Intra- and Postprocedural Management of Coronary Artery Perforation During Percutaneous Coronary Intervention

Hirohide Matsuura, MD, PhD; Yasushi Mukai, MD, PhD; Yasuhiro Honda, MD; Shun Nishino, MD; Honsa Kang, MD; Kosuke Kadooka, MD; Kenji Ogata, MD; Toshiyuki Kimura, MD; Hiroshi Koiwaya, MD, PhD; Kensaku Nishihira, MD, PhD; Nehiro Kuriyama, MD, PhD; Yoshihito Shibata, MD

Background: Little is known regarding the postprocedural management of coronary artery perforation (CAP).

Methods and Results: The characteristics, outcomes, and management of 115 CAP cases among 13,453 patients undergoing percutaneous coronary intervention (PCI) between 2001 and 2017 at Miyazaki Medical Association Hospital were analyzed retrospectively. The incidence of CAP was 0.85% (25 [0.19%] coronary ruptures [CRs], 90 [0.67%] wire perforations [WPs]). The most prevalent causes of CRs and WPs were rotational atherectomy (36.0%) and polymer-jacketed wires (41.1%), respectively. Fifty-two percent of CRs were treated using prolonged balloon inflation, whereas 50% of WPs were treated through embolization. Immediate and delayed cardiac tamponade (CT) occurred in 20% and 24% of CRs, respectively, and in 2.2% and 10% of WPs, respectively. The mean (±SD) right atrial pressure (RAP) during delayed CT in the CR and WP groups was 16.0±1.2 and 14.0±3.0 mmHg, respectively. New-onset atrial fibrillation developed in 24.0% and 11.1% of patients in the CR and WP groups, respectively, whereas late-onset coronary artery aneurysm (CAA) occurred in 24.0% and 0% of patients, respectively. One-year mortality rates in patients with immediate and delayed CT were 28.6% and 20.0%, respectively.

Conclusions: Special attention should be paid to delayed CT, new-onset atrial fibrillation, and late-onset CAA after CAP treatment. Continuous monitoring of RAP after CAP during PCI may be useful for the early detection of delayed CT.

Key Words: Coronary artery perforation; Percutaneous coronary intervention; Postprocedural management

Coronary artery perforation (CAP) is a rare but lethal complication of percutaneous coronary intervention (PCI). Incidence rates of CAP range from 0.17% to 0.93% among all PCIs and from 1.5% to 4.6% among PCIs for chronic total obstructions (CTOs). Predictors of CAP include advanced age, female sex, atherectomy devices, previous coronary artery bypass grafting, and CTOs. Complications like CAP are not completely avoidable in the contemporary era wherein increasingly complex PCIs have been performed; moreover, the incidence of CAP remains unchanged, despite sophisticated knowledge and treatment algorithms for CAP. Hemostasis and management for immediate cardiac tamponade (CT) and hemodynamic collapse during PCI are crucial; however, postprocedural management for delayed CT and late-onset coronary artery aneurysm (CAA) is also important. Interventional cardiologists should be aware of not only the intraprocedural characteristics and management, but also the postprocedural management of CAP. Therefore, the present study aimed to examine the incidence, characteristics, and outcomes of CAPs and their intra- and postprocedural management in the contemporary era with increasingly complex PCIs.

Methods

Between January 2001 and December 2017, 13,453 PCIs were performed at Miyazaki Medical Association Hospital. This study retrospectively analyzed patients who developed coronary rupture (CR) and wire perforation (WP) during PCI. All PCIs were performed by certified interventional cardiologists in accordance with the standard practice at the hospital. Intravascular imaging devices for the examination of lesion characteristics and vessel sizing were used at the discretion of operators.

CR was defined as Ellis Type II and Type III CAP caused
by any device other than guidewires. WP was defined as any CAP caused by guidewires. Guidewires were categorized into 4 types. A coil wire was defined as a workhorse guidewire whose core was wrapped with coils. A polymer-jacketed wire was defined as a guidewire coated with a polymer to increase its lubricity for easier movement in tortuous and/or severely stenosed vessels. A stiff wire was defined as a guidewire for CTO treatment whose tip load was heavier than that of the workhorse wires. A rotawire was defined as a guidewire for rotational atherectomy.

Baseline clinical, lesion, and procedural characteristics; intraprocedural and postprocedural management; and short- and mid-term outcomes of the CR and WP groups were retrospectively determined from the institutional database and via telephone calls. Clinical events included all-cause death, immediate and delayed CT, new-onset AF, late-onset CAA, and target vessel revascularization (TVR). CT was defined as the accumulation of pericardial effusion and hemodynamic or impending collapse requiring pericardiocentesis. Immediate CT was defined as that developed at the cardiac catheterization laboratory, whereas delayed CT was defined as that developed outside the cardiac catheterization laboratory. A pulmonary artery catheter was inserted after the index PCI at the discretion of operators. Patients with right ventricular infarction were excluded from analysis of the mean right atrial pressure (RAP) of CAP patients with and without delayed CT. New-onset AF was defined as that occurring after the CR or WP until discharge. TVR was defined on the basis of the definition set by the Academic Research Consortium. Short-term outcomes included in-hospital mortality and length of hospital stay. Mid-term outcomes included survival and TVR, which were determined during office visits or via telephone contact.

This study was approved by the Ethics Committee of Miyazaki Medical Association Hospital. Informed consent was obtained via the opt-out method, and the study was conducted in accordance with the tenets of the Declaration of Helsinki.

**Statistical Analysis**

Normally distributed continuous variables are expressed as the mean±SD and were compared using Student’s t-test. Continuous variables that were not normally distributed are presented as the median with interquartile range (IQR) and were compared using the Mann-Whitney U test. Categorical variables are presented as frequencies and percentages and were compared using the Chi-squared test or Fisher exact test, as appropriate. In all significance testing, 2-tailed P<0.05 was considered significant. Survival and freedom-from-TV curves for each group were plotted using the Kaplan-Meier method, and comparisons were made using log-rank tests. Statistical analyses were performed using IBM SPSS Statistics for Windows version 25.0 (IBM Corp., Armonk, NY, USA).

**Results**

**Incidence of CAP**

Among all the 13,453 PCI procedures, CRs and WPs occurred in 25 (0.19%) and 90 (0.67%), respectively. In the CR group, 14 (56%) and 11 (44%) patients developed Ellis...
Grade II and III perforation, respectively. The baseline clinical, lesion, and procedural characteristics of the patients are presented in Table 1. Females were more common in the CR than WP group (56.0% vs. 33.3%; P=0.04). CTO and drug-eluting stents were more common in the WP than CR group. Intravascular imaging devices and rotational atherectomy were more common in the CR group.

Mechanisms of CAP
Mechanisms of CAP are presented in Table 2. The most frequent cause of CR was rotational atherectomy (36.0%), followed by balloon dilatation (28.0%). WPs were mainly caused by polymer-jacketed wires (41.1%) and coil wires (34.4%). In the non-CTO group (n=59), the causative guidewires were a coil wire (n=27; 45.8%), polymer-jacketed wire (n=25; 42.4%), stiff wire (n=3; 5.1%), and rotawire (n=4; 6.8%). In the CTO group (n=31), the causative guidewires were a stiff wire (n=15; 48.4%), polymer-jacketed wire (n=12; 38.7%), and coil wire (n=4; 12.9%). Throughout the study period, there were 16 CAPs (Ellis Grades II and III) among the 1,577 patients who needed rotational atherectomy and 13 CAPs (Ellis Grades II and III) among the 11,876 patients who did not undergo rotational atherectomy. The usage rate of rotational atherectomy and directional coronary atherectomy at Miyazaki Medical Association Hospital during the study period was 11.7% (1,577/13,453 cases) and 1.9% (257/13,453 cases), respectively. Laser atherectomy and orbital atherectomy were not used at Miyazaki Medical Association Hospital during the study period.

Intraprocedural Management of CAP
The treatment methods for CAP and stabilization of hemodynamics are presented in Table 3. WP was mainly treated using embolization (n=45; 50.0%), whereas CR was mainly treated using balloons or perfusion balloons (n=13; 52.0%), followed by covered stents (n=6; 24.0%). The embolized materials were microcoils (n=16; 35.6%), fatty tissues (n=14; 31.1%), thrombi (n=9; 20.0%), and gelatin sponges (n=6; 13.3%). Surgery and heparin reversal were more common in the CR (n=4 [16.0%] vs. 0; n=5 [20.0%], vs. n=3 [3.3%], respectively; Table 3) than WP group. The use of...
catecholamines, pericardiocentesis, an intra-aortic balloon pump, temporary pacing, and a ventilator was significantly more common in the CR group, whereas procedure time was similar between the CR and WP groups.

**Immediate and Delayed CT**

Of the 115 perforations, 17 (14.8%) resulted in tamponade requiring pericardiocentesis. Immediate CT occurred in 5 (20.0%) and 2 (2.2%) patients in the CR and WP groups, respectively (P<0.01; Table 3). Delayed CT occurred in 6 (24.0%) and 9 (10.0%) patients in the CR and WP groups, respectively (P=0.04; Table 4). Two (8.0%) and 2 (2.2%) patients in the CR and WP groups, respectively, developed both immediate and delayed CT. All-cause death of patients with CAP was significantly more frequent in the immediate and delayed CT groups than in the no CT group (Figure 1).

**Postprocedural Management of CAP**

More patients in the CR than WP group underwent continuous RAP monitoring after insertion of a pulmonary

### Table 4. Post-Procedural Care After Treatment of Coronary Artery Perforation

| Coronary rupture (n=25) | Wire perforation (n=90) | P value |
|-------------------------|-------------------------|---------|
| Pulmonary artery catheter | 23 (92.0) | 51 (56.7) | <0.01 |
| Delayed CT after cath lab | 6 (24.0) | 9 (10.0) | 0.04 |
| Pericardiocentesis after cath lab | 6 (24.0) | 9 (10.0) | 0.04 |
| Acute (<24h) | 3 (12.0) | 8 (8.9) | 0.51 |
| Rebleeding | 2 (8.0) | 4 (4.4) | 0.31 |
| Late recognition | 1 (4.0) | 4 (4.4) | 0.92 |
| Remote (≥24h) | 3 (12.0) | 1 (1.1) | <0.01 |
| Rebleeding | 1 (4.0) | 0 (0.0) | 0.06 |
| Effusion pericarditis | 2 (8.0) | 1 (1.1) | 0.06 |
| New-onset atrial fibrillation | 6 (24.0) | 10 (11.1) | 0.10 |
| Late-onset coronary artery aneurysm | 6 (24.0) | 0 (0.0) | <0.01 |

### Figure 1. Cumulative incidence of all-cause death in patients with coronary artery perforation (CAP) during percutaneous coronary intervention (PCI), according to immediate or delayed cardiac tamponade (CT). Among patients with CAP, those who had immediate and delayed CT had significantly higher cumulative rates of all-cause death than patients without CT. P values were determined using the log-rank test.
Postprocedural Management of Coronary Perforation

than when no delayed CT was observed (14.0 ± 3.0 vs. 5.0 ± 2.7 mmHg, respectively; P<0.01; Figure 2B).

New-Onset AF
New-onset AF after CAP during the same hospitalization occurred both in the CR and WP groups (n=6 [24.0%] vs. n=10 [11.1%], respectively; P=0.10; Table 4). New-onset AF in all patients with CAP included in the present study was transient only during hospitalization and did not need additional anticoagulation.

Survival Rate and Freedom From TVR in Patients With CAP
The 1-year survival rate was comparable between the CR and WP groups (92.0% vs. 93.2%, respectively; P=0.79; Figure 3A). Freedom from TVR tended to be lower in the CR than WP group, although the difference was not statistically significant (56.0% vs. 71.6%, respectively; P=0.12; Figure 3B). The 1-year TVR rate of patients who underwent covered stent implantation was 62.5%. The incidence of stent thrombosis in patients treated with covered stents was 0%, although 1 patient in the present study had an occluded covered stent at follow-up coronary angiography.

Late-Onset CAA
Follow-up coronary angiogram revealed that 6 of the 25 patients with CR had late-onset CAA and that all of them had undergone rotational atherectomy and had not been implanted with covered stents. However, none of the patients with WP developed CAA. Representative images are shown in Figure 4. The timing of CAA diagnosis was 30.8±18.0 days after the index PCI.
Major Findings
To the best of our knowledge, there have been no reports evaluating delayed CT, continuous mean RAP monitoring, new-onset AF, late-onset CAA, and duration of hospital stay after CAP treatment during PCI. The main findings of the present study are that: (1) the incidence of delayed CT associated with CAP after the catheterization laboratory was 24.0% and 10.0% in the CR and WP groups, respectively; (2) 50% and 88.9% of delayed CT in the CR and WP groups, respectively, occurred <24 h after PCI; (3) continuous mean RAP monitoring was useful for the early detection of delayed CT, and the median RAP of the patients upon detection of delayed CT in the CR and WP groups was 16.0±1.2 and 14.0±3.0 mmHg, respectively; (4) the incidence of new-onset AF during the index PCI hospitalization in the CR and WP groups was 24.0% and 11.1%, respectively; (5) the incidence of late-onset CAA after treatment of CAP was 24.0% and 0.0% in the CR and WP groups, respectively; and (6) the days to discharge of elective cases was significantly longer in the CR than WP group (median [IQR] 13.0 [8.5–38.5] vs. 8.0 [5.0–15.0] days, respectively).
Overall Incidence of CAP
Among 13,453 consecutive PCI cases, the overall incidence of CAP in the present study was 0.85% (n=90; CR, n=115; WP, n=25) and was similar to that reported in previous studies (0.2–1.46%). Recent publications have reported no significant progressive increase in CAP in spite of the complex coronary diseases such as calcific, tortuous, multivessel diseases, or CTOs being routinely treated among the older and frail patients in current clinical practice.\textsuperscript{5,6,11} All interventional cardiologists should have sufficient knowledge regarding treatment strategies and postprocedural care management for CAPs.

Incidence of Delayed CT and Its Mortality
Of the 115 patients with CAP, 17 (14.8%) needed pericardial care management for CAPs.

It has been reported that 6.0–21.3% of CAP cases develop delayed CT, a figure not much different than that for immediate CT (15.2–29.3%). More importantly, the 1-year mortality rate of patients with delayed CT after CAP has been reported to be as high as that in patients with immediate CT after CAP (25.6% vs. 27.5%).\textsuperscript{3} Similarly, in the present study, the incidence of delayed and immediate CT was 13.0% vs. 6.1%, respectively, with 1-year mortality of 20.0% vs. 28.6%, respectively (Tables 3, Figure 1). The incidence of both immediate and delayed CT was significantly higher in the CR than WP group (20.0% vs. 2.2% and 24.0% vs. 10.0%, respectively; Tables 3, Figure 1). Notably, the incidence of delayed CT was high in the WP group (10.0%; Table 4). All deaths among patients with delayed CT were observed both in the CR and WP groups (n=6 [24.0%] vs. n=3 [12.0%], respectively).

Late-onset CAA developed in 24% of patients in the CR group, whereas no new-onset CAA occurred in the WP group. Therefore, close surveillance is extremely important up to 24 h after CAP.

Continuous Monitoring of Mean RAP After CAP Treatment and Early Detection of Delayed CT
Several studies have highlighted the importance of vigilance and close monitoring of CAP patients in the cardiac care unit for the occurrence of delayed CT at least 12–24 h after the treatment. Although echocardiography and estimation of jugular vein pressure via neck vein engorgement in the cardiac care unit for 24 h have been reported for the detection of delayed CT, they are not necessarily reliable. Serial echocardiograms are recommended for the assessment of hemopericardium and tamponade; however, the frequency and duration of echocardiographic monitoring remain undetermined. As pericardial tamponade develops, a significant rise in RAP and a significant decrease in systolic pressure can be expected. In the present study, pulmonary artery catheters were inserted after the index PCI to delayed CT was 4.4 h. Therefore, close surveillance is extremely important up to 24 h after CAP. WP groups, respectively (P<0.01%; Table 4) at the discretion of the operators in order to continuously monitor mean RAP. As shown in the present study, continuous RAP monitoring via pulmonary artery catheterization can be a useful method for detecting delayed CT given that it showed a significant rise in mean RAP (Figure 2). Confirmation of an increase in the pericardial effusion volume via echocardiography following the increase in mean RAP detected using pulmonary artery catheterization is a quick and reliable method for identifying delayed CT as early as possible. A significant rise in mean RAP prompts physicians to consider pericardiocentesis, whereas the absence of an increase in mean RAP helps physicians determine whether the patient can be discharged from the cardiac care unit. Apart from intermittent echocardiographic screening, continuous RAP monitoring may be useful for the postprocedural management of CAP. We cannot determine the exact cut-off values for mean RAP and systolic pressure that would indicate CT given that they differ according to the patient and situation. Noting an upward trend or sudden increase in mean RAP through continuous hemodynamic monitoring can lead to timely echocardiography and prompt pericardiocentesis.

Late Recognition of CAP
In approximately 4% of patients in both the CR and WP groups, CAP was initially recognized later as CT in the ward after the patients had left the catheterization laboratory (Table 4). At the final cineangiogram during PCI, operators should pay special attention to whether extravasation is present anywhere the devices were crossed and the wires were delivered during the PCI.\textsuperscript{9}

New-Onset AF After Treatment of CAP
Af new-onset AF after CAP during the same hospitalization was observed both in the CR and WP groups (n=6 [24.0%] vs. n=10 [41.1%], respectively). This seemed to have been caused by bleeding in the pericardial space; however, although similar findings were described in a case report,\textsuperscript{9} no such finding has been mentioned in previous case series reports. In the present study, none of patients with CAP who developed new-onset AF needed additional anticoagulation. As such, anticoagulation may be considered should AF persist while taking into consideration the risk of bleeding complications.

Late-Onset CAA After CAP Treatment
Late-onset CAA developed in 24% of patients in the CR group, all of whom had undergone rotational atherectomy and had not been implanted with a covered stent. When patients needing rotational atherectomy due to severe calcification develop CR, they require intervention with prolonged balloon inflation given the difficulty of delivering covered stents due to calcification. As such, special consideration should be given to the possibility of the development of late-onset CAA. Fukutomi et al reported that the incidence of late-onset CAA after CAP was 28.6%.\textsuperscript{9}

Length of Hospital Stay After CAP Treatment
The length of hospital stay was significantly longer in the CR than WP group among patients undergoing elective PCI due to differences in the severity of the hemodynamic compromise; however, the length of hospital stay was comparable between the 2 groups for patients undergoing PCI.
emergency PCI given that hospitalization was originally longer in acute coronary syndrome cases.

Rotational Atherectomy as a Cause of CAP and Late-Onset CAA
Throughout the study period, there were 16 CAPs (1.0%) among the 1,577 patients treated with rotational atherectomy and 13 CAPs (0.1%) among the 11,876 patients without rotational atherectomy. The use of rotational atherectomy was significantly more frequent in the CR than WP group. Moreover, the most common cause for CR in the present study was rotational atherectomy. Wang et al reported an incidence of rotational atherectomy-induced CAP of 2.1%, and that the causes included unintended and unnoticed bias cutting (45.5%), rotawire tip (18.2%), inappropriately sized burrs (18.2%), and rotawire damage with subsequent transection and perforation (18.2%). In the report from the British Cardiac Intervention Society Database comprising 10,980 rotational atherectomy PCIs from 2007 to 2014, CAP in rotational atherectomy PCI was rare but significantly higher than for all PCIs (1.52% vs. 0.4%, respectively). In a report involving 56 Ellis Grade III CAPs among 24,465 PCI patients, rotational atherectomy was one of the predictors for CAP (odds ratio 3.47; P=0.002).

In-Hospital and 1-Year Mortality of Patients With CAP
In the present study, the TVR rate at 1 year was 44.0% and 28.4% in the CR and WP groups, respectively. The high TVR rates can be attributed to both the high rate of unsuccessful index PCI procedures and the high rate of restenosis of covered stents. Patients who receive covered stents should be carefully followed because of the potential for adverse events, such as restenosis and stent thrombosis. None of the 10 CAP patients treated with covered stents in the present study developed stent thrombosis; however, Kawamoto et al reported that the incidence of stent thrombosis (definite or probable) among 57 patients treated with covered stents for CAP was 2%, 5%, and 5% at 1, 2, and 3 years, respectively.

Recent large registries have reported in-hospital mortality rates of CAP ranging from 4.0% to 8.0%. The high in-hospital mortality rate underscores the importance of CAP prevention. Despite the high in-hospital mortality rates of CAP, 1-year mortality rates in the present study were not unsatisfactory once the intra- and postprocedural management of CAP had succeeded.

Differences and Similarities Between CR and WP
The mechanisms by which CAPs occur differ between the CR and WP groups; therefore, the treatment for the 2 groups differs, as shown in the present study. Similar to the classification of CR and WP, CAP is classified into large vessel perforation and distal vessel perforation. Conversely, the CR and WP groups show similarities in some aspects, including the incidence of delayed CT and new-onset AF, TVR, and mortality, despite the differences in mechanisms as shown in the present study. The severity of hemodynamics and treatment intensity tended to be milder in the WP than CR group; however, caution should be exercised, especially with regard to delayed CT, even in cases of WP that are similar to CR.

Study Limitations
There are several important limitations to this study. First, given that this is a single-center retrospective observational study, inherent bias cannot be avoided. Our results may have been influenced by unmeasured confounders, which may affect the interpretation of the findings. For example, there may be an institutional gap regarding the PCI indication for complex coronary artery lesions and the usage rate of rotational atherectomy devices. Second, given the small number of CAP cases, the findings of this study may not be conclusive given that the study is underpowered. Third, not all patients underwent angiographic follow-up. Patients who did not undergo angiographic studies were clinically followed up at a regular outpatient clinic. However, given that data on PCI complications can only be analyzed retrospectively, we certainly believe that the present paper is informative given the limitations of analyzing a rare event, such as CAP.

Conclusions
CAP is a rare but life-threatening complication of PCI. Although CAP is mostly treatable via percutaneous intervention, attention should also be paid to delayed CT, new-onset AF, and late-onset CAA. Continuous RAP monitoring may be useful for the early detection of delayed CT after CAP treatment during PCI.

Sources of Funding
The authors received no specific funding for this work.

Disclosures
The authors have no conflicts of interest to disclose.

IRB Information
This study was approved by the Institutional Review Board, Miyazaki Medical Association Hospital (2022-15).

Data Availability
The deidentified participant data will not be shared.
References

1. Nairooz R, Parzynski CS, Curtis JP, Mohsen A, McNulty E, Uretsky BF, et al. Contemporary trends, predictors and outcomes of perforation during percutaneous coronary intervention (from the NCDR Cath PCI Registry). Am J Cardioiol 2020; 130: 37 – 45.

2. Rakowski T, Wegiel M, Sziuk Z, Plens K, Dzwierzaw A, Birkemyer R, et al. Prevalence and predictors of artey perforation during percutaneous coronary interventions (from the ORPK1 National Registry in Poland). Am J Cardioiol 2019; 124: 1186 – 1189.

3. Harnek J, James S, Lagerqvist B. Coronary artery perforation and tamponade: Incidence, risk factors, predictors and outcomes from 12 years’ data of the SCAAR Registry. Circ J 2019; 84: 43 – 53.

4. Parsh J, Seth M, Green J, Sutton NR, Chetcuti S, Dixon S, et al. Coronary artery perforations after contemporary percutaneous coronary interventions: Evaluation of incidence, risk factors, outcomes, and predictors of mortality. Catheter Cardiovasc Interv 2017; 89: 966 – 973.

5. Kiinnaird T, Kwok CS, Kontopantelis E, Osei-Gerning N, Ludman P, Debbeler M, et al. Incidence, determinants, and outcomes of coronary perforation during percutaneous coronary intervention in the United Kingdom Between 2006 and 2013: An analysis of 527121 cases from the British Cardiovascular Intervention Society Database. Circ Cardiovasc Interv 2016; 9: e003449.

6. Cerrato E, Pavan M, Barbero U, Colombo F, Mangieri A, Ryan N, et al. Incidence, management, immediate and long-term outcome of guidewire and device related Grade III coronary perforations (from G3CAP – Cardiogroup VI Registry). Am J Cardioiol 2021; 124: 37 – 45.

7. Patel VG, Brayton KM, Tamayo A, Mogabgab O, Michael TT, Lo N, et al. Angiographic success and procedural complications in patients undergoing percutaneous coronary chronic total occlusion interventions: A weighted meta-analysis of 18,061 patients from 65 studies. JACC Cardiovasc Interv 2013; 6: 128 – 136.

8. Sekiguchi M, Muramatsu T, Kushi K, Muto M, Oikawa Y, Kawasaki T, et al. Assessment of reattempted percutaneous coronary intervention strategy for chronic total occlusion after prior failed procedures: Analysis of the Japanese CTO-PCI Expert Registry. Catheter Cardiovasc Interv 2019; 94: 512 – 524.

9. Fukutomi T, Suzuki T, Popma JJ, Hosokawa H, Yokoya K, Inada T, et al. Early and late clinical outcomes following coronary perforation in patients undergoing percutaneous coronary intervention. Circ J 2002; 66: 349 – 356.

10. Avula V, Karacsonyi J, Kostantinis S, Simsek B, Rangan BV, Gutierrez AA, et al. Incidence, treatment, and outcomes of coronary artery perforation during percutaneous coronary intervention. J Invasive Cardioiol 2012; 24: E499 – E504.

11. Shaukat A, Tajti P, Sandoval Y, Stanberry L, Garberich R, Burke NM, et al. Incidence, predictors, management and outcomes of coronary perforations. Catheter Cardiovasc Interv 2019; 104: 345 – 351.

12. Ellis SG, Ajunsi S, Arnold AZP, Popma JJ, Bittl JA, Eigler NL, et al. Increased coronary perforation in the new device era: Incidence, classification, management, and outcome. Circulation 1994; 90: 2725 – 2730.

13. Cutlip DE, Windecker S, Mehran R, Boam A, Cohen DJ, van ES, et al. Clinical end points in coronary stent trials: A case for standardized definitions. Circulation 2007; 115: 2344 – 2351.

14. Al-Lamee R, Jelasi A, Latib A, Godin C, Ferraro M, Mussardo M, et al. Incidence, predictors, management, immediate and long-term outcomes following Grade III coronary perforations. JACC Cardiovasc Interv 2011; 4: 87 – 95.

15. Gruttmann OP, Jones DA, Gultali A, Kotecha T, Fayed H, Patel D, et al. Prevalence and outcomes of coronary artery perforation during percutaneous coronary intervention. EuroIntervent 2017; 13: e595 – e601.

16. Lemmet ME, van Bonn MJ, Diletti R, Wilschut JM, de Jaegere PP, Zijlstra F, et al. Clinical characteristics and management of coronary artery perforations: A single-center 11-year experience and practical overview. J Am Heart Assoc 2017; 6: e007049.

17. Fejka M, Dixon SR, Safian RD, O’Neill WW, Grines CL, Finta B, et al. Diagnosis, management, and clinical outcome of cardiac tamponade complicating percutaneous coronary intervention. Am J Cardioiol 2002; 90: 1183 – 1186.

18. Doll IA, Hira RS, Kearney KE, Kandzari DE, Riley RF, Marso SP, et al. Management of percutaneous coronary intervention complications: Algorithms from the 2018 and 2019 Seattle Percutaneous Coronary Intervention Complications Conference. Circ Cardiovasc Interv 2020; 13: e008962.

19. Holmes DR Jr, Nishimura R, Fountain R, Turi ZG. Iatrogenic pericardial effusion and tamponade in the percutaneous intracardiac-era. JACC Cardiovasc Interv 2009; 2: 705 – 717.

20. Abhyankar AD, England D, Bernstein L, Harris PJ. Delayed appearance of distal coronary perforation following stent implantation. Catheter Cardiovasc Diagn 1998; 43: 311 – 312.

21. DePersis M, Khan SU, Kalsiki E, Lombardi W. Coronary artery perforation complicated by recurrent cardiac tamponade: A case illustration and review. Cardiovasc Revasc Med 2017; 18(3): S30 – S34.

22. Wang YH, Chen WJ, Chen YW, Lai CH, Su CS, Chang WC, et al. Incidence and mechanisms of coronary perforations during rotational atherectomy in modern practice. J Interv Cardioiol 2020; 2020: 1894389.

23. Potty MB, Hussain HI, Gallagher S, Al-Raisi S, Aldalati O, Farooq V, et al. Rotational atherectomy complicated by coronary perforation is associated with poor outcomes: Analysis of 10,980 cases from the British Cardiovascular Intervention Society Database. Cardiovasc Revasc Med 2021; 28: 9 – 13.

24. Sakakura K, Ito Y, Shibata Y, Okamura A, Kashima Y, Nakamura S, et al. Clinical expert consensus document on rotational atherectomy from the Japanese Association of Cardiovascular Intervention and Therapeutics. Cardiovasc Interv Ther 2021; 36: 1 – 18.

25. Barbato E, Carrié D, Dardas P, Fajadet J, Gaul G, Haude M, et al. European expert consensus on rotational atherectomy. EuroIntervent 2015; 11: 30 – 36.

26. Sharma SK, Toneyi M, Teirstein PS, Kini AS, Reitman AB, Lee AC, et al. North American expert review of rotational atherectomy. Circ Cardiovasc Interv 2019; 12: e807448.

27. Hinohara T, Rowe MH, Robertson GC, Selmon MR, Braden L, Leggett JH, et al. Effect of lesion characteristics on outcome of directional coronary atherectomy. J Am Coll Cardioiol 1991; 17: 1112 – 1120.

28. Khan AA, Murtaza G, Khalid MF, White CJ, Mamas MA, Mukherjee D, et al. Outcomes of rotational atherectomy versus orbital atherectomy for the treatment of heavily calcified coronary stenosis: A systematic review and meta-analysis. Catheter Cardiovasc Interv 2021; 98: 884 – 892.

29. Tsutsui RS, Sammour Y, Kalra A, Reed G, Krishnaswamy A, Ellis S, et al. Excimer laser atherectomy in percutaneous coronary intervention: A contemporary review. Cardiovasc Revasc Med 2021; 25: 75 – 83.

30. Pavani M, Cerrato E, Latib A, Ryan N, Calcagno S, Rolfo C, et al. Acute and long-term outcomes after polytetrafluoroethylene or pericardium covered stenting for Grade 3 coronary artery perforation: Insights from G3-CAP registry. Cardiovasc Intervent Ther 2018; 92: 1247 – 1255.

31. Lee WC, Hsueh SK, Fang CY, Wu CJ, Hang CL, Fang HY. Clinical outcomes following covered stent for the treatment of coronary artery perforation. Interv Cardioiol 2019; 6: 320 – 326.

32. Kim JM, Kim HG, Kim HJ, Kim DJ, Eom EH, Lee MJ, et al. Clinical evaluation of post-procedural management of coronary perforation. Circ Cardiovasc Interv 2016; 9: 116: e003449.

33. Abdalwahab A, Farag M, Brilakis ES, Galassi AR, Egred M. Management of coronary artery perforation. Cardiovasc Revasc Med 2021; 26: 55 – 60.