Procedural and Long-term Ischemic Outcomes of Tight Subtotal Occlusions Treated with Orbital Atherectomy: An ORBIT II Subanalysis

Michael S. Lee, M.D.[a*], Richard A. Shlofmitz, M.D.[b], Evan Shlofmitz, D.O.[c], Ann N. Behrens, B.S.[d], George Revtyak, M.D.[e], Brad J. Martinsen, Ph.D.[d], Jeffrey W. Chambers, M.D.[f]

a. UCLA Medical Center, 100 Medical Plaza Suite 630, Los Angeles, CA 90095, USA, mslee@mednet.ucla.edu

b. St. Francis Hospital—The Heart Center, 100 Port Washington Blvd., Suite 105, Roslyn, NY 11576, USA, hartfixr1@gmail.com

c. Cardiovascular Research Foundation, 1700 Broadway, 8th Floor, New York, NY 10017, USA, eshlofmitz@gmail.com

d. Scientific Affairs, Cardiovascular Systems, Inc., 1225 Old Highway 8 NW, St. Paul, MN 55112, USA, abehrens@csi360.com, bmartinsen@csi360.com

e. IU Health Physicians Cardiology, 1801 N. Senate Blvd., Suite 310, Indianapolis, IN 46202, USA, grevtyak@IUHealth.org

f. Metropolitan Heart and Vascular Institute, Mercy Hospital, 4040 Coon Rapids Blvd, Minneapolis, MN 55433, USA, J.Chambers@mhvi.com

This is the author's manuscript of the article published in final edited form as:

Lee, M. S., Shlofmitz, R. A., Shlofmitz, E., Behrens, A. N., Revtyak, G., Martinsen, B. J., & Chambers, J. W. (2018). Procedural and long-term ischemic outcomes of tight subtotal occlusions treated with orbital Atherectomy: An ORBIT II subanalysis. Cardiovascular Revascularization Medicine. https://doi.org/10.1016/j.carrev.2018.09.011

*Corresponding author:

Michael S. Lee, M.D.

Associate Professor of Medicine

100 Medical Plaza Suite 630

Los Angeles, CA 90095

Office: 310-696-9523

Email: mslee@mednet.ucla.edu

Funding sources: Cardiovascular Systems, Inc. sponsored the ORBIT II study and financially supported the statistical analysis for the subtotal occlusion subanalysis.

Declaration of interest: Michael S. Lee, Richard Shlofmitz, Evan Shlofmitz, and Jeffrey Chambers have consulting agreements with Cardiovascular Systems, Inc. Brad Martinsen and Ann Behrens are employed by Cardiovascular Systems, Inc. George Revtyak has consulting agreements with Cardiovascular Systems, Inc., Terumo, and Lilly.

Abstract

Background/Purpose: Orbital atherectomy is an effective treatment strategy to modify severely calcified coronary lesions prior to stent placement. Traversing a severely calcified subtotal occlusion with the crown may be more challenging compared with a less severely stenotic lesion. The purpose of this ORBIT II subanalysis was to evaluate outcomes post-orbital atherectomy (OA) treatment of lesions with ≥95% stenosis.

Methods/Materials: ORBIT II, a single-arm, prospective, multicenter trial, enrolled 443 subjects with severely calcified coronary lesions. Patients with chronic total occlusions were excluded from the trial. Subjects with the OA device activated were stratified based on pre-procedure percent stenosis: ≥95% stenosis (N=91) and <95% stenosis (N=341). Procedural success and 3-year major adverse cardiac event (MACE) rates were compared.

Results: The severe angiographic complications rates were 6.6% and 6.7% in the ≥95% and <95% stenosis groups, respectively. There was no significant difference in procedural success (94.5% vs. 88.3%, p=0.120). 3-year MACE rates were similar (27.1% vs. 22.5%, p=0.548), as were the rates of cardiac death (5.7% vs. 7.1%, p=0.665) and MI (7.9% vs. 12.1%, p=0.244). The TVR rate was higher in the ≥95% stenosis group (19.1% vs. 7.5%, p=0.004).

Conclusions: In ORBIT II, OA treatment of lesions with ≥95% stenosis resulted in a high rate of procedural success. Although the 3-year revascularization rate was higher in the ≥95% stenosis group, it is not unexpected given the challenge of treating such complex lesions. The results of this analysis suggest that OA may be a reasonable treatment strategy for tight, severely calcified subtotal occlusions.

Keywords: atherectomy, calcification, percutaneous coronary intervention, subtotal occlusion

Summary: The purpose of this ORBIT II subanalysis was to evaluate outcomes post-orbital atherectomy (OA) treatment of lesions with ≥95% stenosis. In ORBIT II, OA treatment of lesions with ≥95% stenosis resulted in a high rate of procedural success. Although the 3-year revascularization rate was higher in the ≥95% stenosis group, it is not unexpected given the challenge of treating such complex lesions. The results of this analysis suggest that OA may be a reasonable treatment strategy for tight, severely calcified subtotal occlusions.

Abbreviations:

ACC = American College of Cardiology

AHA = American Heart Association

CTO = chronic total occlusion

eGFR = estimated glomerular filtration rate

IVUS = intravascular ultrasound

LAD = left anterior descending artery

MACE = major adverse cardiac events

MI = myocardial infarction

MLD = minimal luminal diameter

PCI = percutaneous coronary intervention

OA = orbital atherectomy

OAS = orbital atherectomy system

RCA = right coronary artery

RVD = reference vessel diameter

TLR = target lesion revascularization

TVR = target vessel revascularization

ULN = upper limit of lab normal

Introduction

Coronary artery calcification is commonly observed in patients who undergo coronary angiography, as 73% of lesions contained calcification based upon intravascular ultrasound (IVUS).[1] Percutaneous coronary intervention (PCI) of severely calcified coronary artery lesions is technically challenging due to difficulty in advancing stents and achieving optimal stent expansion. [2] This may explain why PCI of severely calcified lesions is associated with higher rates of ischemic complications.[3]

Coronary atherectomy effectively modifies calcified plaque, facilitating stent delivery and expansion. In the ORBIT II trial, the Diamondback 360® Coronary Orbital Atherectomy System (OAS, Cardiovascular Systems, Inc., St. Paul, MN) was a safe and effective treatment strategy for severely calcified coronary lesions prior to stent delivery at 30-day and 3-year follow-up.[4,5]

The presence of calcium in chronic total occlusions (CTO) is common; calcified CTO PCI is associated with high complication rates.[6] There is no published data regarding orbital atherectomy (OA) treatment of CTOs or tight subtotal occlusions. Subtotal (≥95% stenosis) occlusions may be more complex to treat due to difficulty in traversing the lesion with the OA crown compared with lesions that are not subtotally occluded. The purpose of this ORBIT II subanalysis was to evaluate outcomes post-OA treatment of lesions with ≥95% stenosis.

Material and methods

Study design. ORBIT II was a prospective, non-blinded, single-arm, clinical trial that enrolled 443 consecutive subjects with severely calcified coronary lesions from 49 U.S. centers.[4] Key trial inclusion criteria included: (1) target vessel reference diameter between 2.5 to 4 mm with a

stenosis ≥70% and <100% or stenosis ≥50% and <70% with evidence of clinical ischemia via IVUS minimum lumen area ≤4.0 mm^2, fractional flow reserve value ≤0.8, or positive stress test; (2) target lesion length ≤40 mm; and (3) evidence of severe calcium deposit at the lesion site defined as presence of angiographic radio-opacities noted without cardiac motion prior to contrast injection involving both sides of the arterial wall in at least one location, total calcium length ≥15 mm that extends partially into the target lesion, or presence of ≥270° of calcium on IVUS at one cross section. Key exclusion criteria included: (1) acute myocardial infarction (MI) (defined as creatine kinase-MB [CK-MB] >1× upper limit of lab normal (ULN) within 30 days of the index procedure); (2) target vessel with stent from previous PCI unless the stent was in a different branch than the target lesion and was implanted over 30 days prior with no higher than 30% in-stent restenosis; (3) chronic renal failure unless undergoing hemodialysis, or had a serum creatinine level >2.5 mg/dl; and (4) left ventricular ejection fraction ≤25%. The use of advanced intracoronary imaging was not required as part of the ORBIT II study protocol and was left to operator discretion. All participants provided informed consent and the study was approved by each institutional review/ethics committee. Subject follow-up included a clinic visit at 30 days and telephone call or clinic visit at 1, 2, and 3 years post procedure.

Study population. Subjects with the OA device activated were stratified according to pre-procedure percent stenosis as assessed by the Investigator: ≥95% stenosis (N=91) and <95% stenosis (N=341).

Study device. The mechanism of OA is differential sanding, in which calcified plaque is modified while it flexes away from healthy softer tissue. The eccentrically mounted diamond-coated crown spins over the ViperWire (Cardiovascular Systems, Inc.) and expands radially via centrifugal force. Increasing the time in contact with the lesion, number of passes, and rotational

speed increase luminal gain as the crown is moved back and forth across the lesion. The elliptical orbit permits blood and micro-debris to flow past the crown, which continuously disperses the particulate. The ViperSlide (Cardiovascular Systems, Inc.) solution is infused into the drive shaft to cool the crown and reduce the risk of thermal injury to the target vessel.

Study outcomes. Procedural success was defined as successful stent delivery with a final residual stenosis of < 50% and without in-hospital major adverse cardiac events (MACE). MACE was defined as the composite of cardiac death, MI, and target vessel revascularization/target lesion revascularization (TVR/TLR). Myocardial infarction was defined as creatine kinase-myocardial band level > 3 times upper limit of normal with or without a new pathologic Q-wave. Target vessel revascularization was defined as repeat revascularization of the target vessel (inclusive of the target lesion) after completion of the index procedure. MACE was defined as the composite of cardiac death, MI, and TVR. The angiographic core laboratory (Cleveland Clinic Foundation, Cleveland, Ohio) analyzed the procedural angiograms and reported the final minimum lumen diameter and final percentage of residual stenosis as well as the presence and type of dissections and perforations.

Statistical analysis. Continuous variables are presented as mean ± standard deviation and categorical variables are presented as percentages. The two groups were compared using the Wilcoxon rank-sum test for continuous parameters and Fisher's exact test for categorical parameters. A Kaplan-Meier analysis with a confidence interval based on Peto's method was used to estimate the MACE rate as well as the individual components including cardiac death, MI, and TVR. Statistical comparisons of the Kaplan-Meier event rates were made using Cox proportional hazards model. Multivariable Cox proportional hazards regression was performed to identify independent predictors of 3-year TVR. Covariates in the model included: age, history of

diabetes mellitus, smoking history (current/former vs. never), history of MI, history of coronary artery bypass grafting, eGFR (<50 vs. ≥50), left ventricular ejection fraction, pre-procedure reference vessel diameter (RVD), target lesion length, pre-procedure stenosis (≥95% vs. <95%), bare metal stent vs. drug eluting stent, number of stents, and ratio of highest stent diameter to RVD. The entry criteria in the multivariable model was an alpha level of 0.20; significant predictors of outcomes in the final multivariable model were identified at a 0.05 alpha. Statistical analyses were performed with either SAS software system (SAS Institute, Inc) or R (R Core Team 2012; R Foundation for Statistical Computing).

Results

Subject demographics and lesion characteristics. Subjects with ≥95% stenosis were older (74.2 ± 9.1 years vs. 70.8 ± 10.0 years, p=0.003) and had lower eGFR (70.5 ± 24.5 mL/min/1.73 m^2 vs. 77.0 ± 26.7 mL/min/1.73 m^2, p=0.042) (Table 1). Otherwise, the groups were well matched in terms of baseline demographics. As shown in Table 2, compared with the <95% stenosis group, in the ≥95% stenosis there were fewer left anterior descending (LAD) lesions (35.2% vs. 56.6%, p<0.001) and more right coronary artery (RCA) lesions (45.1% vs. 25.2%, p<0.001). Additionally, there were fewer Type B1 lesions in the ≥95% stenosis group (17.6% vs. 28.2%, p=0.044). The mean pre-procedure percent stenosis was 96.1% and 81.1%, in the ≥95% and <95% stenosis groups, respectively (p<0.001).

Procedural and angiographic results. Procedural parameters are presented in Table 3. Compared with the <95% stenosis group, the ≥95% stenosis group had a smaller post-OAS minimal luminal diameter (1.0 ± 0.6 mm vs. 1.3 ± 0.5, p<0.001), higher post-OAS residual percent stenosis (66.2 ± 19.1% vs. 56.7 ± 16.3%, p<0.001), higher usage of drug-eluting stents

(95.0% vs. 86.8%, p=0.013), and a higher maximum stent deployment pressure (14.6 ± 3.3 atm vs. 13.6 ± 3.1 atm, p=0.006). Stents in the <95% stenosis group were significantly shorter in length (20.2 ± 7.3 mm vs. 22.3 ± 7.7 mm, p=0.006) and significantly larger in diameter (3.0 ± 0.4 mm vs. 2.9 ± 0.4 mm, p=0.020). Procedural success was 94.5% and 88.3% in the ≥95% stenosis and <95% stenosis groups, respectively (p=0.120). The in-hospital MI rate (CK-MB > 3X ULN) was higher in the <95% stenosis group (3.3% vs. 11.1%, p=0.025); however, the MI rates did not differ using the more clinically-relevant SCAI MI definition (≥95% stenosis: 1.1% vs. <95% stenosis: 2.3%, p=0.692).[7] The overall severe angiographic complication rates were nearly identical in both groups (6.6% vs. 6.7%, p>0.99) (Table 4).

30-day and 3-year MACE. There was no difference in the 30-day MACE rate in the ≥95% stenosis and <95% stenosis groups (5.5% vs. 11.7%, p=0.099), or in the components of cardiac death (0% vs. 0.3, p=0.997) and TVR/TLR (2.2% vs. 0.9%, p=0.319) (Table 5, Figure 1). However, the MI rate at 30 days was lower in the ≥95% stenosis group (3.3% vs. 11.4%, p=0.035). At 3-year follow-up, the MACE rates were similar in both groups (27.1% vs. 22.5%, p=0.55), as were the rates of cardiac death (5.7% vs. 7.1%, p=0.665) and MI (7.9% vs. 12.1%, p=0.244). However, the 3–year TVR/TLR rate was higher in the ≥95% stenosis group (19.1% vs. 7.5%, p=0.004). The final multivariable model identified ≥95% stenosis group [HR 2.87 (95% CI: 1.49, 5.53), p=0.002], bare metal stent usage [HR 2.95 (95% CI: 1.19, 7.28), p=0.019], and pre-procedure RVD [HR 0.13 (95% CI: 0.02, 0.76), p=0.024] as independent predictors of 3-year TVR (Table 6).

Discussion

In the only analysis of its kind, the results of our analysis suggest that OA is a feasible and safe treatment for patients with severely calcified subtotal occlusions both at short and long-term follow-up. However, the TVR rate at 3 years was higher in the ≥95% stenosis group.

Percutaneous coronary intervention of heavily calcified coronary artery lesions that are severely stenotic may be technically more challenging compared to less stenotic lesions. Severely calcified lesions that are subtotally occluded may lead to procedural failure due to the inability to cross the lesion. More aggressive advancement of the classic crown may be required to successfully traverse the lesion. Despite the mean pre-procedure minimum luminal diameter of 0.1 mm in the ≥95% stenosis group, the procedural success rate was 94.5%, which fared well compared with the <95% stenosis group (88.3%). The rate of severe angiographic complications was nearly identical in both groups. Despite the higher percent stenosis, the OA crown was able to treat the subtotal occlusion without a higher complication rate. In particular, the rate of persistent slow flow/no reflow was 1.1% even though the plaque burden was high in the ≥95% stenosis group. The perforation rate was numerically higher in the ≥95% stenosis group (3.3% vs. 1.5%, p=0.374). Proper OA technique, including slow advancement of the crown (1 mm/s), may reduce the risk of perforation.[8,9] The in-hospital MI rate (CK-MB > 3X ULN) was significantly lower in the ≥95% stenosis group; however, when calculated using the SCAI MI definition which includes a cardiac biomarker elevation threshold which has been strongly linked to adverse clinical outcomes, the MI rates were similar in both groups.[7]

The ≥95% stenosis group had a higher 3-year TVR rate; as shown in the multivariable analysis, ≥95% stenosis group, bare metal stent usage, and decreasing pre-procedure RVD were independent predictors of 3-year TVR. The ≥95% stenosis group required a higher maximum

deployment pressure, which is also consistent with the larger plaque volume. Despite this, the 3-year TVR/TLR rate of 19.1% in the ≥95% stenosis group compares favorably with the results of the 2-year TVR rate in patients who underwent rotational atherectomy in the ROTAXUS trial (19.3%), albeit differences in level of calcification and types of stents used.[10] There is no published rotational atherectomy study that stratified by lesion stenosis severity.

Several techniques can be utilized to enhance successful passage of the OA crown across subtotal occlusions. Optimal co-axial guide catheter positioning can provide the sufficient support to traverse the lesion. Placement of the ViperWire at the distal portion of the vessel increases stability and anchoring, providing an optimal "rail system." Placement of the crown partially into the lesion at initial activation, but not tight or fully occlusive, may facilitate crossing. A slow and steady advancement of the crown at 1mm/sec is preferred rather than rapidly engaging the lesion. Lastly, the use of a guide extension catheter, such as a Guideliner (Vascular Solutions, Minneapolis, MN), may facilitate procedural success by supporting the guide catheter. Additional OAS techniques and best practices can be found in recently published review articles.[8,9,11,12]

Study Limitations

This was a post-hoc subanalysis of ORBIT II—a non-randomized pivotal trial. The ≥95% stenosis cohort had a small number of subjects and the pre-procedure stenosis was reported by the Investigator via angiography. A stenosis of ≥95% may not be universally accepted as a subtotal occlusion.

Conclusions

In the ORBIT II trial, OA treatment of lesions with ≥95% stenosis resulted in a high rate of procedural success. Although the 3-year revascularization rate was higher in the ≥95% stenosis group, it is not unexpected given the challenge of treating such complex lesions. The results of this analysis suggest that OA may be a reasonable treatment strategy for PCI of tight, severely calcified subtotal occlusions.

References

[1] Mintz GS, Popma JJ, Pichard AD, Kent KM, Satler LF, Chuang YC, et al. Patterns of calcification in coronary artery disease. A statistical analysis of intravascular ultrasound and coronary angiography in 1155 lesions. Circulation 1995;91:1959–65.

[2] Lee MS, Shah N. The Impact and Pathophysiologic Consequences of Coronary Artery Calcium Deposition in Percutaneous Coronary Interventions. J Invasive Cardiol 2016;28:160–7.

[3] Lee MS, Yang T, Lasala J, Cox D. Impact of coronary artery calcification in percutaneous coronary intervention with paclitaxel-eluting stents: Two-year clinical outcomes of paclitaxel-eluting stents in patients from the ARRIVE program. Catheter Cardiovasc Interv 2016;88:891–7.

[4] Chambers JW, Feldman RL, Himmelstein SI, Bhatheja R, Villa AE, Strickman NE, et al. Pivotal trial to evaluate the safety and efficacy of the orbital atherectomy system in treating de novo, severely calcified coronary lesions (ORBIT II). JACC Cardiovasc Interv 2014;7:510–8.

[5] Lee M, Généreux P, Shlofmitz R, Phillipson D, Anose BM, Martinsen BJ, et al. Orbital atherectomy for treating de novo, severely calcified coronary lesions: 3-year results of the pivotal ORBIT II trial. Cardiovasc Revasc Med 2017;18:261–4.

[6] Karacsonyi J, Karmpaliotis D, Alaswad K, Jaffer FA, Yeh RW, Patel M, et al. Impact of Calcium on Chronic Total Occlusion Percutaneous Coronary Interventions. Am J Cardiol 2017;120:40–6. doi:10.1016/j.amjcard.2017.03.263.

[7] Moussa ID, Klein LW, Shah B, Mehran R, Mack MJ, Brilakis ES, et al. Consideration of a new definition of clinically relevant myocardial infarction after coronary revascularization:

an expert consensus document from the Society for Cardiovascular Angiography and Interventions (SCAI). J Am Coll Cardiol 2013;62:1563–70. doi:10.1016/j.jacc.2013.08.720.

[8] Shlofmitz E, Martinsen BJ, Lee M, Rao SV, Généreux P, Higgins J, et al. Orbital atherectomy for the treatment of severely calcified coronary lesions: evidence, technique, and best practices. Expert Rev Med Devices 2017;14:867–79.

[9] Lee MS, Martinsen BJ, Shlofmitz R, Chambers JW. Coronary Orbital Atherectomy. Textb. Catheter-Based Cardiovasc. Interv., Springer, Cham; 2018, p. 681–98. doi:10.1007/978-3-319-55994-0_42.

[10] de Waha S, Allali A, Büttner H-J, Toelg R, Geist V, Neumann F-J, et al. Rotational atherectomy before paclitaxel-eluting stent implantation in complex calcified coronary lesions: Two-year clinical outcome of the randomized ROTAXUS trial. Catheter Cardiovasc Interv 2016;87:691–700.

[11] Chambers JW, Behrens AN, Martinsen BJ. Atherectomy Devices for the Treatment of Calcified Coronary Lesions. Interv Cardiol Clin 2016;5:143–51.

[12] Chambers JW, Martinsen BJ. Orbital Atherectomy in the Coronary Arteries. In: Shammas NW, editor. Textb. Atherectomy, HMP Communications, LLC; 2016, p. 217–40.

Figure Legend

Figure 1. Time-to-Event Curves through 3 Years.

Comparison of the cumulative event rates through 3-year follow-up in ORBIT II subjects with ≥95% pre-procedure stenosis (N=91) and <95% pre-procedure stenosis (N=341). (A) Major adverse cardiac events. (B) Cardiac death. (C) Myocardial infarction. (D) Target vessel revascularization.

Table 1. Subject Demographics.

	≥95% pre-procedure stenosis (N=91)	<95% pre-procedure stenosis (N=341)	P-value
Age (years)	74.2 ± 9.1	70.8 ± 10.0	0.003
Male	56 (61.5)	222 (65.1)	0.540
Ethnicity			0.116
Caucasian	85 (93.4)	297 (87.1)	
Black or African American	2 (2.2)	21 (6.2)	
Asian	0 (0.0)	8 (2.3)	
Hispanic or Latino	2 (2.2)	13 (3.8)	
Native American	0 (0.0)	1 (0.3)	
Other	2 (2.2)	1 (0.3)	
Body mass index	29.3 ± 6.2	29.3 ± 5.7	0.452
eGFR (mL/min/1.73 m^2)	70.5 ± 24.5 (N=90)	77.0 ± 26.7 (N=340)	0.042
eGFR <30 mL/min/1.73 m^2	4 (4.4)	10 (2.9)	0.504
eGFR 30-50 mL/min/1.73 m^2	13 (14.4)	27 (7.9)	0.067
eGFR >50 mL/min/1.73 m^2	73 (81.1)	303 (89.1)	0.049
History of:			
Diabetes mellitus	28 (30.8)	127 (37.2)	0.271
Hypertension	82 (90.1)	313 (91.8)	0.673
Dyslipidemia	83 (91.2)	315/340 (92.6)	0.658
Stroke/transient ischemic attack	9 (9.9)	30/340 (8.8)	0.837
Myocardial infarction	18/88 (20.5)	76/339 (22.4)	0.774
Angina	69 (75.8)	270 (79.2)	0.477
Stable	48/69 (69.6)	169/270 (62.6)	
Unstable	21/69 (30.4)	101/270 (37.4)	
Prior percutaneous coronary intervention	38 (41.8)	160/337 (47.5)	0.346
Prior coronary artery bypass grafting	18 (19.8)	46 (13.5)	0.138
Left ventricular ejection fraction (%)	56.1 ± 10.9	56.7 ± 9.2 (N=335)	0.884

	≥95% pre-procedure stenosis (N=91)	<95% pre-procedure stenosis (N=341)	P-value
Smoking			0.281
No, Never smoked	30 (33.0)	114 (33.4)	
Yes, Current smoker	10 (11.0)	60 (17.6)	
Yes, Former smoker	51 (56.0)	167 (49.0)	

Values are n (%) or mean ± standard deviation
eGFR = estimated glomerular filtration rate

Table 2. Vessel & Lesion Characteristics.

	≥95% pre-procedure stenosis (N=91)	<95% pre-procedure stenosis (N=341)	P-value
Target lesion vessel			
Left anterior descending artery	32 (35.2)	193 (56.6)	<0.001
Left circumflex artery	14 (15.4)	49 (14.4)	0.867
Left main coronary artery	4 (4.4)	6 (1.8)	0.229
Right coronary artery	41 (45.1)	86 (25.2)	<0.001
Ramus	0 (0.0)	7 (2.1)	0.354
Pre-procedure target lesion length (mm)	20.4 ± 9.2	18.5 ± 8.8	0.062
Pre-procedure average reference vessel diameter (mm)	3.0 ± 0.4	3.1 ± 0.4	0.047
ACC/AHA lesion classification			
A	0 (0.0)	0 (0.0)	—
B1	16 (17.6)	96 (28.2)	0.044
B2	42 (46.2)	153 (44.9)	0.906
C	33 (36.3)	92 (27.0)	0.091
Pre-procedure minimum luminal diameter (mm)	0.1 ± 0.1	0.6 ± 0.2	<0.001
Pre-procedure percent stenosis (%)	96.1 ± 1.8	81.1 ± 7.3	<0.001
Subjects with calcification determined by angiography only	90 (98.9)	307 (90.0)	0.004
Total length of calcium (including segmented) (mm)	29.9 ± 14.5	28.0 ± 15.5	0.124
Subjects with calcium visible on both sides of the vessel	90 (100.0)	307 (100.0)	>0.99
Subjects with calcification determined by IVUS	1 (1.1)	34 (10.0)	0.004
Maximum degree of calcium via IVUS (°)	360.0 ± 0	293.1 ± 35.1	0.152

Values are n (%) or mean ± standard deviation

ACC = American College of Cardiology, AHA = American Heart Association, IVUS = intravascular ultrasound

Table 3. Final Overall Procedural Results.

	≥95% pre-procedure stenosis (N=91)	<95% pre-procedure stenosis (N=341)	P-value
OAS speed(s) used (rpm)			0.766
Low only (80,000)	17 (18.7)	76 (22.3)	
Low and high (80,000/120,000)	70 (76.9)	247 (72.4)	
High only (120,000)	4 (4.4)	18 (5.3)	
Average individual device run time (seconds)	19.2 ± 6.5 (N=90)	19.6 ± 5.4 (N=340)	0.831
Total device run time (seconds)	75.3 ± 62.8	64.5 ± 39.6 (N=340)	0.658
Post-OAS minimal luminal diameter (mm)	1.0 ± 0.6	1.3 ± 0.5	<0.001
Post-OAS residual stenosis (%)	66.2 ± 19.1	56.7 ± 16.3	<0.001
Subjects treated with post-OAS/pre-stent balloon dilations	44 (48.4)	133 (39.0)	0.119
Post-OAS/pre-stent balloons used per subject	1.4 ± 0.8 (N=44)	1.4 ± 0.8 (N=133)	0.668
Maximum inflation pressure (atmospheres)	12.0 ± 3.4 (N=44)	12.0 ± 4.1 (N=132)	0.716
Time at maximum pressure (seconds)	30.7 ± 30.4 (N=44)	26.4 ± 21.6 (N=131)	0.709
Post-OAS balloon angioplasty MLD (mm)	1.6 ± 0.7 (N=44)	1.9 ± 0.6 (N=131)	0.095
Post-OAS balloon angioplasty residual stenosis (%)	46.3 ± 22.3 (N=44)	40.5 ± 19.5 (N=131)	0.136
Subjects with stent placed	89 (97.8)	338 (99.1)	0.284
Post-OAS stents used per subject	1.3 ± 0.6 (N=89)	1.2 ± 0.6 (N=338)	0.046
Types of stents used in study			
Bare metal stent	5/119 (4.2)	54/417 (12.9)	0.007
Covered stent	1/119 (0.8)	1/417 (0.2)	0.395
Drug-eluting stent	113/119 (95.0)	362/417 (86.8)	0.013
Stent length* (mm)	22.3 ± 7.7 (N=115)	20.2 ± 7.3 (N=405)	0.006

	≥95% pre-procedure stenosis (N=91)	<95% pre-procedure stenosis (N=341)	P-value
Stent diameter* (mm)	2.9 ± 0.4 (N=115)	3.0 ± 0.4 (N=405)	0.020
Ratio of highest stent diameter to reference vessel diameter*	1.0 ± 0.1 (N=89)	1.0 ± 0.1 (N=336)	0.567
Maximum deployment pressure (atmospheres)	14.6 ± 3.3 (N=89)	13.6 ± 3.1 (N=336)	0.006
Post-stent residual stenosis (%)	5.7 ± 11.2 (N=89)	5.8 ± 11.9 (N=337)	0.958
Final procedure MLD (mm)	2.8 ± 0.6 (N=87)	2.9 ± 0.5 (N=330)	0.546
Final procedure stenosis (%)	5.7 ± 14.6	4.0 ± 13.8 (N=340)	0.298
Total procedure time (minutes)	50.7 ± 31.9	52.0 ± 28.3 (N=340)	0.290
Total fluoroscopy time (minutes)	19.5 ± 15.0 (N=90)	17.4 ± 10.8 (N=338)	0.426
Total volume of contrast used (mL)	178.0 ± 93.7 (N=90)	171.1 ± 82.4 (N=340)	0.646
Procedural success	86 (94.5)	301 (88.3)	0.120
Successful stent delivery	89 (97.8)	336 (98.5)	0.642
< 50% residual stenosis	90 (98.9)	337 (98.8)	>0.99
In hospital MACE	4 (4.4)	39 (11.4)	0.049
Cardiac death	0 (0.0)	1 (0.3)	>0.99
Myocardial infarction (CK-MB >3X ULN)	3 (3.3)	38 (11.1)	0.025
Non Q-wave	3 (3.3)	35 (10.3)	0.037
Q-wave	0 (0.0)	3 (0.9)	>0.99
TVR	1 (1.1)	2 (0.6)	0.509
SCAI MI	1 (1.1)	8 (2.3)	0.692

	≥95% pre-procedure stenosis (N=91)	<95% pre-procedure stenosis (N=341)	P-value
Values are n (%) or mean ± standard deviation			
*Specific to stents successfully deployed			
MACE = major adverse cardiac event; MI = myocardial infarction; MLD = minimal luminal diameter; OAS = orbital atherectomy system; SCAI = Society for Cardiovascular Angiography and Interventions; TVR = target vessel revascularization			

Table 4. Severe Angiographic Complications.

	≥95% pre-procedure stenosis (N=91)	<95% pre-procedure stenosis (N=341)	P-value
Severe angiographic complications	6 (6.6)	23 (6.7)	>0.99
Severe dissection (Type C, D, E, and F)	2 (2.2)	11 (3.2)	>0.99
Perforation	3 (3.3)	5 (1.5)	0.374
Persistent slow flow/no reflow	1 (1.1)	2 (0.6)	0.509
Abrupt closure	1 (1.1)	7 (2.1)	>0.99
Values are n (%)			

Table 5. Cumulative MACE Rates (as estimated by Kaplan-Meier).

	≥95% pre-procedure stenosis (N=91)	<95% pre-procedure stenosis (N=341)	P-value
30-day major adverse cardiac events	5.5	11.7	0.099
Cardiac death	0	0.3	0.997
Myocardial infarction (CK-MB >3X ULN)	3.3	11.4	0.035
Non Q-wave	3.3	10.3	0.056
Q-wave	0	1.2	0.994
TVR/TLR	2.2	0.9	0.319
TLR	1.1	0.6	0.610
TVR (non-TLR)	1.1	0.3	0.355
3-year major adverse cardiac events	27.1	22.5	0.548
Cardiac death	5.7	7.1	0.665
Myocardial infarction (CK-MB >3X ULN)	7.9	12.1	0.244
Non Q-wave	6.6	10.9	0.236
Q-wave	1.3	1.2	0.947
TVR/TLR	19.1	7.5	0.004
TLR	16.9	5.2	0.002
TVR (non-TLR)	4.7	2.6	0.318

Values are %

MACE = major adverse cardiac events; TLR = target lesion revascularization; TVR = target vessel revascularization

Table 6. Analysis of Independent Predictors of 3-Year TVR

	Unadjusted Hazard Ratio (95% CI)	P-value	Adjusted Hazard Ratio (95% CI)	P-value
Pre-procedure stenosis (≥95% vs. <95%)	2.80 [1.47, 5.32]	0.002	2.87 [1.49, 5.53]	0.002
Age (per 10 years)	1.00 [1.00, 1.00]	0.558		
History of diabetes mellitus	0.95 [0.49, 1.86]	0.885		
Current/former smoker	0.76 [0.40, 1.47]	0.419		
History of MI	0.86 [0.38, 1.97]	0.724		
History of coronary artery bypass grafting	0.91 [0.36, 2.33]	0.846		
eGFR (<50 vs. ≥50 mL/min/1.73 m^2)	0.64 [0.20, 2.07]	0.452		
LVEF (per 10%)	1.00 [1.00, 1.00]	0.787		
Pre-procedure RVD (per 0.5 mm)	0.14 [0.02, 0.80]	0.027	0.13 [0.02, 0.76]	0.024
Target lesion length (mm)	1.03 [0.99, 1.06]	0.098		
Bare metal stent vs. drug-eluting stent	1.95 [0.81, 4.66]	0.134	2.95 [1.19, 7.28]	0.019
Number of stents	0.97 [0.48, 1.96]	0.937		
Ratio of highest stent diameter to RVD	0.03 [0.00, 2.96]	0.136		

eGFR = estimated glomerular filtration rate; LVEF = left ventricular ejection fraction; MI = myocardial infarction; RVD = reference vessel diameter; TVR = target vessel revascularization

Highlights

- Outcomes post-OA treatment of severely calcified ≥95% stenosis lesions were assessed
- Procedural success and 3-year MACE were similar in ≥95% and <95% stenosis groups
- Higher 3-year TVR in ≥95% stenosis group not unexpected given challenge of treating such complex lesions
- OA may be a reasonable treatment strategy for tight, severely calcified subtotal occlusions

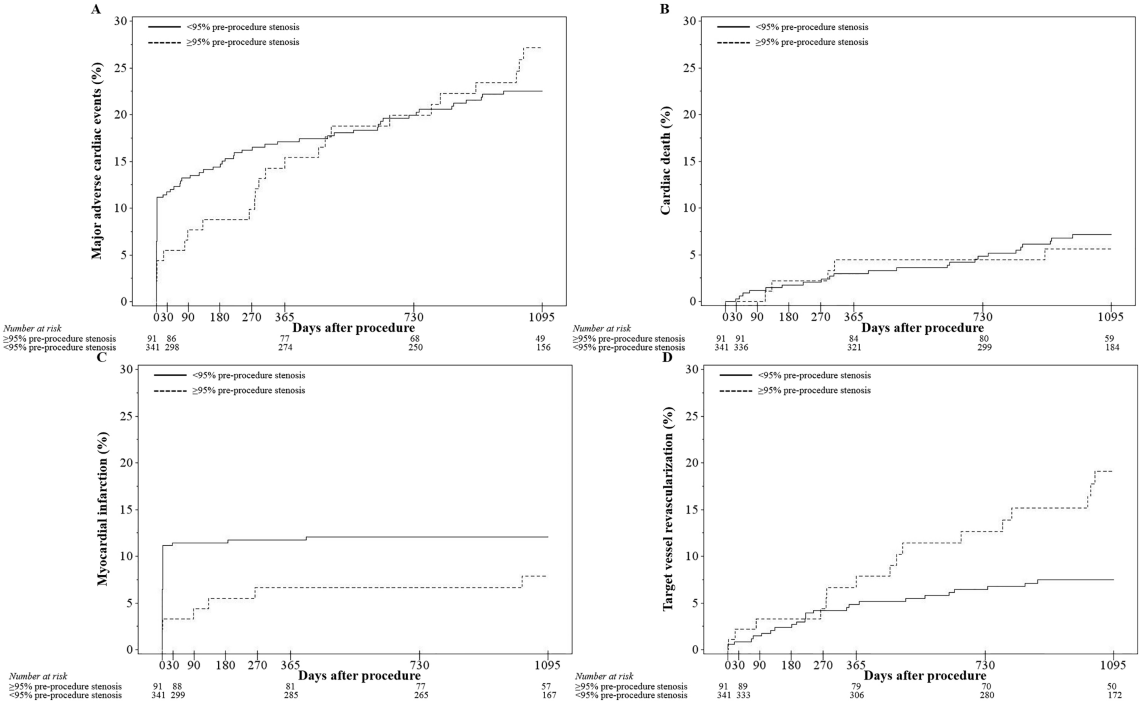

Figure 1