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# Coronary Artery Perforation During Percutaneous Coronary Intervention: A Two-Center Real-World Case Series and Review of Management Strategies

ORIGINAL INVESTIGATION

## ABSTRACT

**Background:** Coronary artery perforation (CAP) is a rare life-threatening complication of percutaneous coronary intervention (PCI). Although several risk factors for CAP have been described, real-world multicenter studies analyzing the clinical outcomes remain limited. This study presents a comprehensive 2-center evaluation of CAP, focusing on angiographic severity, management strategies, and short- and long-term outcomes.

**Methods:** In this study, patients of CAP were included and perforations were classified according to the Ellis system. Primary outcomes were procedural success, cardiac tamponade, pericardiocentesis, cardiogenic shock, and 30-day mortality. Secondary outcomes were late mortality and ejection fraction at the end of first month.

**Results:** Totally, 53 cases of CAP were identified. Ten patients had Ellis grade I, 30 patients had grade II, and 13 patients had grade III perforations. The rate of successful procedure was 100% in grade I, 90% in grade II, and 30.8% in grade III ($P < .001$). Hemodynamic compromise was observed predominantly in grade III perforations. Early mortality occurred in 7 patients (13.2%) and was strongly associated with severe Ellis grades ($P < .001$). Late mortality occurred in 5 patients (9.4%), and chronic renal insufficiency was identified as a significant predictor of mortality ($P = .018$). Ejection fraction was significantly lower in grade III perforations at the end of first month ($P = .005$).

**Conclusion:** Increasing Ellis grade was strongly associated with procedural failure, hemodynamic instability, and early mortality, whereas late outcomes were predominantly influenced by systemic comorbidities rather than the severity of perforation. These findings underscore the importance of prompt intraprocedural management and comprehensive post-discharge care in patients with CAP.

**Keywords:** Complications, coronary artery disease, coronary artery perforation, ellis classification, percutaneous coronary intervention, tamponade

## INTRODUCTION

Coronary artery perforation (CAP) is one of the most feared complications of percutaneous coronary intervention (PCI). Although it is a rare event, it can lead to catastrophic outcomes, rapidly progressing to cardiac tamponade, hemodynamic collapse, the need for emergency surgery, and even death. The reported incidence of CAP in contemporary practice ranges from 0.1% to 0.6%. However, its occurrence is significantly more common in complex PCI scenarios, such as interventions involving heavily calcified lesions, bifurcations, and chronic total occlusions (CTOs).[1-3] With the increase in high-risk PCI procedures globally and a growing number of elderly and comorbid patients undergoing revascularization, the absolute number of CAP cases has risen, despite the overall incidence remaining stable.[4] These trends highlight the importance of understanding the mechanisms, risk factors, and evidence-based management strategies related to CAP in real-world practice.

The mechanisms that lead to CAP are diverse and closely related to factors such as lesion morphology, wire behavior, balloon or stent over-sizing, and the use of

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plaque-modifying technologies. Guide-wire related injuries—particularly those caused by hydrophilic or stiff CTO wires—are the leading cause of distal perforations. In contrast, oversized balloons, high-pressure post-dilatation, rotational or orbital atherectomy, and intravascular lithotripsy (IVL) can increase the risk of proximal or main-vessel perforations in patients.[5-8] Coronary artery perforation severity is commonly graded using the Ellis classification, introduced in 1994. This system categorizes perforations from mild extraluminal crater formation (Grade I) to frank contrast extravasation (Grade III).[1] This classification not only predicts the likelihood of hemodynamic compromise but also guides clinical management. Grades I and II lesions generally respond to prolonged balloon inflation or conservative therapy; however, Grade III perforations often require covered stent implantation, coil or balloon embolization, and may necessitate emergency surgery.[5-6,9-10] Notably, Ellis Grade III perforations have been associated with mortality rates as high as 20%-44%, primarily due to rapid progression to tamponade and cardiogenic shock.[6,11]

Despite these risks, real-world multicenter data evaluating the characteristics, mechanisms, and outcomes of CAP remain limited.[4] Previous studies are often single-center or confined to specific PCI subgroups, such as CTO interventions. Furthermore, many contemporary analyses lack detailed stratification of outcomes based on Ellis grades or do not differentiate between determinants of acute versus late mortality. Therefore, a combined case series with an integrated review can provide meaningful clinical insights by contextualizing experiences from individual centers within a broader evidence base.

Management of CAP necessitates immediate recognition and rapid escalation through a structured therapeutic algorithm. Prolonged balloon inflation is the first-line approach for achieving hemostasis; however, many cases—particularly those classified as Ellis Grade II or III—require additional therapies. Covered stents are preferred for large proximal perforations, while coil or microcoil embolization is often employed for distal vessel injuries and small-caliber branches.[12-14] In severe cases involving evolving tamponade or failed percutaneous strategies, emergency pericardiocentesis and surgical intervention may be life-saving. Despite these established principles, real-world outcomes exhibit variability influenced by perforation severity, lesion complexity, and the presence of shock or renal dysfunction at the time of presentation.

The present study offers a comprehensive 7-year, 2-center retrospective analysis of CAP. A total of 53 cases with complete clinical and procedural data were included in the final evaluation. This dataset represents one of the more detailed real-world cohorts of CAP from the region, encompassing both early and late clinical outcomes while providing insights into the interplay between Ellis classification, procedural strategies, hemodynamic deterioration, and mortality. By integrating detailed angiographic characteristics with contemporary management approaches, this study aims to enhance understanding of CAP prognosis in modern PCI practice and identify potential avenues for prevention, early recognition, and more effective intervention.

## HIGHLIGHTS

- Coronary artery perforation occurred in approximately 0.25% of percutaneous coronary intervention procedures in this real-world 2-center cohort.
- Increasing Ellis grade was strongly associated with procedural failure, hemodynamic instability, and early mortality, with Ellis grade III representing the highest-risk subgroup.
- Ellis grade III perforations were characterized by high rates of cardiac tamponade, cardiogenic shock, emergency surgery, and markedly reduced procedural success.
- Early mortality was primarily driven by acute hemodynamic collapse and unsuccessful hemostasis, whereas late mortality was predominantly related to systemic comorbidities, particularly chronic renal insufficiency.

## METHODS

This retrospective, observational study encompassed all patients who underwent coronary angiography or PCI at 2 high-volume centers from January 2018 to January 2025. Within this time interval, a total of 44 428 coronary angiograms and 21 515 PCI procedures were conducted across the participating institutions. All cases of CAP identified during or immediately following PCI were screened for inclusion. The diagnosis of CAP was based on angiographic visualization and was classified according to the Ellis classification system. Initially, 53 perforation cases were identified, and detailed procedural images, angiography recordings, and operator reports were subsequently reviewed for each specific case.

Data collection was conducted in multiple stages. Initially, imaging archives from the catheterization laboratories were reviewed to extract procedural characteristics, including lesion morphology, types of guidewires used, balloon and stent parameters, inflation pressures, timing of perforation, and treatment modalities employed. Subsequently, electronic hospital databases were searched to gather demographic information, comorbidities, laboratory values, echocardiographic findings, and in-hospital outcomes.

For cases with missing or incomplete clinical follow-up data—such as late mortality, re-hospitalization, or clinical status within the 1- to 12-month period—patients or their first-degree relatives were contacted via telephone. If follow-up data could not be verified through database review or patient contact, those cases were excluded from the final analysis. As a result, the dataset reflects a fully validated cohort in which both procedural and clinical details were reliably obtained.

Management strategies following perforation were categorized into 5 distinct approaches: (1) prolonged balloon inflation, (2) covered stent implantation, (3) coil or wire-induced embolization, (4) balloon embolization, and (5) emergency surgical repair. Hemodynamic complications, including hypotension, cardiac tamponade, pericardiocentesis requirement, and cardiogenic shock, were documented systematically. Early mortality was defined as any death occurring within 30 days after the index procedure, while late mortality referred to death occurring between 1 and 12 months post-procedure. The left ventricular ejection fraction at the 1-month mark was obtained from transthoracic echocardiography reports.

Statistical analysis was conducted using SPSS software (IBM SPSS Statistics, Version 26.0; IBM Corp., Armonk, NY, USA). Normality of continuous variables was assessed using the Shapiro–Wilk test. Continuous variables are reported as mean ± standard deviation for those with a normal distribution or as median (interquartile range) for non-normally distributed variables. Categorical variables are presented as counts and percentages. Group comparisons involved the use of the Student's *t*-test or Mann–Whitney *U*-test for continuous variables, and the chi-square test or Fisher's exact test for categorical variables. For comparisons among Ellis groups, analysis of variance (ANOVA) or Kruskal–Wallis testing was employed. A *P* value of less than .05 was regarded as statistically significant. This study was approved by the Local Ethics Committee (decision date: 17 June 2025, decision number: E-43012747-050.04-481619/351). The study was conducted in accordance with the principles of the Declaration of Helsinki.

## RESULTS

A total of 53 patients with complete clinical and procedural data were included in the final analysis. The mean age of the population was 66 years, with 69.8% of the population being male. According to the Ellis classification, 10 patients (18.9%) were categorized as Ellis grade I, 30 patients (56.6%) as Ellis grade II, and 13 patients (24.5%) as Ellis grade III.

### Baseline Characteristics According to Ellis Classification

Baseline demographic and clinical variables did not show significant differences among the 3 Ellis groups (Table 1).

The Ellis-III group exhibited a higher mean age (70.2 ± 6.3 years) compared to the Ellis-I (61.6 ± 10.9 years) and Ellis-II (65.6 ± 11.9 years) groups, although this difference was not statistically significant (*P* = .159). Key cardiovascular risk factors—including hypertension, diabetes mellitus, hyperlipidemia, chronic renal insufficiency, and prior coronary artery disease—were consistently distributed among the groups (*P* > .05 for all). Furthermore, no significant variations were observed concerning multivessel disease, the presence of CTO, calcification grade, or the rates of pre- and post-dilatation across the groups. These results highlight the uniformity of the patient population, ensuring a more reliable analysis of outcomes based on Ellis classification.

### Procedural Findings

Perforation timing exhibited significant differences among the Ellis groups (*P* = .005). Patients classified as Ellis-I and Ellis-II experienced coronary perforations primarily following balloon predilatation and stent implantation, while wire-induced and post-dilatation perforations were more prevalent in the Ellis-III group. Although inflation pressures were numerically higher in the Ellis-I group (15.6 ± 2.8 atm), these did not reach statistical significance across groups (*P* = .130). Additionally, the use of hydrophilic wires was noted in 23.3% of Ellis-II patients and 15.4% of Ellis-III patients, with no significant difference observed (*P* = .282).

The treatment strategy for perforation varied significantly between the groups (*P* = .001). Balloon tamponade was the most commonly employed approach in Ellis-I (90.0%) and Ellis-II (63.3%) patients, while covered stent implantation (61.5%) and emergency surgery (38.5%) were more frequently necessary in the Ellis-III group.

### Clinical Outcomes and Complications by Ellis Group

An increasing Ellis grade was strongly associated with worse clinical outcomes (Table 1). Procedural success was achieved in 100% of Ellis-I, 90% of Ellis-II, but only 30.8% of Ellis-III patients (*P* < .001). Hemodynamic complications, including cardiogenic shock (69.2%), hypotension (92.3%), cardiac tamponade (69.2%), and the need for pericardiocentesis (38.5%), were overwhelmingly concentrated in the Ellis-III group (*P* < .001 for each). Additionally, early mortality significantly increased with the severity of perforation, reaching 38.5% in Ellis-III patients compared to 0% in Ellis-I and 6.7% in Ellis-II (*P* = .012).

Left ventricular ejection fraction at 1 month also decreased progressively with Ellis severity, showing values of 57.5 ± 5.9% for Ellis-I, 52.1 ± 7.9% for Ellis-II, and 45.0 ± 8.9% for Ellis-III (*P* = .005).

### Early Mortality (First 30 Days)

Among the 53 patients in the study, 7 experienced early mortality, resulting in a rate of 13.2% (Table 2).

Age, sex, and most cardiovascular risk factors did not significantly differ between survivors and non-survivors. However, hypertension was more prevalent among survivors (71.7% vs. 28.6%; *P* = .038). Additionally, procedural variables such as stent implantation, inflation pressure, the use of hydrophilic wires, and the prevalence of CTOs showed no significant association with early mortality.

Several intra-procedural and post-procedural factors were significantly associated with early mortality. Perforation timing was notably different (*P* = .033), with non-survivors often experiencing perforations during the mid-procedure period (after stent implantation). Unsuccessful interventions were more frequent in non-survivors (28.6% vs. 84.8% success in survivors; *P* = .004). Cardiogenic shock (85.7% vs. 8.7%; *P* < .001), tamponade (71.4% vs. 10.9%; *P* = .002), hypotension (85.7% vs. 34.8%; *P* = .016), and the need for pericardiocentesis (57.1% vs. 8.7%; *P* = .007) were significantly associated with early mortality. Ellis-III lesions were also disproportionately represented among early mortality cases (*P* = .013). Thrombolysis in myocardial infarction (TIMI) flow grade scores differed markedly, with lower TIMI flow observed in non-survivors (*P* < .001).

### Late Mortality (1-12 Months)

Late mortality was observed in 5 patients (9.4%) (Table 3).

**Table 1. Distribution of Clinical and Procedural Variables Across Ellis Groups**

| Variables | Ellis Groups | | | P |
|---|---|---|---|---|
| | Group 1 (n = 10) | Group 2 (n = 30) | Group 3 (n = 13) | |
| Age | 61.6 ± 10.9 | 65.6 ± 11.9 | 70.2 ± 6.3 | .159* |
| Gender (F/M) | 2/8 | 11/19 | 4/9 | .671£ |
| HT (%) | 7 (70.0) | 21 (70.0) | 7 (53.8) | .580 £ |
| HL (%) | 3 (30.0) | 22 (73.3) | 8 (61.5) | .053 £ |
| DM (%) | 6 (60.0) | 19 (63.3) | 8 (61.5) | 1.000 £ |
| Chronic renal insufficiency (%) | 3 (30.0) | 11 (36.7) | 3 (23.1) | .785 £ |
| History of CAD (%) | 6 (60.0) | 18 (60.0) | 9 (69.2) | .861 £ |
| History of past percutaneous coronary artery intervention (%) | 4 (40.0) | 15 (50.0) | 6 (46.2) | .930 ¥ |
| Multivessel (%) | 6 (60.0) | 23 (76.7) | 11 (84.6) | .383 £ |
| Calcification Grade (0/I/II/III) | 0/2/3/5 | 2/4/18/6 | 0/1/5/7 | .225 £ |
| CTO (%) | 2 (20.0) | 7 (23.3) | 2 (15.4) | .899 £ |
| Pre-dilatation (%) | 10 (100.0) | 27 (90.0) | 13 (84.6) | .573 £ |
| Stent (%) | 8 (80.0) | 22 (73.3) | 11 (15.4) | .902 £ |
| Post-dilatation (%) | 5 (50.0) | 17 (56.6) | 5 (38.5) | .546 ¥ |
| Perforation time (1/2/3/4) | 4/2/0/4 | 9/4/12/5 | 2/5/0/6 | .005 £ |
| Inflation pressure | 15.6 ± 2.8 | 13.7 ± 2.9 | 13.5 ± 1.7 | .130* |
| Guidewire tip stiffness (operator-reported) | 1 (1-3) | 1 (0.8-4.5) | 1 (0.8-4.5) | .454 # |
| Hydrophilic wire (%) | 0 (0.0) | 7 (23.3) | 2 (15.4) | .282 £ |
| Technique for the treatment of perforation (1/2/3/4/5) | 9/1/0/0/0 | 19/8/2/1/0 | 2/8/0/0/3 | **.001** £ |
| Successful intervention (%) | 10 (100.0) | 27 (90.0) | 4 (30.8) | **<.001** £ |
| Pericardiocentesis (%) | 0 (0.0) | 3 (10.0) | 5 (38.5) | **.018** £ |
| Prompt surgery (%) | 0 (0.0) | 0 (0.0) | 5 (38.5) | **<.001** £ |
| Cardiogenic shock (%) | 0 (0.0) | 1 (3.3) | 9 (69.2) | **<.001** £ |
| Hypotension (%) | 3 (30.0% | 7 (23.3) | 12 (92.3) | **<.001** ¥ |
| Cardiac tamponade (%) | 0 (0.0) | 1 (3.3) | 9 (69.2) | **<.001** £ |
| Anticoagulant usage (%) | 0 (0.0) | 2 (6.6) | 3 (23.1) | .166 £ |
| Anti-aggregant usage (%) | 5 (50.0) | 24 (80.0) | 9 (69.2) | .182 £ |
| Mortality in the first month (%) | 0 (0.0) | 2 (6.7) | 5 (38.5) | **.012** £ |
| Mortality between 1 and 12th months (%) | 1 (10.0) | 5 (16.7) | 6 (46.2) | .999 £ |
| EF at the end of the first month | 57.5 ± 5.9 | 52.1 ± 7.9 | 45.0 ± 8.9 | **.005*** |
| Effusion during discharge (%) | 0 (0.0) | 4 (13.2) | 3 (23.1) | .085 £ |
| TIMI flow grade (0/1/2/3) | 0/0/1/9 | 1/3/3/22 | 4/0/0/4 | **.029** £ |

TIMI flow grade: 0 = no perfusion; 1 = penetration without perfusion; 2 = partial perfusion; 3 = normal perfusion. Guidewire tip stiffness was recorded based on operator assessment and manufacturer-reported characteristics.Technique for the treatment of perforation: (1) prolonged balloon inflation, (2) covered stent implantation, (3) coil or wire-induced embolization, (4) balloon embolization, and (5) emergency surgical repair.
Perforation time: (1) predilatation, (2) stent implantation, (3) wire-induced, (4) postdilatation with non-compliant balloon.
CAD, coronary artery disease; CTO, chronic total occlusion of coronary arteries; DM, diabetes mellitus; EF, ejection fraction (echocardiography); Ellis, Ellis classification of coronary artery perforation during angiography; HL, hyperlipidemia; HT, hypertension.
*ANOVA [mean S.D].
¥$X^2$ test [number (percentage)]
£Fisher Exact test [number (percentage)].
#Kruskal-Wallis H test [median (min.-max.].

No significant differences were noted with respect to age, sex, multivessel disease, the presence of CTOs, calcification grade, or procedural characteristics. Unlike early mortality, the timing of perforation and the Ellis grade did not show a correlation with late mortality rates.

Chronic renal insufficiency was identified as the primary predictor of late mortality, being significantly more prevalent among patients who died within 1-12 months (80.0% vs. 22.0%; *P* = .018). Notably, there were no significant differences in the incidence of cardiac tamponade, pericardiocentesis, or shock during the index hospitalization, suggesting that late mortality was predominantly driven by underlying comorbidities rather than the acute severity of the procedural event. Furthermore, the use of anticoagulants showed a borderline association with outcomes (*P* = .053), suggesting

**Table 2. Distribution of Study Variables According to Early Mortality**

| | Mortality Within the First Month | | |
|---|---|---|---|
| **Variables** | **Survivors (n = 46)** | **Exitus (n = 7)** | ***P*** |
| Age | 66 (44-85) | 72 (44-85) | .269 ℧ |
| Gender (F/M) | 13/33 | 4/3 | .192 £ |
| HT (%) | 33 (71.7) | 2 (28.6) | **.038** £ |
| HL (%) | 30 (65.2) | 3 (42.9) | .405 £ |
| DM (%) | 29 (63.0) | 4 (57.1) | 1.000 £ |
| Chronic renal insufficiency (%) | 13 (28.3) | 4 (57.1) | .192 £ |
| History of CAD (%) | 29 (63.0) | 4 (57.1) | 1.000 £ |
| History of past percutaneous coronary artery intervention (%) | 21 (45.7) | 4 (57.1) | .694 £ |
| Multivessel (%) | 34 (73.9) | 6 (85.7) | .667 £ |
| Calcification Grade (0/I/II/III) | 1/7/24/14 | 1/0/2/4 | .162 £ |
| CTO (%) | 11 (23.9) | 0 (0.0) | .667 £ |
| Pre-dilatation (%) | 43 (93.5) | 7 (100.0) | 1.000 £ |
| Stent (%) | 35 (76.1) | 6 (85.7) | .679 £ |
| Post-dilatation (%) | 24 (52.2) | 3 (42.9) | .704 ¥ |
| Perforation time (1/2/3/4) | 14/7/10/15 | 1/4/2/0 | **.033** £ |
| Inflation pressure | 14 (10-22) | 12 (12-16) | .384 ℧ |
| Guidewire tip stiffness (operator-reported) | 1 (0.8-4.5) | 1 (0.8-4.5) | .953 ℧ |
| Hydrophilic wire (%) | 7 (15.2) | 2 (28.6) | .587 £ |
| Technique for the treatment of perforation (1/2/3/4/5) | 29/11/2/1/3 | 1/6/0/0/0 | **.036** £ |
| Successful intervention (% | 39 (84.8) | 2 (28.6) | **.004** £ |
| Pericardiocentesis (%) | 4 (8.7) | 4 (57.1) | **.007** £ |
| Prompt surgery (%) | 4 (8.7) | 1 (14.3) | 1.000 £ |
| Cardiogenic shock (%) | 4 (8.7) | 6 (85.7) | **<.001** £ |
| Hypotension (%) | 16 (34.8) | 6 (85.7) | **.016** £ |
| Cardiac tamponade (%) | 5 (10.9) | 5 (71.4) | **.002** £ |
| Anticoagulant usage (%) | 4 (8.7) | 1 (14.3) | 1.000 £ |
| Anti-aggregant usage (%) | 35 (76.1) | 3 (42.9) | .090 £ |
| ELLIS Score (1/2/3) | 0/3/9 | 10/27/4 | **.013** £ |
| TIMI flow grade (0/1/2/3) | 1/3/3/34 | 4/0/1/1 | **<.001** £ |

TIMI flow grade: 0 = no perfusion; 1 = penetration without perfusion; 2 = partial perfusion; 3 = normal perfusion. Guidewire tip stiffness was recorded based on operator assessment and manufacturer-reported characteristics.Technique for the treatment of perforation: (1) prolonged balloon inflation, (2) covered stent implantation, (3) coil or wire-induced embolization, (4) balloon embolization, and (5) emergency surgical repair.
Perforation time: (1) predilatation, (2) stent implantation, (3) wire-induced, (4) postdilatation with non-compliant balloon.
CAD, coronary artery disease; CTO, chronic total occlusion of coronary arteries; DM, diabetes mellitus; EF, ejection fraction (echocardiography); Ellis, Ellis classification of coronary artery perforation during angiography; HL, hyperlipidemia; HT, hypertension.
℧Mann–Whitney *U*-test [median (min.*max)].
¥$X^2$ test [number (percentage)].
£Fisher Exact test [number (percentage)].

that pharmacological management may play a significant role in influencing long-term survival among this patient cohort.

### Factors Associated With Procedural Failure

A total of 12 patients (22.6%) experienced an unsuccessful intervention (Table 4).

Baseline characteristics—including age, sex, diabetes, hypertension, hyperlipidemia, and renal insufficiency—were comparable between successful and unsuccessful intervention groups. In contrast, procedural variables exhibited significant differences, suggesting that the factors associated with the intervention's success may be more closely tied to the specific management strategies employed rather than the demographic or clinical baseline features of the patients.

Successful cases are more likely to involve stent implantation (82.9% vs. 58.3%; $P = .007$) and post-dilation (61.0% vs. 16.7%; $P = .007$). Additionally, inflation pressures were significantly higher in successful interventions ($P = .045$), indicating that optimized stent deployment may play a crucial role in effectively sealing perforations.

Severe complications were significantly more prevalent in unsuccessful interventions, including cardiac tamponade (75.0% vs. 2.4%), cardiogenic shock (75.0% vs. 2.4%), hypotension (75.0% vs. 31.7%), and the need for pericardiocentesis (33.3% vs. 9.8%; $P < .01$ for all). Emergency surgery was

**Table 3. Distribution of Study Variables According to Late Mortality**

| | Mortality Between 1st and 12th Months | | |
|---|---|---|---|
| **Variables** | **Survivors (n = 41)** | **Exitus (n = 5)** | ***P*** |
| Age | 66 (44-85) | 66 (64-82) | .437 ℧ |
| Gender (F/M) | 11/30 | 2/3 | .612 £ |
| HT (%) | 29 (70.7) | 4 (80.0) | 1.000 £ |
| HL (%) | 27 (65.9) | 3 (60.0) | 1.000 £ |
| DM (%) | 25 (61.0) | 4 (80.0) | .637 £ |
| Chronic renal insufficiency (%) | 9 (22.0) | 4 (80.0) | **.018** £ |
| History of CAD (%) | 26 (63.4) | 3 (60.0) | 1.000 £ |
| History of past percutaneous coronary artery intervention (%) | 20 (48.9) | 1 (20.0) | .356 £ |
| Multivessel (%) | 34 (73.9) | 6 (85.7) | .594 £ |
| Calcification Grade (0/I/II/III) | 1/6/21/13 | 0/1/3/1 | 1.000 £ |
| CTO (%) | 11 (26.8) | 0 (0.0) | .317 £ |
| Pre-dilatation (%) | 38 (92.7) | 5 (100.0) | .317 £ |
| Stent (%) | 30 (73.2) | 5 (100.0) | .317 £ |
| Post-dilatation (%) | 22 (53.7) | 2 (40.0) | .659 £ |
| Perforation time (1/2/3/4) | 13/5/10/13 | 1/2/0/2 | .311 £ |
| Inflation pressure | 14 (10-22) | 15 (14-16) | .218 ℧ |
| Guidewire tip stiffness (operator-reported) | 1 (0.8-4.5) | 1 (1-1) | .328 ℧ |
| Hydrophilic wire (%) | 7 (17.1) | 0 (0.0) | .580 £ |
| Technique for the treatment of perforation (1/2/3/4/5) | 26/9/2/1/3 | 3/2/0/0/0 | .809£ |
| Successful intervention (%) | 34 (82.9) | 5 (100.0) | .580 £ |
| Pericardiocentesis (%) | 4 (9.8) | 0 (0.0) | 1.000 £ |
| Prompt surgery (%) | 4 (9.8) | 0 (0.0) | 1.000 £ |
| Cardiogenic shock (%) | 4 (9.8) | 0 (0.0) | 1.000 £ |
| Hypotension (%) | 13 (31.7) | 3 (60.0) | .325 £ |
| Cardiac tamponade (%) | 5 (12.2) | 0 (0.0) | 1.000 £ |
| Anticoagulant usage (%) | 2 (4.9) | 2 (40.0) | .053 £ |
| Anti-aggregant usage (%) | 31 (75.6) | 4 (80.0) | 1.000 £ |
| ELLIS Score (1/2/3) | 0/3/9 | 10/27/4 | **.999** £ |
| TIMI flow grade (0/1/2/3) | 1/2/3/30 | 0/1/0/4 | .443 £ |

TIMI flow grade: 0 = no perfusion; 1 = penetration without perfusion; 2 = partial perfusion; 3 = normal perfusion. Guidewire tip stiffness was recorded based on operator assessment and manufacturer-reported characteristics.Technique for the treatment of perforation: (1) prolonged balloon inflation, (2) covered stent implantation, (3) coil or wire-induced embolization, (4) balloon embolization, and (5) emergency surgical repair.
Perforation time: (1) predilatation, (2) stent implantation, (3) wire-induced, (4) postdilatation with non-compliant balloon.
CAD, coronary artery disease; CTO, chronic total occlusion of coronary arteries; DM, diabetes mellitus; EF, ejection fraction (echocardiography); Ellis, Ellis classification of coronary artery perforation during angiography; HL, hyperlipidemia; HT, hypertension.
℧Mann–Whitney *U*-test [median (min.*max)].
¥$X^2$ test [number (percentage)].
£Fisher Exact test [number (percentage)].

required exclusively in the failed-intervention group (41.7%; *P* < .001). Furthermore, the majority of unsuccessful cases were categorized as Ellis grade III (*P* < .001). The TIMI flow grade was also significantly lower in the unsuccessful group, with most patients exhibiting TIMI 0-1 flow (*P* < .001), underscoring the correlation between procedural failure and adverse clinical outcomes.

### Overall Mortality and Follow-Up

At the 12-month follow-up, total mortality reached 22.6% (12 patients), including 7 early deaths and 5 late deaths. The distribution of outcomes aligns with the established bimodal risk pattern associated with coronary perforation, characterized by an initial phase primarily marked by acute hemodynamic collapse, followed by a later phase influenced by underlying systemic comorbidities. The observed survival trends are consistent with findings from previous high-volume registries and multicenter studies on CAP, which similarly report early mortality rates and associated risk profiles.[2,12]

## DISCUSSION

This 2-center, 7-year analysis provides a detailed real-world assessment of CAP in contemporary PCI practice. Although CAP remains an infrequent complication, the findings confirm that it is associated with substantial mortality both in the early and late stages. In this cohort, CAP occurred in approximately 0.25% of PCI procedures, with early and late mortality rates of 13.2% and 9.4%, respectively. These results

**Table 4. Distribution of Study Variables Between Groups Based on Intervention Success**

| | Success of Intervention | | |
|---|---|---|---|
| **Variables** | **Unsuccessful (n = 12)** | **Successful (n = 41)** | ***P*** |
| Age | 67 (57-85) | 66 (44-85) | .509 ℧ |
| Gender (F/M) | 5/7 | 12/29 | .418 ¥ |
| Mortality within the first month (%) | 5 (41.7) | 2 (4.9) | <.001¥ |
| Mortality between 1st and 12th months (%) | 0 (0.0) | 5 (12.2) | .331 £ |
| HT (%) | 6 (50.0) | 29 (70.7) | .182 ¥ |
| HL (%) | 7 (58.3) | 26 (63.4) | .749 ¥ |
| DM (%) | 7 (58.3) | 26 (63.4) | .749 ¥ |
| Chronic renal insufficiency (%) | 3 (25.0) | 14 (34.2) | .551 ¥ |
| History of CAD (%) | 6 (50.0) | 27 (65.9) | .319 ¥ |
| History of past percutaneous coronary artery intervention (%) | 6 (50.0) | 19 (46.3) | .823 ¥ |
| Multivessel (%) | 9 (75.0) | 31 (75.6) | .966 ¥ |
| Calcification Grade (0/I/II/III) | 0/0/5/7 | 2/7/21/11 | .173 £ |
| CTO (%) | 2 (16.7) | 9 (22.0) | .691 ¥ |
| Application of pre-dilatation (%) | 11 (91.7) | 39 (95.1) | 1.000 £ |
| Stent usage (%) | 7 (58.3) | 34 (82.9) | **0.007 ¥** |
| Application of post-dilatation (%) | 2 (16.7) | 25 (61.0) | **0.007 ¥** |
| Perforation time (1/2/3/4) | 2/5/2/3 | 13/6/10/12 | 0.279 £ |
| Inflation pressure | 12 (10-16) | 14 (10-22) | .045 ℧ |
| Guidewire tip stiffness (operator-reported) | 1 (1-4.5) | 1 (0.8-4.5) | .786 ℧ |
| Hydrophilic wire | 1 (8.3) | 8 (19.5) | .364 ¥ |
| Technique for the treatment of perforation (1/2/3/4/5) | 4/5/0/0/3 | 26/12/2/1/0 | **.017 £** |
| Pericardiocentesis (%) | 4 (33.3) | 4 (9.8) | **.044 ¥** |
| Prompt surgery (%) | 5 (41.7) | 0 (0.0) | **<.001 £** |
| Cardiogenic shock (%) | 9 (75.0) | 1 (2.4) | **<.001 ¥** |
| Hypotension (%) | 9 (75.0) | 13 (31.7) | **.007 ¥** |
| Cardiac tamponade (%) | 9 (75.0) | 1 (2.4) | **<.001 ¥** |
| Anticoagulant usage (%) | 2 (4.9) | 2 (40.0) | .576 £ |
| Anti-aggregant usage (%) | 8 (66.7) | 30 (73.2) | .660 £ |
| ELLIS Score (1/2/3) | 0/3/9 | 10/27/4 | **<.001 £** |
| TIMI flow grade (0/1/2/3) | 5/1/0/0 | 0/2/4/35 | **<.001 £** |

TIMI flow grade: 0 = no perfusion; 1 = penetration without perfusion; 2 = partial perfusion; 3 = normal perfusion. Guidewire tip stiffness was recorded based on operator assessment and manufacturer-reported characteristics.Technique for the treatment of perforation: (1) prolonged balloon inflation, (2) covered stent implantation, (3) coil or wire-induced embolization, (4) balloon embolization, and (5) emergency surgical repair.
Perforation time: (1) predilatation, (2) stent implantation, (3) wire-induced, (4) postdilatation with non-compliant balloon.
CAD, coronary artery disease; CTO, chronic total occlusion of coronary arteries; DM, diabetes mellitus; EF, ejection fraction (echocardiography); Ellis, Ellis classification of coronary artery perforation during angiography; HL, hyperlipidemia; HT, hypertension.
℧Mann–Whitney *U*-test [median (min.*max)].
¥$X^2$ test [number (percentage)].
£Fisher Exact test [number (percentage)].

are consistent with prior registry data and meta-analyses, reinforcing the clinical relevance of CAP despite its low incidence.[1,12] A clear association was observed between perforation severity, as defined by the Ellis classification, and adverse procedural and clinical outcomes. An increasing Ellis grade was associated with higher rates of procedural failure, hemodynamic instability, and mortality, underscoring the continued relevance of this classification for risk stratification and management guidance in patients with CAP.[1,7]

The most compelling observation derived from this cohort is the pronounced risk gradient across Ellis grades. Ellis grade III perforations were found to be correlated with significantly higher rates of cardiogenic shock, cardiac tamponade, pericardiocentesis, emergency surgical interventions, and procedural failure, culminating in an early mortality rate approaching 40%. These findings substantiate the foundational observations articulated by Ellis and colleagues.[1] They are consistent with subsequent large-scale analyses that reinforce the association between Ellis grade III perforation and adverse clinical outcomes.[2-3] In contrast to earlier registries that reported early mortality rates ranging from approximately 10% to 20% for Ellis grade III lesions, the higher mortality observed in the cohort is likely reflective of the modern PCI landscape. This landscape is characterized by more complex lesion subsets, an aging patient demographic, and a greater prevalence of comorbid conditions, which collectively contribute to the increased risk associated with these perforations.[3,6]

In this study, nearly all patients with Ellis grade III perforations exhibited profound hemodynamic instability, with hypotension and cardiac tamponade observed in the majority of cases. These rates significantly exceed those reported in various studies focusing on CTOs and registry data, where the frequency of cardiac tamponade typically ranges from 30% to 40%.[2-3,6] This observation implies that, within the context of contemporary clinical practice, Ellis grade III perforation may represent not solely a mechanical complication but also a surrogate marker for extreme procedural and physiological stress. Upon the occurrence of rapid contrast extravasation, the subsequent cascade of acute blood loss, elevated pericardial pressure, myocardial compression, and cardiogenic shock may become self-perpetuating, even when successful angiographic sealing of the vessel is technically accomplished.[2,6,12]

The present study elucidates significant distinctions in the mechanisms underlying CAP and corresponding therapeutic responses. In line with established management algorithms, balloon tamponade was generally effective in Ellis grade I and many grade II perforations.[7,12,15] In contrast, Ellis grade III lesions frequently required the implantation of a covered stent or surgical intervention.[11,13] Although covered stents were promptly deployed in most severe cases, procedural success remained limited, suggesting that mechanical vessel sealing alone may be insufficient once profound hemodynamic deterioration has developed.[10,16]

Distal, wire-related perforations exhibit a distinct clinical profile that warrants specific consideration in the management of CAP. In alignment with existing literature, these injuries—predominantly attributed to hydrophilic or stiff guidewires—demonstrate a favorable response to intervention techniques such as coil or wire-tip embolization. Furthermore, they are infrequently associated with severe complications, including cardiac tamponade, cardiogenic shock, or the necessity for surgical intervention.[5,9,14,17] These findings reinforce the importance of tailoring treatment strategies to both perforation location and mechanism, supporting algorithmic, mechanism-driven management approaches rather than a uniform therapeutic response for all CAP types.[15]

A significant contribution of this study is the precise distinction established between the determinants of early and late mortality related to CAP. Early mortality was predominantly influenced by acute hemodynamic compromise, specifically manifesting as cardiogenic shock, cardiac tamponade, and failure to achieve immediate hemostasis. Notably, cardiogenic shock was identified as the most significant predictor of mortality, corroborating findings from previous registry and observational studies.[2,6,12] These results underscore the premise that early survival following CAP is contingent mainly upon operator skill and procedural dynamics, necessitating swift recognition of complications, prompt and decisive intervention, and effective coordination within the catheterization laboratory team. Such insights are critical for refining clinical strategies and improving patient outcomes in the context of CAP.

In contrast, the patterns of late mortality observed between 1 and 12 months post-procedure exhibited a fundamentally distinct trajectory. Notably, neither the Ellis grade nor specific procedural characteristics demonstrated a significant association with late mortality outcomes. Instead, chronic renal insufficiency emerged as the predominant predictor of late mortality, underscoring the critical influence of systemic disease burden on long-term prognoses following PCI.[18-19] This temporal dissociation between immediate and delayed mortality outcomes supports the conceptualization of a bimodal risk model in the context of CAP. Specifically, the acute phase is characterized by risks that are predominantly driven by the severity of the procedure and the ensuing hemodynamic instability. In contrast, the chronic phase appears to be governed by patient vulnerability as well as the burden of comorbid conditions. Patients who survive the initial perforation event transition away from a risk profile that is directly influenced by the perforation incident, towards a broader cardiovascular risk continuum that is shaped predominantly by renal function and overall systemic health.

Procedural characteristics that correlate with successful intervention underscore the critical importance of technical optimization in PCI. Higher rates of stent implantation, appropriate post-dilation, and adequate inflation pressures were associated with improved procedural success. These results suggest that meticulous attention to vessel sealing and stent expansion might effectively mitigate persistent extravasation and prevent subsequent hemodynamic deterioration.[7] Conversely, unsuccessful interventions predominantly cluster within the category of Ellis grade III perforations, which are characterized by severe complications, poor TIMI flow, and an increased requirement for emergency surgical intervention.[10]

Collectively, these findings suggest that CAP should not be viewed merely as an unpredictable technical mishap; instead, it should be recognized as an operator-dependent complication whose outcomes are significantly influenced by procedural decision-making, the readiness of devices, and established pathways for the rapid escalation of care. While prevention remains paramount, the data emphasize that once perforation occurs, patient survival hinges on the operator's technical expertise within the catheterization laboratory, alongside a systematic and protocol-driven approach to managing hemodynamic compromise.[12,15]

Ultimately, this study offers a comprehensive and contemporary examination of CAP within the context of real-world PCI practice. It substantiates the premise that the severity of perforation serves as a pivotal element in the early risk stratification of affected patients. At the same time, the long-term prognosis is predominantly determined by the presence of systemic comorbidities, rather than the perforation event itself. Conceptualizing CAP as a 2-stage clinical syndrome—encompassing both acute and chronic phases—may facilitate the optimization of immediate management strategies and the development of structured post-discharge follow-up protocols. This approach aims to enhance clinical outcomes in patients experiencing this rare but clinically significant complication.

In the present study, no statistically significant association was observed between traditionally recognized high-risk lesion or device characteristics—such as CTOs, severe calcification, or hydrophilic guidewire use—and early mortality. At first glance, this finding may appear inconsistent with prior registry-based studies that have identified lesion complexity and device-related factors as important contributors to coronary perforation and adverse outcomes.[1-3] However, several considerations may help explain this observation. Contemporary PCI practice has evolved substantially, with improved operator experience, more meticulous procedural planning, and broader application of refined interventional techniques, particularly in high-volume centers. In addition, advances in device technology—including improvements in guidewire design, plaque-modifying systems, and covered stent performance—may attenuate the clinical impact of anatomical complexity once perforation occurs.[3,6] Furthermore, careful patient selection and procedural strategy in modern practice may limit the translation of lesion-related risk into early mortality. Finally, the relatively modest sample size of the cohort may have reduced the statistical power to detect smaller effect sizes. Therefore, the absence of statistical significance in the analysis should not be interpreted as the absence of clinical relevance, but rather as a reflection of evolving PCI practice and improvements in the contemporary management of coronary perforation. Taken together, these findings support the concept that, in contemporary PCI, outcomes following coronary perforation are influenced not only by lesion complexity but also by operator-dependent factors and advances in procedural management.[1,6]

## CONCLUSION

In this contemporary 2-center cohort, CAP remained a rare but clinically serious complication of PCI. Perforation severity, as defined by the Ellis classification, was the primary determinant of procedural failure, hemodynamic instability, and early mortality. Ellis grade III perforations represented a true interventional emergency, frequently leading to tamponade, cardiogenic shock, and the need for surgical intervention despite prompt percutaneous management.

Importantly, this study demonstrates a temporal dissociation in prognostic determinants following CAP. While procedural factors and acute hemodynamic stabilization primarily influenced early survival, late mortality was driven predominantly by systemic comorbidities, particularly chronic renal insufficiency. These findings underscore the importance of both optimized intraprocedural management and comprehensive post-discharge care in enhancing outcomes for patients with CAP.

Collectively, these real-world data underscore the imperative of enhancing outcomes following coronary perforation through excellence in 2 interrelated domains: executing decisive and technically optimized interventions in the acute phase and implementing meticulous, longitudinal management strategies for high-risk patients during the chronic phase.

### Strengths and Limitations

#### *Strengths*

This study represents one of the most enormous real-world, 2-center datasets on CAP in the region, offering a detailed and contemporary profile of this life-threatening complication.

There is a granular analysis of early versus late mortality: unlike most prior studies, the cohort clearly differentiates between acute, perforation-driven mortality and late, comorbidity-driven mortality, providing a more nuanced understanding of patient risk trajectories.

The study provides detailed therapeutic stratification, offering precise comparisons of outcomes based on management strategies, including balloon tamponade, covered stenting, coil/guidewire embolization, balloon embolization, and surgical intervention. These findings deliver insights directly applicable to clinical practice.

A comprehensive hemodynamic assessment is included, which involves the systematic evaluation of conditions such as shock, tamponade, hypotension, and TIMI flow, yielding a multidimensional perspective on clinical instability.

The comparison of Ellis subgroups facilitates a precise characterization of perforation severity, its clinical consequences, and procedural responses, enhancing the understanding of CAP management.

#### *Limitations*

Retrospective design: While reflective of real-world practice, the retrospective methodology introduces inherent limitations related to data completeness and potential selection bias, which may affect the findings.

Absence of a uniform imaging strategy: The lack of standardized use of intravascular ultrasound or optical coherence tomography restricts the ability to evaluate lesion morphology as a predictor of perforation risk or outcomes.

Detailed procedural device selection: Specific details regarding device choices, such as the types of atherectomy systems or IVL used, were not uniformly recorded, limiting the ability to interpret the mechanistic aspects of these interventions.

Limited long-term follow-up: The absence of follow-up data beyond 1 year prevents a comprehensive assessment of very late outcomes, which could provide valuable insights into the long-term effects of CAP management.

### Clinical Implications

Coronary artery perforation is a rare but life-threatening complication of PCI, especially concerning Ellis grade III lesions.

Rapid recognition and immediate hemostasis are crucial for improving early survival rates; therefore, catheterization laboratories performing complex PCI should have easy access to covered stents and embolization tools.

Treatment strategies should be tailored to the mechanism and location of the perforation, with embolization techniques preferred for distal wire-related injuries.

Early mortality primarily results from hemodynamic collapse, while late mortality is more closely related to systemic comorbidities, notably renal dysfunction.

Survivors of acute perforation require structured post-discharge follow-up that emphasizes optimizing comorbidities rather than focusing solely on perforation-specific issues.

**Ethics Committee Approval:** This study was approved by the Sakarya University Faculty of Medicine Scientific Research Ethics Committee (decision date: June 17, 2025, decision number: E-43012747-050.04-481619/351). It was conducted in accordance with the principles of the Declaration of Helsinki.

**Informed Consent:** Verbal informed consent was obtained from the patients who agreed to take part in the study.

**Peer-review:** Externally peer-reviewed.

**Artificial Intelligence:** The authors declare that artificial intelligence—assisted technologies (such as large language models) were used only for language editing and grammar improvement. The authors take full responsibility for the scientific content, data interpretation, and conclusions of the manuscript.

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