Role of Proximal Optimization Technique Guided by Intravascular Ultrasound on Stent Expansion, Stent Symmetry Index, and Side-Branch Hemodynamics in Patients With Coronary Bifurcation Lesions

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Background—Bench models of coronary bifurcation lesions demonstrated that the proximal optimization technique (POT) expanded the stent and opened the side branch (SB). We investigated the role of POT guided by intravascular ultrasound on the main vessel (MV) stent expansion and SB fractional flow reserve (FFR) in patients with coronary bifurcation lesion.

Methods and Results—In 40 patients with coronary bifurcation lesion, 120 intravascular ultrasound examinations of the MV were performed at baseline, after MV stenting, and POT followed by 95 FFR measurements of the SB. In the proximal stent segment, stent volume index and minimum stent area were larger after POT versus MV stenting (9.2±3.4 versus 7.40±2.0 mm^3/mm and 7.65±1.8 versus 6.38±1.7 mm^2, respectively; $P<0.01$). In the bifurcation segment, minimum stent area was larger after POT versus MV stenting (6.45±2.1 versus 5.9±2.0 mm^2, respectively; $P<0.05$). POT expanded the stent symmetrically. After POT, SB FFR was <0.75 in 12 patients (30%), which improved to >0.75 after SB dilation or SB stenting+final POT. SB FFR was significantly higher after POT+SB dilation or SB stenting+final POT versus after MV stenting and POT.

Conclusions—This is the first study of POT guided by intravascular ultrasound in patients with coronary bifurcation lesion, demonstrating that POT symmetrically expanded the proximal and bifurcation segments of the stent. After POT, SB FFR was <0.75 in a third of patients, which improved to >0.75 after SB dilation or SB stenting+final POT. **(*Circ Cardiovasc Interv*. 2017;10:e005535. DOI: 10.1161/CIRCINTERVENTIONS.117.005535.)**

Key Words: bifurcation lesions ■ fractional flow reserve ■ intravascular ultrasound ■ proximal optimization technique

Coronary bifurcation lesions (CBL) represent one of the most difficult technical challenges in percutaneous coronary intervention, and no uniform strategy has been established for the optimal management of CBL.[1,2] The 2 primary interventional strategies for managing CBL include a complex strategy—the main vessel (MV) and side-branch (SB) stenting—and a simple strategy—MV stenting with the provisional stenting of the SB. A recent meta-analysis[3] of randomized trials with follow-up of 4.6±0.7 years showed that the simple strategy, as compared with complex strategy, was associated with a lower risk of all-cause mortality, major adverse cardiac events, and myocardial infarction (MI). Therefore, the simple strategy is the preferred strategy for treating patients with CBL. Now that the simple approach with provisional treatment of the SB is accepted as the preferred strategy, the precise technique by which this is undertaken and the necessary steps involved still require some clarification.

The bench models of CBL[4,5] demonstrated that side-branch dilation (SBD) opened the SB ostium but distorted the MV stent. Likewise, we[6] showed that SBD compromised the MV stent volume and area. On the other hand, kissing balloon inflation (KBI) restored the MV stent volume and area but expanded the stent asymmetrically. Asymmetrical expansion of the proximal segment of the stent induces high strains to the wall and increases the risk of stent damage to the vessel wall.[5] A randomized study[7] of CBL showed that the outcomes of patients randomized to KBI versus no KBI were not significantly different.

Recently, the proximal optimization technique (POT) was introduced, as an alternative to KBI, to expand the stent from the proximal edge of the stent to just proximal to the carina using a short oversized balloon.[8] Several recent bench models of CBL[9,10] demonstrated that POT expanded the proximal segment of the stent symmetrically and opened the SB struts. However, the role of POT on stent expansion and SB

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WHAT IS KNOWN

- In patients with coronary bifurcation lesions, after provisional stenting of the main vessel, kissing balloon inflation is often performed, which expands the stent asymmetrically and opens the side-branch ostium. However, this would lead to low wall shear stress, endothelial proliferation, and in-stent restenosis.
- Recent bench models of coronary bifurcation lesions demonstrated that the proximal optimization technique (POT) expanded the stent symmetrically and opened the side-branch struts.
- The impact of POT on stent expansion and side-branch fractional flow reserve in patients with coronary bifurcation lesions has not been studied.

WHAT THE STUDY ADDS

- The new finding of the present study is that in patients with coronary bifurcation lesions, after main vessel stenting, POT guided by intravascular ultrasound optimized provisional stenting by expanding the proximal and bifurcation stent segments symmetrically.
- We also showed that after POT, side-branch fractional flow reserve was <0.75 in 30% of patients, which improved to >0.75 after side-branch dilation or side-branch stenting+final POT.

hemodynamics in patients with CBL has not been studied. We, therefore, performed POT guided by intravascular ultrasound (IVUS) to investigate the impact of POT on the MV stent expansion, stent symmetry index (SSI), and SB fractional flow reserve (FFR) in patients with CBL undergoing provisional stenting.

Methods

Study Population

This was a prospective study of patients with CBL who underwent provisional stenting of CBL. Inclusion criteria were as follows: patients with stable or unstable angina who are eligible to undergo stenting with DES; bifurcation lesions with stenoses >50% in the MV or SB; and the MV size ≥2.5 mm and the SB ≥2.25 by visual estimation. Exclusion criteria were as follows: SB stenosis length >10 mm; severe calcification or tortuosity in the SB; MI; the left main coronary stenosis; renal failure (serum creatinine >2.0 mg/dL); and left ventricular ejection fraction ≤30%. The institutional review board of the University of Alabama at Birmingham approved the study.

Study Protocol

The study flow chart is shown in Figure 1. All patients were treated with aspirin and either clopidogrel or ticagrelor and heparin. The use of glycoprotein IIb/IIIa inhibitors was left to the discretion of operators. After engaging the coronary artery with a 6-F or 7-F guiding catheter, intracoronary nitroglycerin was administered. A 0.014″ pressure wire (PressureWire Certus FFR measurement system; St. Jude Medical, Minneapolis, MN) was equalized and advanced into the distal part of the MV, and a 0.014″ Whisper guidewire (Whisper guidewire; Abbott Vascular, Santa Clara, CA) was advanced into the SB. In patients with no prior stress test or with multivessel disease, FFR of the MV was performed. Among patients in whom SB rewiring

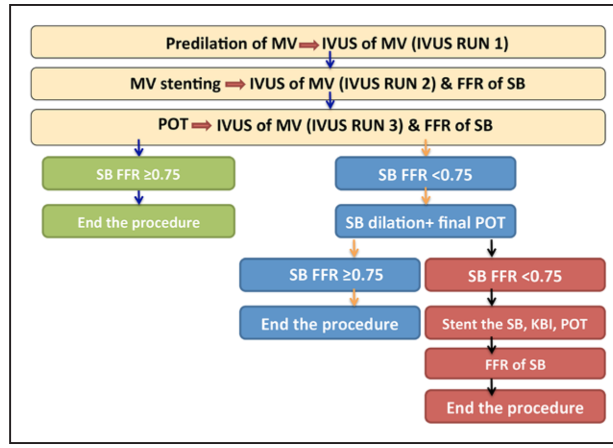

Figure 1. Study flowchart. FFR indicates fractional flow reserve; IVS, intravascular ultrasound; KBI, kissing balloon inflation; MV, main vessel; POT, proximal optimization technique; and SB, side branch.

was deemed difficult after MV stenting, the pressure guidewire was advanced into the SB before MV stenting and jailed underneath the stent struts to measure FFR of the SB after MV stenting and POT, as previously reported.[11]

All patients underwent predilation of the MV with a 2.5 mm noncompliant balloon. Predilation of the SB was avoided to prevent dissection. After MV predilation, IVUS imaging of the MV (IVUS RUN 1) was performed with an Opticross Coronary Imaging catheter (Boston Scientific, Natick, MA). The IVUS catheter was advanced at least 10 mm distal to the bifurcation lesion in the MV, and pullback imaging was obtained automatically at a speed of 0.5 mm/s. The size of the MV stent was determined based on the average distal reference lumen diameter by IVUS. In addition, the length of the stent was determined by measuring the distance from the distal reference segment to the proximal reference segment. After MV stenting with a Xience Alpine stent (Abbott Vascular), the pressure wire was pulled back from the MV and advanced into the SB while jailing the Whisper wire in the SB, and then Whisper wire was removed from underneath the stent and advanced into the MV.

After MV stenting, IVUS of the MV was performed (IVUS RUN 2) followed by FFR of the SB. Next, POT was performed with a short noncompliant balloon; the balloon size for POT was determined based on the IVUS measurement of the proximal-segment external elastic membrane (EEM) diameter. The length of the balloon for POT was determined based on the IVUS measurement of distance between the proximal edge of stent and just proximal to the carina. After POT, IVUS of the MV was performed (IVUS RUN 3) followed by FFR measurements of the SB. In patients in whom SB FFR was ≥0.75 after POT, the procedure was ended. If SB FFR was <0.75 after POT, SBD+final POT was performed using the same balloon as POT. If SB FFR was ≥0.75 after SBD+final POT, the procedure was ended. After SBD+final POT, if SB FFR was still <0.75, a stent was deployed to the SB using the T and protrusion technique followed by KBI+final POT. Next, FFR of the SB was measured, and the procedure was ended. We adopted an FFR cut point of 0.75 in the SB for assessing the significance of SB stenosis based on the previous studies.[12,13] All FFR measurements were performed with intravenous adenosine (140 µg/kg per min).

IVUS Analysis

The IVUS data were stored on DVD, and quantitative IVUS analysis was performed off-line by a single experienced investigator (D. Hakim) at the IVUS core laboratory, the University of Alabama at Birmingham. After MV stenting, the stent was divided into 3 segments, as previously reported[6] (Figure 2): (1) the proximal segment, the segment between the proximal edge of the stent and the tip of the carina; (2) the bifurcation segment, the segment between the tip of the carina and 5.0 mm distal from the carina; and (3) the distal segment,

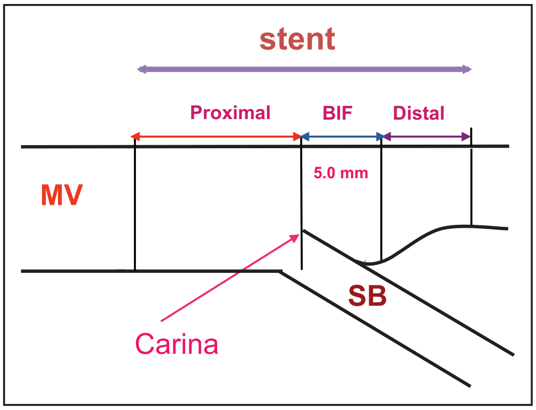

Figure 2. Schematic diagram of intravascular ultrasound (IVUS) analysis. BIF indicates bifurcation; MV, main vessel; and SB, side branch.

the segment between the distal edge of the stent and >5.0 mm distal from the tip of the carina. Quantitative IVUS analysis of the proximal, bifurcation, and distal segments of the stent was performed using commercially available planimetry software (echo plaque; INDEC Medical Systems, Santa Clara, CA). The minimum stent area (MSA), EEM area, plaque plus media area were measured every 1 mm in the 3 segments, as previously reported.[6] The SSI was calculated by dividing the minimal stent diameter by the maximal stent diameter at a cross section with the smallest lumen cross-sectional area in the proximal, bifurcation, and distal stent segments, as previously described.[6] To standardize for different lengths, the stent volume index (SVI), plaque plus media volume index, and EEM volume index were calculated as their volume data divided by length. Plaque plus media volume was calculated as EEM volume minus stent volume. The MSA within each stented segment was defined as the smallest lumen cross-sectional area in the proximal, bifurcation, and distal segment. SVI, MSA, EEM volume index, plaque plus media volume index, and SSI were measured after MV stenting and POT in 240 stented segments. The representative images of IVUS, FFR, and coronary angiography, from a study patient in whom SB FFR increased after POT, are shown in Figure 3.

Quantitative Coronary Angiography

Quantitative coronary angiography (QCA) of the MV and SB was performed off-line at baseline, after MV stenting, and SBD or SB

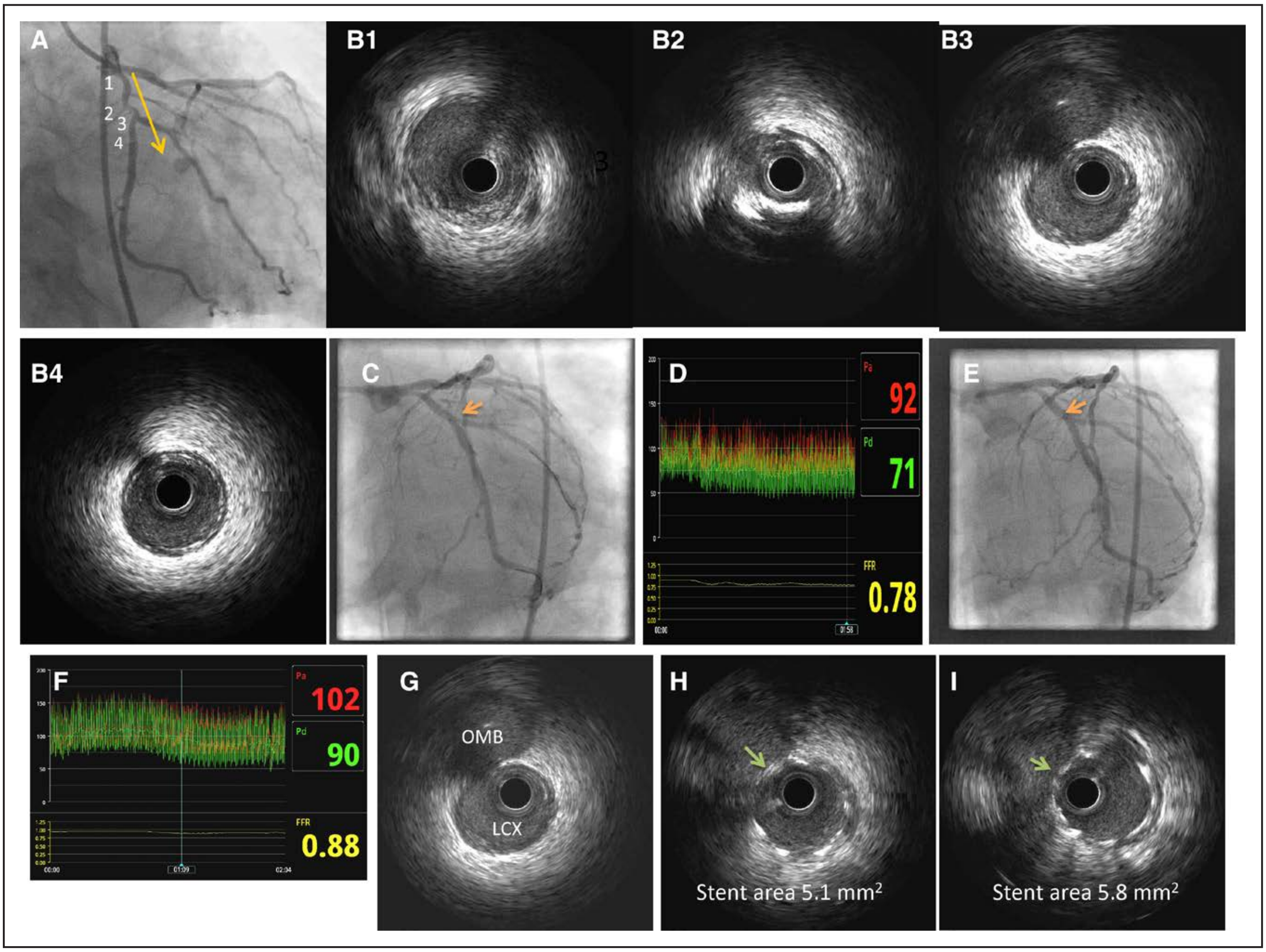

Figure 3. Images of intravascular ultrasound (IVUS), angiography, and fractional flow reserve (FFR) measurements from a study patient. A representative case of study patient in whom FFR of the obtuse marginal branch (OMB) was 0.78 after stenting of the left circumflex (LCX) coronary artery. After proximal optimization technique (POT), OMB FFR improved to 0.88. Therefore, SBD+final POT were not needed. **A**, Baseline coronary angiography shows a significant stenosis of the LCX and OMB; B1–B4 shows IVUS images of the proximal reference, stenosis frame, bifurcation frame, and distal reference, respectively. **C** and **D**, After deployment of a 3.0×23 DES to the LCX; the stenosis in the LCX significantly improved, but there was a 70% stenosis at the ostial OMB (arrow), and FFR of OMB was 0.78. **E** and **F**, After POT with a 3.5×8 mm balloon, the stenosis at the ostial OMB significantly improved, and FFR of OMB has now improved to 0.88. **G**, IVUS of bifurcation frame at baseline shows ostial OMB is patent. **H**, After the LCX stenting, the struts are covering ostial OMB (arrow). **I**, After POT, IVUS shows the struts are now separated (arrow), and stent area increased from 5.1 mm^2 after stenting to 5.8 mm^2 after POT. SBD indicates side-branch dilation.

stenting+final POT by an experienced investigator (D. Hakim) using validated commercially available, edge detection software (QCA-CMS, version 5.2; Medis Medical Imaging Systems, Leiden, the Netherlands), as previously described.[6] For the MV, the reference vessel diameter was the average of the proximal and distal reference lumen diameters. For the SB, the reference vessel diameter was the distal reference lumen diameter. The diameter stenosis was calculated as 100×(RVD−MLD)/RVD, where MLD is the minimum lumen diameter and RVD is the reference vessel diameter.

Study End Points and Definitions

The primary end point of the study was the impact of POT on the MV stent expansion, including SVI, MSA, and SSI. The secondary end points were as follows: SB FFR after MV stenting; SB FFR after POT; and final FFR after POT+SBD or SB stenting+final POT. Periprocedural MI was defined as an elevation of creatine kinase myocardial band >3× upper reference limit or new Q waves in ≥2 contiguous leads of the ECG. Major adverse cardiovascular events were defined as the composite of death, MI, stent thrombosis, and target lesion revascularization during 30-day follow-up.

Statistical Analysis

Statistical analysis was performed with SPSS version 24 (SPSS, Chicago, IL). The normality of data was assessed using the Shapiro–Wilk test. Normally distributed continuous IVUS data are expressed as mean±standard deviation, while non-normally distributed continuous variables are presented as median and interquartile range. The data that derived from quantitative IVUS analyses were compared after MV stenting versus POT using the paired Student's *t* test for normally distributed variables or the Wilcoxon test for non-normally distributed data. The FFR and normally distributed QCA data were compared using the repeated-measures analysis of variance. Significance was determined after multiple pairwise comparisons with the Bonferroni test. The QCA data that were not normally distributed were compared using the Friedman test. To be consistent, all QCA data are reported as median and interquartile range. Intraobserver variability for the IVUS measurements was assessed by the evaluation of 40 random measurements of SVI, MSA, and SSI after MV stenting and POT by the same reader at 2 separate time points. The correlation between 2 cross-sectional IVUS measurements was regarded as intraobserver correlation. The intraobserver correlations were tested using the Pearson regression analysis.

Results

Patient Characteristics

Between August 2014 and February 2016, 55 eligible patients with CBL were enrolled in the study. FFR measurements of the MV were performed in 25 patients with multivessel disease or in those with no prior or equivocal stress tests; of these, FFR was >0.80 in 13 patients, and IVUS images were suboptimal in 2 patient and were excluded from the study. In 40 patients, 120 serial IVUS examinations of the MV were performed after predilation of the MV, MV stenting, and POT. In addition, 95 serial SB FFR measurements were performed after MV stenting, POT, and SBD or SB stenting+final POT (the re-POT technique) in those with an SB FFR <0.75. IVUS and FFR were successfully performed in all 40 patients according to the protocol. The pressure guidewire was jailed in the SB underneath the stent struts in 10 patients. In these patients, SB FFR was >0.75 after MV stenting and POT, and the pressure guidewire was removed from underneath the stent with no complication. The baseline clinical and angiographic characteristics of patients are shown in Table 1. The procedural characteristics of patients are displayed in Table 2.

Table 1. Baseline Clinical and Angiographic Characteristics (n=40)

Age, y	58±13
Male/female, n	34/6
Hypertension, n (%)	32 (80)
Diabetes mellitus, n (%)	14 (35)
Smoking, n (%)	8 (20)
Hyperlipidemia, n (%)	34 (85)
Previous PCI, n (%)	9 (23)
Previous CABG, n (%)	5 (13)
Ejection fraction, %	55±12
Unstable angina, n (%)	9 (23)
Stable angina, n (%)	31 (77)
Medina classification	
1,1,1	25 (63)
1,1,0	8 (20)
1,0,1	4 (10)
0,1,0	2 (5)
0,0,1	1 (2)
LAD/diagonal	30 (75)
LCX/OM	10 (25)
Single-vessel disease	27 (67%)
Two-vessel disease	13 (33%)

CABG indicates coronary artery bypass graft; LAD, left anterior descending coronary artery; LCX/OM, left circumflex/obtuse marginal branch; and PCI, percutaneous coronary intervention.

IVUS Results

The results of quantitative IVUS analysis after MV stenting and POT in the proximal, bifurcation, and distal segments are shown in Table 3. In the proximal stent segment, SVI, MSA, and EEM volume index were significantly larger after POT versus MV stenting (Table 3 and Figure 4). In the proximal and bifurcation segments, MSAs were significantly larger after POT versus MV stenting (Table 3 and Figure 5). In the proximal and bifurcation segments, the stent was symmetrically expanded, and the percentages of SSI were not significantly different after POT versus MV stenting (Table 3 and Figure 6). In the distal segment, IVUS parameters and SSI were not significantly different after POT versus MV stenting. The intraobserver correlations of SVI, MSA, and SSI were 96%, 95%, and 94%, respectively; $P<0.001$.

FFR Measurements

After MV stenting and POT, there was Thrombolysis in Myocardial Infarction (TIMI) 3 flow in the SB in all patients. However, after MV stenting, SB FFR was <0.75 in 9 patients (23%); after POT, SB FFR was <0.75 in 12 patients (30%), which improved to >0.75 after SBD+final POT in 9 patients. In 3 patients, after SB dilation, there was ostial dissection, which was stented using the T and protrusion technique followed by KBI and final POT. The results of FFR measurements after MV stenting, POT, and POT+SBD or SB stenting+final POT

Table 2. Procedural Characteristics (n=40)

MV predilation balloon diameter, mm	2.4±0.2
MV predilation balloon length, mm	15±3.0
MV predilation balloon pressure, atm	16±2.0
IVUS RUN 1 guided measurements	
MV stent diameter, mm	3.2±0.40
MV stent length, mm	23±6.0
POT balloon diameter, mm	3.8±0.4
POT balloon length, mm	10±4.0
MV stent deployment pressure, atm	15.4±1.5
POT balloon inflation pressure, atm	17±1.5
Stent type	
Everolimus-eluting stents, n (%)	40 (100)
Heparin, n (%)	40 (100)
Glycoprotein IIb/IIIa use (2 boluses)	20 (50)
Ticagrelor, n (%)	10 (25)
Clopidogrel, n (%)	30 (75)

IVUS indicates intravascular ultrasound; MV, main vessel; and POT, proximal optimization technique.

are shown in Figure 7. SB FFR was significantly higher after POT+SBD or SB stenting+final POT than after MV stenting and POT (0.87±0.06 versus 0.79±0.10 and 0.78±0.11, respectively; *P*<0.001; Figure 7).

Quantitative Coronary Angiography

The results of QCA measurements at baseline, after MV stenting, and POT+SBD or SB stenting+final POT are shown in Table 4. In the MV, MLD was significantly smaller and diameter stenosis was higher at baseline than those after MV stenting and POT+SBD or SB stenting+final POT. In the SB, MLD was significantly larger and diameter stenosis was lower after POT+SBD or SB stenting+final POT than those after MV stenting and baseline.

Procedural and Clinical Outcomes

There were no complications related to stenting, and all patients were discharged on the next day of the procedure. There were no acute complications. Periprocedural MI occurred in 5 patients. During 30-day follow-up, there were no instances of death, target lesion revascularization, stent thrombosis, or MI.

Table 3. Quantitative IVUS Analysis

	After MV Stenting (IVUS RUN 2)	After POT (IVUS RUN 3)	*P* Value
Proximal segment			
Minimum stent area, mm^2	6.38±1.7	7.65±1.8	0.003
Stent volume index, mm^3/mm	7.40±2.0	9.2±3.4	0.001
EEM volume index, mm^3/mm	16.50±3.9	18.90±5.5	0.03
P&M volume index, mm^2	9.10±2.7	9.11±2.0	0.39
Stent symmetry index	0.87±0.030	0.88±0.035	0.70
Bifurcation segment			
Minimum stent area, mm^2	5.90±2.0	6.45±2.1	0.03
Stent volume index, mm^3/mm	6.90±2.1	7.41±2.2	0.09
EEM volume index, mm^3/mm	14.30±4.7	14.80±4.1	0.40
P&M volume index, median [IQR], mm^2	6.7 [5.3–8.5]	6.90 [5.8–9.1]	0.60
Stent symmetry index	0.88±0.04	0.88±0.035	0.70
Distal segment			
Minimum stent area, mm^2	5.8±1.8	5.72±1.7	0.80
Stent volume index, mm^3/mm	7.0±2.2	7.20±2.3	0.080
EEM volume index, median [IQR], mm^3/mm	12.02 [10.39–16.32]	12.08 [10.40–14.77]	0.78
P&M volume index, median [IQR], mm^2	5.8 [3.98–7.20]	5.2 [3.93–6.90]	0.57
Stent symmetry index	0.89±0.04	0.88±0.045	0.30

EEM indicates external elastic membrane; IQR, interquartile range; IVUS, intravascular ultrasound; MV, main vessel; P&M, plaque plus media; and POT, proximal optimization technique.

Discussion

To the best of our knowledge, this is the first study of POT on stent expansion, SSI, and SB FFR guided by IVUS in patients with bifurcation lesions undergoing provisional stenting. The main findings of the present study are summarized as follows: (1) in the proximal stent segment, SVI, MSA, and EEM volume index were significantly larger after POT versus MV stenting; (2) in the bifurcation segment, MSA was significantly larger after POT versus MV stenting; (3) in the distal segment, stent dimensions were not significantly different after POT versus MV stenting; (4) POT induced symmetrical stent expansion in the proximal and bifurcation stent segments; and (5) we showed that after POT, SB FFR was ≥0.75 in the majority of patients. However, SB FFR was <0.75 in 30% of patients, which improved after SB dilation or SB stenting+final POT.

POT was first described by Darremont et al[8] as a method of expanding the stent from the proximal edge to just proximal to the carina using a short oversized balloon. In the present study, we followed the same technique suggested for provisional stenting in patients with CBL[8,14] but sized the stent for the MV and the balloon for POT by IVUS instead of angiography to accurately expand the stent. Foin et al[9,10] reported that in the bench models, POT facilitates rewiring and access to the SB by the enlargement of the strut cells located in front

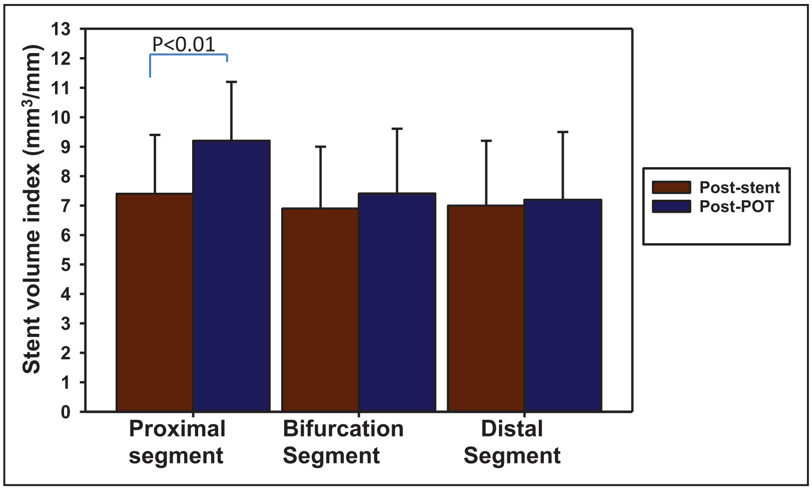

Figure 4. Stent volume index. Comparisons of stent volume index (SVI) in the proximal, bifurcation, and distal stent segments after proximal optimization technique (POT) vs main vessel (MV) stenting.

of the SB. Our data for the first time corroborated the bench study of Foin et al such that MSA in the bifurcation segment was significantly larger after POT compared with that after MV stenting.

In a bench model of CBL, Finet et al[15] reported that the re-POT sequence consisted of routine POT+SBD+final POT opened the strut cells in the SB ostium and corrected malapposed struts in the carina. In the present study, despite the presence of TIMI 3 flow in the SB after POT, SB FFR was <0.75 in 30% of patients, which improved to >0.75 after SBD or SB stenting+final POT. In this respect, the present study corroborated the bench study of Finet et al.[15]

Though routine SBD+final POT, as reported by Finet et al, opens the SB struts and expands the stent, it might lead to SB dissection requiring SB stenting and KBI. Furthermore, it is unknown whether SBD+final POT, among patients with a SB FFR <0.75, would improve clinical outcomes.

After MV stenting, Koo et al[12] demonstrated that 27% of SB lesions with >75% stenosis after MV stenting were significant by FFR. The Nordic trial[7] considered TIMI flow <3, not residual SB stenosis, as an indication for treatment with balloon or stent. However, the Nordic FFR substudy[13] showed that no patient in the KBI group, but 3 patients in the no-KBI group with TIMI 3 flow, had an FFR <0.75 after MV stenting, suggesting that TIMI 3 flow in the SB is not a surrogate of an FFR >0.75. In the present study, SB FFR was ≥0.75 in the majority of patients after POT, but it was <0.75 in 30% of the patients. However, the underlying causes of SB FFR compromise after POT are unknown. In this respect, a bench study[16] showed that the presence of calcification at the SB ostium could lead to SB compromise after POT. Alternatively, carina shift after initial POT can increase the stenosis of the SB ostium.

Notably, the current pressure wires have a similar handing profile to that of conventional coronary wires. Several studies[12,13] reported that FFR was successfully measured after MV stenting in patients with CBL. Likewise, our meta-analysis of CBL trials[17] demonstrated that the success rate of SB rewiring after MV stenting with a pressure wire was not significantly different compared with a coronary guidewire. If SB rewiring is deemed difficult after MV stenting, the pressure wire may be jailed underneath the stent struts with no complication, as previously reported.[11] Likewise, in the present study, we jailed the pressure wire underneath the stent and removed it after POT in 10 patients with no complication. Furthermore, in a pilot study, we compared FFR measurements in the SB with the jailed pressure wire versus nonjailed pressure wire technique in 5 patients. After stenting, we removed the jailed pressure wire from underneath the stent struts, advanced it into the SB, and measured the SB FFR. We found no difference in the SB FFR

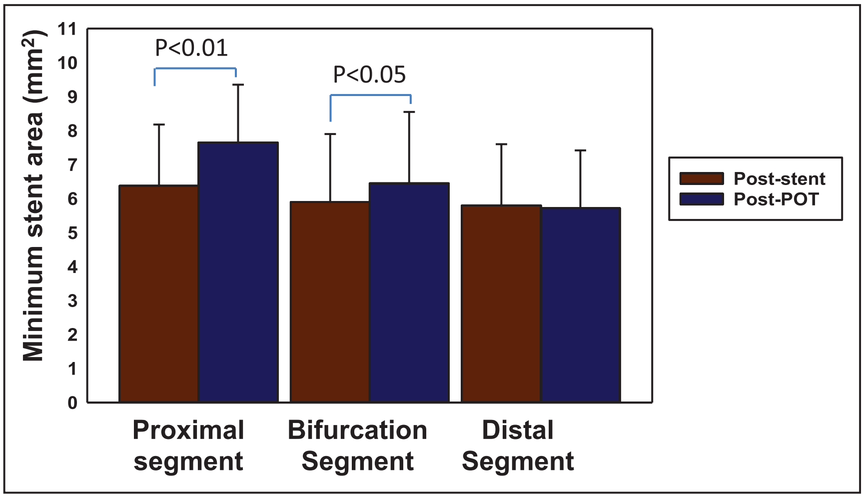

Figure 5. Minimum stent area. Comparisons of minimum stent area (MSA) in the proximal, bifurcation, and distal stent segments after proximal optimization technique (POT) vs main vessel (MV) stenting.

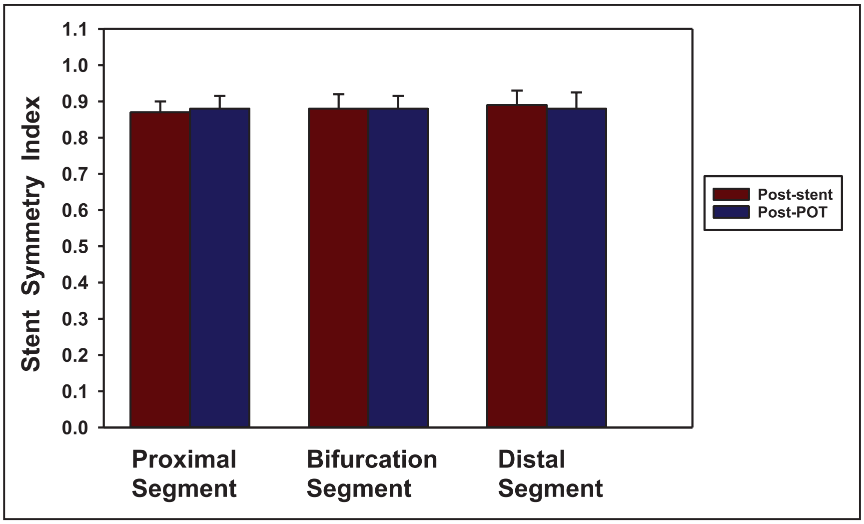

Figure 6. Stent symmetry index. Comparisons of stent symmetry index (SSI) in the proximal, bifurcation, and distal stent segments after proximal optimization technique (POT) vs main vessel (MV) stenting.

values measured by the jailed pressure wire versus nonjailed pressure wire technique in these 5 patients. However, larger studies are needed to determine the accuracy and safety of SB FFR measurements with the jailed pressure wire technique.

Several studies[12,13] used an FFR cut point of 0.75 for deferring revascularization in the SB and demonstrated that functional severity of SB lesions after stenting did not change significantly during 6-month follow-up. Consequently, it is recommended that, in the 3 main epicardial vessels, a more inclusive FFR ischemic threshold of 0.80 be used and more restrictive threshold of 0.75 be reserved for branch vessels, where revascularization often confers symptomatic benefit.[18] We, thus, adopted an FFR cut point of 0.75 for SB in the present study.

Clinical Implications

Provisional MV stenting without KBI or POT can lead to incomplete stent apposition and to an abnormal flow pattern in the jailed SB ostium. From a clinical standpoint, POT has several advantages over KBI after provisional stenting, which are as follows: (1) POT is a simple technique and can be quickly performed after MV stenting, whereas KBI is a complex procedure; (2) POT expands the stent symmetrically in the proximal and bifurcation stent segments. This would induce homogenous strain distribution and high physiological shear stress to the vessel wall, which maintains endothelial cells in quiescent and atheroprotective state[5,19–21]; and (3) In contrast to POT, KBI expands the stent asymmetrically. This would result in low wall shear stress and increase endothelial proliferation, as well as in-stent restenosis.[19–21] In addition, KBI might induce SB dissection requiring stenting of the SB. Furthermore, KBI increases the cost and prolongs the procedure, as well as radiation times.

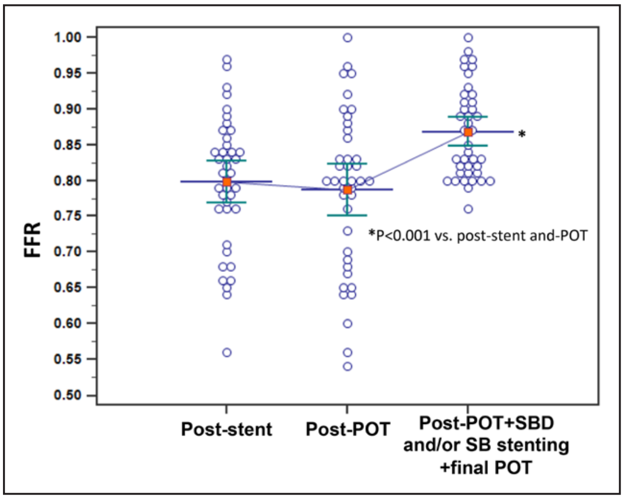

Figure 7. FFR of the side branch (SB). SB fractional flow reserve (FFR) was significantly higher after proximal optimization technique (POT)+SBD or SB stenting+final POT vs main vessel (MV) stenting and POT. SBD indicates side-branch dilation.

Table 4. Quantitative Coronary Angiography

	Baseline	After MV Stenting	After POT+SBD or SB Stenting+Final POT
Main vessel			
MLD, median [IQR], mm	0.87 [0.64–1.15]*	2.55 [2.34–2.82]	2.80 [2.6–3.0]
RVD, median [IQR], mm	2.61 [2.48–2.80]	2.84 [2.63–3.13]	3.1 [2.86–3.30]
DS, median [IQR], %	64 [62–73]*	11 [8.2–14.3]	9.0 [6.3–12.4]
Side branch			
MLD, median [IQR], mm	1.1 [0.68–1.23]	0.90 [0.73–1.30]	1.64 [1.23–2.07]†
RVD, median [IQR], mm	2.1 [1.63–2.24]	2.13 [2.04–2.27]	2.0 [1.82–2.40]
DS, median [IQR], %	46 [38–62]	56 [40–67]	20 [12–28]†

DS indicates diameter stenosis; IQR, interquartile range; MLD, minimum lumen diameter; MV, main vessel; POT, proximal optimization technique; RVD, reference vessel diameter; SB, side branch; and SBD, side-branch dilation.

**P*<0.05 vs after MV stenting and POT+SBD or SB stenting+final POT.

†*P*<0.05 vs after MV stenting and baseline.

A randomized study of CBL[7] showed that the outcomes of patients randomized to KBI versus no KBI were not significantly different. Thus far, there is no study to show direct benefit of POT. A registry study by Mylotte et al[22] showed that the use of POT, noncompliant balloons for KBI, and second-generation DES significantly reduced the 2-year major adverse cardiac events rate by 50% among patients. Therefore, randomized trials are needed to investigate the outcomes of POT versus the re-POT sequence (POT+routine SB dilation+final POT) after MV stenting, as reported by Finet et al,[15] or POT versus sequential SB dilation+POT, as reported by Foin et al.[4]

Because the impact of FFR measurements in the SB after POT is unknown, the European Bifurcation Club[14] remained neutral and recommended that after POT, SBD+final POT can be avoided if there is TIMI 3 flow in the SB. Alternatively, European Bifurcation Club recommended that FFR measurements of SB can be considered to assess the significance of stenosis after POT.

In the present study, we sized the stent and balloon for POT based on the IVUS measurements of the distal lumen and proximal EEM diameters because angiography underestimates the actual vessel size. The value of IVUS versus angiography for sizing the stent and balloon would need to be investigated in the future trials.

Limitations of the Study

There are several limitations of the study. The primary end point of this proof-of-concept study was to investigate the impact of POT on stent expansion assessed by IVUS in patients with CBL. However, our study is small and not powered to show its impact on clinical outcomes; second, we excluded patients with the SB stenosis length >10 mm, severe calcification, or tortuosity of the SB; third, we used only Xience stent to standardize the stent type; our results cannot be generalized to the different types of stents. We included a variety of bifurcation lesions, and nontrue bifurcation lesions represented 27% of patients. It would have been better if we had also standardized the lesions; fourth, the ostium of the SB was not diseased in 10 patients (25% of the study population); and finally, the diameter of the SB vessel was underestimated in the present study because QCA was not performed with a dedicated bifurcation analysis system. We performed QCA of the SB using the distal reference vessel diameter instead of using the average of the proximal and distal reference vessel diameters, as reported previously.[6,13,23]

Conclusions

This is the first comprehensive study of POT on stent expansion, SSI, and SB FFR guided by IVUS in patients with CBL undergoing provisional stenting. We demonstrated that in patients with CBL, POT optimized provisional stenting by expanding the proximal and bifurcation stent segments symmetrically. We also showed that despite the presence of TIMI 3 flow in the SB, SB FFR was <0.75 in 30% of patients after POT, which improved to >0.75 after SBD and SB stenting+final POT.

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Disclosures

None.

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Role of Proximal Optimization Technique Guided by Intravascular Ultrasound on Stent Expansion, Stent Symmetry Index, and Side-Branch Hemodynamics in Patients With Coronary Bifurcation Lesions

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