days, major adverse cardiac event-free survival was higher in the KB group compared with the non-KB group (p = 0.009).

Double kissing showed good immediate- and short-term clinical outcomes (77). In the DKCRUSH-1 study, the double-kissing crush technique was associated with a higher success rate of final KB as compared with classical crush (78). At 8-month follow-up, the rate of major adverse cardiac events was significantly lower in patients treated by double-kissing crush rather than classical crush.

In a study on 132 patients treated by the culotte technique (79), final KB showed a trend toward a protective effect against binary restenosis as assessed by a dedicated bifurcation quantitative coronary angiography system at 6 to 8 months follow-up (odds ratio: 0.37, 95% CI: 0.13 to 1.10, p = 0.07).

Special KB Applications

Recently, kissing inflation with drug-eluting balloons after provisional MV stenting with a bare-metal stent has been reported as a promising treatment in patients with low compliance to prolonged dual antiplatelet therapy (36). This technique has been shown to be feasible through a 6-F guiding catheter with all drug-eluting balloons available and has also been successfully applied to the treatment of several kinds of DES restenosis (80). Clinical and preliminary angiographic and OCT results of this approach appear encouraging (36,81).

Kissing 2 drug-perfusion balloon catheters has been reported to be feasible and effective in the treatment of 3 patients with bifurcation restenosis (82).

Technical Notes

Rewiring the SB. In the provisional technique, both in vitro bench tests (38,39) and in vivo OCT imaging (61) have underscored that rewiring through the cell closest to the carina provides a better scaffolding than proximal crossing. Also, balloon trackability into the SB is found to be easier when effectively recrossing through the distal cell. Accordingly, SB pre-dilation is discouraged to avoid possible dissection of the SB ostium and to take advantage of the carina shift ensuing from MV stenting so the wire could cross the stent exactly at the carina level (83). To increase the chance of crossing through the distal strut, pullback rewiring is advised. The wire should be shaped manually, and after the tip is engaged within the struts at the origin of the SB, a careful steering allows crossing into the SB. Hydrophilic-coated wire might encounter less friction in crossing the struts, but the risk of dissecting the SB increases. Advanced techniques to ensure difficult SB rewiring have been recently reviewed (84).

Balloon diameters. Bench tests have pointed out the importance of the KB diameters (38,39), and several rules have been proposed to appropriately select the diameters of the balloons to be inflated simultaneously during the KB procedure (Fig. 4), with 1 rule being recently validated in an IVUS study (85).

Tracking sequence. Because of the more complex pathway leading to the SB, the balloon that is directed to this branch

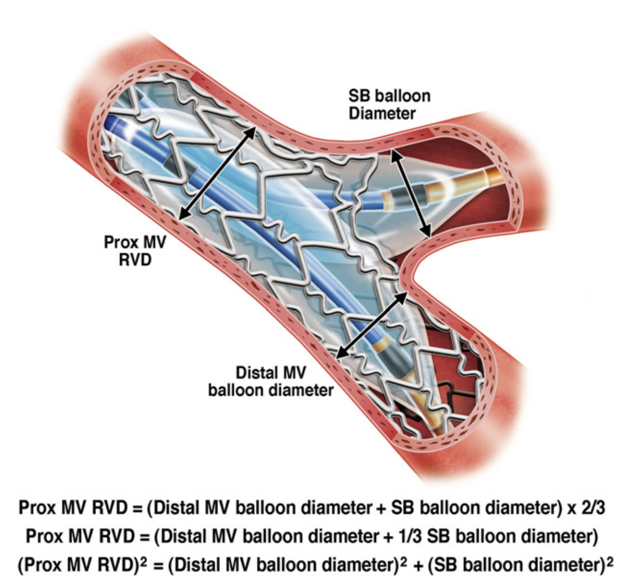

Figure 4. Rules Guiding the Choice of the Balloon Diameters for Kissing Inflation

Among the several rules that have been proposed to select the diameters of the balloons to inflate simultaneously during the kissing balloon procedure, these reported in the figure are the most frequently applied. PROX = proximal; RVD = reference vessel diameter; other abbreviations as in Figure 1.

should be tracked at first. Indeed, in a simple stenting strategy, easy navigability of the balloon to the SB is often a marker of optimal rewiring. Sequential removal starting from the last balloon tracked is advised.

Inflation duration. A recent study has demonstrated that prolonged inflation times up to 60 s result in optimal stent expansion (86). Therefore, a 2-step strategy consisting of 30-s delivery balloon inflation followed by another 30-s KB inflation should be recommended.

Deflation sequence. Bench-testing results suggest that the SB balloon should be deflated at the same time as the MV balloon to avoid MV stent deformation (38,39). A useful method to ensure simultaneous deflation of both balloons is the use of a 3-way stopcock by which the 2 balloons are connected to a single inflation device.

Final Remarks

Owing to its important role in most approaches to percutaneous bifurcation intervention, KB has been deeply investigated by several different methods. However, despite the amount of data favoring KB, clinical studies have supported the value of this technique only in patients undergoing percutaneous bifurcation intervention by a complex 2-stent strategy (75–79). In patients treated by a 1-stent technique, published trials to date do not allow the endorsement of systematic KB owing to the lack of significant advantage or penalty (59,70,71). Surely, KB is a complex procedure influenced by a number of parameters that can be modified by the operator. Bench tests in coronary models and computer simulations have shown how small differences in these parameters could translate into significantly different results (38–41,49–54), leading toward the endeavor of optimal procedural performance in vivo. Although whether such an attempt might be effective and could provide better clinical outcomes has not been explored. More importantly, in the assessment of the value of KB in the simple 1-stent technique, follow-up data extending over 1 year are actually lacking. Since 1 year corresponds to the typical length of dual antiplatelet therapy after DES implantation, this is an especially critical issue because bifurcation lesions are significantly predictive of very late stent thrombosis after DES implantation (87). Notably, recent OCT data have pointed out the lack of coverage of stent struts facing the SB ostium when KB is not performed (62), thus suggesting an increased risk of very late stent thrombosis (88). Moreover, the finding that bifurcation stent thrombosis is associated with a higher in-hospital and long-term mortality than stent thrombosis occurring at non-bifurcation lesions (89) urges one to ascertain the possible impact of KB on the long-term safety of percutaneous coronary interventions.

Therefore, if the advantage of KB in 2-stent bifurcation techniques is undoubtful, its role in a simple bifurcation approach cannot be definitely ruled out until longer clinical follow-up data are available.

Reprint requests and correspondence: Dr. Gregory A. Sgueglia, UOC Emodinamica e Cardiologia Interventistica, Ospedale Santa Maria Goretti, Via Canova, 3, 04100 Latina, Italy. E-mail: g.a.sgueglia@gmail.com.

REFERENCES

1. Al Suwaidi J, Berger PB, Rihal CS, et al. Immediate and long-term outcome of intracoronary stent implantation for true bifurcation lesions. J Am Coll Cardiol 2000;35:929–36.
2. Al Suwaidi J, Yeh W, Cohen HA, Detre KM, Williams DO, Holmes DR Jr. Immediate and one-year outcome in patients with coronary bifurcation lesions in the modern era (NHLBI dynamic registry). Am J Cardiol 2001;87:1139–44.
3. Louvard Y, Thomas M, Dzavik V, et al. Classification of coronary artery bifurcation lesions and treatments: time for a consensus! Catheter Cardiovasc Interv 2008;71:175–83.
4. Popma JJ, Leon MB, Topol EJ. Atlas of Interventional Cardiology. Philadelphia, PA: W. B. Saunders, 1994:77.
5. Spokojny AM, Sanborn TM. The bifurcation lesion. In: Ellis SG, Holmes DR Jr., editors. Strategic Approaches in Coronary Intervention. Baltimore, MD: Williams and Wilkins, 1996:288.
6. Lefèvre T, Louvard Y, Morice MC, et al. Stenting of bifurcation lesions: classification, treatments, and results. Catheter Cardiovasc Interv 2000;49:274–83.
7. Safian RD. Bifurcation lesions. In: Safian RD, Freed MS, editors. The Manual of Interventional Cardiology. 3rd edition. Royal Oak, MI: Physician's Press, 2001:222.
8. Movahed MR, Stinis CT. A new proposed simplified classification of coronary artery bifurcation lesions and bifurcation interventional techniques. J Invasive Cardiol 2006;18:199–204.

9. Medina A, Suárez de Lezo J, Pan M. [A new classification of coronary bifurcation lesions]. Spanish. Rev Esp Cardiol 2006;59:183.
10. Russell ME, Binyamin G, Konstantino E. Ex vivo analysis of human coronary bifurcation anatomy: defining the main vessel-to-side-branch transition zone. EuroIntervention 2009;5:96–103.
11. Louvard Y, Lefèvre T, Morice MC. Percutaneous coronary intervention for bifurcation coronary disease. Heart 2004;90:713–22.
12. Murray CD. The physiological principle of minimum work. The vascular system and the cost of blood volume. Proc Natl Acad Sci U S A 1926;12:207–14.
13. Dzavik V, Kharbanda R, Ivanov J, et al. Predictors of long-term outcome after crush stenting of coronary bifurcation lesions: importance of the bifurcation angle. Am Heart J 2006;152:762–9.
14. Prasad N, Seidelin PH. Sidebranch compromise during percutaneous coronary interventions. J Invasive Cardiol 2002;14:138–45.
15. Ioannidis JP, Karvouni E, Katritsis DG. Mortality risk conferred by small elevations of creatine kinase-MB isoenzyme after percutaneous coronary intervention. J Am Coll Cardiol 2003;42:1406–11.
16. Nienhuis MB, Ottervanger JP, Bilo HJ, Dikkeschei BD, Zijlstra F. Prognostic value of troponin after elective percutaneous coronary intervention: A meta-analysis. Catheter Cardiovasc Interv 2008;71:318–24.
17. Popma JJ, Mauri L, O'Shaughnessy C, et al. Frequency and clinical consequences associated with sidebranch occlusion during stent implantation using zotarolimus-eluting and paclitaxel-eluting coronary stents. Circ Cardiovasc Interv 2009;2:133–9.
18. Poerner TC, Kralev S, Voelker W, et al. Natural history of small and medium-sized side branches after coronary stent implantation. Am Heart J 2002;143:627–35.
19. Burzotta F, Trani C, Todaro D, et al. Prospective evaluation of myocardial ischemia related to post-procedural side-branch stenosis in bifurcated lesions treated by provisional approach with drug-eluting stents. Catheter Cardiovasc Interv 2012;79:351–9.
20. Vassilev D, Gil R. Clinical verification of a theory for predicting side branch stenosis after main vessel stenting in coronary bifurcation lesions. J Interv Cardiol 2008;21:493–503.
21. Suárez de Lezo J, Medina A, Martín P, et al. Predictors of ostial side branch damage during provisional stenting of coronary bifurcation lesions not involving the side branch origin: an ultrasonographic study. EuroIntervention 2012;7:1147–54.
22. Farooq V, Serruys PW, Heo JH, et al. New insights into the coronary artery bifurcation hypothesis-generating concepts utilizing 3-dimensional optical frequency domain imaging. J Am Coll Cardiovasc Intv 2011;4:921–31.
23. Myler RK, McConahay DR, Stertzer SH, et al. Coronary bifurcation stenoses: the kissing balloon probe technique via a single guiding catheter. Cathet Cardiovasc Diagn 1989;16:267–78.
24. Velasquez G, Castaneda-Zuniga W, Formanek A, et al. Nonsurgical aortoplasty in Leriche syndrome. Radiology 1980;134:359–60.
25. Meier B. Kissing balloon coronary angioplasty. Am J Cardiol 1984;54:918–20.
26. Zack PM, Ischinger TM. Experience with a technique for coronary angioplasty of bifurcational lesions. Cathet Cardiovasc Diagn 1984;10:433–43.
27. Pinkerton CA, Slack JD. Complex coronary angioplasty: a technique for dilatation of bifurcation stenoses. Angiology 1985;36:543–8.
28. Pinkerton CA, Slack JD, Van Tassel JW, Orr CM. Angioplasty for dilatation of complex coronary artery bifurcation stenoses. Am J Cardiol 1985;55:1626–8.
29. George BS, Myler RK, Stertzer SH, et al. Balloon angioplasty of coronary bifurcation lesions: the kissing balloon technique. Cathet Cardiovasc Diagn 1986;12:124–38.
30. Oesterle SN, McAuley BJ, Buchbinder M, Simpson JB. Angioplasty at coronary bifurcations: single-guide, two-wire technique. Cathet Cardiovasc Diagn 1986;12:57–63.
31. van Leeuwen K, Blans W, Pijls NH, van der Werf T. Kissing balloon angioplasty of a circumflex artery bifurcation lesion. A new approach utilizing two balloon-on-wire probes and a single guiding catheter. Chest 1989;95:1144–5.
32. den Heijer P, Bernink PJ, van Dijk RB, Twisk SP, Lie KI. The kissing balloon technique with two over-the-wire balloon catheters through a single 8-French guiding catheter. Cathet Cardiovasc Diagn 1991;23:47–9.
33. Castriz JL, Canales ML, Reynolds DW. Kissing balloon technique in complex PTCA: single guiding catheter and dual wire rapid exchange system. Cathet Cardiovasc Diagn 1993;28:358–60.
34. Krikorian RK, Vacek JL, Beauchamp GB. "Kissing balloon" technique in percutaneous transluminal coronary angiography: single-guide catheter, dual-wire, dual-balloon system with single inflation device. Cathet Cardiovasc Diagn 1996;37:331–3.
35. Mylotte D, Hovasse T, Ziani A, et al. Non-compliant balloons for final kissing inflation in coronary bifurcation lesions treated with provisional side branch stenting: a pilot study. EuroIntervention 2012;7:1162–9.
36. Sgueglia GA, Todaro D, Bisciglia A, Conte M, Stipo A, Pucci E. Kissing inflation is feasible with all second-generation drug-eluting balloons. Cardiovasc Revasc Med 2011;12:280–5.
37. Yoshimachi F, Masutani M, Matsukage T, Saito S, Ikari Y. Kissing balloon technique within a 5 Fr guiding catheter using 0.010 inch guidewires and 0.010 inch guidewire-compatible balloons. J Invasive Cardiol 2007;19:519–24.
38. Ormiston JA, Webster MW, Ruygrok PN, Stewart JT, White HD, Scott DS. Stent deformation following simulated side-branch dilatation: a comparison of five stent designs. Catheter Cardiovasc Interv 1999;47:258–64.
39. Ormiston JA, Webster MW, El Jack S, et al. Drug-eluting stents for coronary bifurcations: bench testing of provisional side-branch strategies. Catheter Cardiovasc Interv 2006;67:49–55.
40. Hikichi Y, Inoue T, Node K. Benefits and limitations of cypher stent-based bifurcation approaches: in vitro evaluation using microfocus CT scan. J Interv Cardiol 2009;22:128–34.
41. Rux S, Sonntag S, Schulze R, et al. Acute and long-term results of bifurcation stenting (from the Coroflex registry). Am J Cardiol 2006;98:1214–7.
42. Ormiston JA, Currie E, Webster MW, et al. Drug-eluting stents for coronary bifurcations: insights into the crush technique. Catheter Cardiovasc Interv 2004;63:332–6.
43. Ormiston JA, Webster MW, Webber B, Stewart JT, Ruygrok PN, Hatrick RI. The "crush" technique for coronary artery bifurcation stenting: insights from micro-computed tomographic imaging of bench deployments. J Am Coll Cardiol Intv 2008;1:351–7.
44. Murasato Y. Impact of three-dimensional characteristics of the left main coronary artery bifurcation on outcome of crush stenting. Catheter Cardiovasc Interv 2007;69:248–56.
45. Murasato Y, Hikichi Y, Horiuchi M. Examination of stent deformation and gap formation after complex stenting of left main coronary artery bifurcations using microfocus computed tomography. J Interv Cardiol 2009;22:135–44.
46. Guérin P, Pilet P, Finet G, et al. Drug-eluting stents in bifurcations: bench study of strut deformation and coating lesions. Circ Cardiovasc Interv 2010;3:120–6.
47. Foin N, Secco GG, Ghilencea L, Krams R, Di Mario C. Final proximal post-dilatation is necessary after kissing balloon in bifurcation stenting. EuroIntervention 2011;7:597–604.
48. Nakazawa G, Yazdani SK, Finn AV, Vorpahl M, Kolodgie FD, Virmani R. Pathological findings at bifurcation lesions: the impact of flow distribution on atherosclerosis and arterial healing after stent implantation. J Am Coll Cardiol 2010;55:1679–87.
49. Mortier P, De Beule M, Van Loo D, Verhegghe B, Verdonck P. Finite element analysis of side branch access during bifurcation stenting. Med Eng Phys 2009;31:434–40.
50. Gastaldi D, Morlacchi S, Nichetti R, et al. Modelling of the provisional side-branch stenting approach for the treatment of atherosclerotic coronary bifurcations: effects of stent positioning. Biomech Model Mechanobiol 2010;9:551–61.
51. Mortier P, De Beule M, Dubini G, Hikichi Y, Murasato Y, Ormiston JA. Coronary bifurcation stenting: insights from in vitro and virtual bench testing. EuroIntervention 2010;6 Suppl J:J53–60.
52. Morlacchi S, Chiastra C, Gastaldi D, Pennati G, Dubini G, Migliavacca F. Sequential structural and fluid dynamic numerical simulations of a stented bifurcated coronary artery. J Biomech Eng 2011;133:121010.

53. Foin N, Torii R, Mortier P, et al. Kissing balloon or sequential dilation of the side branch and main vessel for provisional stenting of bifurcations: lessons from micro-computed tomography and computational simulations. J Am Coll Cardiol Intv 2012;5:47–56.
54. Deplano V, Bertolotti C, Barragan P. Three-dimensional numerical simulations of physiological flows in a stented coronary bifurcation. Med Biol Eng Comput 2004;42:650–9.
55. Kolachalama VB, Levine EG, Edelman ER. Luminal flow amplifies stent-based drug deposition in arterial bifurcations. PLoS ONE 2009;4:e8105.
56. Hildick-Smith D, de Belder AJ, Cooter N, et al. Randomized trial of simple versus complex drug-eluting stenting for bifurcation lesions: the British bifurcation coronary study: old, new, and evolving strategies. Circulation 2010;121:1235–43.
57. Shirodaria C, Van Gaal WJ, Banning AP. A bleeding kiss: intramural haematoma secondary to balloon angioplasty. Cardiovasc Ultrasound 2007;5:21.
58. de Lezo JS, Medina A, Martín P, et al. Ultrasound findings during percutaneous treatment of bifurcated coronary lesions. Rev Esp Cardiol 2008;61:930–5.
59. Pan M, Medina A, Suárez de Lezo J, et al. Coronary bifurcation lesions treated with simple approach (from the Cordoba & Las Palmas [CORPAL] Kiss trial). Am J Cardiol 2011;107:1460–5.
60. Foin N, Viceconte N, Chan PH, Lindsay AC, Krams R, Di Mario C. Jailed side branches: fate of unapposed struts studied with 3D frequency-domain optical coherence tomography. J Cardiovasc Med (Hagerstown) 2011;12:581–2.
61. Di Mario C, Iakovou I, van der Giessen WJ, et al. Optical coherence tomography for guidance in bifurcation lesion treatment. EuroIntervention 2010;6 Suppl J:J99–J106.
62. Her AY, Lee BK, Shim JM, et al. Neointimal coverage on drug-eluting stent struts crossing side-branch vessels using optical coherence tomography. Am J Cardiol 2010;105:1565–9.
63. Costa RA, Mintz GS, Carlier SG, et al. Bifurcation coronary lesions treated with the "crush" technique: an intravascular ultrasound analysis. J Am Coll Cardiol 2005;46:599–605.
64. Chen SL, Mintz G, Kan J, et al. Serial intravascular ultrasound analysis comparing double kissing (DK) and classical crush stenting for coronary bifurcation lesions. Catheter Cardiovasc Interv 2011;78:729–36.
65. Zhang JJ, Chen SL, Ye F, et al. Mechanisms and clinical significance of quality of final kissing balloon inflation in patients with true bifurcation lesions treated by crush stenting technique. Chin Med J (Engl) 2009;122:2086–91.
66. Koo BK, Kang HJ, Youn TJ, et al. Physiologic assessment of jailed side branch lesions using fractional flow reserve. J Am Coll Cardiol 2005;46:633–7.
67. Koo BK, Park KW, Kang HJ, et al. Physiological evaluation of the provisional side-branch intervention strategy for bifurcation lesions using fractional flow reserve. Eur Heart J 2008;29:726–32.
68. Kumsars I, Narbute I, Thuesen L, et al. Side branch fractional flow reserve measurements after main vessel stenting: a Nordic-Baltic Bifurcation Study III substudy. EuroIntervention 2012;7:1155–61.
69. Brueck M, Scheinert D, Flachskampf FA, Daniel WG, Ludwig J. Sequential vs. kissing balloon angioplasty for stenting of bifurcation coronary lesions. Catheter Cardiovasc Interv 2002;55:461–6.
70. Korn HV, Yu J, Ohlow MA, et al. Interventional therapy of bifurcation lesions: a TIMI flow-guided concept to treat side branches in bifurcation lesions—a prospective randomized clinical study (Thueringer Bifurcation Study, THUEBIS study as pilot trial). Circ Cardiovasc Interv 2009;2:535–42.
71. Niemelä M, Kervinen K, Erglis A, et al. Randomized comparison of final kissing balloon dilatation versus no final kissing balloon dilatation in patients with coronary bifurcation lesions treated with main vessel stenting: the Nordic-Baltic bifurcation study III. Circulation 2011;123:79–86.
72. Sgueglia GA, Burzotta F, Trani C, et al. Comparative assessment of mammalian target of rapamycin inhibitor-eluting stents in the treatment of coronary artery bifurcation lesions: the CASTOR-Bifurcation registry. Catheter Cardiovasc Interv 2011;77:503–9.
73. Gwon HC, Hahn JY, Koo BK, et al. Final kissing ballooning and long-term clinical outcomes in coronary bifurcation lesions treated with 1-stent technique: results from the COBIS registry. Heart 2012;98:225–31.
74. Niccoli G, Ferrante G, Porto I, et al. Coronary bifurcation lesions: to stent one branch or both? A meta-analysis of patients treated with drug eluting stents. Int J Cardiol 2010;139:80–91.
75. Ge L, Airoldi F, Iakovou I, et al. Clinical and angiographic outcome after implantation of drug-eluting stents in bifurcation lesions with the crush stent technique: importance of final kissing balloon post-dilation. J Am Coll Cardiol 2005;46:613–20.
76. Hoye A, Iakovou I, Ge L, et al. Long-term outcomes after stenting of bifurcation lesions with the "crush" technique: predictors of an adverse outcome. J Am Coll Cardiol 2006;47:1949–58.
77. Jim MH, Ho HH, Chan AO, Chow WH. Stenting of coronary bifurcation lesions by using modified crush technique with double kissing balloon inflation (sleeve technique): immediate procedure result and short-term clinical outcomes. Catheter Cardiovasc Interv 2007;69:969–75.
78. Chen SL, Zhang JJ, Ye F, et al. Study comparing the double kissing (DK) crush with classical crush for the treatment of coronary bifurcation lesions: the DKCRUSH-1 Bifurcation Study with drug-eluting stents. Eur J Clin Invest 2008;38:361–71.
79. Adriaenssens T, Byrne RA, Dibra A, et al. Culotte stenting technique in coronary bifurcation disease: angiographic follow-up using dedicated quantitative coronary angiographic analysis and 12-month clinical outcomes. Eur Heart J 2008;29:2868–76.
80. Sgueglia GA, Todaro D, Stipo A, Pucci E. Simultaneous inflation of two drug-eluting balloons for the treatment of coronary bifurcation restenosis: a concept series. J Invasive Cardiol 2011;23:474–6.
81. Sgueglia GA, Todaro D, Pucci E. Drug-eluting balloon offers a new opportunity in percutaneous bifurcation interventions. EuroIntervention 2011;7:764–6.
82. Herdeg C, Geisler T, Goehring-Frischholz K, et al. Catheter-based local antiproliferative therapy in kissing balloon technique for in-stent stenosis of coronary artery bifurcation lesions. Can J Cardiol 2008;24:309–11.
83. Stankovic G, Darremont O, Ferenc M, et al. Percutaneous coronary intervention for bifurcation lesions: 2008 consensus document from the fourth meeting of the European Bifurcation Club. EuroIntervention 2009;5:39–49.
84. Burzotta F, De Vita M, Sgueglia G, Todaro D, Trani C. How to solve difficult side branch access? EuroIntervention 2010;6 Suppl J:J72–80.
85. Morino Y, Yamamoto H, Mitsudo K, et al. Functional formula to determine adequate balloon diameter of simultaneous kissing balloon technique for treatment of bifurcated coronary lesions: clinical validation by volumetric intravascular ultrasound analysis. Circ J 2008;72:886–92.
86. Kawasaki T, Koga H, Serikawa T, et al. Impact of a prolonged delivery inflation time for optimal drug-eluting stent expansion. Catheter Cardiovasc Interv 2009;73:205–11.
87. Baran KW, Lasala JM, Cox DA, et al. A clinical risk score for the prediction of very late stent thrombosis in drug eluting stent patients. EuroIntervention 2011;6:949–54.
88. Guagliumi G, Sirbu V, Musumeci G, et al. Examination of the in vivo mechanisms of late drug-eluting stent thrombosis: findings from optical coherence tomography and intravascular ultrasound imaging. J Am Coll Cardiol Intv 2012;5:12–20.
89. Armstrong EJ, Yeo KK, Javed U, et al. Angiographic stent thrombosis at coronary bifurcations: short- and long-term prognosis. J Am Coll Cardiol Intv 2012;5:57–63.

Key Words: bench tests ■ bifurcations ■ functional assessment ■ imaging ■ kissing balloon.