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Quantitative Analysis of the Side Branch Orifice after Bifurcation Stenting Using En Face Processing of OCT Images: A Comparison between Xience V and Resolute Integrity Stent

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Abstract

Objective—Methods for intravascular assessment of the side branch (SB) orifice after stenting are not readily available. The aim of this study is to assess the utility of an *en face* projection processing for optical coherence tomography (OCT) images for the SB evaluation.

Methods—Measurements of the SB orifice using *en face* OCT images were validated using a phantom model. Linear regression modeling was applied to estimated area measurements made on the *en face* images. The SB orifice was then analyzed in 88 patients with bifurcation lesions treated with either a Xience V (EES) or a Resolute Integrity (ZES). The SB orifice area (A) and the area obstructed by struts (B) were calculated, and the %open area was evaluated as (A-B)/A*100.

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Supplementary material for online only publication
Supplement Fig. 1 Ex vivo phantom model

Results—Linear regression modeling demonstrated observed departures of the intercept and slope was not significantly different from 0 (-0.12 ± 0.22 , $p=0.59$) and from 1 (1.01 ± 0.06 , $R^2=0.88$, $p=0.87$), respectively. In cases without SB dilatation, the %open area was significantly larger in EES group ($n=25$) than in ZES group ($n=32$) (89.2% [83.7–91.3] vs. 84.3% [78.9–87.8], $P=0.04$). A significant difference in the %open area between with and without SB dilatation was demonstrated in the ZES group (91.4% [86.1–94.0] vs. 84.3% [78.9–87.8], $P=0.04$).

Conclusions—The accuracy of SB orifice measurement on the *en face* OCT image was validated using a phantom model. This novel approach can quantitatively evaluate the differences in SB orifice area free from struts among different stent types and different treatment strategies *in vivo*.

Keywords

optical coherence tomography; drug-eluting stent; bifurcation lesion

Introduction

Stenting for coronary bifurcation lesions is associated with a higher incidence of thrombotic events¹. Potential mechanisms underlying these thrombotic complications include incomplete stent apposition (ISA)^{2, 3} and nonapposed struts crossing the side branch (SB) orifice⁴. A recent study using optical coherence tomography (OCT) demonstrated that, at mid-term follow-up, the neointimal coverage of nonapposed side branch (NASB) struts crossing the orifice was delayed compared with well-apposed struts⁵. Thus, the evaluation and management of NASB struts may help to prevent thrombotic complications.

Using phantom models and micro-computed tomography (CT)^{6, 7}, several *ex vivo* studies have evaluated stent struts around SB orifices. These analyses enabled the quantitative evaluation of SB orifices following stent implantation, providing important preliminary information for selecting the optimal stent type and intervention strategy for bifurcation lesions. On the other hand, no method has previously enabled the quantitative evaluation of stent struts around SB orifices in clinical cases. Recently, several studies introduced the utility of three-dimensional (3D) reconstruction of OCT images for the assessment of SB orifice^{8–10}. This 3D methodology might contribute to the optimization of percutaneous coronary intervention (PCI) in bifurcation lesions¹¹ by, for example, showing the best strut cell for rewiring¹². However, its utility within the realm of qualitative assessment has been limited so far.

In the present study, we introduce an *en face* projection OCT processing for the quantitative assessment of SB orifices, and examined the accuracy using a phantom model. We then apply this algorithm to clinical cases of bifurcation stenting to assess the impact of stent design and treatment strategies on the SB orifice area free from NASB struts.

Methods

Quantification of side branch orifice in an en face projection view

To quantitatively evaluate SB orifices, we developed an algorithm using standard cross-sectional OCT data to create *en face* projection images (Fig. 1). *En face* images provide the user with a view looking directly into the SB orifice, and therefore are useful for measuring orifice dimensions and features. OCT images were first normalized to the range 0–1 by the maximum and minimum values of the OCT pullback for convenience of processing. Since OCT is performed by helical-scanning a catheter inside the artery, a depth-resolved tissue intensity profile is generated at each angular position, which is also known as an A-line. We projected each 2-D cross-sectional image in polar coordinates into one dimension by averaging intensity values along each A-line between the lumen and a depth of 0.5mm. The lumen boundary was identified by a robust algorithm reported previously¹³. By combining all the projected A-line profiles of the stented region into one image, we created an *en face* projection image displayed as a function of pullback distance and the angular position. Because the SB regions have accumulated low intensity, they appear as dark holes in the *en face* projection view. The exact boundaries of SB can be segmented automatically by extracting the region with the pixel intensity value lower than a predefined threshold ($T=0.3$) and with the area larger than another threshold (20 pixels). The segmentation was reviewed and corrected manually by examining the SB orifice in the corresponding cross-sectional view and mapping it back to the *en face* view.

Ex vivo phantom model

The accuracy of area measurements obtained from *en face* views was validated using a bifurcation phantom model with three side holes (Supplement Fig. 1). OCT images were acquired 15 times across each side hole using a commercially available frequency domain (C7-XR OCT Intravascular Imaging System; St. Jude Medical Inc., St. Paul, Minnesota). The side hole orifice area was measured on the *en face* projection image by an independent investigator who was blinded to the actual size of the side holes. The accuracy of area measurements was evaluated by a linear regression model regressing the actual value on the estimated area measurements, and testing departures of the intercept and slope from 0 and 1 respectively. We also examined if there were any measured area values outside of the 95% prediction interval over whole range of experiment.

In vivo study population

All *in vivo* study subjects were selected from the Massachusetts General Hospital (MGH) OCT Registry. We identified 137 cases of bifurcation lesions with SB diameter ≥ 2 mm on angiogram and treated with a Xience V (EES: everolimus-eluting stent) (Abbott Vascular, Santa Clara, CA, USA) or Resolute Integrity (ZES: zotarolimus-eluting stent) (Medtronic, Minneapolis, MN, USA) from August 2010 to January 2014. We excluded cases of restenosis ($n=20$), cases treated with two stents ($n=12$), and those with poor image quality ($n=17$). Finally, we included 42 EES and 46 ZES cases in the analysis. The registry protocol was approved by each institution's ethics committee, and all patients provided written informed consent.

In vivo procedure and OCT image acquisition

All treatment strategies were performed at the discretion of the operators at each institution, including decisions regarding side branch dilatation and/or additional stenting. Cases in which a stent was implanted in the SB were, however, excluded from our study. Off-line quantitative coronary angiography (QCA) was performed to assess the reference and minimal lumen diameters of the target lesions before and after PCI using dedicated software (CASS version 5.10.1, Pie Medical Imaging BV, Maastricht, the Netherlands). OCT images were acquired at the end of PCI using commercially available frequency domain or time domain (M2/M3 Cardiology Imaging System; LightLab Imaging Inc., Westford, Massachusetts) OCT systems. All images were de-identified, digitally stored, and submitted to the MGH-OCT Registry Laboratory for analysis. Quantitative analysis was performed for every cross-sectional frame using proprietary software (St. Jude Medical) by independent, experienced investigators¹⁴.

In vivo quantification of side branch open area in an en face projection view

Using the *en face* projection algorithm, SB orifice area free from stent struts was evaluated *in vivo*. The stent struts were automatically detected based on a previous method¹⁵ and corrected manually, if necessary. The open area can be computed from the segmented SB and stent struts by using stent specific information (i.e. strut width) from the manufacturers. For the entire task, custom designed software was developed in MATLAB (The MathWorks, Inc. Natick, MA) to allow users to visualize, annotate, and review the OCT images of SB and stent struts. The SB orifice area (A) and the area obstructed by struts (B) were calculated on the *en face* view (Fig. 2). The percent open area was defined as $(A-B) / A * 100$.

Definitions

The SB orifice width was defined as the length between both corners which divides the SB and main vessel on the cross sectional view. All parameters were evaluated from the proximal edge to the distal edge of the SB orifice, which were identified on the longitudinal OCT images.

Statistical Methods

If normally distributed according to Kolmogorov Smirnov test, categorical data were summarized as counts and proportions (%), and continuous data were summarized as mean $\pm$ standard deviation. Otherwise, median values with lower and upper quartiles were reported. Mean values were compared by *t*-test or one-way ANOVA when the data were normally distributed and by Mann-Whitney's U test or Kruskal-Wallis test when the data were not normally distributed. Measurement accuracy of *en face* projection views was evaluated by means of a linear regression model. Independent risk factors for the lower %open area (below median; <85.5%) were determined by means of a multivariate logistic model. The statistical significance was defined as $P < 0.05$. All statistical analysis was performed with SPSS version 17.0 (SPSS, Chicago, Illinois, USA).

Results

Measurement accuracy of an en face projection view

The measurement values of three side branch holes (actual area: 3.14mm², 3.97mm², 4.91mm²) in *ex vivo* phantom were 3.09 ± 0.22 mm², 3.79 ± 0.27 mm², 4.87 ± 0.30 mm², respectively. The estimated area predicted the value accurately in that the observed intercept was not different from 0 (-0.12434 ± 0.22782 , $p=0.588$) and the slope was not different from 1 (1.00896 ± 0.05596 , R-square = 0.88, $p=0.874$) (Fig. 3).

Baseline characteristics of in vivo assessment

Of the total 88 cases, 31 (17 EES and 14 ZES) cases were treated with SB dilatation and 57 (25 EES and 32 ZES) cases were treated with crossover stenting without SB dilatation (Fig. 4). Baseline characteristics are shown in Table 1. All variables other than the clinical presentation in cases without SB dilatation were comparable between patients treated with EES and those treated with ZES. There was no significant difference in the target vessel or medina classification between lesions treated with EES and those treated with ZES (Table 2). In both pre and post QCA analysis, the minimal lumen diameter was smaller in EES group than in ZES group in cases without SB dilatation. The frequency of use of the kissing balloon technique (KBT) was significantly higher in EES group than in ZES group (82.4% vs. 35.7%, $P<0.01$) (Table 2).

Comparison between cases treated with EES and ZES

The results for quantitative OCT analysis are shown in Table 3 and Fig. 5. On the analysis using *en face* views, the %open area was significantly larger in cases treated with EES than with ZES (89.2% [83.7 – 91.3] vs. 84.3% [78.9 – 87.8], $P=0.04$) in cases without SB dilatation. However, the %open area was not significantly different between the EES group and the ZES group (89.0% [87.8 – 90.9] vs. 91.4% [86.1 – 94.0], $P=0.33$) in the cases with SB dilatation. The difference of %open area was statistically significant between SB dilatation and no SB dilatation in ZES group (91.4% [86.1 – 94.0] vs. 84.3% [78.9 – 87.8], $P=0.04$), whereas the difference was not significant in EES group ($P=0.58$). The representative images are shown in Fig. 6. Multivariate analysis showed that the use of ZES was an independent predictor for the smaller %open area (below median; <85.5%, odds ratio 4.85, 95% confidential interval [1.23 – 19.1], $P=0.02$) in addition to small orifice width in no SB dilatation (Table 4).

Comparison between single balloon and kissing balloon dilatation

Different treatment strategies for the treatment of bifurcation lesions are compared. The %open area of both single balloon dilatation (91.1% [83.7 – 93.6]) and kissing balloon dilatation (89.4% [87.9 – 91.0]) were significantly larger than no SB dilatation cases (85.5% [81.0 – 89.5], $P=0.02$, $P=0.02$, respectively). No statistically significant difference was seen in %open area between single balloon dilatation and kissing balloon dilatation ($P=0.78$).

Discussion

The main findings of this study are: 1) The quantitative evaluation of SB orifice by an *en face* projection processing of OCT images was validated using a bifurcation phantom model, and 2) In vivo application of the *en face* projection processing demonstrated differences in %open area among stent types and treatment strategies. In the no SB dilatation case, the Xience V stent provides a larger %open area compared to the Resolute Integrity stent. A significant difference in the %open area between with and without SB dilatation was demonstrated in the Resolute Integrity stent.

Risk of thrombotic complications after PCI for bifurcation lesions

Bifurcation lesions remain a challenging subset in PCI due to procedural complexity, and they are associated with worse clinical outcomes, including a higher incidence of stent thrombosis¹. Several pathological studies^{4, 16} have demonstrated that ISA and uncovered struts crossing the SB orifice can serve as a nidus for stent thrombosis. Indeed, a recent OCT study demonstrated both ISA and NASB struts were not well covered by the neointima in the chronic phase, in contrast to well apposed struts⁵. The incidence of ISA and the percent of uncovered struts is significantly lower with current generation drug-eluting stent (DES) compared to the first generation DES^{17, 18}. However, side branch orifice and NASB struts had not previously been well evaluated *in vivo* due to lack of diagnostic modality.

Assessment of stent struts around the side branch orifice in ex vivo models

Several *ex vivo* studies have attempted to quantitatively evaluate stent struts around the SB orifice. Ormiston et al. investigated the area of SB orifice obstructed by the residual struts after crush stenting using a micro-computed tomographic imaging of bench top model⁶. They demonstrated that the obstruction area was dependent on the stenting / ballooning strategy and the stent cell size. Mortier et al. evaluated the SB orifice after provisional stenting using a dedicated finite element simulation model⁷. They assessed the SB orifice *en face* and compared orifice area stenosis due to the remaining struts among different ballooning techniques and stent types. They reported the modified KBT (2-step dilatation) was better than simultaneous KBT (1-step dilatation) and the results were similar among three stent types [Integrity (Medtronic, Minneapolis, MN, USA), Omega (Boston Scientific, Natick, MA, USA), and Multi-link 8 (Abbott Vascular, Santa Clara, California)]. Another study also reported the characteristics of the stent platform affected the orifice area free from strut after SB dilatation¹⁹. These studies indicate that the quantitative evaluation of the SB orifice and NASB struts *in vivo* might give new insight into optimal strategies for bifurcation treatment.

In vivo assessment of side branch orifice area free from non-apposed strut

To quantitatively evaluate the SB orifice area after stenting *in vivo*, we developed an algorithm and reconstructed raw OCT digital data into *en face* projection images. We demonstrated the accuracy of area measurement on the *en face* projection images using a bifurcation phantom model, though important differences exist between a mimic side hole in a phantom model and a SB orifice in a human coronary artery (e.g. angulation between main vessel and side branch¹⁰, variation of shape, and border irregularity). Next, we applied the

algorithm to actual cases of bifurcation lesion stenting to examine the impact of stent design and treatment strategies on the SB orifice area free from non-apposed struts *in vivo*, as the previous *ex vivo* studies examined. To the best of our knowledge, this is the first study quantitatively evaluating SB orifice after stenting in consecutive bifurcation cases.

Stent cell design and orifice area free from non-apposed strut

In this study, the %open area in cases with no SB dilatation was significantly larger in the EES group compared with the ZES group, which was confirmed by multivariate analysis. In the provisional approach for bifurcation lesions, if the angiographic results of both the main vessel and SB are satisfactory after initial stent placement, the SB orifice would not be further dilated²⁰. Therefore, the SB orifice remains jailed by the struts of stent within the main vessel. In those cases, the number of crossing struts should depend on the stent cell design itself, and the relative position and size between stent struts and SB orifice. The Xience V is a cobalt-chromium-based, open-cell design DES with thinner strut thickness (81 μ m) covered by a 7.8 μ m fluoropolymer coating. The Resolute Integrity stent is the open-cell and cobalt-chromium-based DES with 91 μ m strut thickness and 6 μ m polymer. The platform is made with a continuous sinusoid technology with laser fusion of the adjacent crown²¹. We believe that the difference in %open area among the two stents in cases without SB dilatation was mainly caused by these differences in the mechanical performance.

Side branch dilatation and orifice area free from non-apposed strut

Unlike the results in no SB dilatation cases, the %open area was similar between the two stents after SB dilatation. In EES cases, the %open area after SB dilatation was not significantly different from cases without SB dilatation indicating that sufficient open area was already achieved without SB dilatation and additional balloon dilatation of the SB did not further improve the open area. On the other hand, the %open area was significantly larger in cases with SB dilatation than in those without SB dilatation in ZES group, whereas we need further study to evaluate the importance of SB dilatation in cases treated with ZES.

In contrast to our results, Burzotta et al. demonstrated with a virtual simulation model that the %open area after SB dilatation varied among stent types¹⁹. They reported the %open area after KBT was better with EES (90.6%) than with Cypher stents (Cordis, Johnson & Johnson, Warren, NJ, USA) (84.7%) but worse than with the TAXUS Liberte (Boston Scientific, Natick, MA, USA) (98.3%) and the Endeavor Resolute (Medtronic, Minneapolis, MN, USA) (97.2%). Therefore, the %open area after SB dilatation might also be affected by the stent design. However, they simulated only a single case for each stent type in a silicon phantom model without any varieties of vessel morphologies. Thus, their findings need to be confirmed in larger number of cases *in vivo*.

As for the dilatation strategies, we did not find an advantage of KBT over single balloon technique with respect to %open area. Foin et al. also demonstrated comparable results of SB orifice area free from strut between KBT and single ballooning²² in a micro CT computational model.

Clinical implication and future issues

To date, there has been no clinical study which demonstrates the impact of NASB on the long-term clinical outcomes. This is partly due to the lack of a diagnostic modality to quantitatively assess NASB despite the development in the field of intracoronary image reconstruction. The recent development of 3D OCT image reconstruction enables us to qualitatively evaluate the anatomical structure of bifurcation lesions and struts around the SB orifice after the implantation of bioresorbable vascular scaffolds or stents^{8–10}. These might contribute to the optimization of PCI in bifurcation lesions¹¹. In addition, a fusion of 3D angiography and OCT images using a dedicated software was reported to more accurately measure the SB orifice area by taking into account the angle between the main branch and SB²³. However, these methods could not quantitatively evaluate stent struts around the SB orifice so far whereas those have given some new aspects in the field of bifurcation PCI. In the present study, we report the differences in open area within the SB orifice among different stent types and strategies using a novel approach. This method can be applied to standard intravascular OCT data and is therefore widely applicable with existing clinical OCT systems. We believe our method should provide information to better understand the mechanisms of restenosis and stent thrombosis at previously treated bifurcation lesions, and will therefore lead to better strategies with optimal stent design and techniques to prevent these complications.

Limitations

Several limitations should be noted. First, this is not a randomized study but rather a retrospective analysis with limited number of cases from a registry database. Therefore, some underlying differences in patient or procedural characteristics might have affected the results. Second, we didn't take account of the SB angulation and plaque burden, since this algorithm is not 3D. In future development, these features may be incorporated. Third, we applied our method in only two cases of left main disease due to the limited utilization of OCT for them in our registry. Fourth, most EES cases with SB dilatation were dilated by KBT. Thus, the results of open area should be interpreted with caution. Finally, due to the small number of cases, we could not examine the impact of %open area on clinical outcomes. Further studies with larger cohorts will be needed to evaluate the clinical impact of our findings.

Conclusions

The accuracy of SB orifice measurements using an *en face* image processing algorithm was demonstrated. This novel approach could quantitatively evaluate the area of NASB obstructing the SB orifice after bifurcation stenting *in vivo*. The SB orifice %open area was larger in the EES group compared to the ZES group after no SB dilatation. However, after SB balloon dilatation the SB orifice %open area was significantly improved in the ZES group.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Fig. 1. *En face* projection view for quantification of side branches

(A) – (B) OCT images in polar coordinates were projected to one dimension curves by averaging intensity values along each A-line between the lumen and a depth of 0.5mm. The side branch regions have low intensities in the projected curve. (C) By combining all the projected A-line profiles of the stented region into one image, an *en face* projection image can be created as a function of pullback distance and the angular position. *Guide wire artifact.

Fig. 2. Definitions

(Left) A representative image of *en face* OCT reconstruction. *Guide wire artifact. (Right)

A: Orifice area; B: Strut area. %Open area was calculated as $(A-B) / A * 100$.

Fig. 3. Accuracy of area measurement on an *en face* image

Horizontal-axis: estimated area of mimic side branch orifice in a phantom model; Vertical-axis: measured area of mimic side branch orifice on an *en face* projection image.

Fig. 4. Study flow chart

EES: everolimus-eluting Stent (Xience V); ZES: zotarolimus-eluting stent (Resolute Integrity).

Fig. 5. Comparison of %open area between EES and ZES

Comparison of %open area measured on the *en face* view. Gray column: Xience V (EES); white column: Resolute Integrity (ZES); Y-axis: percent of open area; *P=0.04 vs. ZES with side branch (SB) dilatation.

Fig. 6. Representative cases

(A) – (C) A case of no side branch dilatation with Xience V (EES). No strut was seen at the center of SB orifice (*) in the longitudinal reconstructed view (A), cross sectional view (B), and *en face* view (C). (D) – (F) A case of no side branch dilatation with Resolute Integrity (ZES). Two struts (white arrow) in the SB orifice were visible in the cross sectional view (E). The shape of crossing struts was well depicted in the *en face* view (F). (G) – (I) A case of SB dilatation after main vessel stenting with Resolute Integrity (ZES). Struts were well eliminated from the center of SB orifice (I). Stent struts crossing the SB orifice were highlighted by gray color in the *en face* view.

Table 1

Baseline clinical characteristics

	Side branch dilatation			No side branch dilatation		
	EES (n=17)	ZES (n=14)	P value	EES (n=25)	ZES (n=32)	P value
Male, n (%)	14 (82.4)	10 (71.4)	0.47	24 (96.0)	29 (90.6)	0.43
Age (years), mean $\pm$ SD	63.7 $\pm$ 18.5	62.3 $\pm$ 13.7	0.81	62.8 $\pm$ 11.6	64.0 $\pm$ 9.69	0.67
BMI, mean $\pm$ SD	26.0 $\pm$ 4.21	26.2 $\pm$ 3.30	0.92	26.3 $\pm$ 4.52	25.0 $\pm$ 3.74	0.27
Hypertension, n (%)	10 (58.8)	8 (57.1)	0.25	20 (80.0)	22 (68.8)	0.50
Hyperlipidemia, n (%)	10 (58.8)	7 (50.0)	0.27	19 (76.0)	22 (68.8)	0.29
Diabetes, n (%)	7 (41.2)	5 (35.7)	0.53	7 (28.0)	9 (28.1)	0.98
Renal insufficiency, n (%)	2 (11.8)	1 (7.1)	0.50	0 (0)	2 (6.3)	0.20
Current smoker, n (%)	2 (11.8)	2 (15.4)	0.77	7 (28.0)	7 (23.3)	0.69
Family history of CAD, n (%)	5 (29.4)	2 (14.3)	0.36	3 (12.0)	1 (3.1)	0.39
Previous MI, n (%)	3 (17.6)	5 (35.7)	0.25	5 (20.0)	5 (15.6)	0.63
Previous PCI, n (%)	3 (17.6)	1 (7.1)	0.39	7 (28.0)	7 (21.9)	0.59
Clinical presentation			0.76			<0.01
Stable angina, n (%)	11 (64.7)	11 (78.6)		11 (44.0)	28 (87.5)	
Acute coronary syndrome, n (%)	6 (35.3)	3 (21.4)		14 (56.0)	4 (12.5)	

BMI: body mass index; CAD: coronary artery disease; EES: everolimus-eluting stent = Xience V; MI: myocardial infarction; PCI: percutaneous coronary intervention; ZES: zotarolimus-eluting stent = Resolute Integrity

Table 2

Angiographic and procedural characteristics

	Side branch dilatation		P value	No side branch dilatation		P value
	EES (n=17)	ZES (n=14)		EES (n=25)	ZES (n=32)	
Angiographic characteristics						
Target lesion, n (%)			0.09			0.27
LAD	12 (70.6)	6 (42.9)		16 (64.0)	22 (68.8)	
LCX	2 (11.8)	7 (50.0)		7 (28.0)	10 (31.3)	
RCA	2 (11.8)	0 (0)		2 (8.0)	0 (0)	
LMT	1 (5.9)	1 (7.1)		0 (0)	0 (0)	
Medina classification, n (%)			0.77			0.28
(1,1,1)	3 (17.6)	3 (21.4)		4 (16.0)	3 (9.4)	
(1,1,0)	3 (17.6)	1 (7.1)		3 (12.0)	4 (12.5)	
(0,1,1)	2 (11.8)	3 (21.4)		2 (8.0)	3 (9.4)	
(1,0,1)	2 (11.8)	0 (0)		4 (16.0)	0 (0)	
(1,0,0)	1 (5.9)	2 (14.3)		4 (16.0)	9 (28.1)	
(0,1,0)	5 (29.4)	4 (28.6)		8 (32.0)	12 (37.5)	
(0,0,1)	1 (5.9)	1 (7.1)		0 (0)	1 (3.1)	
True bifurcation, n (%)	7 (41.2)	6 (42.9)	0.93	10 (40.0)	6 (18.8)	0.08
Calcified lesion, n (%)	7 (41.2)	3 (21.4)	0.24	14 (56.0)	11 (34.4)	0.10
Pre procedure QCA						
Main vessel						
Proximal REF (mm)	2.94±0.76	2.79±0.80	0.61	2.90±0.82	2.99±0.48	0.62
Distal REF (mm)	2.45±0.86	2.56±0.59	0.72	2.35±0.89	2.55±0.49	0.28
MLD (mm)	0.99±0.46	1.17±0.48	0.32	0.83±0.43	1.12±0.51	0.03
% DS	64.2±16.2	57.7±12.5	0.26	69.6±15.2	59.1±17.3	0.02
Side branch						
REF (mm)	2.25±0.30	2.39±0.43	0.29	2.23±0.18	2.38±0.37	0.05
MLD (mm)	1.43±0.42	1.42±0.37	0.93	1.37±0.48	1.47±0.48	0.43
% DS	34.3±15.9	38.1±10.6	0.44	34.5±17.6	38.4±16.4	0.39

Post procedure QCA	Side branch dilatation		No side branch dilatation			
	EES (n=17)	ZES (n=14)	P value	EES (n=25)	ZES (n=32)	P value
Main vessel						
MLD (mm)	2.35±0.23	2.59±0.70	0.19	2.48±0.51	2.87±0.61	0.02
%DS	16.7±9.61	18.5±8.02	0.58	17.8±10.5	12.9±8.09	0.07
Acute gain (mm)	1.36±0.48	1.46±0.76	0.65	1.57±0.73	1.80±0.66	0.26
Side branch						
MLD (mm)	1.20±0.44	1.21±0.46	0.95	1.46±0.36	1.57±0.47	0.37
%DS	16.7±9.09	20.3±8.17	0.29	34.9±13.7	35.7±18.2	0.87
Acute gain (mm)	0.23±0.06	0.21±0.08	0.88	0.04±0.59	0.09±0.49	0.76
Procedural characteristics						
Main branch						
Pre dilatation	8 (47.1)	11 (78.6)	0.07	19 (76.0)	26 (81.3)	0.63
Post dilatation	15 (88.2)	10 (71.4)	0.24	20 (80.0)	19 (59.4)	0.10
Stent diameter (mm)	2.96±0.46	3.07±0.59	0.55	2.86±0.36	2.88±0.46	0.84
Stent length (mm)	22.9±7.67	21.3±6.99	0.53	23.2±9.35	23.0±8.25	0.92
Stent / Vessel ratio	1.13±0.17	1.15±0.32	0.77	1.06±0.25	1.06±0.21	0.96
Side branch						
Pre dilatation	5 (29.4)	1 (7.1)	0.12	-	-	-
KBT	14 (82.4)	5 (35.7)	<0.01	-	-	-
Balloon diameter	2.13±0.40	2.38±0.21	0.09	-	-	-
Balloon / Vessel ratio	0.99±0.24	0.91±0.21	0.50	-	-	-
Max balloon pressure (atm)	9.73±5.01	12.0±4.00	0.34	-	-	-

KBT: kissing balloon technique; LAD: left anterior descending artery; LCX: left circumflex artery; LMT: left main trunk; MLD: minimal vessel diameter; QCA: quantitative coronary angiography; RCA: right coronary artery; REF: reference vessel diameter; %DS: percent diameter stenosis

Table 3

OCT comparison of open area between EES and ZES

	Side branch dilatation		No side branch dilatation		P value
	EES (n=17)	ZES (n=14)	EES (n=25)	ZES (n=32)	
En face view analysis					
Orifice area (mm ²)	3.34 [2.33–5.44]	3.54 [2.45–4.92]	1.37 [0.97–2.34]	1.57 [0.91–2.24]	0.72
Strut area (mm ²)	0.40 [0.25–0.57]	0.31 [0.18–0.45]	0.19 [0.11–0.30]	0.23 [0.19–0.32]	0.29
Open area (mm ²)	2.80 [2.00–4.95]	3.47 [2.20–4.55]	1.17 [0.79–2.18]	1.29 [0.77–1.91]	0.60
% Open area	89.0 [87.8–90.9]	91.4 [86.1–94.0]	89.2 [83.7–91.3]	84.3 [78.9–87.8]	0.04
Cross sectional analysis					
Orifice length (mm)	2.10 [1.35–2.20]	1.85 [1.48–2.23]	1.20 [1.05–1.55]	1.10 [0.90–1.30]	0.19
Max orifice width (mm)	2.11 [1.85–2.44]	2.28 [1.74–2.95]	1.76 [1.59–2.28]	1.85 [1.71–2.28]	0.38
Malapposed strut * (%)	10.6 [2.21–25.9]	9.52 [2.50–12.5]	5.71 [3.19–10.5]	4.01 [0.00–9.63]	0.10

* Stent strut malapposition was defined as any strut with the distance from the middle of the strut to the adjacent visible surface of the vessel being greater than the sum of the strut thickness plus polymer thickness which were provided by the manufacture.

Table 4

Independent predictors for smaller %open area* in no SB dilatation cases

Factors	OR	95% CI	P value
ZES (Resolute Integrity)	4.85	1.23 – 19.1	0.02
Orifice width < 1.84mm [†]	7.52	1.84 – 30.8	0.01
Orifice length < 1.1mm [†]	1.64	0.40 – 6.80	0.49
Small vessel < 2.5mm [‡]	3.06	0.59 – 15.8	0.18
Small side branch < 2.5mm [‡]	0.33	0.07 – 1.57	0.16

* Smaller %open area was defined as below median (85.5) in no side branch dilatation cases;

[†] Measured on the cross sectional OCT image. The values 1.84 and 1.1 were the median of orifice width and length respectively;

[‡] Measured by quantitative coronary angiography;

SB: side branch; OR: odds ratio; CI: confidential interval