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Impact of Strut Width in Periprocedural Myocardial Infarction

A Propensity-Matched Comparison Between Bioresorbable Scaffolds and the First-Generation Sirolimus-Eluting Stent

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ABSTRACT

OBJECTIVES This study aimed to assess the clinical impact of strut width (evaluated by abluminal strut surface area [ASSA]) on periprocedural myocardial infarction (PMI) and clinical outcomes in patients treated with bioresorbable scaffolds (BRS) versus first-generation sirolimus-eluting stents (SES).

BACKGROUND To date, there are no reports on the impact of ASSA on PMI and clinical outcomes.

METHODS We compared the impact of ASSA on outcomes and PMI in propensity-matched patients treated with BRS and SES. The primary outcome was the incidence of major adverse cardiac events (MACE), defined as the combination of all-cause mortality, follow-up myocardial infarction, and target vessel revascularization, at 30-days and 1-year follow-ups. The secondary endpoint was the incidence of PMI.

RESULTS After propensity-matched analysis, 499 patients (147 BRS patients vs. 352 SES patients) were evaluated. Mean ASSA was higher in patients treated with BRS versus SES (BRS: 132.3 ± 76.7 mm^2 vs. SES: 67.6 ± 48.4 mm^2, $p < 0.001$). MACE was not significantly different between groups (30-days MACE: BRS: 0% vs. SES: 1.4%, $p = 0.16$, and 1-year MACE: BRS: 15.7% vs. SES: 11.4%, $p = 0.67$). The incidence of PMI was significantly higher in the BRS group (BRS: 13.1% vs. SES: 7.5%, $p = 0.05$). Multivariable analyses indicated that treatment of left anterior descending artery and ASSA were independent predictors of PMI.

CONCLUSIONS BRS implantation, compared with SES implantation, was associated with a higher incidence of PMI. MACE at 30 days and 1 year were not significantly different. Left anterior descending artery percutaneous coronary intervention and ASSA were independent predictors of PMI. (J Am Coll Cardiol Intv 2015;8:900–9) © 2015 by the American College of Cardiology Foundation.

The advent of drug-eluting stents (DES) has dramatically reduced the rate of restenosis (1) and serves as the gold standard for the percutaneous interventional treatment of coronary artery disease. However, the widespread use of DES has brought to the surface concerns regarding delayed neointimal coverage, endothelial dysfunction, late catch-up phenomenon, and late stent thrombosis (2–6). Despite the constantly improving DES platforms with thinner struts, the lower profiles, biodegradable polymers, and abluminal drug release, the limitations of the permanent caging remain (7–10).

Bioresorbable scaffolds (BRS) are considered the fourth revolution in the treatment of coronary artery disease. They appear to be very attractive as BRS leave nothing behind after 2 to 3 years

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post-implantation and have the potential to restore normal vasomotor function (11,12). Furthermore, the absorption of struts does not preclude future surgical revascularization should the need arise. The ABSORB A (Bioabsorbable Vascular Solutions First in Man Clinical Investigation: A Clinical Evaluation of the Bioabsorbable Vascular Solutions Everolimus Eluting Coronary Stent System in the Treatment of Patients With Single De Novo Native Coronary Artery Lesions) trial demonstrated favorable short-term and late clinical outcomes out to 5 years in patients with relatively simple coronary lesions (13).

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The strut thickness of the Absorb (version 1.1, Abbott Vascular, Santa Clara, California) BRS is 157 μm, which is comparable to that of the Cypher first-generation sirolimus-eluting stents (SES) (Cypher Bx Velocity and Cypher Select, Cordis Corporation, Johnson & Johnson, Warren, New Jersey), which is 152.6 μm (14,15). To secure sufficient radial strength and prevent acute scaffold recoil, the current BRS needs not merely increased strut thickness but also strut width figures (2.5- and 3.0-mm BRS: 190.5 μm, and 3.5-mm BRS: 215.9 μm) that are much wider than those of SES (strut width of all SES sizes: 130 μm). DES with thicker struts have been associated with more angiographic and clinical restenosis than the thinner-strut stents have, especially when treating small coronary vessels (16). Moreover, the wider struts of BRS may lead to a higher prevalence of side branch occlusion and periprocedural myocardial infarction (PMI) (17,18). PMI has in turn been related to higher occurrences of short-term and late clinical outcomes (19–21). In the ABSORB EXTEND (ABSORB EXTEND Clinical Investigation: A Continuation in the Clinical Evaluation of the ABSORB Bioresorbable Vascular Scaffold System in the Treatment of Subjects With De Novo Native Coronary Artery Lesions) substudy, BRS implantation was associated with a higher incidence of post-procedural side branch occlusions than everolimus-eluting stent implantation was (22).

METHODS

STUDY POPULATION. A retrospective analysis in 2 high volume centers in Milan, Italy, was performed on 157 consecutive patients who underwent percutaneous coronary intervention (PCI) with Absorb BRS between May 1, 2012 and April 30, 2014, and 895 patients who were implanted with the SES (Cypher) between January 1, 2004 and October 30, 2009. Exclusion criteria included PCI for ST-segment elevation myocardial infarction, non-ST-segment elevation myocardial infarction, bypass grafting, bifurcation lesions treated with a 2-stent/scaffold strategy, and patients with end-stage renal failure (on hemodialysis). If 2 stents/scaffolds were implanted with overlap of more than 10 mm length by quantitative coronary angiography, the lesions were excluded from this study. The total study population is described in Figure 1. Of the total 1,052 patients, 990 patients were assessed for eligibility (150 patients in BRS group, and 840 patients in SES group). All patients provided written informed consent, according to the Declaration of Helsinki. All clinical data at follow-up were collected from hospital visits or telephone consultations.

STUDY DEVICES. The details of each device (BRS group: Absorb, Abbott Vascular; and SES group: Cypher, Cordis Corporation) are presented in Figure 2. Although both types of stents are constructed with a similar strut thickness (BRS: 157 μm vs. SES: 152.6 μm), their strut-width components differ at the narrow link part (BRS: 140 μm vs. SES: 60 μm) and at the wide hoop part (2.5- and 3.0-mm BRS: 190.5 μm, 3.5-mm BRS: 215.9 μm vs. 130 μm; all sizes of SES). As an index representing the strut width, we used the abluminal strut surface area (ASSA). ASSA was calculated using the percentages of stent or scaffold surface area/vessel surface area (χ) $\left[\text{ASSA}\ (\text{mm}^2) = \text{stent diameter}\ (\text{mm}) \times \pi \times \frac{\chi}{100} \times \text{stent length}\ (\text{mm})\right]$ (Figure 2). If more than 2 stents/scaffolds were implanted, the ASSA of the each stent/scaffold was calcu-lated and summed regardless of the stent/scaffold overlapping.

STUDY DEFINITIONS. Death was considered cardiac in origin unless obvious noncardiac causes were identified. The definition of myocardial infarction (MI) was an increase in the creatine kinase level to greater than twice the upper limit of the normal, accompanied by an increased level of creatine kinase-myocardial band (CK-MB). In the absence of CK, it was defined as an increase in the CK-MB level over 3× the upper limit of normal. PMI was classified as MI occurring within 48 h after PCI (23). Target lesion revascularization (TLR) was defined as repeat PCI or coronary artery bypass graft (CABG) for the lesion in the previously stented segment or in the adjacent 5 mm. Target vessel revascularization (TVR) was defined as PCI or CABG of the target lesion or any segment of the epicardial coronary artery containing the target lesion. Stent thrombosis (ST) was classified

ABBREVIATIONS AND ACRONYMS

ASSA = abluminal strut surface area

BRS = bioresorbable scaffold(s)

CABG = coronary artery bypass graft

CI = confidence interval

CK-MB = creatine kinase-myocardial band

DES = drug-eluting stent(s)

LAD = left anterior descending coronary artery

MACE = major adverse cardiac events

MI = myocardial infarction

OR = odds ratio

PCI = percutaneous coronary intervention

PMI = periprocedural myocardial infarction

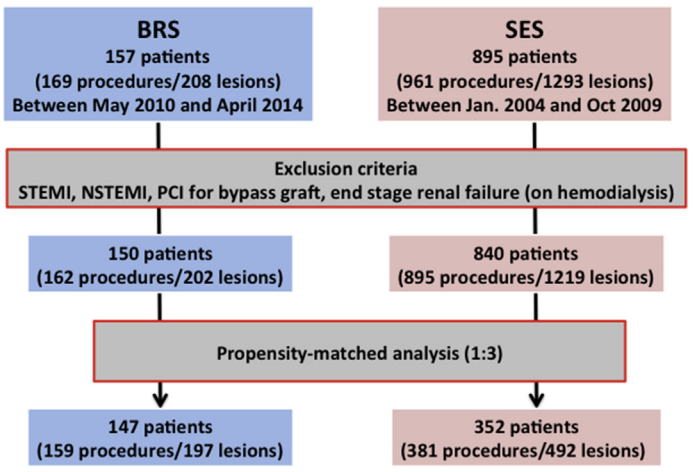
SES = sirolimus-eluting stent(s)

ST = stent thrombosis

TLR = target lesion revascularization

TVR = target vessel revascularization

FIGURE 1 Chart Demonstrating the Study Design and the Inclusion Criteria



Of the total 1,052 patients, 990 patients were assessed for eligibility (150 patients in the BRS group, and 840 patients in the SES group). If 2 stents/scaffolds were implanted with an overlap of more than 10 mm length by quantitative coronary angiography, the lesions were excluded from this study. BRS = bioresorbable scaffold; NSTEMI = non–ST-segment elevation myocardial infarction; PCI = percutaneous coronary intervention; SES = sirolimus-eluting stent; STEMI = ST-segment elevation myocardial infarction.

according to the Academic Research Consortium definitions and cumulative ST as a combination of all episodes of ST during follow-up (24).

Quantitative coronary angiographic analyses were performed by 2 experienced cardiologists (H.K. and T.N.). Minimum lumen diameter, percentage of diameter stenosis, and reference vessel diameter were evaluated using a validated edge detection system (CMS, version 5.2, Medis Medical Imaging Systems BV, Leiden, the Netherlands).

ENDPOINTS. The primary endpoint was the rate of major adverse cardiac events (MACE) defined as the combination of all-cause mortality, follow-up MI (after 48-h post-index procedure), and TVR at 30-days and 1-year follow-ups. The secondary endpoint was the incidence of PMI.

STATISTICAL ANALYSIS. All continuous variables were tested for normality using the Kolmogorov-Smirnov test. Continuous variables are presented as the mean ± SD or the median ± interquartile range (25th to 75th percentile) for normally and not normally distributed variables, respectively. Differences in continuous variables between groups were analyzed using Student *t* test or Mann-Whitney U test. After propensity matching, differences in continuous variables were analyzed using paired *t* test. Categorical variables are expressed as numeric values and percentages. Categorical data were compared using the chi-square or Fisher exact tests (overall cohort) or the McNemar test (propensity-matched cohort). The cumulative incidences were generated using Kaplan-Meier analysis, and the significance of observed differences was assessed with the log-rank test (overall cohort) or Klein-Moeschberger test (propensity-matched cohort). To identify the independent risk factors of PMI, we performed multivariable logistic regression analysis using the following covariates: all variables with values of $p < 0.10$ on the univariate analysis and those judged to be of clinical significance (chronic kidney disease, insulin-dependent diabetes mellitus, and acute gain). The multivariable model was created with a stepwise elimination procedure, where the independent variables were entered into the model at the 0.20 significance level and removed at the 0.25 level. To avoid overfitting, the number of independent variables entered into the final multivariable logistic regression model was limited to 1 for every 8 to 10 events. The results are reported as odds ratios (ORs) and 95% confidence intervals (CIs). Analyses were performed using SPSS (version 20.0, SPSS Inc., Chicago, Illinois) and R (version 2.12, R Development Core Team, Vienna, Austria). All reported p values were 2-sided, and values of $p < 0.05$ were regarded as statistically significant.

To reduce the effect of treatment selection bias and other confounding in this retrospective study with different recruitment periods, we performed propensity score matching. The propensity scores were estimated using multiple logistic regression analysis including the following baseline patient or procedural characteristics as covariates: previous MI, previous CABG, family history of coronary artery disease, history of smoking, dyslipidemia, diabetes mellitus, insulin-dependent diabetes mellitus, PCI of the left anterior descending coronary artery (LAD), use of rotational atherectomy, stent/scaffold post-dilation, total stent or scaffold length, and total number of treated vessels. Considering the larger number of patients in the SES group (n = 840) than in the BRS group (n = 150), a multiple matching (BRS:SES = 1:3) was performed in this study. After propensity score matching, all of the standardized differences for each of the baseline variables were <0.10 (10%).

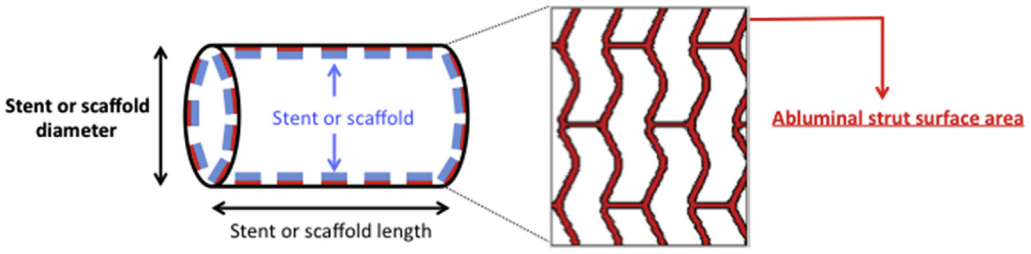
RESULTS

STUDY POPULATION. Of the total of 990 patients who met the inclusion criteria (150 patients in the BRS, and 840 patients in the SES group), the propensity score was not calculable for 89 patients in the SES group due to missing values in baseline

FIGURE 2 Strut Thickness, Width, and Abluminal Strut Surface Area of Absorb BRS and Cypher SES

	Absorb	Cypher	
Strut thickness	157μm	152.6μm	
Strut width (link)	140μm	60μm	
Strut width (hoop)	2.5, 3.0mm; 190.5μm 3.5mm; 215.9μm	130μm	
Vessel wall area covered by stent or scaffold (χ %)	2.5mm; 32% 3.0mm; 27% 3.5mm; 26%	Cypher Bx; 12-15%	Cypher Select; 14-15%

$$\text{Abluminal strut surface area } (mm^2) = \text{stent or scaffold diameter } (mm) \times \pi \times \frac{\chi}{100} \times \text{stent or scaffold length } (mm)$$



		Absorb	Cypher Bx	Cypher Select
Abluminal strut surface area (mm^2)	2.5mm	2.51 x scaffold length	1.06 x stent length	1.14 x stent length
	3.0mm	2.54 x scaffold length	1.27 x stent length	1.37 x stent length
	3.5mm	2.86 x scaffold length	1.48 x stent length	1.59 x stent length

Abluminal strut surface area (ASSA) was calculated using percentage of vessel area covered by stent or scaffold (×%). If more than 2 stents/scaffolds were implanted, the ASSAs of the each stent/scaffold were calculated and summed regardless of the stent/scaffold overlapping. Absorb (Abbott Vascular, Santa Clara, California) BRS and Cypher (Cordis Corporation, Johnson & Johnson, Warren, New Jersey). Abbreviations as in Figure 1.

characteristics. Therefore, 147 patients in the BRS group were matched with 352 patients in the SES group in the current analysis (Figure 1).

BASELINE CHARACTERISTICS. The baseline clinical and lesion characteristics of the BRS and SES group were compared, as shown in Table 1. In the overall cohort, the SES group had a significantly higher rate of previous MI, previous CABG, family history of coronary artery disease, and dyslipidemia than the BRS group did. In addition, the number of treated vessels was smaller, and ejection fraction was higher in the BRS group than in the SES one. In the matched cohort, there were no longer any significant differences in the aforementioned covariates between the 2 groups.

The lesion characteristics in both groups were also comparable, as shown in Table 2. Only few procedural characteristics remained significantly different between the 2 groups after propensity matching. Namely, the prevalence of pre-dilation and usage of intravascular ultrasound was higher in the BRS group. There was also a significant difference in the treated target vessel, with a lower rate of the right coronary artery being treated in the BRS group (BRS: 12.7% vs. SES: 21.7%, $p = 0.001$). Although the BRS group had lower percentage of diameter stenosis and acute gain, there were no significant differences in stent or scaffold sizes, final reference vessel diameter or minimum lumen diameter sizes. Mean ASSA was

TABLE 1 Patient Demographic and Procedural Characteristics in the Overall and the Propensity-Matched Cohort

	Overall Cohort			Propensity-Matched Cohort		
	BRS (n = 150)	SES (n = 840)	p Value	BRS (n = 147)	SES (n = 352)	p Value
Procedures	162	895		159	381	
Patient characteristics						
Age, yrs	64.0 ± 11.2	63.6 ± 10.6	0.65	63.9 ± 11.3	64.4 ± 10.6	0.66
Male	135 (90.0)	719 (85.6)	0.15	132 (89.8)	296 (84.1)	0.10
Previous MI	39 (26.0)	386 (46.0)	<0.001	39 (26.5)	119 (33.8)	0.11
Previous PCI	72 (48.0)	380 (45.2)	0.53	71 (48.3)	145 (41.2)	0.14
Previous CABG	11 (7.3)	132 (15.7)	0.007	11 (7.5)	36 (10.2)	0.34
Family history of CAD	62 (41.3)	431 (51.3)	0.02	61 (41.5)	178 (50.6)	0.06
Hypertension	94 (62.7)	548 (65.2)	0.54	91 (61.9)	219 (62.2)	0.95
Dyslipidemia	89 (59.3)	566 (67.4)	0.06	88 (59.9)	222 (63.1)	0.50
History of smoking	79 (52.7)	413 (49.2)	0.43	76 (51.7)	158 (44.9)	0.16
DM	41 (27.3)	226 (26.9)	0.91	40 (27.2)	82 (23.3)	0.35
Insulin dependent DM	11 (7.3)	52 (6.2)	0.60	10 (6.8)	18 (5.1)	0.46
eGFR < 60 (ml/min/1.73 m^2)	76 (51.4)	234 (46.3)	0.25	75 (51.7)	164 (46.9)	0.32
Ejection fraction < 35%	3 (2.3)	38 (4.8)	0.20	3 (2.0)	14 (4.0)	0.28
Procedural characteristics						
Total number of stents/scaffolds	2.2 ± 1.1	2.1 ± 1.4	0.79	2.1 ± 1.1	2.1 ± 1.4	0.99
Total stent/scaffold length, mm	51.2 ± 29.4	54.3 ± 38.8	0.24	50.8 ± 29.5	54.6 ± 39.0	0.22
Stent/scaffold diameter, mm	2.99 ± 0.31	2.93 ± 0.39	0.04	2.99 ± 0.31	2.94 ± 0.41	0.11
Number of treated vessels	1.2 ± 0.5	1.5 ± 0.7	<0.001	1.3 ± 0.5	1.3 ± 0.6	0.15
ASSA, mm^2	133.3 ± 76.5	67.4 ± 48.9	<0.001	132.3 ± 76.7	67.6 ± 48.4	<0.001

Values are n (%) or mean ± SD.

ASSA = abluminal strut surface area; BRS = bioresorbable scaffold(s); CABG = coronary artery bypass graft; CAD = coronary artery disease; DM = diabetes mellitus; eGFR = estimated glomerular filtration rate; MI = myocardial infarction; PCI = percutaneous coronary intervention; SES = sirolimus-eluting stent(s).

higher in patients treated with BRS versus SES (BRS: 132.3 ± 76.7 mm^2 vs. SES: 67.6 ± 48.4 mm^2, p < 0.001).

MAJOR ADVERSE CARDIAC EVENTS AND PERI-PROCEDURAL MYOCARDIAL INFARCTION. The clinical outcomes at 30- days and 1 year are shown in Table 3. There were no significant differences in MACE (MACE at 30 days: BRS: 0% vs. SES: 1.4%, p = 0.15, and MACE at 1 year: BRS: 15.7% vs. SES: 11.4%, p = 0.61) or their individual components (Figure 3). MACE rates were mainly driven by TVR in both groups (BRS: 14.1% vs. SES: 9.4%, p = 0.36). On the other hand, the incidence of PMI was significantly higher in the BRS group than in the SES group (BRS: 19 [13.1%] vs. SES: 26 [7.5%], p = 0.05). In our study, definite ST occurred in 1 patient treated with BRS and 3 patients treated with SES, with no statistical significant differences between the 2 groups (BRS: 0.9% vs. SES: 0.9%, p = 0.89).

PREDICTORS OF PERIPROCEDURAL MYOCARDIAL INFARCTION. Univariate analysis revealed the following risk factors for PMI: BRS (OR: 1.86, 95% CI: 1.00 to 3.47, p = 0.05), LAD (OR: 2.84, 95% CI: 1.24 to 6.50, p = 0.01), pre-dilation (OR: 4.37, 95% CI: 1.03 to 18.50, p = 0.05), post-dilation (OR: 0.15, 95% CI: 0.02 to 0.93, p = 0.04), total stent or scaffold number (OR: 1.33, 95% CI: 1.10 to 1.61, p = 0.003), total stent or scaffold length (OR [per 10-mm increase]: 1.10, 95% CI: 1.03 to 1.18, p = 0.004), and ASSA (OR [per 10-mm^2 increase]: 1.07, 95% CI: 1.03 to 1.12, p < 0.001). The covariates entered into the final logistic regression model included LAD PCI, insulin-dependent diabetes mellitus, pre-dilation, total stent or scaffold length, and ASSA. Multivariable analyses indicated LAD PCI and ASSA to be independent predictors of PMI (LAD PCI OR: 2.60, 95% CI: 1.16 to 5.81, p = 0.02, and ASSA OR [per 10-mm^2 increase]: 1.07, 95% CI: 1.03 to 1.12, p = 0.001) (Table 4). The C-statistic was 0.69, and the Hosmer-Lemeshow test p value was 0.58, confirming good discrimination and calibration of the logistic regression model, respectively.

DISCUSSION

The present study is the first comparison between BRS and SES, demonstrating the clinical impact of strut width on PMI and 1-year clinical outcomes. The main findings of our study are the following: 1) the incidence of PMI was higher among patients treated with BRS versus SES despite similar strut thickness;

TABLE 2 Lesion and Procedural Characteristics in the Overall and the Propensity-Matched Cohort

	Overall Cohort			Propensity-Matched Cohort		
	BRS (n = 202)	SES (n = 1,219)	p Value	BRS (n = 197)	SES (n = 492)	p Value
In-stent restenosis	15 (7.5)	121 (9.9)	0.27	15 (7.6)	40 (8.1)	0.82
Chronic total occlusion	12 (6.0)	121 (9.9)	0.07	12 (6.1)	47 (9.6)	0.14
Rotational atherectomy	8 (4.0)	30 (2.5)	0.22	6 (3.0)	8 (1.6)	0.23
Pre-dilation	198 (99.0)	811 (73.7)	<0.001	195 (99.0)	391 (79.5)	<0.001
Post-dilation	200 (99.5)	628 (57.8)	<0.001	196 (99.5)	482 (98.0)	0.15
IVUS	159 (79.1)	266 (21.8)	<0.001	156 (79.2)	145 (29.5)	<0.001
Target vessel						
LAD	121 (60.2)	498 (40.9)	<0.001	117 (59.4)	255 (51.8)	0.07
LCX	51 (25.4)	334 (27.4)	0.55	51 (25.9)	112 (22.8)	0.38
RCA	25 (12.4)	325 (26.7)	<0.001	25 (12.7)	107 (21.7)	0.01
Type B2/C lesion (ACC/AHA)	162 (80.6)	956 (78.4)	0.49	158 (80.2)	413 (83.9)	0.24
Number of stents/scaffolds	1.7 ± 0.8	1.6 ± 0.8	0.02	1.7 ± 0.8	1.6 ± 0.9	0.27
Stent/scaffold length, mm	41.3 ± 22.4	40.2 ± 25.1	0.56	40.9 ± 22.3	41.7 ± 27.4	0.7
Stent/scaffold diameter, mm	3.00 ± 0.34	2.94 ± 0.39	0.02	3.00 ± 0.34	2.95 ± 0.39	0.08
RVD, mm	2.82 ± 0.51	2.74 ± 0.66	0.07	2.81 ± 0.51	2.75 ± 0.66	0.24
MLD, mm	0.88 ± 0.48	0.80 ± 0.55	0.08	0.88 ± 0.49	0.76 ± 0.54	0.02
Percentage stenosis, %	68.5 ± 17.4	74.1 ± 16.0	<0.001	68.4 ± 17.6	74.3 ± 16.7	<0.001
Final RVD, mm	3.09 ± 0.47	3.11 ± 0.55	0.6	3.10 ± 0.48	3.15 ± 0.55	0.23
Final MLD, mm	2.70 ± 0.49	2.71 ± 0.55	0.81	2.69 ± 0.49	2.75 ± 0.54	0.23
Acute gain, mm	1.83 ± 0.64	1.97 ± 0.61	0.007	1.83 ± 0.64	2.03 ± 0.60	<0.001
Pre-balloon size, mm	2.84 ± 0.35	2.51 ± 0.49	<0.001	2.84 ± 0.36	2.56 ± 0.49	<0.001
Post-balloon size, mm	3.24 ± 0.42	3.17 ± 0.47	0.09	3.23 ± 0.42	3.17 ± 0.45	0.12
Post-balloon pressure, atm	20.8 ± 4.5	18.8 ± 5.3	<0.001	20.8 ± 4.5	18.9 ± 5.3	<0.001
Post-balloon/stent or scaffold ratio	1.08 ± 0.09	1.05 ± 0.10	<0.001	1.08 ± 0.09	1.06 ± 0.10	0.01

Values are n (%) or mean ± SD.

ACC/AHA = American College of Cardiology/American Heart Association; IVUS = intravascular ultrasound; LAD = left anterior descending artery; LCX = left circumflex artery; MLD = minimum lumen diameter; RCA = right coronary artery; RVD = reference vessel diameter.

2) there were no significant differences in clinical outcomes between the BRS group and the SES group; 3) LAD PCI and ASSA were independent predictors of PMI.

PMI is mainly related to either side branch occlusion or iatrogenic plaque rupture by balloons and stents (25,26). In the bare-metal stent era, although bare-metal stents reduced acute major complications, a paradoxical increase in the incidence of PMI was reported after stent implantation compared with that of balloon angioplasty (27). In the early DES era, the greater strut thickness of the first-generation DES had been implicated in a higher incidence of side branch occlusion and PMI than had the second-generation DES with thinner struts (17,18). With the advent of BRS, a main concern was the higher incidence of post-procedural side branch occlusion compared with that of second-generation DES (22). In our study, the univariable model revealed both total stent or scaffold length and ASSA to be risk factors for PMI. After multivariable analysis, however, the latter was the only independent predictor of PMI. The comparison between BRS and SES, stents with similar strut thickness but different strut widths, highlights the impact of strut width on PMI. ASSA can resolve these discrepancies in strut dimensions between stents and provide a more comprehensive quantification of strut size and its impact on periprocedural outcomes. Even though ASSA is affected by stent design and strut platforms, it is mainly influenced by strut width. This implies that the strut width is among the most important factors for PMI. As shown in **Figure 2**, ASSA of BRS is approximately 2× larger than that of SES when comparing devices of the same diameter (e.g., 3.0-mm BRS = 2.544 × scaffold length, and 3.0-mm SES [Cypher Bx] = 1.272 × stent length). This difference could have an impact on both the incidence of side branch occlusion and PMI. BRS scaffold expansion is more asymmetric than that of metal stents (28). This asymmetric expansion of BRS with its wider struts may lead to nonuniform strut distribution and result in a more frequent incidence of side branch occlusions and PMI. The other independent predictor of PMI in this study was PCI for the LAD. LAD generally has many small branches such as septal and diagonal branches and supplies a larger territory,

TABLE 3 Incidence of PMI and Estimated Incidences (Kaplan-Meier Analysis) of Outcomes at 30 Days and 1 Year

	Overall Cohort			Propensity-Matched Cohort		
	BRS (n = 150)	SES (n = 840)	p Value	BRS (n = 147)	SES (n = 352)	p Value
Procedures	162	895		159	381	
PMI	20 (13.5)	52 (6.3)	0.002	19 (13.1)	26 (7.5)	0.05
Clinical outcomes at 30 days						
MACE	0	11 (1.3)	0.16	0	5 (1.4)	0.16
All-cause death	0	5 (0.6)	0.35	0	2 (0.6)	0.41
Follow-up MI	0	8 (1.0)	0.23	0	4 (1.1)	0.20
TLR (per lesion)	0	5 (0.4)	0.36	0	1 (0.2)	0.62
TVR (per patient)	0	5 (0.6)	0.35	0	2 (0.4)	0.36
Clinical outcomes at 1 year						
MACE	12 (15.3)	100 (13.3)	0.89	12 (15.7)	37 (11.4)	0.67
All-cause death	1 (1.7)	19 (2.5)	0.33	1 (1.8)	6 (1.8)	0.54
Follow-up MI	3 (4.0)	12 (1.5)	0.4	3 (4.1)	5 (1.5)	0.59
TLR (per lesion)	11 (10.7)	98 (9.1)	0.98	11 (10.9)	31 (6.9)	0.24
TVR (per patient)	11 (13.7)	81 (11.0)	0.75	11 (14.1)	30 (9.4)	0.38

Values are n (%). P values of clinical outcomes were calculated with log-rank test (overall cohort) or Klein-Moeschberger test (propensity-matched cohort).

MACE = major adverse cardiac event; PMI = periprocedural myocardial infarction; TLR = target lesion revascularization; TVR = target vessel revascularization; other abbreviations as in Table 1.

which may explain the increase in PMI when manipulating this vessel (stents, pre-, post-dilation, etc.). In a pooled analysis of 11 PCI studies with bare-metal stents and DES (including patients with acute coronary syndromes), the occurrence of PMI, defined as CK-MB >3× the upper limit of normal within 48 h, was about 7%, and more than one-half of cases were attributed to side branch occlusion (29). Muramatsu et al. (22) reported that BRS implantation is associated with a higher incidence of post-procedural side branch occlusions than everolimus-eluting stents are, particularly in small side branches (6.0% in the overall cohort and 10.5% in the group with side branch reference vessel diameter ≦0.5 mm). In the current study, the incidence of post-procedural side branch occlusion in patients treated with SES was not calculated due to the inability to review some archived angiography films.

Our definition of PMI used the one reported by Vranckx et al. (23), which was also used in the ABSORB trials. Although Abizaid et al. (30) did not comment particularly on the rate of PMI, the incidence of MI at 30 days in the ABSORB EXTEND study was 2.1%, whereas in the more recent ABSORB II (ABSORB II Randomized Controlled Trial: A Clinical Evaluation to Compare the Safety, Efficacy, and Performance of Absorb Everolimus Eluting Bioresorbable Vascular Scaffold System Against Xience Everolimus Eluting Coronary Stent System in the Treatment of Subjects With Ischemic Heart Disease Caused by De Novo Native Coronary Artery Lesion), a 5% incidence of PMI was reported (31). The higher incidence of PMI in the current study is attributed to the severity of the lesions treated and the more complex patient characteristics. The missing values of cardiac enzymes incorporated in clinical practice in recent years (CK-MB, troponins) in the SES group (study period: between 2004 and 2009) did not allow for the use of a more up-to-date definition of periprocedural MI that would allow direct comparisons with the ABSORB II trial. Of note, the introduction of troponins T or I was first introduced in the 2007 Academic Research Consortium universal definition of MI (32). The figures of PMI and their clinical relevance should be interpreted with caution due to their arbitrary character, a limitation highlighted also in the ABSORB II trial, which demonstrated that PMI rates ranging from 1% to 30% could be generated depending on the PMI definition used.

In the current analysis, clinical outcomes at 30 days and 1 year were evaluated. No significant differences in MACE and their individual components were observed between the 2 groups (BRS vs. SES: 0% vs. 1.4% at 30 days and 15.7% vs. 11.4% at 1 year, respectively). The increased MACE rate was attributed to an increased TVR (BRS vs. SES: 14.1% vs. 9.4%, p = 0.36). In the ABSORB EXTEND study, Abizaid et al. (30) reported ischemia-driven MACE rate (cardiac death, MI, and ischemia-driven TLR) at 4.3% at 1-year follow-up. The higher rate of MACE in our study can be explained by the higher complexity of the lesions treated and the broader definition of MACE used. The BRS cohort in the current study reflects real-world patients, true “all-comers” who underwent implantation of BRS. Hence, 80% of the lesions are classified as American College of Cardiology/American Heart Association type B2/C, whereas total scaffold length (mean length: 40.9 ± 22.3 mm) is longer than that reported in the ABSORB cohorts. The definition of MACE in the current analysis did not include TLR but did include TVR and also included nonischemic driven TVR, which resulted in higher MACE rates than were reported in previous studies. Kimura et al. (4) reported the incidence of very late ST and late TLR in the j-Cypher registry, which revealed an ongoing risk of late ST of 0.26% per year and late TLR of 2.2% per year without attenuation up to 5 years after SES implantation. On the other hand, BRS struts are resorbed completely after 2 to 3 years and may prevent late ST or target-lesion neoatherosclerosis. Even though there were no significant differences in clinical outcomes between groups at 1 year, the BRS group may demonstrate better long-term outcomes at 5 years after PCI than the SES

group will. Studies with longer follow-up are eagerly awaited to confirm the long-term efficacy of BRS implantation.

Clinical predictors for PMI include multivessel disease, stent length, lesion length, complex lesions, presence of thrombus, treatment of saphenous vein grafts, acute coronary syndromes, and use of glycoprotein IIb/IIIa inhibitors (33-37). In the present study, the rate of PMI was higher in the BRS group than in the SES group (BRS: 13.1% vs. SES: 7.5%). Univariate analysis revealed BRS, LAD PCI, pre-dilation, post-dilation, total stent or scaffold number, total stent or scaffold length, and ASSA to be risk factors for PMI. Multivariable analysis showed LAD PCI and ASSA to be independent predictors of PMI. Therefore, BRS with thinner struts with narrower width may reduce the incidence of PMI and be more suitable for the treatment of bifurcation lesions with small side branches (e.g., in LAD). Of note, in the current study we could not evaluate the impact of strut thickness and total stent or scaffold "volume" as we assessed 2 devices with similar strut thickness. Furthermore, we were not able to analyze the impact of stent/scaffold overlap on outcomes due to missing archived angiographic films in the SES group. A larger strut volume could theoretically lead to more frequent iatrogenic plaque ruptures and micro-embolizations. To evaluate this possible mechanism of PMI, plaque characteristics by intravascular ultrasound, final TIMI (Thrombolysis In Myocardial Infarction) flow grade, myocardial blush grade, or myocardial filling time should be simultaneously evaluated in future studies. Higher rates and aggressive pre- and post-dilation may cause iatrogenic plaque injury. Univariable analysis revealed both pre- and post-dilation to be risk factors for PMI. Oddly, in the current analysis, post-dilation had a protective effect for PMI. However, the wide OR of post-dilation (95% CI: 0.02 to 0.93) reflects the unbalanced population after propensity matching (post-dilations were performed in more than 98% in both BRS and SES groups) and limits the interpretability of the results. We also evaluated the effect of aggressive post-dilation (balloon diameter larger than that of the stent and use of higher than rated pressures) in this study. Multivariate analysis revealed that none of them is an independent predictor for PMI, despite both exhibiting numerically increased OR for PMI (post-dilation with larger balloon than stent/scaffold [OR: 1.61, 95% CI: 0.79 to 3.29, p = 0.19] and post-dilation with more than rated pressure [OR: 1.55, 95% CI: 0.69 to 3.48, p = 0.29]). To generalize the impact of strut width and ASSA on PMI, larger studies including different types of stents are required.

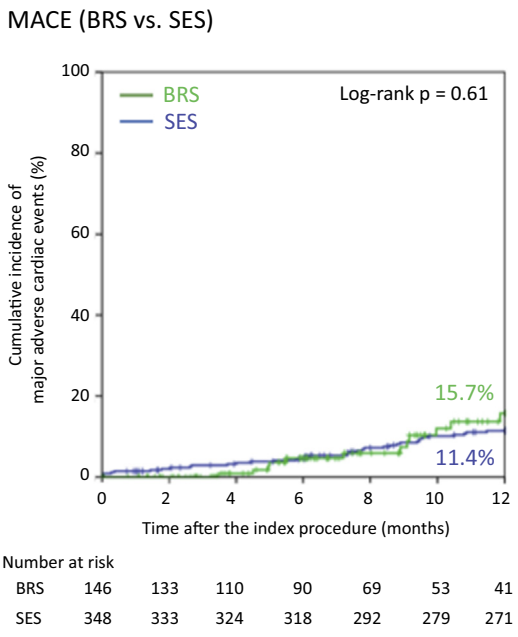
TABLE 4 Univariate and Multivariable Analyses for PMI

	Univariable		Multivariable	
	OR (95% CI)	p Value	OR (95% CI)	p Value
Patient-related factors				
Chronic kidney disease (eGFR <60 ml/min/1.73 m^2)	1.20 (0.61–2.35)	0.60		
Previous MI	0.74 (0.37–1.47)	0.39		
Previous CABG	0.96 (0.33–2.83)	0.95		
Hypertension	1.14 (0.60–2.18)	0.69		
Dyslipidemia	0.76 (0.41–1.40)	0.37		
DM	0.89 (0.44–1.81)	0.75		
Insulin-dependent DM	1.46 (0.49–4.36)	0.50		
Lesion and procedure-related factors				
Bioresorbable scaffold	1.86 (1.00–3.47)	0.05		
LAD PCI	2.84 (1.24–6.50)	0.01	2.60 (1.16–5.81)	0.02
RCA PCI	0.46 (0.16–1.32)	0.15		
In-stent restenosis	0.50 (0.12–2.14)	0.35		
Chronic total occlusion	0.57 (0.17–1.89)	0.36		
Type B2/C lesion (ACC/AHA)	1.64 (0.63–4.30)	0.31		
Rotational atherectomy	CS	CS		
Pre-dilation	4.37 (1.03–18.50)	0.05		
Pre-balloon diameter, mm	1.55 (0.64–3.73)	0.33		
Post-dilation	0.15 (0.02–0.93)	0.04		
Post-dilation balloon/stent or scaffold ratio per 0.1 increase	1.16 (0.83–1.62)	0.38		
Mean pre-procedural RVD, mm	0.98 (0.56–1.73)	0.95		
Mean pre-procedural DS, %	0.99 (0.97–1.00)	0.12		
Acute gain	0.94 (0.58–1.53)	0.80		
Post-dilation with larger balloon than stent/scaffold diameter	1.61 (0.79–3.29)	0.19		
Post-dilation with more than rated pressure	1.55 (0.69–3.48)	0.29		
Final MLD, mm	0.57 (0.64–2.24)	0.57		
Total number of stents/scaffolds	1.33 (1.10–1.61)	0.003		
Total stent/scaffold length, 10-mm increase/procedure	1.10 (1.03–1.18)	0.004		
ASSA per 10-mm^2 increase	1.07 (1.03–1.12)	<0.001	1.07 (1.03–1.12)	0.001

CI = confidence interval; CS = complete separation; DS = diameter stenosis; OR = odds ratio; other abbreviations as in Tables 1 to 3.

STUDY LIMITATIONS. First, the main limitation includes the lack of randomization and angiographic evaluation of side branch occlusion. Even though we used propensity matching, it is still possible that there are unadjusted confounders (particularly related to lesion characteristics), which may have influenced our results. Second, one should take into account differences in PCI techniques (in particular treatment of bifurcations) and in medical therapy (e.g., administration of statin) due to the temporal differences in BRS and SES implantation. Third, in the current study we did not use the universal definition of MI (32) due to the absence of data on troponin in the SES group. Our definition of MI was the same as that reported by Vranckx et al. (23), which was also used in the ABSORB trials. Although it is possible to

FIGURE 3 Rates of Outcomes Among Study Patients



Kaplan-Meier curves are shown for major adverse cardiac events (MACE) for both the bioresorbable scaffold (BRS) and sirolimus-eluting stent (SES) groups. Event rates are Kaplan-Meier estimates with log-rank p values.

compare our results with those of initial BRS trials, the PMI criteria used may overestimate the true incidence of PMI.

CONCLUSIONS

Despite their similar strut thicknesses, BRS implantation was associated with a higher incidence of PMI than SES implantation was. LAD PCI and ASSA were independent predictors of PMI. Further larger, randomized controlled trials including different stent types are required to evaluate the impact of strut width or ASSA on PMI and long-term outcomes.

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PERSPECTIVES

WHAT IS KNOWN? Strut thickness is important for stent deliverability, for endothelization, and to lower intimal hyperplasia. Most of the current metal stents have a strut thickness <100 μm. Strut width is a parameter not frequently taken into account and current metal stents have a strut width similar to their thickness. The Absorb stent and most current BRS have a strut width about 200 μm, higher than their strut thickness. This manufacturing decision allows for maintaining a good radial strength.

WHAT IS NEW? This study clearly demonstrates that a wide strut can contribute to increased rates of periprocedural myocardial infarction either by distal embolisation or by completely covering a side branch that does not become accessible any more with a wire.

WHAT IS NEXT? The next step would be to be able to manufacture BRS with struts that are not so wide. These new devices are expected to become available in 2016. Presently, operators should be aware of this limitation and they should be more liberal to protect a side branch by placing a guidewire until the end of the procedure. Placement of a guidewire may prevent the occlusion of a side branch, although this can not be fully guaranteed.

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