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*Percutaneous Coronary Intervention*

# Clinical Outcomes of Polytetrafluoroethylene-Covered Stents for Coronary Artery Perforation in Elderly Patients Undergoing Percutaneous Coronary Interventions

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***Background:*** Coronary artery perforation (CAP) during percutaneous coronary intervention (PCI) is associated with increased mortality. Polytetrafluoroethylene covered stents (CS) are an effective approach to treat CAP, but data regarding elderly patients requiring CS implantation for CAP are limited. The aim of this study is to report clinical data for elderly CAP patients undergoing CS implantation during PCI.

***Methods:*** Nineteen consecutive elderly patients (≥ 65 years) undergoing CS implantation due to PCI-induced CAP in a tertiary referral center from July 2003 to April 2016 were retrospectively examined.

***Results:*** There were 13 men and six women, with a mean age of 75.3 ± 5.6 years (range: 65-86 years). Perforation grade was Ellis type II in five patients (26.3%), and Ellis type III in 14 patients (73.7%). Cardiac tamponade developed in six patients (31.6%), and intra-aortic balloon pumping was needed in four patients (21.1%). The overall success rate for CS implantation rate was 94.7%. The overall in-hospital mortality rate was 15.8%; the in-hospital myocardial infarction rate was 63.2%. Among 16 survival-to-discharge cases, dual antiplatelet therapy (DAPT) was prescribed in 14 cases (87.5%) for a mean duration of 14 months. Overall, there were five angiogram-proven CS failures among 18 patients receiving successful CS implantation. The 1, 2 and 4 years of actuarial freedom from the CS failure were 78%, 65%, and 43% in the angiogram follow-up patients.

***Conclusions:*** CS implantation for CAP is feasible and effective in elderly patients, while CS failure remains a major concern that encourages regular angiographic follow-up in these case.

**Key Words:** Coronary artery perforation • Elderly patients • Percutaneous coronary intervention • Polytetrafluoroethylene covered stents • Stent thrombosis

## INTRODUCTION

Coronary artery perforation (CAP) during a percutaneous coronary intervention (PCI) is a rare but life-threatening complication. In a systemic meta-analysis, the pooled incidence of CAP was 0.43%,[1] and depending on the institution and severity of the perforation grade according to the Ellis criteria,[2] the overall mortality in patients developing CAP was 8.6% (range 2.5%-20.0%),[1] with a mortality rate of up to 44% in cases with an Ellis type III perforation.[3] Several risk factors have been re-

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ported to cause CAP, including complex lesions (e.g. chronic total occlusion (CTO), angulated or tortuous lesions, bifurcation lesions, and heavily calcified lesions), the use of atheroablative devices, female sex, previous coronary artery bypass surgery (CABG), and old age.[1,2,4,5]

Traditional management approaches include prolonged balloon inflation (5-15 minutes), protamine use, pericardiocentesis for cardiac tamponade, discontinued use of glycoprotein IIb/IIIa inhibitors, gel foam embolization, and emergent CABG.[1,4,6] Since the approval of polytetrafluoroethylene (PTFE)-covered stents (CSs) by the US Food and Drug Administration (FDA) in January 2001, CSs have become an important treatment modality for CAP, especially for patients with Ellis type III perforations. The use of CSs has also been shown to decrease the occurrence of cardiac tamponade and the need for emergent surgery.[7]

Both the severity and prevalence of coronary artery disease (CAD) increase with age, and multivessel disease and comorbid conditions are also more common in geriatric patients.[8] Despite the relative frailty of elderly patients, the increased utilization of PCI for coronary revascularization has been reported.[9] There has also been an increased trend of complex PCI in elderly patients, allowing for the observation of a series of cases of CS implantation for PCI-induced CAP in elderly subjects. During the initial enrollment phase, we found that all of our consecutive CAP patients who received CS were older than 65 years of age.

Although PTFE-CSs are an effective approach to treat CAP,[10,11] data regarding elderly patients requiring CS implantation for CAP are limited. In addition, the optimal duration of dual antiplatelet therapy (DAPT) in patients receiving CS implantation and the failure rate of CS implants have not been reported. Therefore, the aim of this study was to report single-center data for elderly patients with CAP (≥ 65 years) undergoing PTFE-CS implantation, as well as to report our findings about the duration of DAPT after CS implantation and CS failure rates.

## MATERIALS AND METHODS

We identified 20 consecutive patients with PCI-induced CAP out of 15225 total PCI procedures (0.13%). One of these patients (< 65 years old) was managed successfully with prolonged balloon inflation and protamine reversal, and was excluded from this study. The remaining 19 patients with PCI-induced CAP who underwent at least one PTFE-CS JOSTENT Graftmaster stent (Abbott Vascular, Santa Clara, CA) implantation at our hospital between July 2003 and July 2016 were enrolled. CAP was classified according to the Ellis criteria.[2] Type 1 CAP was defined as development of an extraluminal crater without extravasation; type 2 CAP was defined as pericardial or myocardial blush without contrast jet extravasation; and type 3 CAP was defined as extravasation through a frank (≥ 1 mm) perforation or cavity spilling into an anatomic cavity. Demographic data, risk factors for CAD, comorbidity status, indications for PCI, clinical data, and angiographic data were collected. Renal insufficiency was defined as a creatinine level > 115 μmol/L. The devices or procedures responsible for CAP and the CAP management strategies were also recorded. Detailed in-hospital and out-of-hospital outcomes were obtained from the medical charts of the index admission and outpatient clinic visits. Myocardial infarction (MI) was defined as the presence of at least two of the following criteria: prolonged chest pain > 20 minutes, elevation of serum creatine kinase level with a corresponding MB isoform ≥ 2 times the reference range, or new electrocardiographic changes (ST-T waves or new Q waves) indicative of myocardial damage. Target lesion revascularization (TLR) was defined as any repeat PCI for the target lesion (included 5 mm proximal and distal to the CS) performed for restenosis or occlusion. All-cause mortality was defined as any death in the discharged patients regardless of the cause. The Institutional Review Board of our hospital approved this study.

Major adverse in-hospital outcomes were recorded, including cardiac tamponade requiring pericardiocentesis, intra-aortic balloon pumping for cardiogenic shock, MI due to side-branch stent jail or prolonged balloon inflation, subacute CS thrombosis, prolonged requirement of mechanical ventilation (> 30 days) during the index admission, and in-hospital mortality. The use and duration of DAPT were also recorded. Repeat angiograms were recorded starting from the CAP index day until the end of observation. Definite stent thrombosis was defined as the occurrence of symptoms suggestive of acute coronary syndrome (ACS) and angiographic confir-

mation of stent thrombosis. CS failure was defined as CS thrombosis or CS restenosis in the follow-up angiogram among the patients who received successful CS implantation.

### Statistical analysis

Statistical analysis was performed using SPSS software (version 12.0; SPSS Inc., Chicago, IL). Continuous variables were expressed as means ± standard deviation, and categorical data as numbers and percentages. The Kaplan-Meier method was used to determine actuarial freedom from CS-failure.

## RESULTS

### Baseline clinical characteristics of the patients with CAP

The baseline clinical characteristics of the index admission are listed in Table 1. Nineteen elderly patients developed PCI-induced CAP during the study period (13 men and six women; mean age 75.3 ± 5.6 years, range: 65-86 years). The most common underlying or concomitant conditions were hypertension [16 patients (84.2%)], hypercholesterolemia [10 (52.6%)], diabetes mellitus [nine (47.4%)], renal insufficiency [eight (42.1%)], and congestive heart failure [eight (42.1%)]. The most frequent indications for PCI were stable [five (26.3%)] and unstable angina [five (26.3%)]. The mean left ventricle ejection fraction was 51.6 ± 13.4% (range: 25% to 69%). Common laboratory findings on admission were hyperglycemia and abnormal renal function, with a mean glucose level of 10.9 ± 6.4 mmol/L and mean creatinine level of 194 ± 159 μmol/L.

### Baseline angiographic characteristics of the patients

The baseline angiographic findings of the 19 patients are listed in Table 2. Nine perforations (47.4%) were noted in the left anterior descending coronary artery (LAD), two (10.5%) in the left circumflex coronary artery (LCX), two (10.5%) in the right coronary artery (RCA), one (5.3%) in the posterolateral artery, one (5.3%) in the ramus artery, one (5.3%) in the obtuse marginal artery, and one (5.3%) in a saphenous vein graft. Most of the patients with CAD presented with left main and triple vessel disease [seven (36.8%)] or triple vessel disease alone [six (31.6%)]. Overall, 16 patients (84.2%) presented with multiple vessel disease. Vessel rupture was most frequent in the distal coronary artery [nine (47.4%)], followed by the proximal coronary artery [five (26.3%)]. Based on the American College of Cardiology and American Heart Association Classification for lesion complexity, most cases were type B2 [nine (47.4%)] or type C [nine (47.4%)]. Three patient (15.8%) received intravascular ultrasound (IVUS) procedures before the occurrence of CAP. In the elderly patients requiring CSs for CAP to obtain complete hemostasis, most had an Ellis type III perforation [14 (73.7%)], followed by Ellis type II perforation [five (26.3%)]. None of the patients received glycoprotein IIb/IIIa inhibitors.

### Devices or procedures responsible for CAP

The devices or procedures causing CAP are listed in Table 3. The most common conditions responsible for CAP were post-stent dilation [seven patients (36.8%)] and stent deployment [three (15.8%)]. Traditional ablative device rotational atherectomy caused only two cases (10.5%). Kissing balloon dilation caused two cases

**Table 1.** Baseline clinical characteristics of coronary artery perforation patients undergoing covered stent implantation (n = 19)

| | |
|---|---|
| Age | 75.3 ± 5.6 |
| Males | 13 (68.4%) |
| Diabetes | 9 (47.4%) |
| Hypertension | 16 (84.2%) |
| Hypercholesterolemia | 10 (52.6%) |
| Renal insufficiency without hemodialysis | 8 (42.1%) |
| End-stage renal disease under hemodialysis | 3 (15.8%) |
| Current smoker | 2 (10.5%) |
| Prior percutaneous coronary intervention | 7 (36.8%) |
| Prior myocardial infarction | 4 (21.1%) |
| Prior stroke | 5 (26.3%) |
| Prior coronary artery bypass graft | 3 (15.8%) |
| Congestive heart failure | 8 (42.1%) |
| Percutaneous coronary intervention indication | |
| Stable ischemic heart disease | 5 (26.3%) |
| Unstable angina | 5 (26.3%) |
| Non-ST elevation myocardial infarction | 3 (15.8%) |
| ST-elevation myocardial infarction | 2 (10.5%) |
| Congestive heart failure | 4 (21.1%) |
| Laboratory data | |
| Baseline glucose (mmol/L) | 10.9 ± 6.4 |
| Baseline creatinine (μmol/L) | 194 ± 159 |

Values presented as numbers (%) or mean ± SD.

(10.5%), and antegrade balloon dilation while preparing retrograde wiring during reverse controlled antegrade and retrograde subintimal tracking (CART) caused one (5.3%).

### Management strategies of CAP

The management strategies of CAP are listed in Table 4. The total procedure time was 120 ± 56 (range 55~280) minutes. All patients received prolonged balloon dilation after the occurrence of CAP, and protamine reversal for heparin was given in seven patients (36.8%). Cardiac tamponade developed in six patients (31.6%), all of whom underwent emergent pericardiocentesis for hemodynamic relief. None of the patients required emergent surgery for CAP. CS implantation was successful in 18 patients, with an overall success rate of 94.7%. One case failed early in the study (ten years ago) due to a very angulated and diffusely diseased LCX vessel. The perforation grade in this case was Ellis type II, and CAP

**Table 2.** Baseline angiographic characteristics of coronary artery perforation patients undergoing covered stent implantation (n = 19)

| | |
|---|---|
| Site of coronary perforation | |
| Left main | 2 (10.5%) |
| Left anterior descending artery | 9 (47.4%) |
| Left circumflex artery | 2 (10.5%) |
| Right coronary artery | 2 (10.5%) |
| Posterolateral artery | 1 (5.3%) |
| Ramus | 1 (5.3%) |
| Obtuse marginal artery | 1 (5.3%) |
| Saphenous vein graft | 1 (5.3%) |
| Coronary artery disease | |
| Single vessel | 3 (15.8%) |
| Double vessel | 3 (15.8%) |
| Triple vessel | 6 (31.6%) |
| Left main + triple vessel | 7 (36.8%) |
| Multivessel disease | 16 (84.2%) |
| Lesion location | |
| Ostial | 1 (5.3%) |
| Proximal | 5 (26.3%) |
| Middle | 4 (21.1%) |
| Distal | 9 (47.4%) |
| Lesion complexity* | |
| Type A | 0 (0%) |
| Type B1 | 1 (5.3%) |
| Type B2 | 9 (47.4%) |
| Type C | 9 (47.4%) |
| Chronic total occlusion | 2 (10.5%) |
| Significant calcification | 4 (21.1%) |
| Intravascular ultrasound use before CAP | 3 (15.8%) |
| perforation grade# | |
| Ellis type I | 0 (0%) |
| Ellis type II | 5 (26.3%) |
| Ellis type III | 14 (73.7%) |
| Cavity spilling | 0 (0%) |
| Glycoprotein IIb/IIIa inhibitors | 0 (0%) |

Values presented as number (%).
* Based on American College of Cardiology/American Heart Association Classification; # Based on classification of Ellis et al.[2]

**Table 3.** Devices or procedures responsible for coronary artery perforation (n = 19)

| | |
|---|---|
| Guidewire | 1 (5.3%) |
| Pre-stent balloon dilation | 2 (10.5%) |
| Post-stent balloon dilation | 7 (36.8%) |
| Kissing balloon dilation in bifurcation disease | 2 (10.5%) |
| Cutting balloon dilation | 1 (5.3%) |
| Antegrade balloon dilation during Reverse CART* | 1 (5.3%) |
| technique | |
| Stent implantation | 3 (15.8%) |
| Rotational atherectomy | 2 (10.5%) |

Values presented as numbers (%).
* Controlled antegrade and retrograde subintimal tracking.

**Table 4.** Management of coronary artery perforation (n = 19)

| | |
|---|---|
| Procedure times (minutes) | 120 ± 56 |
| Protamine | 7 (36.8%) |
| Prolonged balloon inflation | 19 (100%) |
| Cardiac tamponade | 6 (31.6%) |
| Pericardiocentesis | 7 (36.8%) |
| Intra-aortic balloon pump | 4 (21.1%) |
| Emergent surgery | 0 (0%) |
| Covered stent implantation success | 18 (94.7%) |
| Numbers of covered stent per patient | |
| One covered stent | 17 (89.5%) |
| Two covered stent | 2 (10.5%) |
| Covered stent diameter (mm) | |
| 2.8 mm | 4 (19.0%) |
| 3.0 mm | 12 (57.1%) |
| 3.5 mm | 3 (14.3%) |
| 4.0 mm | 2 (9.5%) |
| Covered stent length (mm) | |
| 16 mm | 14 (66.7%) |
| 19 mm | 6 (28.6%) |
| 26 mm | 1 (4.8%) |
| GuideLiner® catheter use | 2 (10.5%) |
| Post-dilation of covered stent | 14 (73.7%) |

Values presented as numbers (%).

was successfully managed by protamine reversal and several prolonged balloon dilations. Seventeen patients (89.5%) received one CS (89.5%) and two patients received two CSs (10.5%). The most common CS diameter was 3.0 mm [12 CSs (57.1%)], and the most common CS length was 16 mm [14 CSs (66.7%)]. Since the introduction of smaller stents, four 2.8-mm diameter CSs (19.0%) were implanted in three cases in the last year of the study. A rapid exchange guide extension catheter designed for complex PCI, GuideLiner®, was recently introduced. Two cases (10.5%) of CAP (one with an angulated LCX and the other with an angulated and diffusely calcified LAD) received GuideLiner®-facilitated delivery of a CS in the last year of the study. In both cases, CS deployment was considered very difficult, if not impossible, without the help of the GuideLiner® catheter. Additional post-CS dilation was done in 14 patients (73.7%).

### In-hospital outcomes

The in-hospital outcomes of the study cases are listed in Table 5. The mean admission duration was 14 ± 19 days (range: 3 to 77 days). In-hospital MI occurred in 12 cases (63.2%), and three patients died despite aggressive management, with an overall in-hospital mortality rate of 15.8%. Two patients (10.5%) received in-hospital follow-up angiograms, both of whom had subacute thrombosis of the CS. Among the discharged 16 patients, only 14 (87.5%) received DAPT. Prolonged mechanical ventilation > 30 days was required by two patients (10.5%), neither of whom received DAPT. Antiplatelet drugs were discontinued due to in-hospital gastrointestinal bleeding in one patient, and clopidogrel alone was prescribed to another patient at the discretion of the attending critical care doctor in the respiratory care unit. Neither case underwent TLR at our hospital, and they were transferred to a local hospital for prolonged mechanical ventilation support.

**Table 5.** In-hospital outcomes of coronary artery perforation patients undergoing covered stent implantation (n = 19)

| | |
|---|---|
| Admission duration (days) | 14 ± 19 |
| Myocardial infarction | 12 (63.2%) |
| In-hospital angiogram follow-up | 2 (10.5%) |
| In hospital covered stent thrombosis | 2 (10.5%) |
| Prolonged mechanical ventilation (> 30 days) | 2 (10.5%) |
| Death | 3 (15.8%) |
| Dual antiplatelet therapy use after discharge (n = 16) | 14 (87.5%) |

Values presented as numbers (%) or mean ± SD.

### Out-of-hospital outcomes and CS failure rate

The out-of-hospital outcomes of the 16 survival-to-discharge cases are listed in Table 6. The mean follow-up duration of these 16 cases was 49 ± 41 months, and the mean duration of the 14 cases who received DAPT was 14 ± 17 months. There was only one non-cardiac death (6.3%) during follow-up, due to an intracranial hemorrhage caused by a falling accident. Follow-up angiography was performed in seven patients (43.8%), at a mean duration of 37 ± 28 months. Of these patients, three required TLR (1: very late thrombosis of the CS, 2: restenosis of the CS); and the CSs in the remaining four were patent.

Overall, there were five angiogram-proven CS failures (in-hospital: two subacute CS thrombosis; out-of-hospital: one very late CS thrombosis, and two CS restenosis) among the 18 patients who received successful CS implantation. The 1-, 2- and 4-year actuarial freedom rates from CS failure were 78%, 65%, and 43%, respectively, in the patients with angiogram follow-up (Figure 1).

### Representative case

Figures 2A-2H show the angiographic findings of an

**Table 6.** Out-of-hospital outcomes of coronary artery perforation patients undergoing covered stent implantation (n = 16)

| | |
|---|---|
| Follow-up duration (months) | 49 ± 41 |
| Duration of Dual antiplatelet therapy (months, n = 14) | 14 ± 17 |
| All-cause mortality | 1 (6.3%) |
| Cardiac mortality | 0 (0%) |
| Myocardial infarction | 1 (6.3%) |
| Out-of-hospital angiogram follow-up | 7 (43.8%) |
| Time of follow-up angiogram (months, n = 7) | 37 ± 28 |
| Target lesion revascularization | 3 (18.8%) |
| Covered stent occlusion | 1 (6.3%) |
| Covered stent restenosis | 2 (12.5%) |
| Overall covered stent failure rate* (n = 18) | 5 (27.8%) |

Values presented as numbers (%) or mean ± SD.
* Includes in-hospital and out-of-hospital covered stent failure after successful implantation.

Ellis type III grade CAP caused by rotational atherectomy. The CAP was treated successfully with a GuideLiner® catheter-facilitated delivery of two CSs.

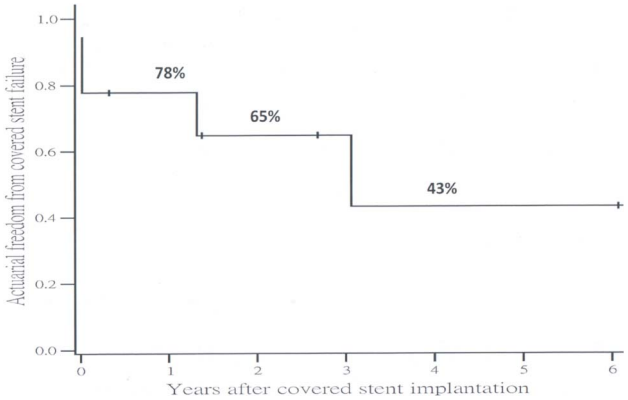


***Figure 1.*** *The actuarial freedom from covered stent failure in the patients who received angiographic follow-up.*

## DISCUSSION

The management of CAP with a CS is an emergency procedure during PCI. This study demonstrated that management of PCI-induced CAP with CS implantation in elderly patients is a feasible option, with a high CS implantation success rate and acceptable acute outcomes. The mean duration of DAPT of 14 months provided reasonable long-term outcomes. The findings showed that the 1-, 2- and 4-year actuarial freedom rates from CS failure were 78%, 65%, and 43%, respectively, in the patients with follow-up angiograms, suggesting that more aggressive angiographic follow-up may be helpful for post-CS implantation patients.

With regards to clinical outcomes, the 19 elderly patients (mean age 75.3 $\pm$ 5.6 years, range 65-86 years) in this study had a high percentage of complex lesions and ACS. The overall mortality rate was 15.8%, a figure much

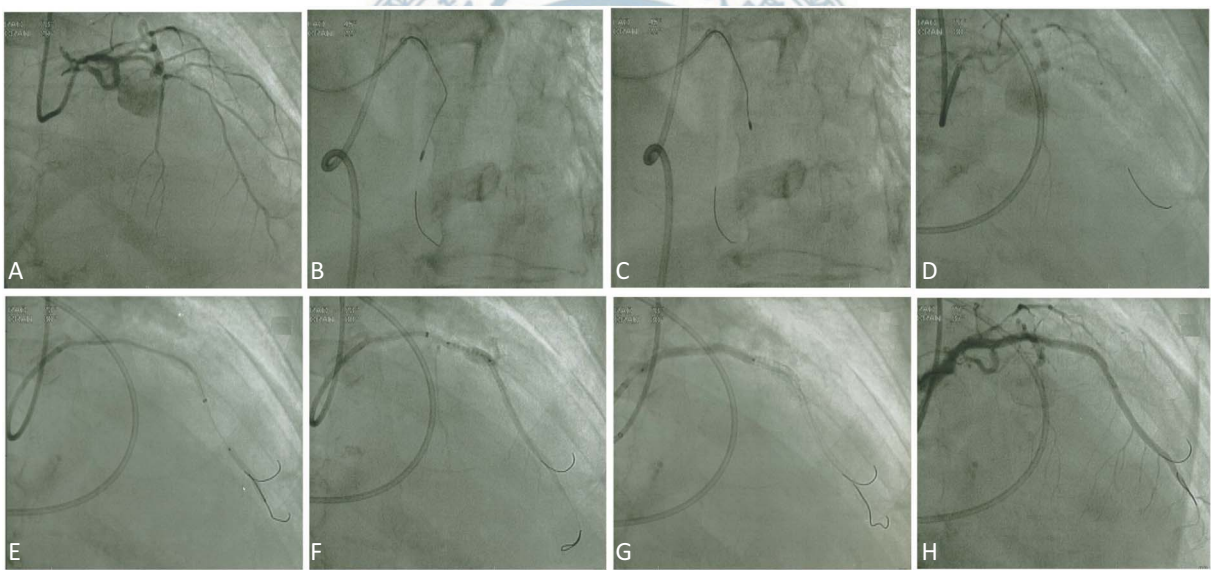


***Figure 2.*** *Representative case of a GuideLiner® catheter-facilitated implantation of two covered stents (CSs). (A) An 80-year-old male referred from a local hospital for left main (LM) plus triple vessel disease. He presented with congestive heart failure with a left ventricular ejection fraction of 28%. An initial angiogram (right anterior oblique view) showed 80% LM ostium stenosis and a diffuse, angulated, heavily calcified 90% left anterior descending (LAD) artery stenosis. (B) Rotational atherectomy was performed in the LAD, noting the angulated angle from the left anterior oblique view. (C) After a few passages of a 1.25-mm burr, the rotablator guidewire fractured at the point of angulation, resulting in direct perforation of the LAD by the rotating burr. (D) Immediate inflation of a 2.0/15-mm balloon via the fractured rotablator guidewire to prevent cardiac tamponade. (E) A new floppy guidewire was then placed into the LAD. However, a 2.8/19-mm covered stent failed to insert into the LAD despite several aggressive pre-dilations of the proximal-middle LAD with a 3.0/12-mm non-compliant balloon. A 6 Fr GuideLiner® was then inserted into the distal LAD. Two bare metal stents (2.25/23 mm, 2.25/18 mm) were deployed to cover the fractured rotablator guidewire to prevent guidewire-induced thrombosis. (F) After implantation of a 2.8/19-mm CS, there was still an unsealed perforation with contrast leakage. A second 2.8/16-mm CS was then deployed, which completely sealed the coronary perforation. (G) The LM and proximal LAD were further stented with a 3.0/38-mm drug-eluting stent. (H) Aggressive post-dilations were done in the whole stented LAD under intravascular ultrasound guidance. Final LAD results were optimal with TIMI-3 flow. Unfortunately, several diagonal branches were jailed out with post-procedure myocardial infarction. The patient was discharged in a stable condition 11 days after the complex coronary intervention.*

higher than the reported mortality rate for PCI for 70-80-year-olds of 2%.[12] All three patients who died in this study has ACS and Ellis type III perforations. The first patient was a 75-year-old male who presented with ST-elevation MI. The second patient was a 78-year-old female with non-ST-elevation myocardial infarction (NSTEMI), and the third was an 85-year-old man who also presented with NSTEMI. Aykan et al. reported that clinical outcomes of CAP were similar between patients with ACS and stable coronary arteries, although they included 25 CAP patients with a relatively younger age (67.2 $\pm$ 5.2 years) and fewer Ellis type 3 perforations (44%).[13] Although no firm conclusion can be derived from this study due to the lower mortality rate and small number of cases, caution should be exercised when managing patients with ACS complicated with CAP.

Seven patients (36.8%) received pericardiocentesis in this study, including six for cardiac tamponade. Due to concerns over clinical deterioration, one patient without clinical signs of cardiac tamponade received pericardiocentesis two days later at the discretion of the operator. Recently, Lee et al. reported that patients with CAP who developed cardiac tamponade had a higher 30-day cardiovascular mortality rate.[14] Although only six of our patients developed cardiac tamponade, all of the cases of in-hospital mortality (n = 3) had cardiac tamponade, resulting in a significant increase in in-hospital mortality rate (p = 0.005, chi-square test) in the patients who developed cardiac tamponade. The deteriorating hemodynamic status during cardiac tamponade clearly played a role in determining the worse prognosis in these patients with CAP. The devices and procedures responsible for CAP vary in different catheterization laboratories. In an early report, atherectomy and laser devices were responsible for a higher percentage of CAP than traditional percutaneous transluminal coronary angioplasty.[2] Although guidewires have been reported to bean important cause of CAP, the majority have not involved Ellis type III.[15] This is consistent with our findings, in which only one case of guidewire-induced Ellis type II CAP was treated with CS. Because the use of stents with post-dilation for adequate deployment has become more popular than atherectomy and laser devises, stenting causes more cases of CAP during PCI.[5,16] The cases of CAP in this study also showed a similar trend, with regular stent deployment and post-stent dilation causing more than half of the cases requiring CS implantation. In our cases, IVUS was used in only three patients before the occurrence of CAP, which probably explains the occurrence of CAP in the different PCI steps including pre-stent balloon dilation, stent implantation, and post-stent balloon dilation. In complex PCI, the more liberal use of IVUS may be a reasonable approach to decrease the occurrence of CAP. In addition, newer techniques for treating bifurcation lesions and CTO[17] also caused CS-requiring CAP, including kissing balloon inflation in different bifurcation techniques (two cases) and antegrade balloon inflation in the reverse CART technique (one case). Our findings suggest that caution should be taken to avoid oversizing balloons when treating such complex lesions.

Despite the more complex lesions in elderly patients, improvements in techniques and devices have resulted in a high success rate of CS implantation. CSs are bulky and non-flexible devices, and can be very difficult to deploy in vessels with a small diameter, angulated or tortuous vessels, or heavily calcified vessels. One case of CS implantation failure occurred early in this study due to an angulated and diffusely diseased LCX vessel. This case would now be considered treatable with CS implantation. The major reason for the improvement in CS implantation technique is the introduction of the GuideLiner®, a monorail catheter with a flexible and soft tip allowing for deep intubation of the target vessel to deliver a bulky or nonflexible device.[18] The increased use of GuideLiner® catheters in treating complex lesions has been well documented.[19-21] With the use of the GuideLiner® catheter, successful implantation of three CSs was performed in two recent cases; one due to an angulated LCX similar to our previous failure case, and the other due to a small diameter, angulated, and heavily calcified LAD. Importantly, the 6 Fr GuideLiner® catheter not only provides adequate support to implant a bulky CS, but also provides partial lumen occlusion to lessen bleeding into the pericardial space due to its large profile. In both cases, implanting the CS without the help of the GuideLiner® catheter would be difficult or impossible. The GuideLiner® catheter virtually eliminates the need for more invasive surgical approaches.

Subacute thrombosis still occurred in two of our cases, emphasizing the importance of adequate CS deployment using a final CS high-pressure balloon dilation and early initiation of DAPT. However, little is known

about the optimal duration of DAPT after hospital discharge. Elsner et al. reported a higher rate (33%) of thrombotic occlusion in CS with about four weeks of ticlopidine therapy and life-long aspirin.[22] When ticlopidine was used for up to three months, Briguori et al. found that none of the seven patients who received CS implantation experienced stent thrombosis in angiographic follow-up at a mean of six months, although two patients developed angiographic restenosis (29%).[7] In contrast, when CSs were implanted for cases with saphenous vein graft rupture, angiographic follow-up in four CS-implanted patients showed that two CSs were occluded at five and eight months, respectively, and another developed severe restenosis at 11 months.[23] In a canine model, implanted PTFE-CSs showed neointima formation from the stent edge, with delayed endothelialization at the center of the CS.[24] Similar to the animal study, Takano et al. reported that angioscopy and optical coherence tomography failed to detect endothelialization in a patient with a CS placed nine months previously for a RCA aneurysm.[25] Currently, there are no firm recommendations for patients with CAP treated with CS, although some authors suggest that at least six months of DAPT is required.[4,11] Given that nine months of follow-up still showed a lack of endothelialization in CS,[25] it may be necessary to extend the duration of DAPT for longer than nine months.

The major limitations of this study is that it is a single-center, retrospective, follow-up study. The small sample size limits any firm conclusions about the management of patients with CS implantation. In addition, CAP patients in our cases were mainly elderly patients. Therefore, we could not investigate differences in CS implantation between younger and older patients. Although we believe that the clinical results and the decision to implant CS would not be altered by age, a large multi-center study is needed to answer the optimal management of CS-implanted patients.

## CONCLUSIONS

CS implantation for CAP is a feasible and effective approach to treat this life-threatening complication in elderly patients. CS failure due to CS thrombosis or restenosis remains a major concern, and thus regular follow-up angiography is suggested for this population.

## CONFLICT OF INTEREST

None.

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