Diagnostic Performance of High-Resolution Intravascular Ultrasound for Abnormal Post-Stent Findings After Stent Implantation

— A Comparison Study Between High-Resolution Intravascular Ultrasound and Optical Coherence Tomography —

Hirohiko Ando, MD, PhD; Yusuke Nakano, MD, PhD; Hiroaki Sawada, MD; Hirofumi Ohashi, MD; Hiroaki Takashima, MD, PhD; Akihiro Suzuki, MD, PhD; Shinichiro Sakurai, MD, PhD; Tetsuya Amano, MD, PhD

Background: High-resolution intravascular ultrasound (HR-IVUS) is the most recently developed IVUS technology, which allows the detailed assessment of intravascular structures. The aim of this study was to evaluate the diagnostic performance of HR-IVUS in the detection of abnormal post-stent findings.

Methods and Results: Patients with acute coronary syndrome underwent both HR-IVUS and optical coherence tomography (OCT) for post-stent evaluations. Quantitative measurements for stented segments and qualitative assessments for abnormal post-stent findings (stent edge dissection, intrastent tissue protrusion, and incomplete stent apposition [ISA]) were performed. Forty-seven patients underwent both HR-IVUS and OCT after stent implantation. HR-IVUS identified a larger minimal lumen area and a larger minimal lumen diameter than OCT ($6.66 \pm 1.98 \text{ mm}^2$ vs. $5.61 \pm 1.79 \text{ mm}^2$ and $2.87 \pm 0.42 \text{ mm}$ vs. $2.63 \pm 0.43 \text{ mm}$, respectively; both $P < 0.001$). The sensitivity of HR-IVUS for the identification of stent edge dissection, intrastent tissue protrusion, and ISA were 20.0%, 48.9%, and 27.2%, respectively.

Conclusions: In terms of post-stent evaluation, the diagnostic performance of HR-IVUS remains insufficient. Abnormal post-stent findings might be underestimated when performing HR-IVUS due to its low sensitivity.

Key Words: Incomplete stent apposition; Intrastent tissue protrusion; Intravascular ultrasound; Optical coherence tomography; Stent edge dissection

As post-procedural evaluations after coronary stenting, intravascular ultrasound (IVUS) and optical coherence tomography (OCT) have been used for the detection of correctable abnormalities related to the stent and the underlying vessel wall, such as stent underexpansion, geographic plaque miss, stent edge dissection, intrastent tissue protrusion, and incomplete stent apposition (ISA). Some of these abnormalities are reported to be associated with subsequent adverse outcomes.^{1–3} OCT has been proven to be superior to IVUS in the detection of abnormal post-stent findings (stent edge dissection, intrastent tissue protrusion, and ISA).^{4–6} However, OCT has several limitations, including the requirement for complete blood removal, limited soft tissue penetration, additional contrast medium use, and failure to visualize ostium lesions, which sometimes preclude the assessment of lesion

morphology.^{7,8} The novel 60-MHz high-resolution IVUS (HR-IVUS) has evolved as a next-generation IVUS imaging technology to provide higher image resolution than that obtained by conventional IVUS (20–40 MHz), with maintenance of the potential benefits of IVUS over OCT; namely, greater penetration depth without the need for luminal blood removal by a contrast agent.⁹ It is expected that the improved properties of HR-IVUS will allow the accurate detection of abnormal findings after stent implantation, and that HR-IVUS will become a leading modality for post-stent evaluation instead of OCT. Therefore, the present study aimed to evaluate the diagnostic performance of 60-MHz HR-IVUS in the detection of abnormal post-stent findings.

Received August 6, 2020; revised manuscript received November 15, 2020; accepted December 3, 2020; J-STAGE Advance Publication released online February 5, 2021 Time for primary review: 33 days

Department of Cardiology, Aichi Medical University, Nagakute, Japan

Mailing address: Hirohiko Ando, MD, PhD, Department of Cardiology, Aichi Medical University, 1-1 Yazakokarimata, Nagakute 480-1195, Japan. E-mail: anhiro@aichi-med-u.ac.jp

All rights are reserved to the Japanese Circulation Society. For permissions, please e-mail: cj@j-circ.or.jp

ISSN-1346-9843

Methods

Study Population

The present study was a post-hoc analysis of a prospective study to compare the diagnostic performance of OCT and HR-IVUS for detection of plaque rupture in patients with acute coronary syndrome (ACS).¹⁰ Patients with ACS who underwent percutaneous coronary intervention with stent implantation between September 2017 and July 2019 for de novo native coronary artery lesions were enrolled. For all patients, both OCT and HR-IVUS were performed after stent implantation. The exclusion criteria were culprit lesions in bypass grafts, lesions with stent restenosis, bifurcation lesions requiring 2 stents, and lesions with poor image quality. This study was conducted in accordance with the Declaration of Helsinki established by the World Medical Association, and the study protocol was approved by the Ethics Committee of Aichi Medical University (Nagakute, Japan), with all patients providing their written informed consent.

Intracoronary Imaging

Both OCT and HR-IVUS were performed via 6F or 7F

guiding catheters. All patients received an intracoronary bolus injection of nitroglycerine (0.2 mg) before each coronary imaging session. OCT imaging data were acquired with a frequency domain ILUMIEN OPTIS system (Abbott Vascular, Santa Clara, CA, USA) using a Dragonfly™ catheter (Abbott Vascular). The Dragonfly™ catheter was advanced distally to the target lesion over a 0.014-inch guidewire. Automated pullback with a speed of 18–36 mm/s was performed during continuous intracoronary injection of 100% contrast medium from the guiding catheter, acquiring images at a rate of 180 frames/s.

HR-IVUS imaging data were acquired with a VISICUBE IVUS imaging system (Terumo, Tokyo, Japan) using a 60-MHz mechanically rotating IVUS catheter (AltaView™; Terumo). After the AltaView™ catheter was advanced distally to the target lesion over a 0.014-inch guidewire, the catheter was pulled back to the coronary ostium using a motorized pull-back device at 9.0 mm/s.

Quantitative and Qualitative Image Analysis

OCT images were analyzed using a dedicated offline review system with a semi-automated contour-detection software program (Abbott Vascular). HR-IVUS images were analyzed using a computerized offline software (VISIATLAS; Terumo). Imaging analyses were performed by 2 experienced investigators. The HR-IVUS and OCT findings were blinded for OCT and HR-IVUS image evaluations, respectively. In case of discordance between the observers, a consensus reading was obtained. Minimum lumen area (MLA) was determined as the smallest lumen area within the stented segment. Minimum lumen diameter (MLD) was defined as the mean diameter of the lumen at the MLA site. The same definition was applied to confirm the presence of stent edge dissection and intrastent tissue protrusion in both OCT and HR-IVUS evaluations. Stent edge dissection was defined as the disruption of the luminal vessel surface at the edge segments.^{11,12} Both proximal and distal ends were evaluated for stent edge dissection. Intrastent tissue protrusion was defined as the protrusion of the tissue through the stent struts.^{11,12} Furthermore, in the OCT evaluations, the protrusion area and the protrusion height at the most protruding site were evaluated. The protrusion area was calculated by subtracting the lumen area from the stent area, and the protrusion height was obtained by measuring the distance from the top of the protrusion to the stent.¹³ The presence of ISA on the OCT images was defined in the presence of a strut with an ISA distance >100 μm, which was determined by adding the actual strut thickness and polymer thickness to the OCT resolution limit.^{11,14–16} The largest ISA distance among all the observed struts in the target cross section was analyzed as the maximum ISA distance. When the strut was well-

Table 1. Baseline Characteristics

	N=47
Age, years	67.3±13.4
Men	35 (74.5)
Risk factors	
Hypertension	23 (48.9)
Dyslipidemia	25 (53.2)
Diabetes mellitus	18 (38.3)
Chronic kidney disease	8 (17.0)
Current smoker	15 (31.9)
Clinical presentation	
STE-ACS	34 (72.3)
NSTEMI-ACS	13 (27.7)
Target vessel	
Right coronary artery	11 (23.4)
Left anterior descending	32 (68.1)
Left circumflex	4 (8.5)
Stent type	
Xience/Synergy/Resolute/Orsiro/Ultimeaster	27/8/5/5/2
Stent diameter, mm	3.25±0.42
Stent length, mm	22.8±8.0

Data are presented as mean±SD or n (%). NSTEMI-ACS, non-ST elevation-acute coronary syndrome; STE-ACS, ST elevation-acute coronary syndrome.

Table 2. Quantitative Measurements Using HR-IVUS and OCT

	HR-IVUS	OCT	P value
Minimal lumen area, mm ²	6.66±1.98	5.61±1.79	<0.001
Minimal lumen diameter, mm	2.87±0.42	2.63±0.43	<0.001
Reference lumen area, mm ²	8.09±2.28	7.05±2.19	<0.001
Reference lumen diameter, mm	3.14±0.46	2.94±0.47	0.001
Area stenosis, %	16.3±17.9	19.0±16.4	0.277
Diameter stenosis, %	8.0±9.6	10.2±9.0	0.157

HR-IVUS, high-resolution intravascular ultrasound; OCT, optical coherence tomography.

Table 3. Detection of Abnormal Post-Stent Findings Using OCT and HR-IVUS			
(A) Stent edge dissection	OCT		Total
	Edge dissection (+)	Edge dissection (–)	
HR-IVUS			
Edge dissection (+)	1	0	1
Edge dissection (–)	4	89	93
Total	5	89	94
(B) Intrastent tissue protrusion	OCT		Total
	Protrusion (+)	Protrusion (–)	
HR-IVUS			
Protrusion (+)	22	0	22
Protrusion (–)	23	2	25
Total	45	2	47
(C) Incomplete stent apposition	OCT		Total
	ISA (+)	ISA (–)	
HR-IVUS			
ISA (+)	6	0	6
ISA (–)	16	25	41
Total	22	25	47

HR-IVUS, high-resolution intravascular ultrasound; ISA, incomplete stent apposition; OCT, optical coherence tomography.

apposed or the ISA distance was $<100\mu\text{m}$, the ISA distance was calculated as $100\mu\text{m}$, the minimum value. The presence of ISA on HR-IVUS images was defined as a clear separation between at least 1 stent strut and the vessel wall.^{4,17} Every frame of the OCT and HR-IVUS image was assessed for the evaluation of stent edge dissection, intrastent tissue protrusion and ISA.

Statistical Analyses

All analyses were performed using the SPSS software program (version 22.0; IBM, Armonk, NY, USA). Data were expressed as means $\pm$ standard deviations (SDs) or as

median and interquartile range with differences (95% confidence interval). Categorical variables were expressed as frequencies (%). Continuous variables were compared using the unpaired Student's t-test, and categorical variables were compared using the chi-squared test. The Mann-Whitney U-tests were performed for non-parametric data. A receiver operating characteristic (ROC) curve analysis was applied to determine the cut-off value of protrusion area in discriminating HR-IVUS-identified protrusion. The Bland-Altman plot method was used to assess the agreement between 2 imaging devices. The Bland-Altman plot depicted the differences in paired measure-

ments vs. their mean values, with reference lines for the mean difference of paired measurements. The limits of agreement were defined as $\text{mean} \pm 1.96 \text{ SD}$ of the absolute difference. Statistical significance was assumed at a probability (P) value of <0.05 .

Results

Patient Characteristics

A total of 48 patients underwent both OCT and HR-IVUS after stent implantation. Of these, 1 patient was excluded due to poor OCT image quality. Eventually, 47 sets of OCT/HR-IVUS pullbacks were included in the present study. Patient clinical characteristics are summarized in Table 1.

Quantitative Measurements Using HR-IVUS and OCT

Quantitative HR-IVUS and OCT measurements are summarized in Table 2. HR-IVUS identified a larger minimal lumen area and a larger minimal lumen diameter than did OCT ($6.66 \pm 1.98 \text{ mm}^2$ vs. $5.61 \pm 1.79 \text{ mm}^2$ and $2.87 \pm 0.42 \text{ mm}$ vs. $2.63 \pm 0.43 \text{ mm}$, respectively, $P < 0.001$ for both comparisons). There were no significant differences in percent area stenosis and percent diameter stenosis between HR-IVUS and OCT. The Bland–Altman analyses for MLA are shown in Figure 1. There was a direct correlation and good agreement in MLA between HR-IVUS and OCT ($r = 0.80$, $P < 0.001$; mean difference, 1.05 mm^2).

Stent Edge Dissection Detected by OCT and HR-IVUS

Assessing both ends of the stent ($n = 94$), OCT identified stent edge dissections at 5 sites (5.3%), whereas HR-IVUS identified a stent edge dissection at 1 site (1.0%, Table 3A). With detection using OCT as the gold standard, the sensitivity, specificity, and diagnostic accuracy of HR-IVUS for the detection of stent edge dissection were 20.0%, 100%, and 95.7%, respectively (Figure 2A).

Intrastent Tissue Protrusion Detected by OCT and HR-IVUS

Of 47 stented segments, OCT identified intrastent tissue protrusion at 45 lesions (95.7%), whereas HR-IVUS identified intrastent tissue protrusion at 22 lesions (46.8%, Table 3B). With detection by OCT as the gold standard, the sensitivity, specificity, and diagnostic accuracy of HR-IVUS for the detection of the intrastent tissue protrusion were 48.9%, 100%, and 51.1%, respectively (Figure 2B). The lesions with HR-IVUS-identified protrusion demonstrated significantly larger protrusion area than those without ($0.99 [0.58–2.13]$ vs. $0.50 [0.31–0.84] \text{ mm}^2$, $P < 0.01$). There was no significant difference in the protrusion height between lesions with and without HR-IVUS-identified protrusion ($0.36 [0.28–0.56]$ vs. $0.34 [0.21–0.43] \text{ mm}$, $P = 0.13$). The ROC curve analysis demonstrated that the optimal cut-off value of the protrusion area for discriminating HR-IVUS-identified protrusion was $>0.57 \text{ mm}^2$; the sensitivity, the specificity, and the area under the curve were 81.8%, 60.9%, and 0.73, respectively. Representative OCT and HR-IVUS images of intrastent tissue protrusion after stent implantation are shown in Figure 3.

ISA Detected by OCT and HR-IVUS

Of 47 stented segments, OCT identified the ISA at 22 lesions (46.8%), whereas HR-IVUS identified the ISA at 6 lesions (12.8%, Table 3C). With detection by OCT as the gold standard, the sensitivity, specificity, and diagnostic accuracy of HR-IVUS for the detection of the ISA were 27.2%, 100%, and 66.0%, respectively (Figure 2C). There was a distinct difference in the ISA distance between the ISAs detected by HR-IVUS and those that could not be detected by HR-IVUS. All ISAs with an ISA distance of $<400 \mu\text{m}$ could not be detected by HR-IVUS. Of the 7 ISAs

Figure 3. Intrastent tissue protrusion in OCT Images with corresponding HR-IVUS images. The images of OCT (A–C) and HR-IVUS (A'–C') obtained at the same position and angle. (A,A') An OCT image representing an intrastent tissue protrusion (arrowheads). The protrusion area was 0.32 mm² and the protrusion height was 0.26 mm. However, HR-IVUS could not identify the protrusion. (B,B') An OCT image representing an intrastent tissue protrusion (arrowheads). The protrusion area was 0.43 mm² and the protrusion height was 0.38 mm. However, HR-IVUS could not identify the protrusion. (C,C') An OCT image representing an intrastent tissue protrusion (arrowheads). The protrusion area was 2.35 mm² and the protrusion height was 0.82 mm. HR-IVUS could identify the protrusion. OCT, optical coherence tomography; HR-IVUS, high-resolution intravascular ultrasound.

with an ISA distance of $\geq 400 \mu\text{m}$, 6 ISAs could be detected by HR-IVUS. The minimum ISA distance detectable by HR-IVUS was $430 \mu\text{m}$ (Supplementary Figure). Representative OCT and HR-IVUS images of ISA after stent implantation are shown in Figure 4.

Clinical Outcome

During a median follow up of 26 months, no device-oriented events (cardiovascular death, target vessel myocardial infarction, or clinically driven target lesion revascularization) were identified in the participating patients.

Discussion

The present study aimed to evaluate the diagnostic performance of a 60-MHz HR-IVUS in identifying abnormal

post-stent findings. The main findings were as follows: (1) quantitative measurements after stent implantation using HR-IVUS were significantly larger than those measured using OCT; and 2) the sensitivity of HR-IVUS to detect abnormal post-stent findings, including stent edge dissection, intrastent tissue protrusion, and ISA, was low.

Improvement in the Resolution of HR-IVUS

The novel 60-MHz HR-IVUS has evolved as a next-generation IVUS imaging technology to provide higher image resolution than that obtained by conventional IVUS (20–40 MHz).⁹ A previous study demonstrated that polymeric struts of bioresorbable scaffold were better visualized with the 60-MHz IVUS than with the 40-MHz IVUS.¹⁸ We previously reported that HR-IVUS has a high sensitivity for identifying OCT-detected plaque rupture in ACS

Figure 4. Incomplete stent apposition in OCT Images with corresponding HR-IVUS images. The images of OCT (A–C) and HR-IVUS (A'–C') obtained at the same position and angle. (A,A') An OCT image representing an incomplete stent apposition (arrowheads). The maximum ISA distance was 130 μ m. However, HR-IVUS could not identify the apposition. (B,B') An OCT image representing an incomplete stent apposition (arrowheads). The maximum ISA distance was 300 μ m. However, HR-IVUS could not identify the apposition. (C,C') An OCT image representing an incomplete stent apposition (arrowheads). The maximum ISA distance was 520 μ m. HR-IVUS could identify the apposition. OCT, optical coherence tomography; HR-IVUS, high-resolution intravascular ultrasound; ISA, incomplete stent apposition.

patients.¹⁰ Furthermore, in some cases, plaque ruptures that could not be identified by OCT were successfully identified by HR-IVUS.¹⁹ It is expected that HR-IVUS will be useful in terms of post-stent evaluation.

Quantitative Measurements Using HR-IVUS and OCT

In the present study, MLD measured by HR-IVUS was significantly greater than that measured by OCT (relative reference 9%). Our findings were in good agreement with a previous report comparing the conventional 40-MHz IVUS with the frequency domain OCT (relative reference 9% in MLA measurement).⁴ The measurements by frequency domain OCT were equal to the actual measurements of the phantom model, whereas the conventional IVUS usually overestimated the measurements.⁴ A possible reason for the difference between the measurement values of the 2 devices was considered to be the superior ability of

OCT to visualize the lumen interface compared to conventional IVUS.⁴ However, the results of the present study revealed that although the resolution properties of HR-IVUS were improved, its quantitative measurements were similar to that of conventional IVUS.

Assessment of Abnormal Post-Stent Findings Using HR-IVUS

Previous studies comparing conventional IVUS and OCT demonstrated that OCT is superior to conventional IVUS in the detection of abnormal post-stent findings.^{4–6} Kubo et al reported that dissection, tissue protrusion, and ISA were more frequently identified by OCT compared to conventional IVUS (13% vs. 0% for dissection, 95% vs. 18% for tissue protrusion, and 39% vs. 14% for ISA).⁴ Similarly, in the subgroup analysis of the ILUMIEN (Observational Study of Optical Coherence Tomography in Patients Undergoing Fractional Flow Reserve and Percutaneous

Coronary Intervention) III study, the superiority of OCT over conventional IVUS in identifying abnormal post-stent findings was reported (40% vs. 16% for dissection, 74% vs. 19% for tissue protrusion, and 39% vs. 19% for ISA).⁶ After the advent of HR-IVUS, it is expected that HR-IVUS will provide a detailed assessment of intravascular structures and allow the identification of abnormal post-stent findings. However, the present study revealed that the identification of abnormal post-stent findings by HR-IVUS was too insensitive for clinical use. The sensitivity of HR-IVUS in identifying stent edge dissection, intrastent tissue protrusion, and ISA were 20.0%, 48.9%, and 27.2%, respectively. These results suggest that OCT evaluations are still superior to HR-IVUS in the detection of abnormal post-stent findings. However, it has also been suggested that abnormal findings that cannot be detected by HR-IVUS were often minor findings that had little effect on the adverse cardiac events. A recent European consensus document recommended that an ISA distance $<400\mu\text{m}$ was the optimal cut-off value for stent optimization.¹⁹ This recommendation was based on previous OCT studies demonstrating that struts with ISA distance $<400\mu\text{m}$ at post-stenting resulted in complete integration to the vessel wall at 6–24 months after stent implantation.^{15,20,21} In the present study, all ISA that could not be detected by HR-IVUS had an ISA distance of $\leq 400\mu\text{m}$, which is an acceptable range based on the European consensus document. In contrast, for complete integration to vessel wall in the earlier phase, the ISA distance needs to be controlled more strictly. We reported that the optimal cut-off value of baseline ISA distance for predicting persistent ISA at 2 weeks and 4 months was $>140\mu\text{m}$ and $>215\mu\text{m}$, respectively.¹⁴ In such a situation, the diagnostic performance of HR-IVUS may not be sufficient. Furthermore, Sugiyama et al reported that the larger protrusion area immediately after PCI was related to the larger neointimal hyperplasia area at 9-month follow up.²² In the present study, the lesions without HR-IVUS-identified protrusion had a significantly smaller protrusion area than those with HR-IVUS-identified protrusion. It also suggests that protrusions not identified by HR-IVUS may have less clinical effect. The association between these unidentifiable findings on HR-IVUS and long-term outcomes requires validation in prospective studies.

Study Limitations

Some limitations need to be acknowledged in the present study. First, this was a single-center study with a relatively small cohort, and the findings need to be confirmed by a larger population study. Second, all patients enrolled in this study had ACS, most of which were associated with the presence of thrombus. The thrombus within the stented lesion might have affected the quantitative measurements and the assessment of lesion morphologies. Third, although OCT and HR-IVUS image evaluations were performed by 2 experienced investigators, there were some interobserver variability, especially in HR-IVUS image evaluations (Supplementary Table). It suggested that the objectivity of the HR-IVUS interpretation was not sufficiently guaranteed. Finally, in the present study, HR-IVUS was performed at a pullback speed of 9 mm/s, which was faster than that used in conventional IVUS studies. The fast pullback speed made it difficult to distinguish between intraluminal blood and the vessel wall structures, which may have affected the visualization of the lesion morphologies.

Conclusions

In terms of post-stent evaluation, the diagnostic performance of HR-IVUS remains insufficient. Abnormal post-stent findings may be underestimated when performing HR-IVUS due to its low sensitivity. OCT should continue to be used as the gold standard until superior methods are developed.

Acknowledgments

The authors would like to thank all staff and patients who contributed to this study.

Disclosures

H.A. has received research grants for this study from Chukyo Geriatric Research Promotion Financial Group. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

T. A. is a member of *Circulation Journal* Editorial Team.

IRB Information

This study was approved by Aichi Medical University (reference number: 2020-040).

Data Availability

The deidentified participant data will not be shared.

References

1. Mintz GS, Guagliumi G. Intravascular imaging in coronary artery disease. *Lancet* 2017; **390**: 793–809.
2. Kubo T, Akasaka T. Late clinical outcome of suboptimal stent implantation defined by intracoronary optical coherence tomography. *EuroIntervention* 2018; **14**: e370–e372.
3. Prati F, Romagnoli E, La Manna A, Burzotta F, Gatto L, Marco V, et al. Long-term consequences of optical coherence tomography findings during percutaneous coronary intervention: The Centro Per La Lotta Contro L'infarto - Optimization Of Percutaneous Coronary Intervention (CLI-OPCI) LATE study. *EuroIntervention* 2018; **14**: e443–e451.
4. Kubo T, Akasaka T, Shite J, Suzuki T, Uemura S, Yu B, et al. OCT compared with IVUS in a coronary lesion assessment: The OPUS-CLASS study. *JACC Cardiovasc Imaging* 2013; **6**: 1095–1104.
5. Bezerra HG, Attizzani GF, Sirbu V, Musumeci G, Lortkipanidze N, Fujino Y, et al. Optical coherence tomography versus intravascular ultrasound to evaluate coronary artery disease and percutaneous coronary intervention. *JACC Cardiovasc Interv* 2013; **6**: 228–236.
6. Ali ZA, Maehara A, Genereux P, Shlofmitz RA, Fabbiochi F, Nazif TM, et al. Optical coherence tomography compared with intravascular ultrasound and with angiography to guide coronary stent implantation (ILUMIEN III: OPTIMIZE PCI): A randomised controlled trial. *Lancet* 2016; **388**: 2618–2628.
7. Maehara A, Matsumura M, Ali ZA, Mintz GS, Stone GW. IVUS-guided versus OCT-guided coronary stent implantation: A critical appraisal. *JACC Cardiovasc Imaging* 2017; **10**: 1487–1503.
8. Kubo T, Tanaka A, Kitabata H, Ino Y, Tanimoto T, Akasaka T. Application of optical coherence tomography in percutaneous coronary intervention. *Circ J* 2012; **76**: 2076–2083.
9. Chin CY, Maehara A, Fall K, Mintz GS, Ali ZA. Imaging comparisons of coregistered native and stented coronary segments by high-definition 60-MHz intravascular ultrasound and optical coherence tomography. *JACC Cardiovasc Interv* 2016; **9**: 1305–1306.
10. Ohashi H, Ando H, Takashima H, Waseda K, Shimoda M, Fujimoto M, et al. Diagnostic performance of high-resolution intravascular ultrasound for the detection of plaque rupture in patients with acute coronary syndrome. *Circ J* 2019; **83**: 2505–2511.
11. Tearney GJ, Regar E, Akasaka T, Adriaenssens T, Barlis P, Bezerra HG, et al. Consensus standards for acquisition, measurement, and reporting of intravascular optical coherence tomography studies: A report from the International Working Group for Intravascular Optical Coherence Tomography Standardization and Validation. *J Am Coll Cardiol* 2012; **59**: 1058–1072.

12. Prati F, Guagliumi G, Mintz GS, Costa M, Regar E, Akasaka T, et al. Expert review document part 2: Methodology, terminology and clinical applications of optical coherence tomography for the assessment of interventional procedures. *Eur Heart J* 2012; **33**: 2513–2520.
13. Sugiyama T, Kimura S, Akiyama D, Hishikari K, Kawaguchi N, Kamiishi T, et al. Quantitative assessment of tissue prolapse on optical coherence tomography and its relation to underlying plaque morphologies and clinical outcome in patients with elective stent implantation. *Int J Cardiol* 2014; **176**: 182–190.
14. Wakabayashi H, Ando H, Nakano Y, Takashima H, Waseda K, Shimoda M, et al. Temporal changes of incomplete stent apposition during early phase after everolimus-eluting stent implantation: Serial optical coherence tomography analyses at 2-week and 4-month. *Int J Cardiovasc Imaging*, doi:10.1007/s10554-020-02023-z.
15. Shimamura K, Kubo T, Akasaka T, Kozuma K, Kimura K, Kawamura M, et al. Outcomes of everolimus-eluting stent incomplete stent apposition: A serial optical coherence tomography analysis. *Eur Heart J Cardiovasc Imaging* 2015; **16**: 23–28.
16. Fujii K, Kubo T, Otake H, Nakazawa G, Sonoda S, Hibi K, et al. Expert consensus statement for quantitative measurement and morphological assessment of optical coherence tomography. *Cardiovasc Interv Ther* 2020; **35**: 13–18.
17. Maehara A, Ben-Yehuda O, Ali Z, Wijns W, Bezerra HG, Shite J, et al. Comparison of stent expansion guided by optical coherence tomography versus intravascular ultrasound: The ILUMIEN II Study (Observational Study of Optical Coherence Tomography [OCT] in Patients Undergoing Fractional Flow Reserve [FFR] and Percutaneous Coronary Intervention). *JACC Cardiovasc Interv* 2015; **8**: 1704–1714.
18. Okada K, Kitahara H, Mitsutake Y, Tanaka S, Kimura T, Yock PG, et al. Assessment of bioresorbable scaffold with a novel high-definition 60 MHz IVUS imaging system: Comparison with 40-MHz IVUS referenced to optical coherence tomography. *Catheter Cardiovasc Interv* 2018; **91**: 874–883.
19. Raber L, Mintz GS, Koskinas KC, Johnson TW, Holm NR, Onuma Y, et al. Clinical use of intracoronary imaging. Part 1: Guidance and optimization of coronary interventions. An expert consensus document of the European Association of Percutaneous Cardiovascular Interventions. *EuroIntervention* 2018; **14**: 656–677.
20. Gutierrez-Chico JL, Wykrzykowska J, Nuesch E, van Geuns RJ, Koch KT, Koolen JJ, et al. Vascular tissue reaction to acute malapposition in human coronary arteries: Sequential assessment with optical coherence tomography. *Circ Cardiovasc Interv* 2012; **5**: 20–29, S21–S28.
21. Sotomi Y, Onuma Y, Dijkstra J, Miyazaki Y, Kozuma K, Tanabe K, et al. Fate of post-procedural malapposition of everolimus-eluting polymeric bioresorbable scaffold and everolimus-eluting cobalt chromium metallic stent in human coronary arteries: Sequential assessment with optical coherence tomography in ABSORB Japan trial. *Eur Heart J Cardiovasc Imaging* 2018; **19**: 59–66.
22. Sugiyama T, Kimura S, Ohtani H, Hishikari K, Kojima K, Sagawa Y, et al. Relationship between quantities of tissue prolapse after percutaneous coronary intervention and neointimal hyperplasia at follow-up on serial optical coherence tomography examination. *Int J Cardiol* 2017; **241**: 470–477.

Supplementary Files

Please find supplementary file(s);
<http://dx.doi.org/10.1253/circj.CJ-20-0817>