The International Journal of Cardiovascular Imaging (2019) 35:1979–1987
https://doi.org/10.1007/s10554-019-01657-y

ORIGINAL PAPER

Cut-off value of mal-apposition volume and depth for resolution at early phase of acute incomplete stent apposition after CoCr-EES implantation

Yohei Uchimura[1] · Tomonori Itoh[1] · Hideto Oda[1] · Yuya Taguchi[1] · Wataru Sasaki[1] · Kyosuke Kaneko[1] · Tsubasa Sakamoto[1] · Iwao Goto[1] · Masafumi Sakuma[1] · Masaru Ishida[1] · Tatsuo Kikuchi[2] · Daisuke Terashita[3] · Hiromasa Otake[4] · Yoshihiro Morino[1] · Toshiro Shinke[5]

Received: 12 February 2019 / Accepted: 21 June 2019 / Published online: 29 June 2019

Abstract

The purpose of this study was to clarify a cut-off value for acute incomplete stent apposition (ISA) volume and maximum-depth to predict ISA resolution at 1- and 3-month follow-up in patients treated with cobalt–chromium everolimus-eluting stents. In total, 95 cases and 103 stents were registered in the MECHANISM-Elective sub-study. Acute ISA-volume was measured by the trapezoid rule. ISA resolution of cut-off value at 1- and 3-month was estimated by ISA-volume and maximum-depth using receiver operatorating characteristic curve analysis. The total number of analysed acute ISAs was 202 in the 1-month group and 225 in the 3-month group. A total of 123 ISAs at 1-month and a total of 169 ISAs at 3-month had been resolved. The cut-off value of ISA resolution by ISA-volume was 0.169 mm^3 at 1-month (AUC: 0.725, sensitivity: 72.2%, specificity: 61.0%) and 0.295 mm^3 at 3-month (AUC: 0.757, sensitivity: 75.0%, specificity: 60.4%). The cut-off value of ISA resolution by ISA maximum-depth demonstrated was 0.285 mm at 1-month (area under curve (AUC): 0.789, sensitivity: 70.9%, specificity: 69.9%) and 0.305 mm at 3-month (AUC: 0.663, sensitivity: 60.7%, specificity: 66.9%). Incidence of ISA resolution was significantly lower in combination with cut-off values of ISA-volume and maximum-depth (33%, $p < 0.001$, at 1-month; 56%, $p = 0.003$, at 3-month). Combining the cut-off value of ISA-volume with the maximum-depth might be helpful to consider the endpoint of the PCI procedure.

Keywords Incomplete stent apposition · Cobalt–chromium everolimus-eluting stent · Coronary artery disease · Optical coherence tomography · Late acquired mal-apposition

Introduction

Currently, drug-eluting stents (DES) coated with a drug for suppressing cell proliferation are widely used in metallic stents to overcome restenosis in intracoronary stents. After percutaneous coronary angioplasty (PCI), dual antiplatelet drug combination therapy (DAPT) must be started for prevention of intra-stent thrombosis. However, because bleeding risk increases as the DAPT period is prolonged, shortening of the DAPT period is an important issue [1, 2].

Several risk factors of stent thrombosis, including stents under expansion, resistance to antiplatelet therapy, neo-atherosclerosis, and stent un-coverage, have been reported [3]. Previous studies have shown that incomplete stent apposition (ISA), including late acquired mal-apposition [4], is one of the major risk factors of stent thrombosis [5–8]. Previous optical coherence tomography (OCT) studies have reported

✉ Tomonori Itoh
tomoitoh@iwate-med.ac.jp

1 Division of Cardiology, Department of Internal Medicine, Memorial Heart Center, Iwate Medical University, 19-1, Uchimaru, Morioka City, Iwate, Japan

2 Department of Cardiology, Edogawa Hospital, 2-24-28, Higashikoiwa, Edogawa-ku, Tokyo, Japan

3 Division of Cardiovascular Medicine, Department of Internal Medicine, Kitaharima Medical Center, Ono, Japan

4 Division of Cardiology, Department of Internal Medicine, Graduate School of Medicine, Kobe University, 7-5-1, Kusunoki-cho, Chuo-ku, Kobe, Japan

5 Division of Cardiovascular Medicine, Showa University School of Medicine, 1-5-8, Hatanodai, Shinagawa-ku, Tokyo, Japan

the cut-off value of strut-vessel distance (SVD) for ISA resolution after stent implantation [9–13]. However, few studies have investigated the cut-off value of ISA-volume for ISA resolution. Only one previous study showed the cut-off value of ISA-volume for ISA resolution at 4–8 months [14]. Currently, there is no study assessing the ISA-volume cut-off value of ISA elimination for shorter periods and focusing on cobalt–chromium everolimus-eluting stents (CoCr-EES).

The purpose of this study was to clarify the cut-off value for acute ISA-volume and maximum-depth to predict ISA resolution at 1- and 3-month follow-up in patients treated with CoCr-EES.

Methods

Study patients

The MECHANISM Elective (Multicenter comparison of Early and late vascular responses to an everolimus-eluting cobalt–CHromium stent and platelet AggregatioN studies In patients with Stable angina Managed as Elective cases (Clinicaltrials.gov ID: NCT02014818, UMINID: UMIN000012616)) study is a multi-centre registry designed to elucidate early and late vascular responses to EES for stable coronary artery disease (CAD) patients using OCT.

Patients with stable CAD and the existence of proven ischaemia were subjects who met all of the selection criteria at entry and did not fall under either of the exclusion criteria. Inclusion and exclusion criteria were shown at "Clinicaltrials.gov ID: NCT02014818: (https://clinicaltrials.gov/ct2/show/NCT02014818?term=NCT02014818&rank=1)".

In the present sub-study, 1- and 3-month cohorts were evaluated to elucidate stent apposition of early vascular responses to EES in stable CAD patients by OCT. Target lesion characteristics visualized by OCT, and post-procedure OCT images were evaluated immediately and at 1 (30 ± 10 days) and 3 months (90 ± 30 days) after stent implantation. DAPT was prescribed during follow-up period in the all study patients.

This study complies of the Declaration of Helsinki. The Ethical Committee of each participating institution approved the MECHANSIM Elective study protocol. All patients provided written informed consent before inclusion.

OCT image acquisition and analysis

OCT imaging acquisition method was described in the previous report [15]. OCT analysis was performed using LightLab OCT imaging proprietary software (LightLab Imaging/St. Jude Medical, Westford, MA, USA) by experienced observers of the Iwate core analysis laboratory (ICAL) as a central core laboratory staff independent of PCI. Baseline and follow-up OCT images were displayed side by side, and serial OCT analysis was performed using information about the motorized pullback speed and landmarks such as the presence of calcium deposits, side branches, and plaque shape. Resolved ISA was defined as acute mal-apposition integrated into coronary vessel wall at follow-up. Persistent ISA was defined as incomplete strut apposition at both acute phase and follow-up.

Calculation of ISA-volume and ISA maximum (max.) depth

Acute ISA-volume was measured using the trapezoid rule for target mal-apposition. The acute ISA max-depth was measured according to the standard operating procedure of the MECHANISM-Elective main study. Additionally, the prevalence of ISA resolution at 1 and 3 months was evaluated using acute ISA-volume, and max-depth was estimated. ISA-volume was defined as the presence of mal-apposition where the stent-vessel distance was more than 110 μm away from the whole thickness of the CoCr-EES stent. Whole thickness was the integrated strut thickness (81 μm), the half thickness of the applied polymer and the drug (8 μm) and OCT resolution limit ($81 + 8 + 20 = 109$ μm). For the mal-apposition volume, the area measured by bordering the margin of the stent area trace line and the lumen area of the mal-appositioning stent strut portion was defined as the ISA area.

The area measured on the edge of the lumen area was taken as the ISA area. The area of the ISA immediately after stent placement and at 1- or 3-month follow-up was measured every 0.2 mm (72 mm/s) or 0.4 mm (36 mm/s) from the proximal edge to the distal edge, and its volume was calculated as follows:

$$\text{ISA - volume} = 0.2\text{mm (or } 0.4\text{ mm)} \times \text{number of CS}$$

$$(A + B + \sqrt{(\text{A} \times \text{B})})/3$$

where CS Cross section, A ISA area of proximal edge, B ISA area of distal edge (Fig. 1).

Late acquired mal-apposition

Late-acquired mal-apposition (LAM) was defined as incomplete strut apposition that was not present immediately after the procedure but was observed at follow-up. LAM was evaluated by serial OCT image analysis. Prevalence of LAM was shown by the number of each stent.

Statistical analysis

Data are presented as the means ± SD. Statistical comparison of the differences in categorical data between the two groups

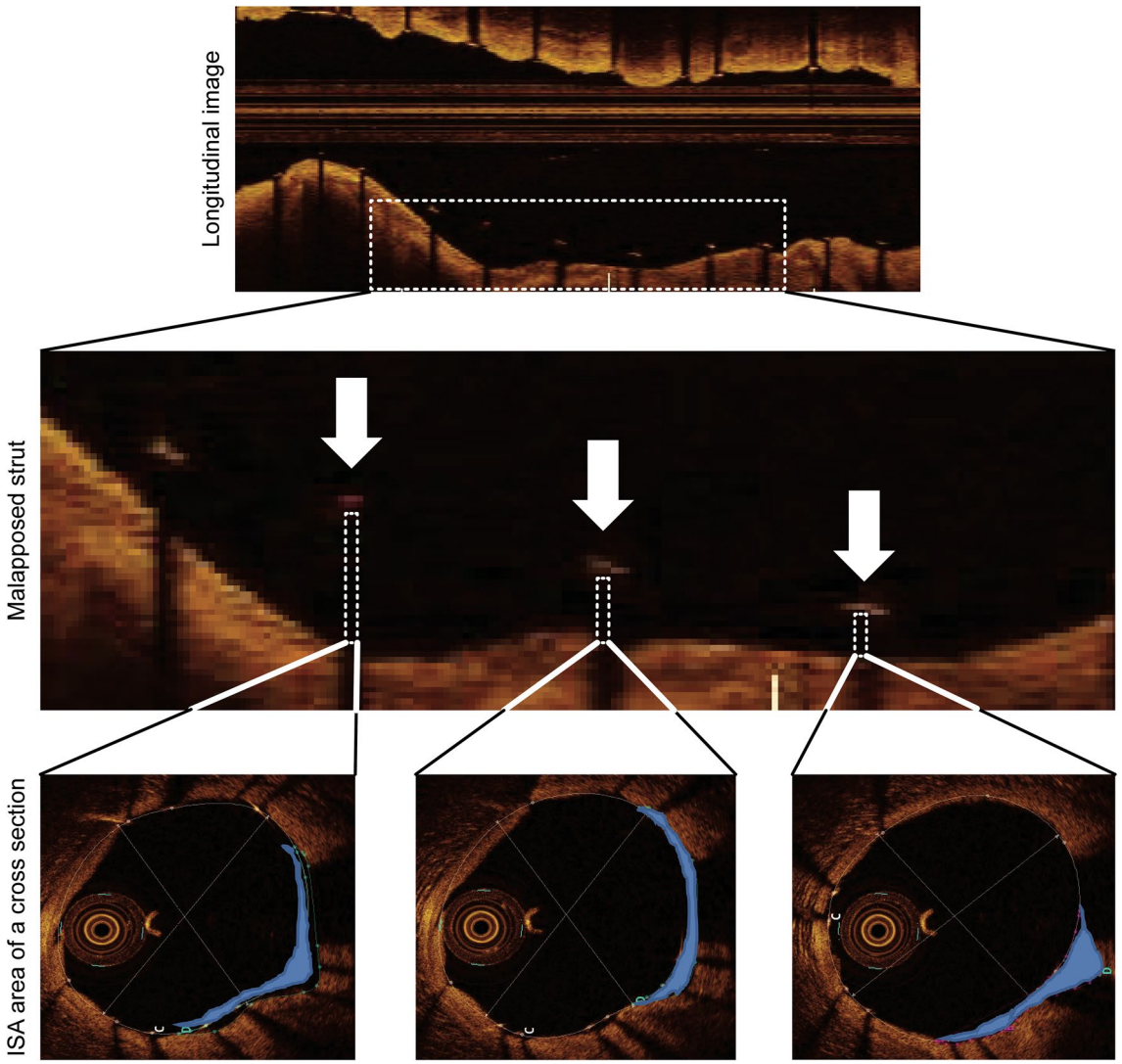

Fig. 1 Calculation of ISA-volume. ISA volume = 0.2 mm (or 0.4 mm) × number of CS $(A+B+\sqrt{(A\times B)})/3$, where*CS* cross section, *A* ISA area of proximal edge, *B* ISA area of distal edge

was performed using the chi-square contingency test. The receiver operating curve (ROC) analyses were performed for detection of cut-off values of ISA-volume and max-depth. Differences were considered statistically significant for $p<0.05$. All statistical analyses were performed using SPSS for Windows, version 21.0 (Chicago, Illinois, US).

Results

Patient characteristics

Baseline patient characteristics are shown in Table 1. A total of 52 stents in 49 patients in the 1-month cohort and 51 stents in 46 patients in the 3-month cohort were registered in the present sub-study.

One-month cohort group

A flowchart of acute ISA in the 1-month cohort group is shown in Fig. 2. In total, 202 acute ISAs were observed immediately after stent implantation. A total of 123 of those with acute ISA were resolved at 1-month. Figure 3 demonstrates the incidence of acute ISA resolution after dividing into quantiles of acute ISA volume and ISA max-depth. Incidence of ISA resolution was significantly lower in the quantile with ISA-volumes of more than 0.462 mm^3 ($p<0.001$; Fig. 3). Incidence of ISA resolution was significantly lower in the quantile with ISA max-depths of more than 0.36 mm ($p<0.001$; Fig. 3). The cut-off value of ISA resolution by ISA-volume using ROC analysis was 0.169 mm^3 (area under curve (AUC): 0.725, sensitivity: 72.2%, specificity: 61.0%) (Fig. 4). The cut-off value of ISA

Table 1 Baseline characteristics of the present main-study

	1-month cohort Patients ($n=50$)	3-month cohort Patients ($n=50$)	p-value
Age (years)	71 ± 8	70 ± 8	0.585
Male (%)	35 (70.0)	40 (80.0)	0.248
BMI (kg/m^2)	24.6 ± 3.6	24.5 ± 4.4	0.899
Diabetes mellitus (%)	28 (56.0)	30 (60.0)	0.685
Hypertension (%)	42 (84.0)	43 (86.0)	0.779
Dyslipidemia (%)	35 (70.0)	42 (84.0)	0.096
Smoker (%)	17 (34.0)	18 (36.0)	0.834
Clinical status			
Stable angina (%)	25 (50.0)	30 (60.0)	0.315
Silent myocardial ischemia (%)	25 (50.0)	20 (40.0)	
History of myocardial infarction (%)	6 (12.0)	15 (30.0)	0.027
Medication at the index procedure			
Clopidogrel (%)/ticlopidine (%)	48 (96.0) / 2(4.0)	49 (98.0) /1 (2.0)	0.710
Statin (%)	35 (70.0)	38 (76.0)	0.499
Stent status			
Culprit vessel, LAD, RCA, LCx (n)	21/18/11	25/14/11	0.724
Implanted stent number (n)	1.2 ± 0.5	1.2 ± 0.4	0.651
Stent diameter (mm)	2.94 ± 0.39	2.88 ± 0.35	0.383
Stent length (mm)	24.8 ± 7.9	22.2 ± 7.5	0.145
Reference diameter (mm)	2.58 ± 0.48	2.54 ± 0.46	0.543
MLD (mm)	0.85 ± 0.30	0.80 ± 0.33	0.678
%diameter stenosis (%)	66.5 ± 12.2	68.1 ± 12.3	0.633

BMI body mass index, *LAD* left anterior descending artery, *RCA* right coronary artery, *Lcx* left circumflex artery, *MLD* minimal lumen diameter

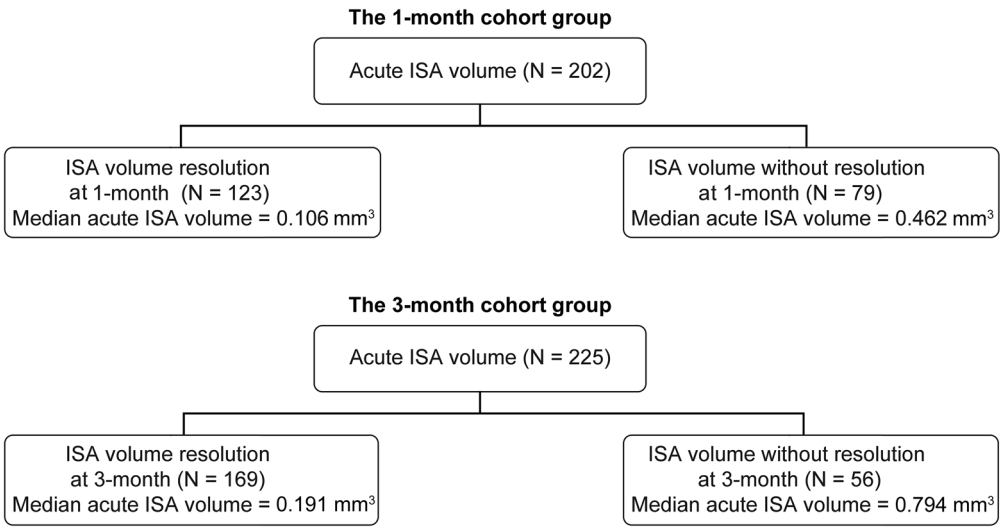

Fig. 2 Flowchart of acute ISA in the 1- and 3-month cohort groups

resolution by ISA maximum-depth using ROC analysis was 0.285 mm (AUC: 0.789, sensitivity: 70.9%, specificity: 69.9%) (Fig. 4). The incidence of ISA resolution was significantly lower in combination with cut-off values of ISA volume (0.169 mm^3) and maximum-depth (0.285 mm) ($p < 0.001$; Fig. 5).

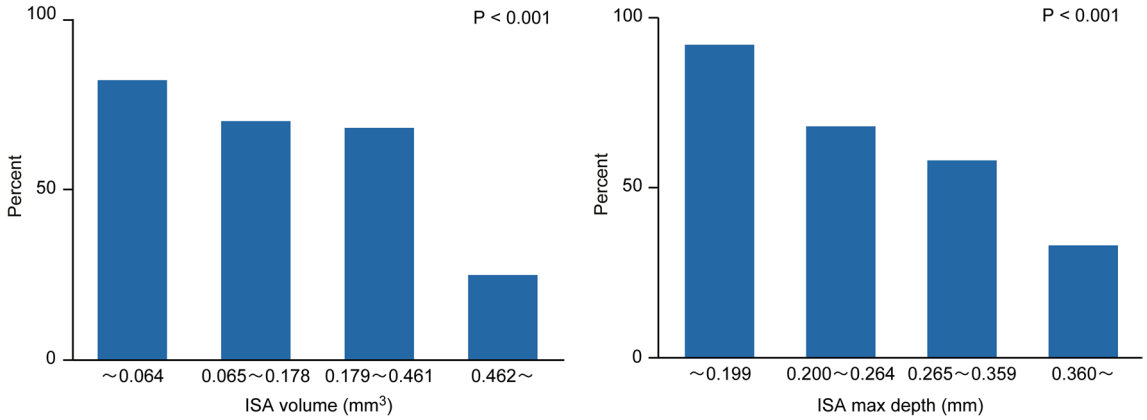

Fig. 3 Prevalence of ISA resolution at 1-month evaluated using acute ISA-volume and depth. Incidence of ISA resolution was significantly lower in the quantile with ISA-volume more than 0.462 mm^3 ($p < 0.001$). Incidence of ISA resolution was significantly lower in the quantile with ISA max-depth more than 0.36 mm ($p < 0.001$)

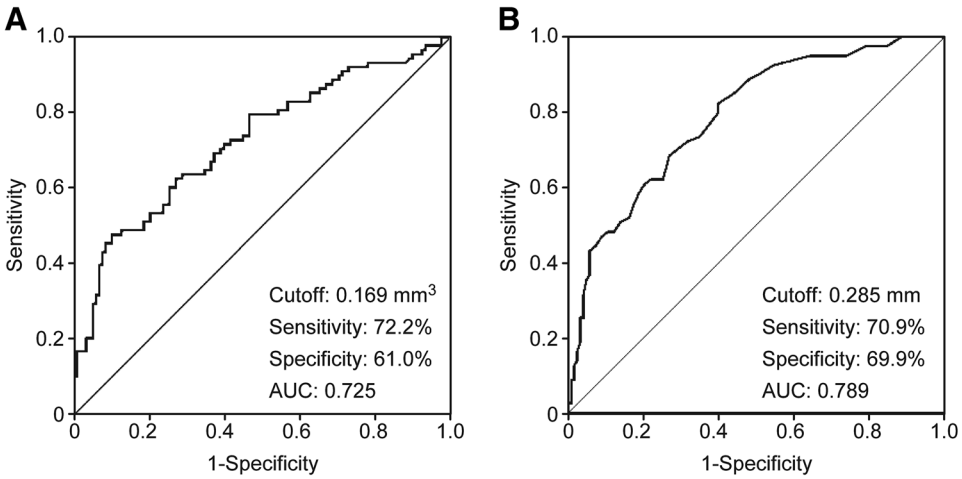

Fig. 4 ROC analysis for the prediction of ISA resolution evaluated using acute ISA-volume (**A**) and depth (**B**) at 1-month follow-up

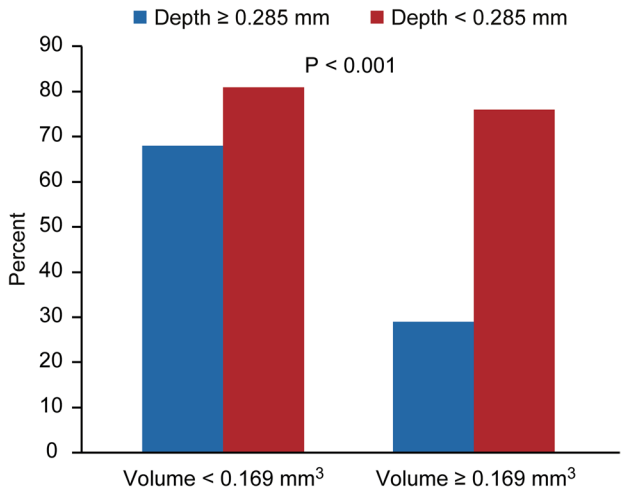

Fig. 5 Prevalence of ISA resolution at 1-month. Incidence of ISA resolution was significantly lowest in combination with cut-off value of ISA-volume (0.169 mm^3) and maximum-depth (0.285 mm) ($p < 0.001$)

Three-month cohort group

The flowchart of acute ISA in the 3-month cohort group is shown in Fig. 2. A total of 225 acute ISAs were observed immediately after stent implantation, and 169 of those with acute ISA were resolved at 3-month. Figure 6 demonstrates the incidence of acute ISA resolution after dividing into quantiles of acute ISA-volume. Incidence of ISA resolution was significantly lower in the quantile with ISA-volumes of more than 0.708 mm^3 ($p < 0.001$; Fig. 6). Incidence of ISA resolution was significantly lower in the quantile with ISA max-depths of more than 0.40 mm ($p = 0.003$; Fig. 6). The cut-off value of ISA resolution by ISA-volume using ROC analysis was 0.295 mm^3 (AUC: 0.757, sensitivity: 75.0%, specificity: 60.4%) (Fig. 7). The cut-off value of ISA resolution by ISA max-depth using ROC analysis was 0.305 mm (AUC: 0.663, sensitivity: 60.7%, specificity: 66.9%) (Fig. 7). The incidence of ISA resolution was significantly lower in combination with

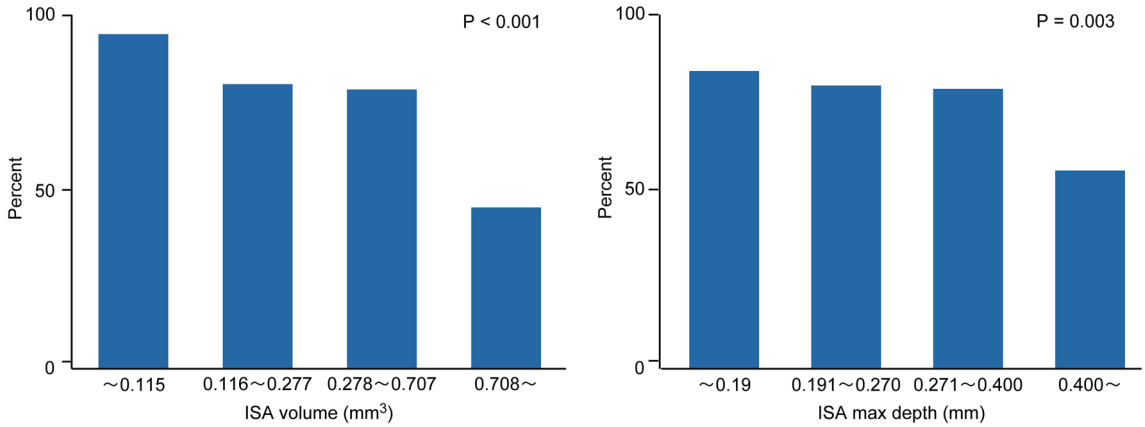

Fig. 6 Prevalence of ISA resolution at 3-month evaluated using acute ISA-volume and depth. Incidence of ISA resolution was significantly lower in the quantile with ISA-volume more than 0.708 mm^3 ($p < 0.001$). Incidence of ISA resolution was significantly lower in the quantile with ISA max-depth more than 0.40 mm ($p = 0.003$)

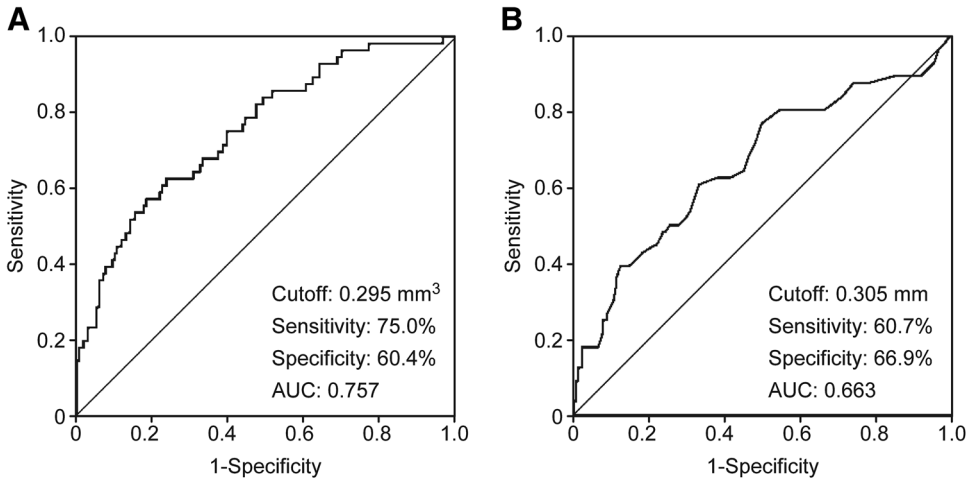

Fig. 7 ROC analysis for the prediction of ISA resolution evaluated using acute ISA-volume (**A**) and depth (**B**) at 3-month follow-up

cut-off values of ISA-volume (0.295 mm^3) and max-depth (0.305 mm) ($p < 0.001$; Fig. 8).

Thrombus formation in ISA

There was hardly any thrombus inside the ISA area at follow-up (none in the 1-month group and 2 sites in the 3-month group).

Late acquired mal-apposition

LAM was observed in 28.8% of the 1-month cohort group and 21.8% of the 3-month cohort group.

Discussion

In our post-hoc analysis from a prospective study in elective PCI patients treated with CoCr-EES, ISA-volume and max-depth were evaluated. As a result, cut-off values for ISA resolution at early phases of 1- and 3-month were shown. Our study demonstrates that combining both parameters could predict ISA resolution.

Comparing previous studies with cut-off values of ISA-volume

There were two studies of ISA-volume using OCT. Only one study evaluated cut-off values of acute ISA-volume to predict ISA resolution. This previous study demonstrated that the cut-off value of resolution of ISA-volume was 2.56 mm^3 at an average of 173 days of follow-up [14].

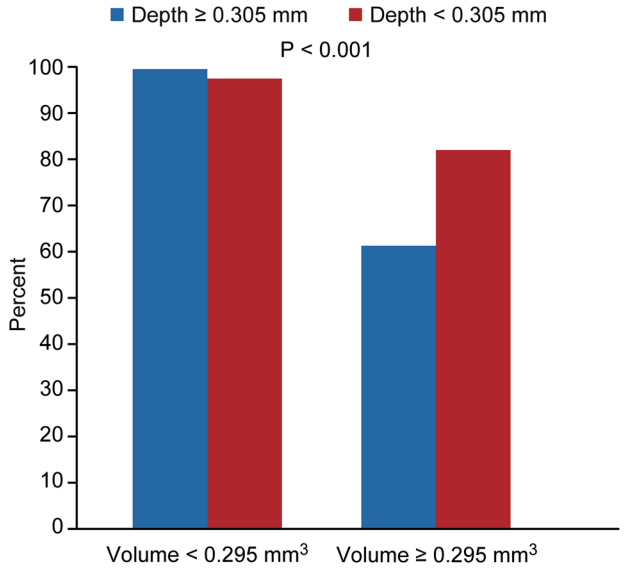

Fig. 8 Prevalence of ISA resolution at 3-month. Incidence of ISA resolution is significantly lowest in combination with cut-off values of ISA-volume (0.295 mm^3) and max-depth (0.305 mm) ($p < 0.001$)

In our analysis, cut-off values of ISA resolution were 0.169 mm^3 for 1-month and 0.295 mm^3 for 3-month. Although the former ISA-volume analysis was performed every 1 mm, our analysis was performed at each cross Sections (0.2–0.4 mm) to predict early ISA resolution, requiring detection of a very small volume. CoCr-EES was included in only 8% of patients in the former study. Our results are the first report of cut-off values of acute ISA-volume to predict ISA resolution at early phases in patients treated with CoCr-EES, which is widely used.

Difference between ISA max-depth and SVD

ISA max-depth, which was analysed in our study, was different from the previously reported SVD. Since ISA max-depth was defined as the maximum-depth in the ISA-volume, ISA max-depth was measured regardless of strut existence. SVD and maximum-depth have different meanings. In terms of SVD, the evagination remaining between the struts is not considered. In our study, by measuring the ISA max-depth, we also observed the expanded area as a volume similar to evagination, which cannot be distinguished by SVD alone. As a risk of stent thrombosis, the existence of peri-strut staining is a problem. Evaluation, including the evagination thought to be the preliminary stage, may evaluate whether the shape of the coronary vessel wall has recovered to the physiological state.

Significance of evaluation with combination ISA-volume and max-depth

Guitterez and colleagues reported that ISA-volume alone was not a significant indicator of ISA resolution [16]. In our analysis, we also examined why the AUC of the ROC curve did not become a good parameter with only ISA-volume. Even if the max ISA depth is small, if the mal-apposition is long in the long axis direction, the volume becomes large. In this case, the ISA may be resolved despite the ISA-volume being large. On the other hand, even if the max ISA depth is large, if there are only a few cross sections of mal-apposition, in many cases the ISA has not been resolved at the follow-up, even though the ISA-volume is small. Therefore, it appears that there is a limit in the estimation of the ISA-volume alone to evaluate ISA resolution. Based on this point, it is thought that by using not only the ISA-volume but also the ISA depth, the accuracy will increase more than the prediction using a single factor. This attempt has not been reported so far, and it is conceivable that it will become an indicator in the future.

Comparison with previous reports of late acquired mal-apposition

In our present analysis, LAM was observed in 28.8% of the 1-month cohort group and 21.8% of the 3-month cohort group. Inoue et al. [10] reported that LAM was observed in 11% after 8 months of CoCr-EES implantation. Compared with our results, the use of CoCr-EES may increase LAM in a short period of time and decrease with time. This result may be because biocompatibility improves after several months due to fluoropolymers [17, 18] with less inflammatory response.

ISA and thrombus formation

The presence of ISA is regarded as a risk of intra-stent thrombosis [5, 7, 6]. There was hardly any thrombus inside the ISA area (none in the 1-month group and 2 sites in the 3-month group). There are three possible reasons for this result: the effect of the CoCr-EES with fluoropolymer, the good apposition resulting from PCI using OCT, and the effect of the DAPT. Based on the EXAMINATION study result that CoCr-EES results in less stent thrombosis than bare metal stent in patients with acute myocardial infarction [19], it is thought that it has the high antithrombogenicity, of which the fluoropolymer [17, 18] plays an important role.

Application of OCT guided PCI

OCT is known to have better resolution than intravascular ultrasound (IVUS) [20]. OCT has a spatial resolution of 10 to

15 µm, has 10 times the IVUS, has a fast pullback speed, and can observe the entire coronary artery in a few seconds [21]. In addition, high-resolution OCT clearly shows the boundary between the intravascular lumen and the endothelial surface and can measure coronary cross-sectional images accurately and reproducibly [22, 23]. According to Kim and colleagues, OCT revealed small ISAs that could not be identified by IVUS [20] in 62% of patients. To detect the resolution of ISA in the short term, there is a need to evaluate a small ISA. For this reason, the IVUS guided PCI is not sufficient, and OCT guided PCI is considered desirable [24]. In the future, if OCT guided PCI using artificial intelligence (AI) is developed, the data of this research will be deep, and there is a possibility that it will be utilized for stent optimization.

Study limitations

There are several limitations with this study. First, our study has relatively few patients. In the future, it is necessary to evaluate a large number of cases. Second, although it is a prospective observation study, it is a post hoc analysis. In the future, it is also necessary to evaluate ISA-volume as the end point in a prospective study. Third, our research used ISA max-depth, but there have been few reports of ISA max-depth in other studies. Therefore, it is difficult to compare with other studies studied using SVD. Fourth, our result is a study on CoCr-EES alone with elective cases. It could not be applied to other stents, and its application is unclear in acute myocardial infarction. Last, the prognosis associated with ISA of the study patients was not evaluated. In the future, it is necessary to investigate a large number of cases that analyse whether ISA is suitable as a surrogate marker of prognostic evaluation.

Acknowledgements The authors are deeply grateful to the core-analysis laboratory members: Kanako Omiya and Yumiko Okuyama (ARCHIMEDES (The Academic ResearCH Group for Exploring Undiscovered Mechanisms of Cardiovascular DiseasES), Kayoko Fujiwara (secretary, ICAL) and Tatsuya Shinke (image technician, ICAL).

Compliance with ethical standards

Conflict of interest Tomonori Itoh: Lecture honoraria (Daiichi-Sankyo, Abbott Vascular Japan). Hiromasa Otake: Lecture honoraria (Abbott Vascular Japan). Yoshihiro Morino: Research grant (Daiichi Sankyo), Lecture honoraria (Daiichi-Sankyo, Abbott Vascular). Toshiro Shinke: Research grant (Daiichi-Sankyo), Lecture honoraria (Daiichi Sankyo, Abbott Vascular). Any other authors do not have any conflict of interest.

References

1. Giustino G, Baber U, Sartori S et al (2015) Duration of dual antiplatelet therapy after drug-eluting stent implantation: a systematic review and meta-analysis of randomized controlled trials. J Am Coll Cardiol 65:1298–1310. https://doi.org/10.1016/j.jacc.2015.01.039
2. Stefanini GG, Siontis GC, Cao D et al (2014) Short versus long duration of DAPT after DES implantation: a meta-analysis. J Am Coll Cardiol 64:953–954. https://doi.org/10.1016/j.jacc.2014.06.1158
3. Kirac D, Erdem A, Avcilar T et al. (2016) Effects of genetic factors to stent thrombosis due to clopidogrel resistance after coronary stent placement. Cell Mol Biol (Noisy-le-grand) 62:51–55
4. Guagliumi G, Musumeci G, Sirbu V et al (2010) Optical coherence tomography assessment of in vivo vascular response after implantation of overlapping bare-metal and drug-eluting stents. JACC Cardiovasc Interv 3:531–539. https://doi.org/10.1016/j.jcin.2010.02.008
5. Finn AV, Nakazawa G, Joner M et al (2007) Vascular responses to drug eluting stents: importance of delayed healing. Arterioscler Thromb Vasc Biol 27:1500–1510. https://doi.org/10.1161/atvbaha.107.144220
6. Nakazawa G, Finn AV, Joner M et al (2008) Delayed arterial healing and increased late stent thrombosis at culprit sites after drug-eluting stent placement for acute myocardial infarction patients: an autopsy study. Circulation 118:1138–1145. https://doi.org/10.1161/circulationaha.107.762047
7. Karalis I, Ahmed TA, Jukema JW (2012) Late acquired stent malapposition: why, when and how to handle? Heart 98:1529–1536. https://doi.org/10.1136/heartjnl-2011-301220
8. Ozaki Y, Okumura M, Ismail TF et al (2010) The fate of incomplete stent apposition with drug-eluting stents: an optical coherence tomography-based natural history study. Eur Heart J 31:1470–1476. https://doi.org/10.1093/eurheartj/ehq066
9. Kawamori H, Shite J, Shinke T et al (2013) Natural consequence of post-intervention stent malapposition, thrombus, tissue prolapse, and dissection assessed by optical coherence tomography at mid-term follow-up. Eur Heart J Cardiovasc Imaging 14:865–875. https://doi.org/10.1093/ehjci/jes299
10. Inoue T, Shinke T, Otake H et al (2014) Impact of strut-vessel distance and underlying plaque type on the resolution of acute strut malapposition: serial optimal coherence tomography analysis after everolimus-eluting stent implantation. Int J Cardiovasc Imaging 30:857–865. https://doi.org/10.1007/s10554-014-0422-z
11. Prati F, Di Vito L, Biondi-Zoccai G et al (2012) Angiography alone versus angiography plus optical coherence tomography to guide decision-making during percutaneous coronary intervention: the centro per la lotta contro l'infarto-optimisation of percutaneous coronary intervention (CLI-OPCI) study. Euro Interv 8:823–829. https://doi.org/10.4244/eijv8i7a125
12. Izumi D, Miyahara M, Fujimoto N et al (2016) Optical coherence tomography analysis of the stent strut and prediction of resolved strut malapposition at 3 months after 2nd-generation drug-eluting stent implantation. Heart Vessels 31:1247–1256. https://doi.org/10.1007/s00380-015-0737-2
13. Shimamura K, Kubo T, Akasaka T et al (2015) Outcomes of everolimus-eluting stent incomplete stent apposition: a serial optical coherence tomography analysis. Eur Heart J Cardiovasc Imaging 16:23–28. https://doi.org/10.1093/ehjci/jeu174
14. Im E, Kim BK, Ko YG et al (2014) Incidences, predictors, and clinical outcomes of acute and late stent malapposition detected by optical coherence tomography after drug-eluting stent implantation. Circ Cardiovasc Interv 7:88–96. https://doi.org/10.1161/circinterventions.113.000797
15. Taguchi Y, Itoh T, Oda H et al (2017) Coronary risk factors associated with OCT macrophage images and their response after CoCr everolimus-eluting stent implantation in patients with stable coronary artery disease. Atherosclerosis 265:117–123. https://doi.org/10.1016/j.atherosclerosis.2017.08.002

16. Gutierrez-Chico JL, Wykrzykowska J, Nuesch E et al (2012) Vascular tissue reaction to acute malapposition in human coronary arteries: sequential assessment with optical coherence tomography. Circ Cardiovasc Interv 5:20–29. https://doi.org/10.1161/circinterventions.111.965301
17. Otsuka F, Cheng Q, Yahagi K et al (2015) Acute thrombogenicity of a durable polymer Everolimus-eluting stent relative to contemporary drug-eluting stents with biodegradable polymer coatings assessed ex vivo in a swine shunt model. JACC Cardiovasc Interv 8:1248–1260. https://doi.org/10.1016/j.jcin.2015.03.029
18. Kolandaivelu K, Swaminathan R, Gibson WJ et al (2011) Stent thrombogenicity early in high-risk interventional settings is driven by stent design and deployment and protected by polymer-drug coatings. Circulation 123:1400–1409. https://doi.org/10.1161/circulationaha.110.003210
19. Sabate M, Cequier A, Iniguez A et al (2012) Everolimus-eluting stent versus bare-metal stent in ST-segment elevation myocardial infarction (EXAMINATION): 1 year results of a randomised controlled trial. Lancet 380:1482–1490. https://doi.org/10.1016/s0140-6736(12)61223-9
20. Kim WH, Lee BK, Lee S et al (2010) Serial changes of minimal stent malapposition not detected by intravascular ultrasound: follow-up optical coherence tomography study. Clin Res Cardiol 99:639–644. https://doi.org/10.1007/s00392-010-0163-5
21. Takarada S, Imanishi T, Liu Y et al (2010) Advantage of next-generation frequency-domain optical coherence tomography compared with conventional time-domain system in the assessment of coronary lesion. Catheter Cardiovasc Interv 75:202–206. https://doi.org/10.1002/ccd.22273
22. Okamura T, Onuma Y, Garcia-Garcia HM et al (2011) First-in-man evaluation of intravascular optical frequency domain imaging (OFDI) of Terumo: a comparison with intravascular ultrasound and quantitative coronary angiography. Euro Interv 6:1037–1045. https://doi.org/10.4244/eijv6i9a182
23. Fedele S, Biondi-Zoccai G, Kwiatkowski P et al (2012) Reproducibility of coronary optical coherence tomography for lumen and length measurements in humans (The CLI-VAR [Centro per la Lotta contro l'Infarto-VARiability] study). Am J Cardiol 110:1106–1112. https://doi.org/10.1016/j.amjcard.2012.05.047
24. Mintz GS (2007) What to do about late incomplete stent apposition? Circulation 115:2379–2381. https://doi.org/10.1161/circulationaha.107.697136