Journal of Cardiology 72 (2018) 186–192

Contents lists available at ScienceDirect

Journal of Cardiology

journal homepage: www.elsevier.com/locate/jjcc

Review

The role of optical coherence tomography in the setting of acute myocardial infarction

Yongcheol Kim (MD)[a], Thomas W. Johnson (MD)[b], Takashi Akasaka (MD)[c], Myung Ho Jeong (MD)[a,*]

[a] Chonnam National University Hospital, Gwangju, Republic of Korea
[b] Bristol Heart Institute, Bristol, United Kingdom
[c] Wakayama Medical University, Wakayama, Japan

ARTICLE INFO

Article history:
Received 27 February 2018
Accepted 1 March 2018
Available online 9 April 2018

Keywords:
Optical coherence tomography
Myocardial infarction
Percutaneous coronary intervention

ABSTRACT

In recent years, intravascular imaging-guided percutaneous coronary intervention (PCI) has been increasing in patients with acute myocardial infarction (AMI). However, the role of optical coherence tomography (OCT) has not been established in the setting of AMI despite OCT providing superior resolution (10 μm axial resolution) and facilitating assessment of baseline lesion characteristics and post-intervention evaluation of the acute result of stent implantation, including visualization of procedural dissections, malapposition, tissue prolapse, and thrombus. We provide an overview of the potential benefits of OCT-guidance in various situations of AMI.

Contents

Introduction

Coronary angiography is the most commonly utilized imaging modality for assessment of coronary artery disease (CAD) and facilitates percutaneous coronary intervention (PCI). However, a 2-dimensional (2-D) lumenogram of the 3-dimensional structure of the coronary artery, provided by coronary angiography, has fundamental limitations in the accurate evaluation of plaque characteristics, vessel wall, and lumen dimensions [1]. The limitations of 2-D, angiography-guided PCI for complex lesion subsets, such as bifurcation or left main disease, are reflected by procedural success rates and long-term clinical outcomes [2,3]. Intravascular ultrasound (IVUS) has been a useful tool for providing information in terms of pre-intervention lesion characteristics, including plaque morphology and vessel dimensions with improved resolution (100–200 μm axial resolution)

* Corresponding author at: Principal Investigators of Korea Acute Myocardial Infarction Registry, Heart Research Center, Chonnam National University Hospital, 671 Jabongro, Dong-gu, Gwangju 61469, Republic of Korea.
E-mail address: myungho@chollian.net (M.H. Jeong).

https://doi.org/10.1016/j.jjcc.2018.03.004
0914-5087/

compared with angiography [4]. As a result, IVUS-guided stent implantation has facilitated better clinical outcomes when compared with angiography-guided intervention in randomized studies [5,6].

Optical coherence tomography (OCT) provides superior resolution (10 μm) for assessment of the coronary vasculature and detailed post-intervention information, including visualization of edge dissections and strut apposition [7–9]. Although both IVUS and OCT provide images of the coronary artery by intra-coronary imaging catheter, there are different characteristics offered by both modalities. OCT has greater accuracy in detecting post-procedural dissections, malapposition, and tissue prolapse compared with IVUS, providing assessment of pathology of coronary vessel wall and post-intervention intraluminal components [10,11]. Moreover, OCT measurement demonstrates greater accuracy regarding lumen diameter and area, both in vivo and ex vivo, compared with IVUS and angiography [12,13]. However, OCT has a limited depth of penetration in comparison to IVUS hampering visualization of the vessel border and plaque burden.

The role of OCT has not been established in patients with acute myocardial infarction (AMI), although the application of OCT has been increasing in clinical practice. In this review article, we focus on the potential role of OCT in the setting of AMI and its clinical benefits.

Current status of OCT-guided PCI in patients with AMI: from the Korea Acute Myocardial Infarction Registry

The Korea Acute Myocardial Infarction Registry (KAMIR), launched in November 2005, is the first nationwide, prospective, observational registry reflecting 'real-world' clinical practice in Korean patients presenting with AMI. Data relating to the use of OCT have been collected since 2012 [14]. Between January 2012 and April 2017, a total of 17,800 consecutively listed patients were enrolled in the KAMIR, and 3843 AMI patients underwent intravascular imaging-guided PCI. The utilization of intravascular imaging guidance has increased gradually from 17.5% in 2012 to 28.7% in 2017 (p for trend <0.001). A gradual increase in OCT utilization was observed from 1.0% in 2012 to 2.2% in 2016, but more than doubled to 4.7% in 2017 (p for trend <0.001). Conversely, IVUS utilization has increased from 16.5% in 2012 to 25.9% in 2016 with a decrease to 24.1% observed in 2017 (p for trend <0.001) (Fig. 1).

Intravascular imaging-guided PCI in patients with AMI is progressively increasing and OCT-guided PCI has been growing in recent years.

The role of OCT in the setting of AMI

Assessment for ambiguous angiographic findings in patients with AMI

Spontaneous coronary artery dissection (SCAD) is defined as a spontaneous separation of the coronary wall associated with intramural hematoma [15]. Even though SCAD was reported as a rare disease in the studies based on coronary angiography, studies using OCT to aid diagnosis have demonstrated a greater prevalence of SCAD [16–18]. An angiographic classification has been developed by Saw et al., with evidence of the pathognomonic 'double lumen' with contrast staining in the vessel wall and a radiolucent flap defined as type 1. Type 2 SCAD is characterized by a long and diffuse stenosis, with either an abrupt onset and recrudescence of normal caliber vessel (type 2a) or caliber reduction to the distal coronary bed (type 2b). Type 3 SCAD is difficult to distinguish from native CAD [19]. In cases of type 2b/3 SCAD angiographic diagnosis can be challenging and a role for diagnosis confirmation by use of intra-coronary imaging, particularly the high resolution (10 μm) provided by OCT, may be considered to confirm intima tear, intramural hematoma, and false lumen [20].

Although suboptimal blood clearance has potential limitations with OCT in the setting of SCAD, we reported equivalent medial area in lesion and normal segment supported the diagnosis of intramural compression, particularly when observed in association with luminal folding, which was difficult to evaluate by IVUS [21]. In particular, SCAD type 3, which mimics atherosclerosis, is the most challenging to differentiate from atherosclerosis and may be misdiagnosed if intravascular imaging is not performed. However, intravascular imaging must be undertaken with caution, as propagation of SCAD is possible through inadvertent wiring of the false lumen or extension by contrast injection [22]. Where possible, a conservative approach to the treatment of SCAD should be considered, as there are numerous reports of vessels healing spontaneously [20].

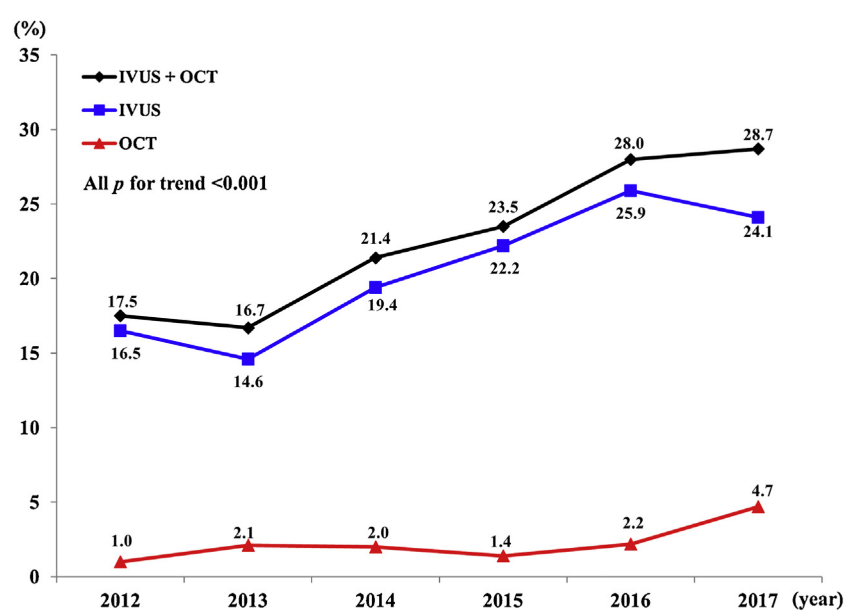

Fig. 1. Annual trends of intravascular imaging guided percutaneous coronary intervention in patients with acute myocardial infarction from KAMIR. IVUS, intravascular ultrasound; OCT, optical coherence tomography.

Overall, OCT is preferred to diagnose SCAD, not confirmed by coronary angiography, over IVUS in the SCAD patients presenting with AMI because of better resolution for identifying the evidence of SCAD although there are potential limitations regarding shallow optical penetration and blood clearance.

Assessment for stent failure in patients with AMI

Guidelines recommend that IVUS or OCT guidance should be considered in order to assess the mechanism of stent failure, including in-stent restenosis and stent thrombosis [23]. IVUS demonstrated that smaller stent area and stent underexpansion was associated with stent failure in the drug-eluting stent (DES) era [24,25]. However, IVUS is limited in its ability to assess characteristics of in-stent tissue components. The superior resolution of OCT was able to evaluate the morphologic characteristics of neointima and demonstrated that the mechanism of restenosis is heterogeneous with varying neointimal patterns, from homogeneous fibrotic tissue to complex neoatherosclerotic responses [26]. In two OCT-guided registries of stent failure, OCT has demonstrated the benefit of obtaining greater detail of the nature of stent failure [27,28]. Malapposition is the most commonly reported abnormality and stent underexpansion is likely to be the major driver in the early phase and OCT has revealed neoatheroma, defined as the neointimal diffuse thickening with lipid-core plaque and fibrous cap, as an important mode of late stent failure. Thin-cap (<65 μm) neoatheroma, similar to thin-cap fibroatheroma, the classically defined 'vulnerable' plaque, in a native coronary artery, also can be detected by high resolution of OCT as shown in Fig. 2 [29].

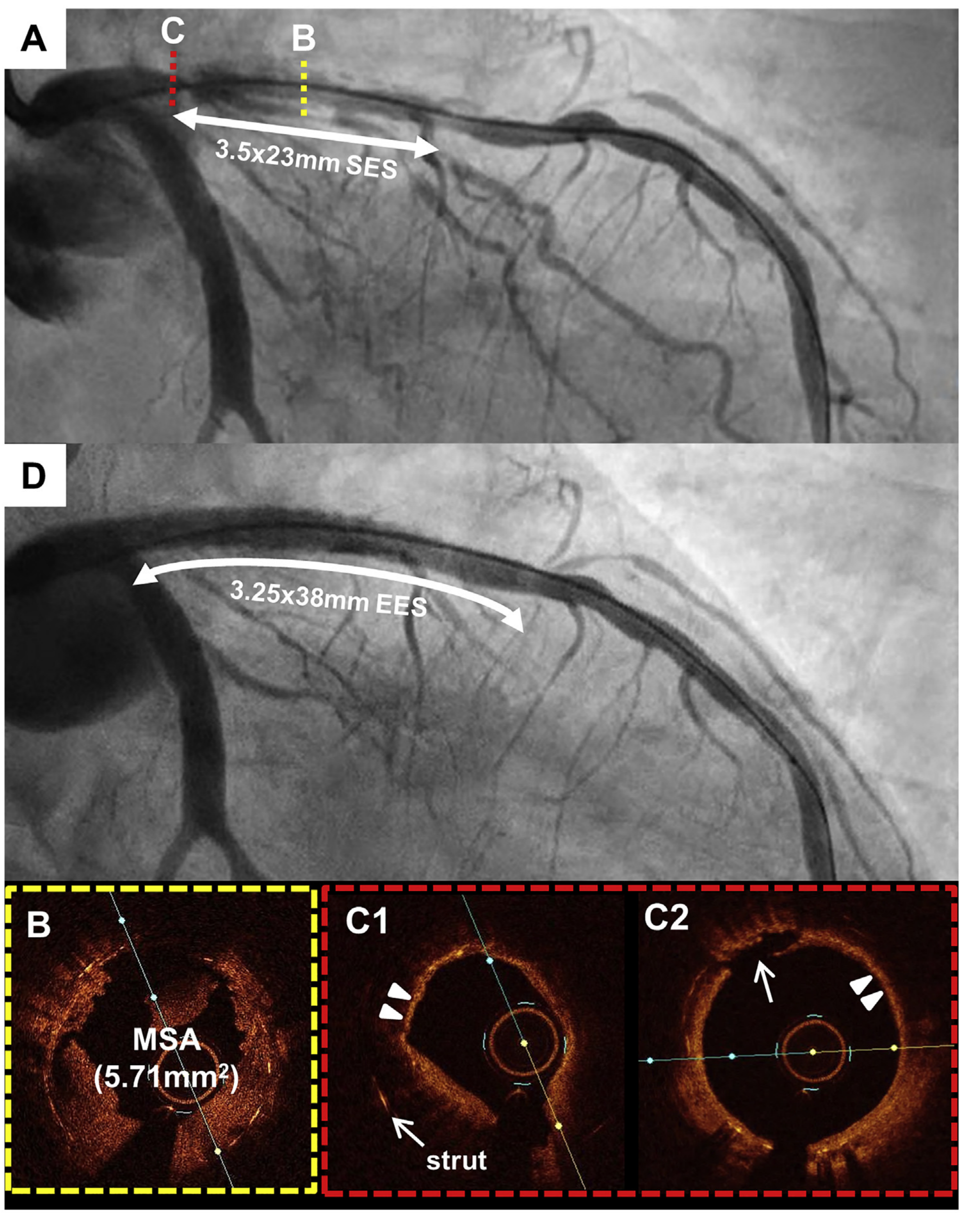

Fig. 2. Thin-cap neoatheroma in very late stent thrombosis assessed by OCT. (A) Angiographic assessment demonstrating stent failure in proximal LAD in a 49-year-old woman who underwent a 3.5 mm × 23 mm sirolimus-eluting stent (SES) implantation 10 years previously complaining of sudden onset chest pain with electrocardiographic evidence of anterior ST-segment elevation. (B) OCT demonstrating minimal stent area of 5.71 mm^2 and minimal stent diameter of 2.70 mm. (C) OCT demonstrating thin-cap neoatheroma (arrowheads in C1 and C2) and plaque rupture (arrow in C2). (D) Final coronary angiography demonstrating good distal flow without residual stenosis by treating with a 3.25 mm × 38 mm everolimus-eluting stent (EES) and pre- and post-dilation with a 3.5 mm × 10 mm noncompliance balloon. LAD, left anterior descending artery; OCT, optical coherence tomography; MSA, minimal stent area.

Therefore, OCT is beneficial to evaluate the mechanism of stent failure and can offer direction in how to provide interventional strategies for stent failure [27].

DES optimization for the stenotic lesion in AMI patients with dilated coronary arteries

Coronary artery aneurysm and ectasia are defined by dilatation of the coronary artery exceeding 50% of an adjacent segment diameter and are dichotomized by ectasia extending across two or more coronary segments [30]. We reported that the prevalence of combined coronary artery aneurysm, including probable Kawasaki disease, and ectasia in a UK population was 3.4% in a cohort of under-50-year-olds undergoing angiography and 6.5% in patients with ST-elevation myocardial infarction (STEMI) [31]. Three-year follow-up data, however, showed that AMI patients with ectatic vessels had a higher adverse event rate when compared with patients with non-ectatic vessels [32]. Therefore, greater attention is needed in the prevention and treatment of patients with dilated vessels presenting with AMI.

Recently, 2nd generation DES implantation is recommended over BMS for PCI in patients with AMI due to superior efficacy and safety [33]. However, DES optimization for stenotic lesion of dilated coronary artery is challenging for interventional cardiologists. OCT is a utility that can accurately measure reference vessel diameter and lesion length pre-PCI, which is useful for stent optimization by a suitable stent selection and pre- and post-interventional strategies [34]. However, we must acknowledge that vessel size may hamper imaging due to the restrictive depth of penetration of OCT. Therefore, IVUS is preferred in excessively dilated vessels. OCT also demonstrated higher sensitivity to detect stent malapposition, edge dissection, and tissue prolapsed than IVUS post-PCI [35]. In particular, OCT has shown superiority in thrombus detection to IVUS, albeit red thrombus attenuates the image and precludes deeper vessel evaluation [36]. Aneurysmal and ecstatic vessels are more likely to contain high burden thrombus and intravascular imaging may guide therapy. Therefore, OCT can have an impact on decision making for additional treatment strategy, such as pharmacotherapy and thrombus aspiration in AMI patients with dilated vessels.

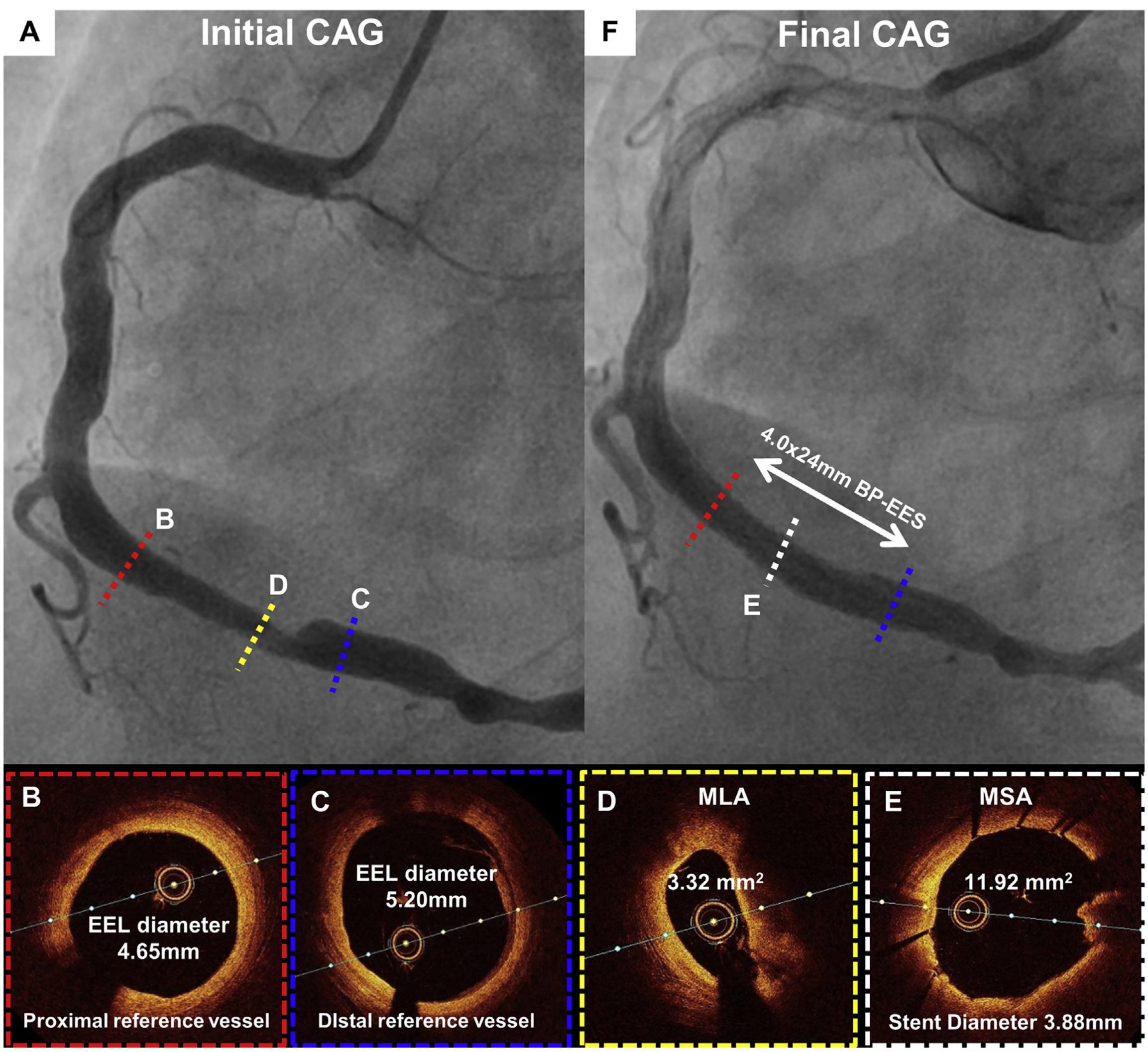

Fig. 3. OCT-guided PCI with DES optimization for the stenotic lesion in AMI patients with coronary artery ectasia. (A) Angiographic assessment demonstrating the severe stenosis in the ectatic distal RCA in a 59-year-old man presenting with NSTEMI. (B and C) OCT assessment demonstrating EEL diameter of 4.65 mm and 5.20 mm in the proximal and distal reference vessel, respectively. (D) OCT demonstrating MLA of 3.32 mm^2. (E) OCT cross-section demonstrating MSA of 11.92 mm^2 and excellent strut apposition (Video 1) after a 4.0 mm × 24 mm 2nd generation DES implantation and post-dilation using a 5.0 mm × 12 mm noncompliant balloon following EEL-guided stent sizing (F) Final CAG showing successful PCI result. BP-EES, bioresorbable polymer-everolimus eluting stent; OCT, optical coherence tomography; PCI, percutaneous coronary intervention; DES, drug-eluting stent; AMI, acute myocardial infarction; RCA, right coronary artery; NSTEMI, non-ST-elevation myocardial infarction; EEL, external elastic lamina; MLA, minimal lumen area; MSA, minimal stent area; CAG, coronary angiography.

Thus, OCT-guided PCI can be helpful to optimize DES implantation in AMI patients with dilated coronary arteries despite the potential limitation of depth penetration and attenuation images by thrombus (Fig. 3).

Assessment of side branch during PCI for AMI with bifurcation lesions

Bifurcation lesions account for approximately 25% of PCI in patients with AMI and PCI for bifurcation lesions are still challenging despite multiple technical strategies [37]. In particular, side branch occlusion after bifurcation stenting is a major procedural complication during bifurcation PCI. Coronary angiography is limited to evaluate 3D complex coronary vessel anatomy of bifurcations. On the other hand, OCT provides high-resolution cross-sectional and 3D reconstruction images to assess side branch ostium and geographic features of bifurcation. OCT studies demonstrated the independent predictors for side branch occlusion regarding plaque shift and carina shift after single-stent crossover technique. Side branch occlusion was more frequent in the proximal main vessel with high lipid-rich plaque, which may result in plaque shift [38]. In terms of carina shift, the carina tip angle of less than 50° and length between proximal branching point to carina tip of less than 1.70 mm were the independent risk factors for side branch occlusion [39].

Therefore, OCT can be a useful tool for assessment of side branch during PCI for bifurcation lesions by providing detailed geographic information as shown in Fig. 4.

Assessment for etiology of acute plaque event in AMI–plaque erosion vs. rupture

Plaque rupture has been reported to be the main cause of AMI with plaque erosion, defined as thrombosis without plaque rupture, responsible for approximately 25% of patients [40,41]. Given the high resolution images, OCT has been shown to have the ability of distinction between the plaque erosion and rupture in vivo [42]. Diagnosing erosion as a cause of AMI may facilitate tailored treatment regarding interventional and pharmacological therapies as plaque erosion evidently has different underlying pathology compared with plaque rupture. It is not clear that stent implantation has an important role in a non-flow limiting lesion with plaque erosion. In the EROSION study, cases of plaque erosion without significant flow-limitation could be treated pharmacologically and avoid stent implantation and OCT has an essential role in

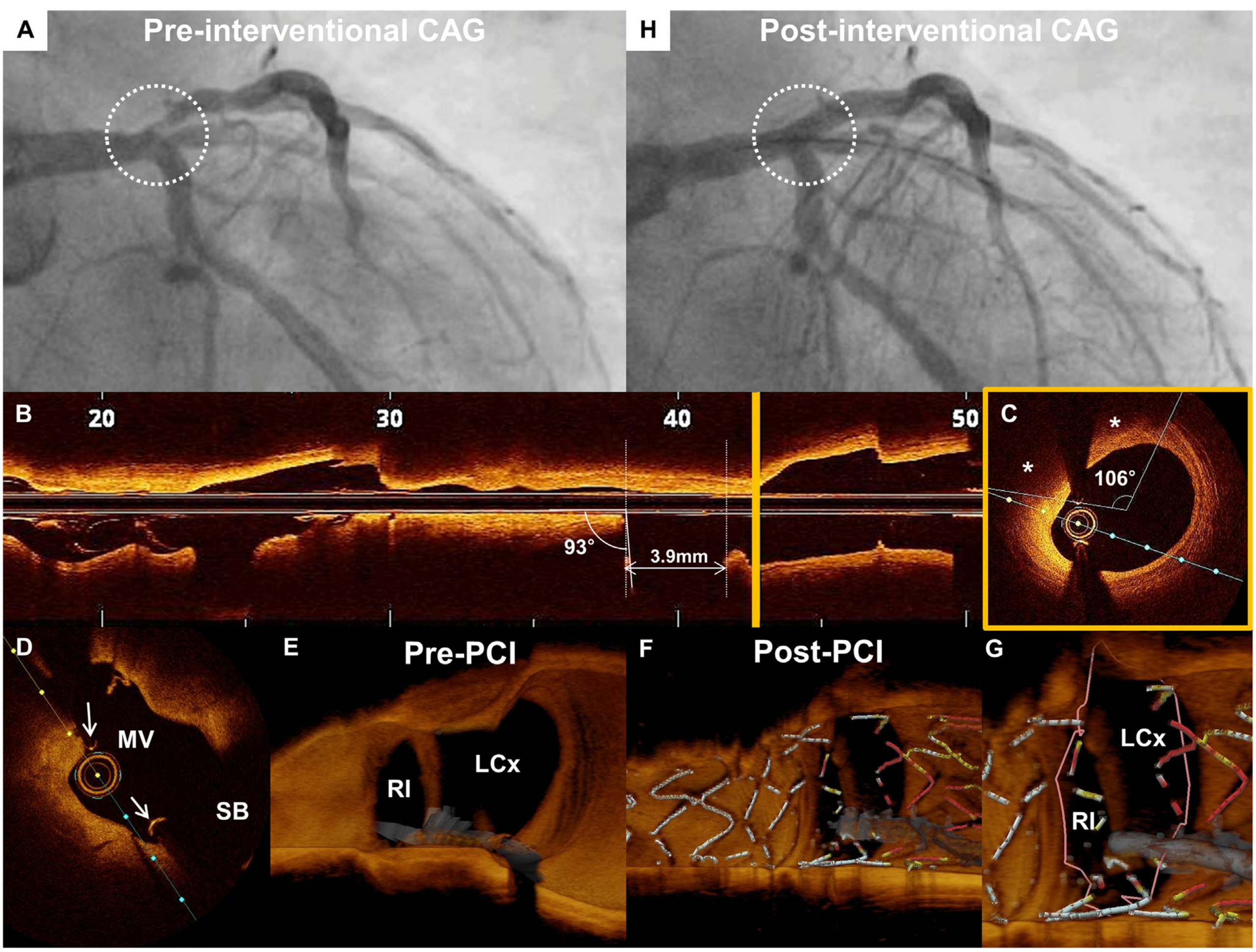

Fig. 4. Successful bifurcation stenting with the aid of OCT in patients with acute myocardial infarction. (A) Angiographic assessment demonstrating the severe stenosis in the ostium of LAD and intermediate stenosis in the RI branch in a 56-year-old man presenting with NSTEMI. (B) Pre-intervention OCT longitudinal image showing wide carina angle (93°) and wide length between proximal branching point to carina tip (3.90 mm) in bifurcation lesion. (C) Pre-intervention OCT cross-section showing a lipid-rich plaque (asterisks) with maximal lipid arc of 106° in the proximal main vessel segment. (D and E) Pre-intervention OCT cross-section image and 3D reconstruction image demonstrating intact ostium of both side branches (arrows in B: guide wires). (F and G) Post-intervention (3.0 mm × 18 mm zotarolimus-eluting stent) 3D images demonstrating no jailed side branches. (F) Final CAG demonstrating good distal flow in main vessel and side branches. OCT, optical coherence tomography; LAD, left anterior descending artery; RI, ramus intermedius; NSTEMI, non-ST-elevation myocardial infarction; CAG, coronary angiography; MV, main vessel; SB, side branch; LCx, left circumflex artery.

dichotomizing between erosion and rupture [43]. Further OCT-based study for etiology of acute plaque events will be needed to determine tailored treatment in AMI.

Conclusions

Pre- and post-intervention OCT is a useful modality in selected patients with AMI. First of all, OCT is beneficial to provide detailed information for ambiguous angiography and stent failure. In addition, OCT is helpful for DES optimization in dilated vessels, including aneurysm and ectasia, and bifurcation PCI. OCT provides detailed insights into the underlying mechanisms of AMI and is the only modality to differentiate plaque erosion from plaque rupture. Further investigation and clinical research are required to confirm the utility of OCT in various situations in AMI.

Funding

This research received no grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of interest

All authors declare that there is no conflict of interest relevant to the submitted work.

References

[1] Topol EJ, Nissen SE. Our preoccupation with coronary luminology. The dissociation between clinical and angiographic findings in ischemic heart disease. Circulation 1995;92:2333–42.
[2] Hahn JY, Chun WJ, Kim JH, Song YB, Oh JH, Koo BK, et al. Predictors and outcomes of side branch occlusion after main vessel stenting in coronary bifurcation lesions: results from the COBIS II Registry (COronary BIfurcation Stenting). J Am Coll Cardiol 2013;62:1654–9.
[3] Andell P, Karlsson S, Mohammad MA, Götberg M, James S, Jensen J, et al. Intravascular ultrasound guidance is associated with better outcome in patients undergoing unprotected left main coronary artery stenting compared with angiography guidance alone. Circ Cardiovasc Interv 2017;10:e004813.
[4] Prati F, Regar E, Mintz GS, Arbustini E, Di Mario C, Jang IK, et al. Expert review document on methodology, terminology, and clinical applications of optical coherence tomography: physical principles, methodology of image acquisition, and clinical application for assessment of coronary arteries and atherosclerosis. Eur Heart J 2010;31:401–15.
[5] Kim JS, Kang TS, Mintz GS, Park BE, Shin DH, Kim BK, et al. Randomized comparison of clinical outcomes between intravascular ultrasound and angiography-guided drug-eluting stent implantation for long coronary artery stenoses. JACC Cardiovasc Interv 2013;6:369–76.
[6] Hong SJ, Kim BK, Shin DH, Nam CM, Kim JS, Ko YG, et al. Effect of intravascular ultrasound-guided vs angiography-guided everolimus-eluting stent implantation: the IVUS-XPL randomized clinical trial. JAMA 2015;314:2155–63.
[7] Jang IK, Tearney GJ, MacNeill B, Takano M, Moselewski F, Iftima N, et al. In vivo characterization of coronary atherosclerotic plaque by use of optical coherence tomography. Circulation 2005;111:1551–5.
[8] Tanigawa J, Barlis P, Di Mario C. Intravascular optical coherence tomography: optimisation of image acquisition and quantitative assessment of stent strut apposition. EuroIntervention 2007;3:128–36.
[9] Wijns W, Shite J, Jones MR, Lee SW, Price MJ, Fabbiocchi F, et al. Optical coherence tomography imaging during percutaneous coronary intervention impacts physician decision-making: ILUMIEN I study. Eur Heart J 2015;36:3346–55.
[10] Liu W, Zhou YJ, Liu YY, Shi DM. Is this spontaneous coronary intramural hematoma or fibrotic plaque? An inconsistent finding between optical coherent tomography and intravascular ultrasound. JACC Cardiovasc Interv 2013;6:983–4.
[11] Mintz GS, Guagliumi G. Intravascular imaging in coronary artery disease. Lancet 2017;390:793–809.
[12] 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;6:1095–104.
[13] Kim IC, Nam CW, Cho YK, Park HS, Yoon HJ, Kim H, et al. Discrepancy between frequency domain optical coherence tomography and intravascular ultrasound in human coronary arteries and in a phantom in vitro coronary model. Int J Cardiol 2016;221:860–6.
[14] Sim DS, Jeong MH. Differences in the Korea Acute Myocardial Infarction Registry compared with Western registries. Korean Circ J 2017;47:811–22.
[15] Saw J. Spontaneous coronary artery dissection. Can J Cardiol 2013;29:1027–33.
[16] Hering D, Piper C, Hohmann C, Schultheiss HP, Horstkotte D. Prospective study of the incidence, pathogenesis and therapy of spontaneous, by coronary angiography diagnosed coronary artery dissection [in German]. Z Kardiol 1998;87:961–70.
[17] Vanzetto G, Berger-Coz E, Barone-Rochette G, Chavanon O, Bouvaist H, Hacini R, et al. Prevalence, therapeutic management and medium-term prognosis of spontaneous coronary artery dissection: results from a database of 11,605 patients. Eur J Cardiothorac Surg 2009;35:250–4.
[18] Nishiguchi T, Tanaka A, Ozaki Y, Taruya A, Fukuda S, Taguchi H, et al. Prevalence of spontaneous coronary artery dissection in patients with acute coronary syndrome. Eur Heart J Acute Cardiovasc Care 2016;5:263–70.
[19] Saw J. Coronary angiogram classification of spontaneous coronary artery dissection. Catheter Cardiovasc Interv 2014;84:1115–22.
[20] Johnson TW, Smith D, Strange JW, Bucciarelli-Ducci C, Lowe R, Baumbach A. Spontaneous multivessel coronary intramural hematoma: an insight with OCT. JACC Cardiovasc Imaging 2012;5:1070–1.
[21] Kim Y, Deharo P, Adlam D, Baumbach A, Johnson TW. The role of optical coherence tomography in decision making during the acute phase of spontaneous coronary artery dissection. Int J Cardiol Heart Vasc 2017;14:6–7.
[22] Smith DK, Bourenane H, Strange JW, Baumbach A, Johnson TW. Catheter-induced coronary dissection during optical coherence tomography investigation. Eurointervention 2012;7:1124–5.
[23] Windecker S, Kolh P, Alfonso F, Collet JP, Cremer J, Falk V, et al. 2014 ESC/EACTS guidelines on myocardial revascularization. Eur Heart J 2014;35:2541–619.
[24] Fujii K, Carlier SG, Mintz GS, Yang YM, Moussa I, Weisz G, et al. Stent underexpansion and residual reference segment stenosis are related to stent thrombosis after sirolimus-eluting stent implantation: an intravascular ultrasound study. J Am Coll Cardiol 2005;45:995–8.
[25] Hong MK, Mintz GS, Lee CW, Park DW, Choi BR, Park KH, et al. Intravascular ultrasound predictors of angiographic restenosis after sirolimus-eluting stent implantation. Eur Heart J 2006;27:1305–10.
[26] Lee SY, Hong MK, Shin DH, Kim JS, Kim BK, Ko YG, et al. Mechanisms of postintervention and nine-month luminal enlargement after treatment of drug-eluting in-stent restenosis with a drug-eluting balloon. Am J Cardiol 2014;113:1468–73.
[27] Amabile N, Trouillet C, Meneveau N, Tissot CM, Belle L, Combaret N, et al. Mechanical abnormalities associated with first- and second-generation drug-eluting stent thrombosis analyzed by optical coherence tomography in the national PESTO French registry. Int J Cardiol 2017;227:161–5.
[28] Adriaenssens T, Joner M, Godschalk TC, Malik N, Alfonse F, Xhepa E, et al. Optical coherence tomography findings in patients with coronary stent thrombosis: a report of the PRESTIGE Consortium (Prevention of Late Stent Thrombosis by an Interdisciplinary Global European Effort). Circulation 2017;136:1007–21.
[29] Kim Y, Jeong MH, Kim MC, Sim DS, Hong YJ, Kim JH, et al. Very late stent thrombosis derived from thin-cap neoatheroma and fibroatheroma with plaque rupture assessed by optical coherence tomography. Cardiol J 2017;24:704–5.
[30] Swaye PS, Fisher LD, Litwin P, Vignola PA, Judkins MP, Kemp HG, et al. Aneurysmal coronary artery disease. Circulation 1983;67:134–8.
[31] Waterhouse BR, Tulloh RMR, Kim Y, Creasy W, Adlam D, Johnson TW. Retrospective study of the impact of unrecognised Kawasaki disease, coronary aneurysm and ectasia. Int J Cardiol 2017;248:308–13.
[32] Bogana Shanmugam V, Psaltis JP, Wong TLD, Meredith TI, Malaiapan Y, Ahmar W. Outcomes after primary percutaneous coronary intervention for ST-elevation myocardial infarction caused by ectatic infarct related arteries. Heart Lung Circ 2017;26:1059–68.
[33] Ibanez B, James S, Agewall S, Antunes MJ, Bucciarelli-Ducci C, Bueno H, et al. 2017 ESC guidelines for the management of acute myocardial infarction in patients presenting with ST-segment elevation. Eur Heart J 2018;39:119–77.
[34] Ali ZA, Karimi Galougahi K, Maehara A, Shlofmitz RA, Ben-Yehuda O, Mintz GS, et al. Intracoronary optical coherence tomography 2018: current status and future directions. JACC Cardiovasc Interv 2017;10:2473–87.
[35] 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;6:228–36.
[36] Onuma Y, Thuesen L, van Geuns RJ, van der Ent M, Desch S, Fajadet J, et al. Randomized study to assess the effect of thrombus aspiration on flow area in patients with ST-elevation myocardial infarction: an optical frequency domain imaging study – TROFI trial. Eur Heart J 2013;34:1050–60.
[37] Abdel-Hakim DE, Garot P, Champagne S, Maklady F, el-Hawary A, Dubois-Randé JL, et al. Impact of bifurcation lesions on clinical outcome and prognosis of primary angioplasty in acute myocardial infarction. EuroIntervention 2008;4:93–8.
[38] Kini AS, Yoshimura T, Vengrenyuk Y, Amirian J, Hasan C, Baber U, et al. Plaque morphology predictors of side branch occlusion after main vessel stenting in coronary bifurcation lesions: optical coherence tomography imaging study. JACC Cardiovasc Interv 2016;9:862–5.
[39] Watanabe M, Uemura S, Sugawara Y, Ueda T, Soeda T, Takeda Y, et al. Side branch complication after a single-stent crossover technique: prediction with frequency domain optical coherence tomography. Coron Artery Dis 2014;25:321–9.
[40] Arbustini E, Dal Bello B, Morbini P, Burke AP, Bocciarelli M, Specchia G, et al. Plaque erosion is a major substrate for coronary thrombosis in acute myocardial infarction. Heart 1999;82:269–72.

[41] Kubo T, Imanishi T, Takarada S, Kuroi A, Ueno S, Yamano T, et al. Assessment of culprit lesion morphology in acute myocardial infaction: ability of optical coherence tomography compared with intravascular ultrasound and coronary angioscopy. J Am Coll Cardiol 2007;50:933–9.
[42] Jia H, Abtahian F, Aguirre AD, Lee S, Chia S, Lowe H, et al. In vivo diagnosis of plaque erosion and cacified nodule in patients with acute coronary syndrome by intravascular optical coherence tomography. J Am Coll Cardiol 2013;62:1748–58.
[43] Jia H, Dai J, Hou J, Xing L, Ma L, Liu H, et al. Effective anti-thrombotic therapy without stenting: intravascular optical coherence tomography-based management in plaque erosion (the EROSION study). Eur Heart J 2017;38:792–800.