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Clinical efficacy of optical coherence tomography-guided versus intravascular ultrasound-guided rotational atherectomy for calcified coronary lesion

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Running title: OCT vs IVUS rotational atherectomy

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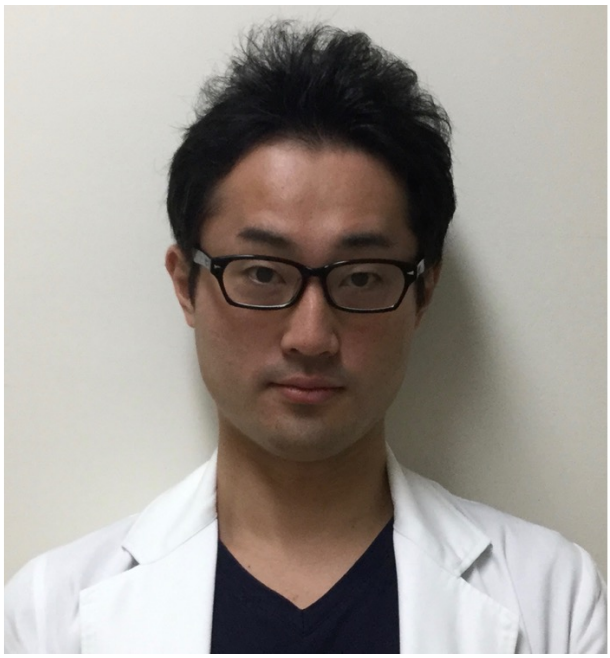

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<Abstract>

Aims

We aimed to evaluate whether optical coherence tomography (OCT)-guided rotational atherectomy (RA) improves stent expansion and clinical outcomes compared to intravascular ultrasound (IVUS)-guided RA.

Methods and results

We identified 247 de-novo calcified coronary lesions that underwent RA from our database between September 2013 and December 2017. Of these, lesions with no intravascular imaging data (n=11), poor image quality (n=7), balloon angioplasty alone (n=16), and complications (2 burr entrapment, 2 perforation) were excluded. Finally, 88 and 121 lesions that underwent OCT-guided and IVUS-guided RA, respectively, were enrolled. The primary endpoint of the present study was percent stent expansion. Burr upsizing was more frequently performed (55% vs. 32%, P=0.001) and the final burr size was significantly larger (1.75[1.50-1.75] vs. 1.50[1.50-1.75] mm, P<0.001) in the OCT-guided RA group. Percent stent expansion was significantly larger in the OCT-guided RA group (83±15% vs. 72±16%, P=0.0004). Although TLR at 1 year was lower in the OCT-guided RA group, there was no statistical difference (6.8% vs. 11.6%, P=0.25).

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Conclusion

OCT-guided RA for calcified coronary lesions resulted in larger percent stent expansion compared to IVUS-guided RA. OCT-guided RA may be ideal for treating calcified coronary lesions.

Keywords: optical coherence tomography; Rotablator; Calcified stenosis

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Condensed Abstract

Optimal calcified lesion modification via RA is crucial for good stent expansion and for preventing restenosis. OCT is superior to IVUS for the detailed evaluation of calcification. Our study was a retrospective analysis of 88 and 121 lesions that underwent OCT-guided and IVUS-guided RA, respectively. Burr upsizing was more frequently performed and the final burr size was significantly larger in the OCT-guided RA. Percent stent expansion was significantly larger in the OCT-guided RA. OCT-guided RA may be ideal for improving the clinical outcomes of calcified coronary lesions that are still challenging.

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Abbreviations

Percutaneous coronary intervention (PCI)

Drug-eluting stent (DES)

Target lesion revascularization (TLR)

Rotational atherectomy (RA)

Intravascular ultrasound (IVUS)

Optical coherence tomography (OCT)

Optical frequency domain imaging (OFDI)

Cross-sectional area (CSA)

Quantitative coronary angiography (QCA)

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<Introduction>

The severely calcified lesion still remains challenging to treat with percutaneous coronary intervention (PCI). Severe calcification is commonly associated with procedural complications, balloon delivery failure, stent under-expansion, and high target lesion revascularization (TLR) incidence.[1, 2] Lesion modification using rotational atherectomy (RA) facilitates optimal stent implantation and reduces major adverse cardiac events at follow-up.[3] Intravascular ultrasound (IVUS)-guided PCI is known to be associated with better clinical outcomes compared to angiography-guided PCI.[4] However, IVUS cannot provide detailed quantitative assessment of calcifications because ultrasound cannot penetrate calcium. Optical coherence tomography (OCT) has a higher resolution than IVUS and can clearly visualize calcium distribution without an acoustic shadow.[5] To achieve maximum drug-eluting stent (DES) performance for severely calcified lesions, selecting the optimal RA endpoint is important. We aimed to evaluate how OCT-guided RA affects PCI, including the selection of burr size for RA, stent expansion, and whether restenosis is reduced, compared with IVUS-guided RA for calcified coronary lesions.

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<METHODS>

Study protocol and subjects

This study was a single-center retrospective observational study. Between September 2013 and December 2017, we performed RA for 247 de-novo calcified coronary lesions. The indication for RA was lesions with >180° arc of calcium assessed by intracoronary imaging or lesions with angiographic calcification where an imaging catheter could not pass through. Although the intravascular imaging devices used were at each operator's discretion, OCT-guided RA was preferred except in renal dysfunction (serum creatinine >2.0 mg/dl), ostial lesion with challenging blood removal, and tortuous calcified lesions in which OCT catheter delivery appeared difficult. The study protocol conformed to the Declaration of Helsinki and was approved by the institutional review board of our hospital. All patients provided written informed consent regarding the procedures and collection, and analysis of anonymized data for research purposes.

Procedure and follow-up

All patients received a bolus injection of heparin (5000 IU) and activated coagulation time was maintained at >300 s with an additional bolus of heparin. Dual antiplatelet therapy with 100 mg/day aspirin and either 75 mg/day clopidogrel or 3.75 mg/day prasugrel was continued

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for at least 1 year post-procedurally. Initially, we evaluated the severity of calcification using intravascular imaging. A frequency-domain OCT system (Ilumien Optis™; Abbott Vascular, Santa Clara, CA, U.S.A.) or optical frequency domain imaging (OFDI) system (LUNAWAVE™; Terumo, Tokyo, Japan) was used for OCT-guided RA, and an IVUS system (iLab™; Boston Scientific, Natick, MA, USA, or VISIWAVE™; Terumo, Tokyo, Japan) was used for IVUS-guided RA. We used Rotablator™ Rotational Atherectomy System (Boston Scientific, Natic, MA, USA) for lesion atherectomy in all cases. The conventional 0.014-inch guidewire was replaced with the 0.009-inch RotaWire™ Floppy guidewire (Boston Scientific, Natic, MA, USA) or RotaWire™ Extra Support guidewire (Boston Scientific, Natic, MA, USA) at the operator's discretion. We used up to 2 burr sizes in the procedure. The initial burr size was chosen based on the pre-procedural intravascular imaging findings, and when the imaging catheter could not pass the lesion, we selected either a 1.25 or 1.5-mm burr based on the angiographic vessel size. Burr speed was selected at 220,000 rpm, with a run duration of 10–15 s, or less in cases where there was a drop of >5000 rpm. After initial atherectomy, we performed intravascular imaging again and decided whether burr upsizing was needed. Representative burr selection in OCT-guided RA is shown in Fig. 1. In OCT-guided RA, we measured the thickness of the calcification at the smallest cross-sectional area (CSA) with the

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greatest extent of calcification and decided whether burr upsizing was needed. Operators tried to make a thin part of the calcification, so it could crack with subsequent balloon dilatation; however, the target thickness of calcification was dependent on each operator's discretion. Stent diameter was determined by measuring the external elastic lamina diameter at the proximal and distal reference sites. We determined stent length by measuring the distance from the distal to the proximal reference sites. Fig. 2 shows a representative case of IVUS-guided RA. In-IVUS guided RA, we were unable to measure calcium thickness; therefore, we estimated the need for burr upsizing depending on the minimum lumen CSA, whether crack formation occurred after RA, and whether the vessel behind the calcification was viewable. Stent diameter was determined by measuring the external elastic lamina at the proximal and distal reference sites. Stent length was determined as in OCT-guided RA. We performed a final intracoronary imaging after stent implantation with subsequent post-dilatation. Patients were followed up at our outpatient clinic, and clinical data were obtained from hospital records and by telephone interview when patients did not attend the outpatient clinic.

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Quantitative coronary angiography

Quantitative coronary angiography (QCA) analysis was performed pre- and

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post-procedurally using computer-based software (Heart II ver 2.0.2.3, GADELIUS) by an experienced independent operator who was unaware of the patient characteristics and study objectives. Optimal views of the lesions were obtained at baseline, and the same projection angle was used after stenting.

Intracoronary image acquisition and analysis

In OCT-guided RA, the OCT catheter (Dragonfly^{TM} OPTIS; Abbott Vascular, Santa Clara, CA, U.S.A.) or OFDI catheter (Fast View^{TM}; Terumo, Tokyo, Japan) was advanced distal to the lesion, and contrast medium was injected during automatic pullback of the catheter at a rate of 20 mm/s. OCT images were analyzed using an offline review workstation (LightLab Imaging, Inc., Abbott Vascular, Santa Clara, CA, U.S.A.) or offline OFDI analysis software (Lunawave Offline Viewer; Terumo, Tokyo, Japan). In IVUS-guided RA, the IVUS catheter (OPTICROSS^{TM}; Boston Scientific, Natick, MA, USA or ViewIT® Terumo, Tokyo, Japan) was located at the distal site of the lesions and automatically pull-backed at a rate of 1.0 mm/s. IVUS images were analyzed using computerized planimetry software (EchoPlaque; INDEC Medical Systems, Mountain View, CA). In OCT or OFDI images, calcification was defined as signal-poor or heterogeneous regions with sharply delineated borders.[6] In IVUS images, calcification was defined as bright echoes with acoustic shadowing. All images were

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independently assessed by two investigators who were blinded to patient and clinical data. A third reviewer resolved any discordance. All intravascular images after stent implantation were analyzed at 1-mm intervals within the stented segment. Minimum stent area was measured in each stent. The proximal and distal reference were set at sites with the largest lumen area within 10 mm of the stenosis.[6] The mean reference lumen CSA was defined as the average lumen CSA at the proximal and distal reference sites. Percent stent expansion was defined as minimum stent area divided by the mean reference lumen CSA. Qualitative analysis regarding stent malapposition, stent edge dissection, and tissue protrusion was performed in every frame. [7, 8] Stent malapposition was considered when the distance between the center reflection of the stent and the vessel wall was greater than stent thickness plus the OCT resolution limit (20μm). Stent edge dissection was defined as arterial disruption adjacent to the stent where a flap of tissue could be clearly differentiated from the underlying plaque. Tissue protrusion was defined as the prolapse of tissue through the stent struts into the lumen.

Endpoints

The primary endpoint was percent stent expansion at the time of final intravascular imaging evaluation. As OCT measurements are smaller than IVUS measurements,[8] percent stent

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expansion was chosen as a primary endpoint to compare the stent expansion between the two groups in the present study with reference to a previous study.[9] Major secondary endpoints included the rate of burr upsizing in RA, final burr size in RA, and TLR at 1 year.

Statistical analysis

Categorical data are presented as counts and percentages and were compared using Fisher's exact test. Continuous variables with normal distributions were presented as means ± standard deviations and were compared using an unpaired t-test. Continuous variables without normal distributions were expressed as the median and interquartile range and were compared using Mann-Whitney U-test. The reproducibility of percent stent expansion was assessed in 20 randomly selected patients. Intra- and inter-observer agreement was evaluated after the same observer and another experienced reader repeated the analysis using intraclass correlation coefficients (ICCs). Multivariable linear regression analysis was used to test whether differences in percent stent expansion remain significant after adjusting for diabetes, hemodialysis, acute coronary syndrome, and bifurcation. All probability values were two-sided and $P<0.05$ was considered statistically significant. All statistical analyses were conducted using SPSS (version 19; IBM-SPSS, Chicago, IL).

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<RESULTS>

Patient enrollment

Of 247 de-novo lesions that underwent RA, we excluded lesions with no intravascular imaging data (n=11), poor image quality (n=7), balloon angioplasty alone (n=16), and complications (2 burr entrapment, 2 perforation). Finally, 88 and 121 de-novo calcified lesions that underwent OCT/OFDI-guided RA and IVUS-guided RA, respectively, were enrolled.

Baseline characteristics and procedure results

The baseline characteristics were similar between the groups except for the significantly more frequent prescription of prasugrel in the OCT-guided RA group (19% vs. 5%, P=0.001) (Table 1). Regarding lesion characteristics, there was no significant difference between the groups. Procedure results are summarized in Table 2. Burr upsizing was more frequent (55% vs. 32%, P=0.001) and the final burr size was significantly larger in the OCT-guided RA group (1.75[1.50-1.75] vs. 1.50[1.50-1.75] mm, P<0.001). There was no significant difference regarding pre and post-balloon dilatation between the groups. OCT-guided RA required larger volume of contrast media, however, it did not induce exacerbation of renal function in non-hemodialysis patients (Table 1).

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Quantitative coronary angiography findings

There was no difference in pre and post-procedure QCA measurements between the groups (Table 3).

Intravascular imaging findings

The OCT-guided RA group had significantly smaller quantitative measurements in the proximal reference and lesion sites before stenting compared to the IVUS-guided RA group (Table 4). However minimum stent CSA was similar between the groups, as a result, percent stent expansion was significantly larger in the OCT-guided RA group compared to IVUS-guided RA group (83±15% vs. 72±16%, P=0.0004) (Fig. 3). This remained significant after adjusting for diabetes, hemodialysis, acute coronary syndrome, and bifurcation (adjusted p value = 0.0009). The intra- and inter-observer agreement for percent stent expansion was 0.90 and 0.87, respectively.

Clinical outcomes

Clinical 1-year follow-up was similarly achieved in both groups (97% in OCT-guided RA group vs. 96% in IVUS-guided RA group, P=0.79). TLR at 1 year was lower, but non-significantly, in the OCT-guided RA group (6.8% vs. 11.6%, P=0.25) (Fig. 4).

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<DISCUSSION>

Previous studies demonstrated that aggressive burr size selection (burr to artery ratio of >0.7) was not associated with improved clinical outcomes and had a high incidence of complications.[10, 11] These studies suggested that lesion modification with a small burr size (burr to artery ratio ≤0.7) was a reasonable strategy for calcified lesions. However, burr size selection based on angiographic findings is non-substantial, because the main focus of RA is the superficial calcium in the lumen. Intravascular imaging aids the operator to determine which part of the lesion should be thoroughly ablated due to heavy calcium and the part of the lesion that should not be ablated with a large burr based on the wire bias or lipid-rich plaque location. We consider that intravascular imaging-guided RA is useful for obtaining maximum calcium ablation and preventing complications.

Several studies have shown that OCT-guided PCI is comparable to IVUS-guided PCI.[9, 12] To our knowledge, this is the first study comparing OCT-guided and IVUS-guided RA for calcified coronary lesion with respect to burr selection difference, stent expansion, and clinical outcomes. IVUS is useful for localizing the calcium but is limited in evaluating calcium thickness because of high-intensity reflection with acoustic shadow. OCT can penetrate calcium, allowing the determination of remnant calcium thickness after initial RA.

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The thin part of the calcium is associated with crack formation after balloon angioplasty and is related to stent expansion.[13-15] A previous study showed that minimum thickness of the calcium was significantly correlated with stent expansion, while the maximum thickness of the calcium was not.[14] Furthermore, Maejima et al. suggested that the optimal cutoff point of calcium thickness for obtaining a crack after ballooning is 670 μm,[13] and in another study, the median calcium thickness for obtaining a crack was 450 μm.[15] Routine burr upsizing based on angiographic findings is arbitrary and even be harmful, however, OCT findings after initial atherectomy will provide information whether lesion modification after initial RA is inadequate and if burr upsizing is appropriate to obtain more optimal lesion modification and facilitate good stent expansion. In IVUS-guided RA, we usually consider the necessity of burr upsizing according to the minimum lumen CSA, presence of crack, and the visibility of the vessel behind the calcification. However, these criteria cannot reliably guarantee stent expansion as shown in our representative case. Thus, OCT-guided RA seems a better strategy than IVUS-guided RA and our results suggested larger stent expansion with OCT-guided RA.

Although high restenosis and TLR within 1 year after RA with DES implantation have been reported (11.3-18.6%),[3, 16, 17] our TLR at 1 year with OCT-guided RA (6.8%) was better than that of previous studies. Jinnouchi et al.[17] reported that second-generation DES after RA

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improved TLR at 1 year compared to first-generation DES (13.4% vs. 25.2%, P=0.047). Although the incidence was not clearly described, they also used IVUS during the procedure; however OCT was not used. We expect that OCT-guided RA with subsequent implantation of second and third-generation DES may improve clinical outcomes for challenging calcified lesions.

Study limitations

There were several limitations to the present study. First, it was a retrospective observational study with a small sample size. Second, the number of excluded lesions was relatively large, therefore, selection bias may have existed. Third, lesions that underwent IVUS-guided RA might have been more complex compared to those that underwent OCT-guided RA. The IVUS catheter has superior cross ability than the OCT catheter; therefore, operators may have preferred IVUS for severely tortuous and large calcified lesion. In addition, OCT involves the injection of contrast media, so IVUS may be preferred for patients with renal insufficiency who usually have more complex lesions. These potential biases may have been associated with more challenging stent expansion in IVUS-guided RA. Fourth, the PCI protocol including burr size selection, balloon dilatation strategy, and stent selection, was not strictly determined because of the retrospective design. Inter-operator differences in technical and

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therapeutic strategy might have affected outcomes. Fifth, the primary endpoint of the present study was stent expansion, which was not a widely accepted endpoint. In addition, stent expansion was evaluated by different modalities. This study was retrospective in nature; therefore, we could not optimize this issue. In addition, the small sample size may be associated with smaller area at the proximal reference site in the OCT-guided group. This might be associated with a better stent expansion in the OCT-guided group. Sixth, in the OCT-guided group, the target thickness of the calcification was unclear. During the study period, several studies reported a cutoff point of calcium thickness for obtaining a crack after ballooning.[13, 15] This limitation should be compromised in other prospective studies. Finally, the difference in TLR at 1 year between the groups may have been underpowered because of the small sample. Here, the role of RA is not a treatment itself; however, it is just an adjunctive therapy to achieve optimal stent expansion. In addition, lesion selection bias of candidate for RA technic may be unavoidable and a large sample size will be required to prove the clinical impact of RA.

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<CONCLUSIONS>

OCT-guided RA could obtain larger stent expansion compared with IVUS-guided RA. To decide the need for burr upsizing and the final burr size, taking into account detailed calcium characteristics, is an effective modification strategy using RA. We consider that OCT-guided RA may be ideal for improving the clinical outcomes of calcified coronary lesions that are still challenging.

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Impact on daily practice

Burr upsizing was more frequently performed and the final burr size was larger in the OCT-guided RA compared to IVUS-guided RA. OCT-guided RA was associated with better stent expansion, and may be ideal for improving the clinical outcomes of calcified coronary lesions.

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<Figure Legends>

Figure 1. Representative case of rotational atherectomy (RA) with optical frequency domain imaging (OFDI)

(A) OFDI pre-procedure image showing severe thick calcium with a 360° calcium arc.

(B) OFDI image after rotational atherectomy with a 1.75-mm burr. The thinnest part of the calcium was 540 μm; however, a large volume of the calcium remained and a considerable part was thick. The operator decided to upsize the burr.

(C) OFDI image after additional RA with a 2.0-mm burr. The thinnest part of the calcium became <500 μm and some part of the calcium cracked (arrow).

(D) Final OFDI image after stent implantation with subsequent post-dilatation. There were some malapposed struts, however, the stent expansion rate was acceptable (87.6%).

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Figure 2. Representative case of rotational atherectomy (RA) with intravascular ultrasound (IVUS)

(A) IVUS could not cross the lesion, so RA with a 1.5-mm burr was performed. Subsequent

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IVUS image showed cracks at some parts of the calcium (arrows). Moreover, behind, a high echo band with acoustic shadow could be seen (asterisk), therefore, the operator considered that the calcium was not notably thick. The operator did not perform burr upsizing in this case.

(B) IVUS image after stent implantation with subsequent post-dilatation. Stent under-expansion was not improved even after post-dilation with high pressure. The stent expansion rate was 62.6%.

Figure 3. Comparison of stent expansion rate between the groups

Figure 4. Target lesion revascularization at 1 year between the groups

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Table 1. Baseline characteristics

	OCT-guided RA (84 patients, 88 lesions)	IVUS-guided RA (112 patients, 121 lesions)	P
Patient characteristics			
Age (years)	73±9	75±10	0.21
Male	60 (71)	77 (69)	0.69
Hypertension	65 (77)	79 (71)	0.28
Diabetes mellitus	32 (38)	40 (36)	0.73
Dyslipidemia	45 (54)	49 (44)	0.17
Hemodialysis	18 (21)	22 (20)	0.76
Current smoker	3 (4)	7 (6)	0.40
Previous PCI	36 (43)	40 (36)	0.31
Previous MI	2 (2)	2 (2)	0.77
Previous CABG	1 (1)	0 (0)	0.25
Medications			
Aspirin	80 (95)	102 (91)	0.26

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Clopidogrel	61 (73)	69 (62)	0.11
Prasugrel	16 (19)	5 (5)	0.001
Clinical presentation			
Stable angina pectoris	87 (99)	116 (96)	0.23
Acute coronary syndrome	1 (1)	5 (4)	
Lesion characteristics			
Target lesion site			
RCA	22 (25)	34 (28)	0.62
LAD	55 (63)	69 (57)	0.43
LCX	7 (8)	14 (12)	0.39
LMT	4 (4)	4 (3)	0.65
Bifurcation lesion	18 (20)	25 (21)	0.97
Ostial lesion	12 (14)	26 (21)	0.15
ACC/AHA classification type C	43 (49)	62 (51)	0.73
Preprocedural Cr (mg/dl) (non-hemodialysis patients)	0.87±0.25	1.01±0.36	0.007
Δ Cr (mg/dl) (non-hemodialysis patients)	0.07 (-0.02, 0.16)	0.06 (0, 0.13)	0.73

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OCT=optical coherence tomography; IVUS=intravascular ultrasound; RA=rotational atherectomy; PCI=percutaneous coronary intervention; MI=myocardial infarction; CABG=coronary artery bypass grafting; RCA=right coronary artery; LAD=left anterior descending artery; LCX=left circumflex artery; LMT=left main trunk; ACC/AHA=American College of Cardiology/American Heart Association, ΔCr was defined as postprocedural Cr minus preprocedural Cr.

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Table 2. Procedure results

	OCT-guided RA (88 lesions)	IVUS-guided RA (121 lesions)	P
Rotational atherectomy			
Initial burr size (mm)	1.50 (1.50-1.75)	1.50 (1.25-1.50)	0.06
Final burr size (mm)	1.75 (1.50-2.00)	1.50 (1.50-1.75)	<0.001
Burr upsizing	48 (55)	39 (32)	0.001
Number of rotablator burrs	2.0 (1.0-2.0)	1.0 (1.0-2.0)	<0.001
Pre-balloon			
Frequency of pre-balloon dilatation	84 (96)	118 (98)	0.41
Diameter (mm)	2.7±0.4	2.6±0.4	0.25
Length (mm)	14±3	13±2	0.19
Balloon pressure (atm)	17±3	17±4	0.98
Stent			
EES-Cocr	11 (13)	34 (28)	0.007
EES-PrCr	10 (11)	21 (17)	0.23

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ZES	22 (25)	26 (22)	0.55
BES	8 (9)	5 (4)	0.14
BP-SES	12 (14)	10 (8)	0.21
BP-EES	25 (28)	25 (21)	0.20
Number of stents	1.2±0.4	1.4±0.6	0.001
Mean stent diameter (mm)	3.0±0.4	2.9±0.4	0.15
Total stent length (mm)	30±13	36±18	0.05
Post-balloon			
Frequency of post-balloon dilatation	73 (83)	98 (81)	0.72
Diameter (mm)	3.1±0.4	3.0±0.5	0.27
Length (mm)	15±7	14±7	0.62
Balloon pressure (atm)	17±5	17±5	0.76
Contrast volume (ml)	215±76	179±79	0.001
Slow-flow phenomenon	15 (17)	27 (22)	0.35

OCT=optical coherence tomography; IVUS=intravascular ultrasound; RA=rotational atherectomy; EES=everolimus-eluting stent; ZES=zotarolimus-eluting stent; BES=biolimus-eluting stent; BP=bioresorbable polymer; SES=sirolimus-eluting stent

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Table 3. Quantitative coronary angiography findings

	OCT-guided RA (88 lesions)	IVUS-guided RA (121 lesions)	P
Pre-PCI measurements			
Reference lumen diameter (mm)	2.8±0.5	2.7±0.6	0.71
Minimum lumen diameter (mm)	1.0±0.4	0.9±0.5	0.55
Diameter stenosis (%)	65±14	66±17	0.83
Lesion length (mm)	23±10	23±13	0.59
Post-PCI measurements			
Reference lumen diameter (mm)	3.0±0.5	2.9±0.4	0.10
Minimum lumen diameter (mm)	2.7±0.5	2.6±0.4	0.11
Diameter stenosis (%)	10±9	12±11	0.35
Acute gain (mm)	1.7±0.5	1.6±0.6	0.25

OCT=optical coherence tomography; IVUS=intravascular ultrasound; RA=rotational atherectomy; PCI=percutaneous coronary intervention

Table 4. Intravascular imaging findings

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	OCT-guided RA (88 lesions)	IVUS-guided RA (121 lesions)	P
Before stenting			
Proximal reference			
Minimum lumen diameter (mm)	2.6±0.6	3.0±0.4	0.002
Maximum lumen diameter (mm)	3.1±0.6	3.7±0.6	0.0005
Lumen CSA (mm^2)	6.5±2.5	8.9±2.5	0.001
Minimum vessel diameter (mm)	3.0±0.5	3.3±0.6	0.002
Maximum vessel diameter (mm)	3.5±0.5	4.1±0.5	0.001
Vessel CSA (mm^2)	8.4±3.0	10.1±2.9	0.001
Distal reference			
Minimum lumen diameter (mm)	2.3±0.5	2.6±0.5	0.15
Maximum lumen diameter (mm)	2.7±0.6	2.9±0.6	0.21
Lumen CSA, mm^2	5.3±2.4	5.8±2.3	0.49
Minimum vessel diameter (mm)	2.6±0.4	2.9±0.5	0.12
Maximum vessel diameter (mm)	3.0±0.5	3.3±0.5	0.10
Vessel CSA (mm^2)	6.1±2.7	6.9±2.6	0.32

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Mean reference lumen CSA, mm^2	5.9±2.2	7.3±1.9	0.02
Lesion minimum lumen diameter (mm)	1.2±0.3	1.5±0.2	<0.0001
Lesion maximum lumen diameter (mm)	1.8±0.5	2.1±0.5	0.06
Lesion lumen CSA (mm^2)	1.8±0.7	2.5±1.2	0.02
After stenting			
Minimum stent CSA (mm^2)	5.3±2.1	5.4±1.7	0.86
Malapposition (%)	57 (65)	38 (31)	<0.0001
Stent edge dissection (%)	13 (15)	9 (7)	0.09
Tissue protrusion (%)	15 (17)	8 (7)	0.02

OCT=optical coherence tomography; IVUS=intravascular ultrasound; RA=rotational atherectomy; CSA=cross-sectional area.

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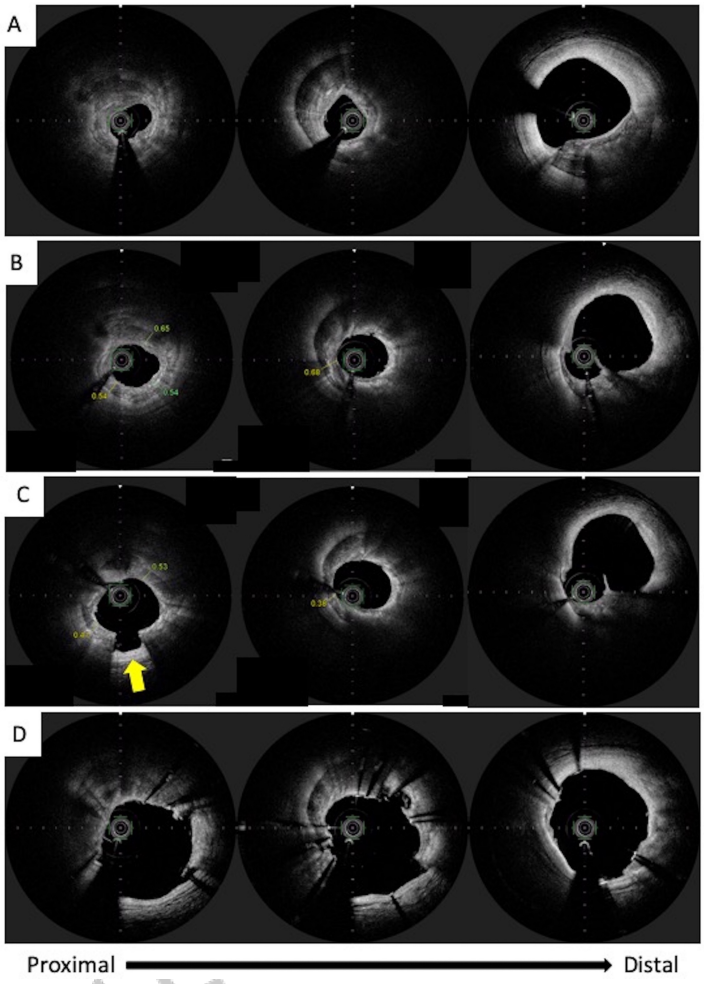

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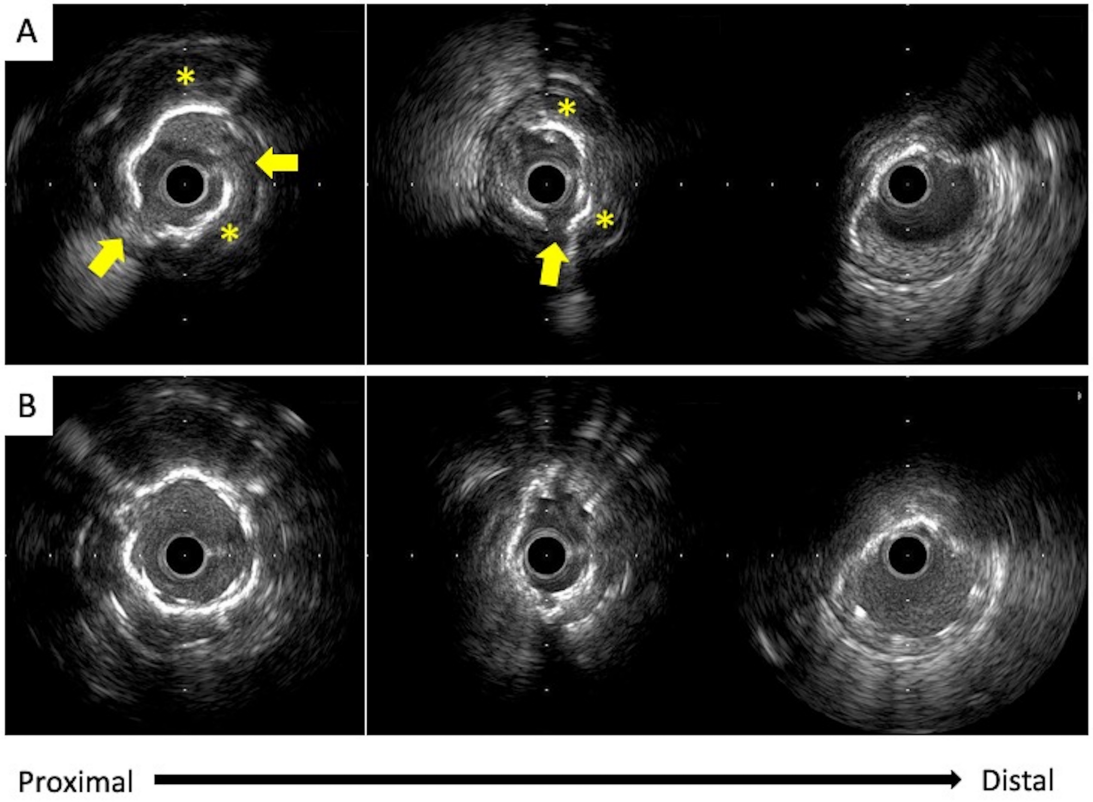

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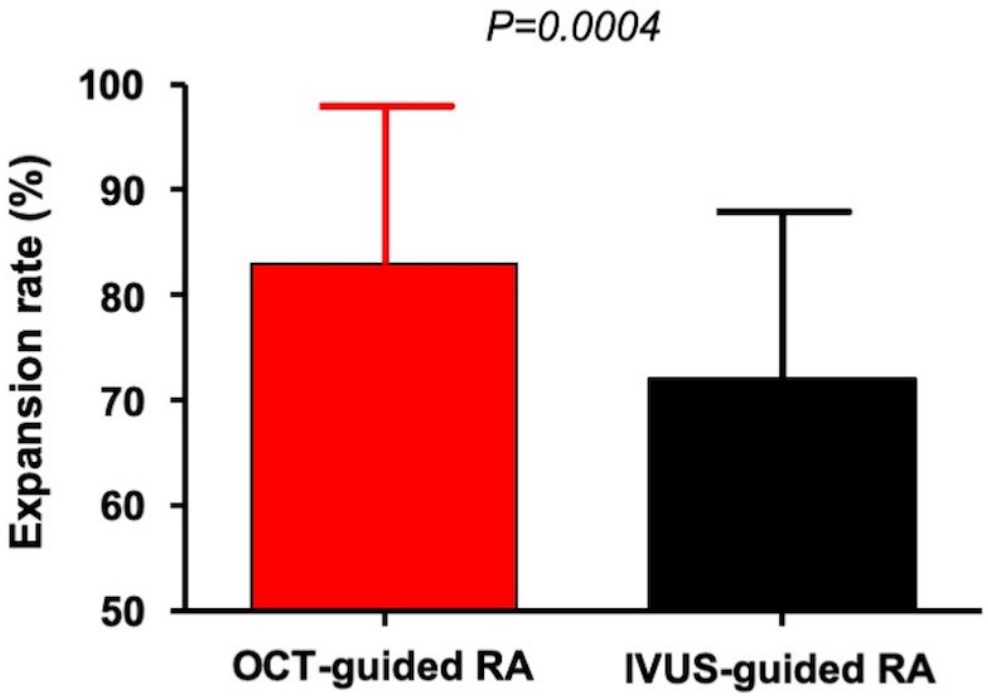

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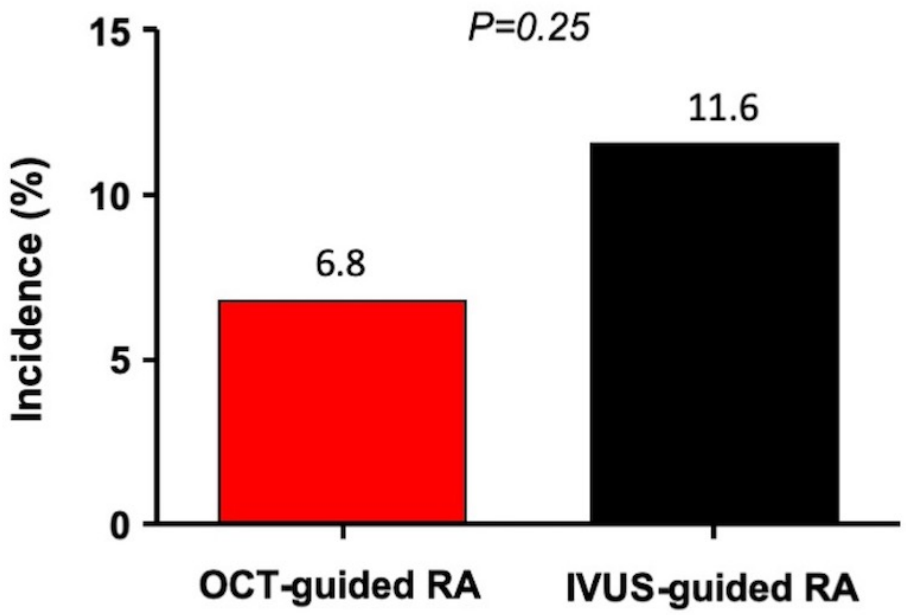

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