Contemporary Trends, Predictors and Outcomes of Perforation During Percutaneous Coronary Intervention (From the NCDR Cath PCI Registry)

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Coronary artery perforation (CP) is a rare but potentially life-threatening complication of percutaneous coronary intervention (PCI). Given the marked increase in high-risk and complex PCIs, careful review and understanding of PCI complications may help to improve procedural and clinical outcomes. Our aim was to study the trends, predictors and outcomes of CP in the contemporary era. This cross-sectional multicenter analysis included data collected from institutions participating in the National Cardiovascular Data Registry CathPCI Registry between July 2009 and June 2015. Multivariable logistic regression models were created to identify predictors of CP and compare the in-hospital outcomes of CP and non-CP patients. Of 3,759,268 PCIs performed during the study period, there were 13,779 CP (0.37%). During the study period, the proportion of PCI that developed CP remained unchanged (0.33% to 0.4%) (p for trend 0.16). Chronic total occlusion (CTO) PCI as percentage of total PCI volume increased over the study period (3% to 4%) (p for trend <0.001) with a concomitant significant increase in CTOs with perforation (1.2% to 1.5%, p for trend = 0.02). CTO PCI (Odds Ratio [OR] 2.59) female gender (OR 1.38), saphenous vein graft PCI (OR 1.2), ACC Type C lesion (1.48), cardiogenic shock on presentation (1.15), and use of atherectomy (laser/ rotational) (OR 2.38) were significant predictors of CP. CP patients had significantly higher rates of cardiogenic shock (7.73% vs 1.02%), tamponade (9.6% vs 0.05%) and death (4.87% vs 1.14%) compared with those without CP. Strongest predictors of any adverse events amongst CP were cardiogenic shock (OR 3.93), cardiac arrest (OR 2.02) and use of atherectomy device (OR 2.5). Use of covered stents was also strongly associated with adverse events (OR 3.67) reflecting severity of these CPs. CP in CTO PCI had higher rates of any adverse event than non-CTO CP (26.8% vs 22%, p < 0.001). However non-CTO CP had higher rates of coronary artery bypass grafting (CABG) (urgent, emergent, or salvage) (5.8% vs 4.5%, p = 0.03) and death (6.9% vs 5.6%, p = 0.04). CP in CABG PCI had fewer adverse events compared with those without previous CABG (16.1% vs 24.7%). In a large real world experience, we identified several clinical and procedural factors associated with increased risk of CP and adverse outcomes. The trends in CP remained constant over the study period. **(Am J Cardiol 2020;130:37−45)**

Coronary artery perforation (CP) is a rare but potentially catastrophic complication of percutaneous coronary intervention (PCI).[1] The reported incidence from previously published studies is <1%.[2−8] In part due to its rarity, CP remains understudied with a resultant incomplete understanding of its incidence, etiology, therapy, and outcomes. In particular, previous studies were underpowered to identify predictors of CP in high-risk subgroups of patients who underwent PCI.[2−7] Given the marked increase in high-risk and complex PCIs, careful review and understanding of PCI complications may help to improve procedural and clinical outcomes. Using the National Cardiovascular Data Registry (NCDR) database, we sought to identify trends, predictors and outcomes of patients with CP in the United States in the contemporary era using the NCDR CathPCI registry, the largest PCI registry in the world. Our specific aims were to 1) examine predictors and in-hospital adverse events of CP compared with those without CP, 2) examine the association of different anticoagulation strategies during PCI and the risk of CP and in-hospital adverse events, and 3) compare the incidence and outcomes of CP in patients who underwent complex PCI including chronic total occlusion (CTO) PCI, saphenous vein graft (SVG) PCI, PCI in previous coronary artery bypass graft

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No financial or other disclosures for any of the authors relevant to this publication.

See page 45 for disclosure information.

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0002-9149/
https://doi.org/10.1016/j.amjcard.2020.06.014

coronary artery bypass grafting (CABG) patients, and those who received a covered stent with the reference PCI population. To our knowledge, these aims have either not been evaluated in previously published reports or evaluated in small patient populations precluding meaningful conclusions.

Methods

The NCDR CathPCI Registry includes more than 1000 US hospitals using a standardized dataset collection method. A data quality program monitors and oversees the data collection process. For this study, we examined the NCDR CathPCI registry for all patients who underwent PCI between July 2009 and June 2015. Details on data collection and variable definitions have been previously published.[9,10] Patients who had multiple PCIs within the same visit were excluded (2.68% of patients).

Adverse in-hospital outcomes as recorded in the NCDR dataset were as follows: cardiogenic shock, cerebrovascular accident, cardiac tamponade, major bleeding, CABG (urgent, emergent, or salvage), CABG due to PCI complication, and death. Major bleeding was defined as bleeding requiring blood transfusion, retroperitoneal bleeding, and hematoma larger than 10 cm. A composite of any adverse event was also reported.

Continuous variables are presented as mean ± standard deviation (SD) for normally distributed variables or median and interquartile range otherwise. Categorical variables are reported as frequency and percentages. Baseline clinical characteristics, PCI procedural findings, and in-hospital outcomes were compared between patients with and without CP. Secondary analyses were performed to examine the predictors and outcomes of CP stratified based on the following variables: anticoagulants (heparin, bivalirudin) / antithrombotic use (glycoprotein IIb/IIIa inhibitors), SVG PCI, CTO PCI, previous CABG and use of covered stents. Comparisons between groups were performed using Pearson chi-square tests for all categorical variables and *t* tests or Wilcoxon tests for all continuous variables.

Two multivariable logistic regression analyses were performed. First, a model was built to identify the magnitude and significance of different variables associated with CP and a second model examined the association of different variables with adverse outcomes in those with CP. Correlation within facility was not accounted for in these models because within facilities estimates of rho were near 0 (0.002 for perforation and 0.03 for adverse events). To determine significant predictors in each of the models, all candidate variables were first entered into the model. Variables were then iteratively removed based on the significance of their relations with the outcome using Likelihood Ratio tests. At each step, the variable with the highest p-value was removed, and the effect of its removal on the other variables was evaluated. Any variables exhibiting significant confounding (defined as a >20% change in model estimate) on other variables retained in the model were flagged for further evaluation at the end of the model selection. After all variables without a significant relations with the outcome were iteratively removed, the preliminary model was reevaluated by adding in variables that were previously decreased or indicated for confounding. Any variables still exhibiting confounding or significant when reentered in the model were retained for the final model. Continuous variables were assessed for nonlinear relations and accounted for using polynomial terms when present. Odds ratio with 95% confidence intervals are presented for final models. For continuous variables with nonlinear relations, odds ratios (OR) are provided for important comparisons to demonstrate how the nonlinearity impacts the association between the variable and outcome. Missing

Table 1
Characteristics of patients with and without coronary perforation

Variable	Total		Perforation				p
			Yes		No		
Total − n	3,759,268		13,779		3,745,489		
Age (years)	64.89		67.54		64.88		<.0001
Women	1,203,805	32%	5,297	38%	1,198,508	32%	<.0001
White	3,277,548	87%	12,218	88%	3,265,330	87%	<.0001
Black	313,926	8.3%	880	6.3%	313,046	8.3%	<.0001
Current Smoker	1,020,570	27%	3,455	25%	1,017,115	27%	<.0001
Hypertension	3,095,882	82%	11,548	84%	3,084,334	82%	<.0001
Previous myocardial infarction	1,137,567	30%	4,478	32%	1,133,089	30%	<.0001
Previous Percutaneous coronary intervention	1,540,582	41%	5,729	41%	1,534,853	41%	0.1509
Previous coronary artery bypass graft surgery	685,480	18%	2,955	21%	682,525	18%	<.0001
Diabetes	1,407,883	37%	4,894	35%	1,402,989	37%	<.0001
Presentation							<.0001
Asymptomatic	243,163	6%	992	7%	242,171	6%	
Unlikely iIschemic	90,351	2.4%	305	2.2%	90,046	2.4%	
Stable angina pectoris	569,557	15%	2,250	16%	567,307	15%	
Unstable angina pectoris	1,460,148	39%	5,244	38%	1,454,904	39%	
Non-ST elevation myocardial infarction	777,505	21%	2,721	19%	774,784	20%	
ST elevation myocardial infarction	617,660	16%	2,264	16%	615,396	16%	
Cardiomyopathy or Left ventricular systolic dysfunction	411,426	11%	1,746	12%	409,680	11%	<.0001
Cardiogenic shock	78,622	2%	445	3%	78,177	2%	<.0001
Cardiac arrest	78,838	2%	386	2.8%	78,452	2.1%	<.0001

data was rare with the majority of variables missing < 1% of the time and the maximum deficiencies occurring 2% of the time. All missing variables were single imputed before model selection. Binary variables, such as history of heart failure, were considered to not occur if missing. Categorical and continuous variables were imputed using conditional specification.[11]

All tests were 2-sided, and $p < 0.05$ was considered statistically significant. All analyses were performed using SAS software (version 9.4, SAS Institute, Cary, North Carolina) by the ACC Analytic Center at Yale University, New Haven, CT. The authors had full access to the data and take responsibility for its integrity. All authors have read and agree to the report as written.

Results

3,968,168 PCI procedures performed between July 2009 and June 2015 were identified. After exclusion of patients with multiple PCI during the same visit (2.68%), the final cohort comprised 3,759,268 PCI visits in 1,594 hospitals across the United States. 13,779 patients had CP (0.37%). Clinical characteristics of patients with and without CP are summarized in Table 1. CP patients were more likely to be older, female, white, hypertensive, have had previous MI, previous CABG, and LV systolic dysfunction. Compared with non-CP, patients with CP were less likely to be smokers, have diabetes and have a lower BMI.

Patients with CP were more likely to have a higher contrast volume and longer fluoroscopy time compared with those without CP. Overall, femoral access was the predominant access used (84%). Unfractionated heparin was used in 54% of PCI and bivalirudin used in 58%. A proportion of patients received heparin bolus before bivalirudin, which explains the overlap. CP patients were more likely to be on unfractionated heparin (57% vs 54%), whereas bivalirudin was more commonly used in patients without CP (58% vs 53%). Patients with CP were more likely to have had PCI for complex lesions including type C, bifurcation, SVG, and CTO lesions (Table 2).

To study trends, we analyzed 914 hospitals enrolled in the NCDR throughout the entirety of our study period. This encompassed 3,152,176 PCIs, or 84% of our sample. PCI volume at these hospitals decreased from approximately 574,000 in 2010 to approximately 501,203 in 2014. The proportion of PCI that developed CP remained unchanged over the study period (0.33% to 0.4%) (p for trend 0.16). CTO PCI as percentage of total PCI volume increased over the study period (3% to 4%) (p for trend <0.001) with a concomitant significant increase in CTOs with perforation (1.2% to 1.5%, p for trend = 0.02) (Supplementary Table & Figure 1).

Multivariable clinical and procedural predictors of coronary perforation are shown in Figure 2. The highest odds of CP was with CTO PCI (OR 2.59; 95% CI 2.39, 2.80), laser atherectomy (OR 2.56; 95% CI 2.0, 3.27) and rotational atherectomy use (OR 2.38; 95% CI 2.16, 2.63). Degree of stenosis before treatment and lesion length showed significant nonlinear associations with the probability of CP (Figures 3 and 4). Multiple odds ratios are provided to demonstrate how the association with perforation changes depending on the values of stenosis before treatment or lesion length.

CP patients were more likely to experience cardiogenic shock (8.8% vs 1.1%), tamponade (10% vs 0.05 %), major bleeding (11% vs 2.4%), CABG (either urgent, emergent, or salvage) (5.7% vs 1%) and death (6.8% vs 1.5%). Total adverse event rate was higher with CP (3,153, 22.9%) compared with no CP (185,070, 4.9%). In an adjusted model accounting for age, gender, race, diabetes status and left ventricular systolic dysfunction, CP remained significantly associated with all individual and composite adverse in-hospital events (p <0.001 for all comparisons between CP vs no CP). (Table 3)

Using a multivariable model, we found that age, female gender; lower BMI, ACS, highly complex lesion (type C), bifurcation lesion and CTO PCI to be associated with increased odds of adverse events in CP patients. The strongest associations with any adverse event included cardiogenic shock (OR 3.9, 95% CI 3.05, 5.07), cardiac arrest (OR 2.02, 95% CI 1.54, 2.65), use of atherectomy device (OR 2.5, 95% 2.02, 3.09) or covered stent (OR 3.67, 95% CI 3.18, 4.23). It is likely that cardiogenic shock, cardiac arrest, and covered stent use are secondary to the severity of CP whereas atherectomy contributed to increased incidence of CP. African-American race (OR 0.75, 95% CI 0.61, 0.92), previous PCI (OR 0.88, 95% CI 0.81, 0.97), previous CABG (OR 0.5, 95% CI 0.44, 0.57), radial access (OR 0.7, 95% CI 0.61, 0.8), and bivalirudin use without GPI (OR 0.75, 95% CI 0.66, 0.85) appeared to be associated with lower odds of adverse events (Figure 5).

Bivalirudin was the most commonly used anticoagulant during PCI in patients with CP (48.6%), followed by heparin (29%), heparin and GPI (16%) and the least utilized was bivalirudin and GPI (6%). Bivalirudin alone was more commonly used in females, less complex and short lesions compared with other anticoagulants in CP. Patients with CP who received heparin alone were more likely hypertensive, had a history of previous MI, previous PCI, and previous CABG compared with other anticoagulants. In 1,696 CTO perforations, heparin alone was most commonly used anticoagulant (1,032 CP cases) followed by bivalirudin (450 CP cases). Characteristics of CP patients according to anticoagulant used during PCI detailed in Supplementary Table 2.

In CP patients, bivalirudin without GPI was associated with unadjusted lower risk of cardiogenic shock (7.16% vs 9.38% vs 11.72%), tamponade (7.94% vs 11.91% vs 13.47%), and major bleeding (8.67% vs 11.63% vs 14.62%) compared with heparin alone and heparin with GPI. Bivalirudin was also associated with the lowest incidence of unadjusted any adverse event (19%) in CP patients compared with any other anticoagulant (heparin alone 24.6%, heparin with GPI 29.1%, bivalirudin with GPI 28.1%). There were no differences in CABG (urgent, emergent, or salvage) and CABG due to PCI complication among all anticoagulants. (Supplemental Table 3).

Given significant baseline and procedural differences among the different anticoagulant subgroups, a fully adjusted model to study the association of different anticoagulation regimens with adverse outcomes in CP patients was created. Use of bivalirudin alone remained associated

Table 2
Procedural details for coronary perforation versus no perforation

Variable	Total		Perforation				p
			Yes		No		
Diagnostic cath	3,305,314	88%	11,705	84%	3,293,609	88%	<.0001
FluroTime - median (IQR)	11.70	11	18.60	20.10	11.70	11	<.0001
Contrast volume - median (IQR)	180.00	105	210.00	140.00	180	105	<.0001
IABP	89,999	2.4%	981	7%	89,018	2.3%	<.0001
Other mechanical ventricular support	21,257	0.6%	288	2%	20,969	0.5%	<.0001
Access site							<.0001
Femoral	3,144,687	84%	11,746	85%	3,132,941	84%	
Radial	599,836	16%	1,948	14%	597,888	16%	
PCI indication							<.0001
Immediate PCI for ST	551,274	14%	2,005	14%	549,269	14%	
PCI for STEMI (unstable, >12 hrs from Sx onset)	34,589	0.9%	176	1.3%	34,413	0.9%	
PCI for STEMI (stable, >12 hrs from Sx onset)	15,331	0.4%	71	0.5%	15,260	0.4%	
PCI for STEMI (stable after successful full-dose thrombolysis)	13,347	0.4%	27	0.2%	13,320	0.4%	
Rescue PCI for STEMI (after failed full-dose lytics)	18,384	0.5%	53	0.4%	18,331	0.5%	
PCI for high risk non-STEMI or unstable angina	1,934,625	51%	6,789	49%	1,927,836	51%	
Staged PCI	215,684	5.7%	1,044	7.58	214,640	5.7%	
Other	974,902	25%	3,612	26%	971,290	26%	
Low molecular weight heparin	354,136	9.4%	1,172	8.5%	352,964	9.4%	0.0003
Unfractionated heparin	2,044,284	54%	7,945	57%	2,036,339	54%	<.0001
Aspirin	3,310,664	88%	11,753	85%	3,298,911	88%	<.0001
Bivalirudin	2,178,801	58%	7,323	53%	2,171,478	58%	<.0001
Glycoprotein IIb/IIIa	876,313	23%	3,081	22%	873,232	23%	0.009
Clopidogrel	2,556,685	68%	8,835	64%	2,547,850	68%	<.0001
Prasugrel	545,891	15%	1,362	10%	544,529	15%	<.0001
Ticagrelor	260,915	11%	780	8.9%	260,135	11%	<.0001
Culprit lesion	2,425,522	64%	8,405	61%	2,417,117	64%	<.0001
Stenosis Previous to Rx - mean (SD)	89.57	10	91.77	10.56	89.56	10.62	<.0001
Previously treated lesion	418,904	11%	1,503	10%	417,401	11%	0.366
Lesion in graft							<.0001
Not in graft	3,518,766	93%	12,664	92%	3,506,102	94%	
Vein	219,682	5.8%	1,011	7.3%	218,671	5.8%	
LIMA graft	12,103	0.3%	59	0.4%	12,044	0.3%	
Other artery	6,060	0.1%	40	0.3%	6,020	0.1%	
Lesion complexity							<.0001
Nonhigh/non-C lesion	1,655,715	44%	4,148	30%	1,651,567	44%	
High/C lesion	2,095,395	56%	9,564	69%	2,085,831	55%	
Lesion length - mean (SD)	19.99	11%	23.25	16%	19.97	11%	
Bifurcation lesion	430,652	11%	1,895	14%	428,757	11%	<.0001
Guidewire across lesion	3,690,260	98%	12,983	94%	3,677,277	98%	<.0001
Stenosis post procedure - mean (SD)	3.20	14%	14.47	32%	3.16	13%	<.0001
CTO*	130,175	3.4%	1,746	12%	128,429	3.4%	<.0001
Any SVG†	194,666	5.1%	935	6.8%	193,731	5.1%	<.0001

CTO = chronic total occlusion; IABP = intra aortic balloon pump; IQR = inter quartile range; LIMA = left internal mammary artery; PCI = percutaneous coronary intervention; STEMI = ST elevation myocardial infarction; SD = standard deviation.

with significantly lower adjusted rate of any adverse event compared with both heparin alone (15% vs 19%; p <0.001) and heparin with GPI (15% vs 20.3%) in CP patients (Table 4). In the fully adjusted multivariable model, the odds of CP in patients treated with bivalirudin was lower than that of patients treated with heparin alone (OR 0.89; 95% CI 0.84, 0.95; p = 0.0005) (Figure 2).

1,746 CP during CTO PCI were identified. CTO CP had higher rates of tamponade (14% vs 9.5%, p < 0.001), major bleeding (12% vs 10%, p = 0.02) and any adverse event (26.8% vs 22%, p <0.001) than non-CTO CP. No difference in rates of cardiogenic shock were observed (9.2% vs 8.7%, p = 0.44). However non-CTO CP had higher rates of CABG (urgent, emergent, or salvage) (5.8% vs 4.5%, p = 0.03), CABG due to PCI complication (4.3% vs 2.9%, p = 0.004) and death (6.9% vs 5.6%, p = 0.04). (Supplementary table 4)

SVG CP was associated with fewer adverse events compared with non-SVG CP (18.5% vs 23.2%, p = 0.001) including tamponade (5.4% vs 10.5%, p <0.001), major bleeding (8.5% vs 10.8%, p = 0.02), CABG (urgent, emergent, or salvage) (2% vs 5.9%, p <0.001), CABG due to PCI complication (1.6% vs 4.3%, p <0.001) and any adverse event (18.5% vs 23%, p = 0.001) compared with non-SVG CP. No difference in cardiogenic shock (7.8% vs 8.8%, p = 0.26) or death was observed between SVG CP and non-SVG CP (6.7% vs 6.8%, p = 0.9). (Supplementary table 5)

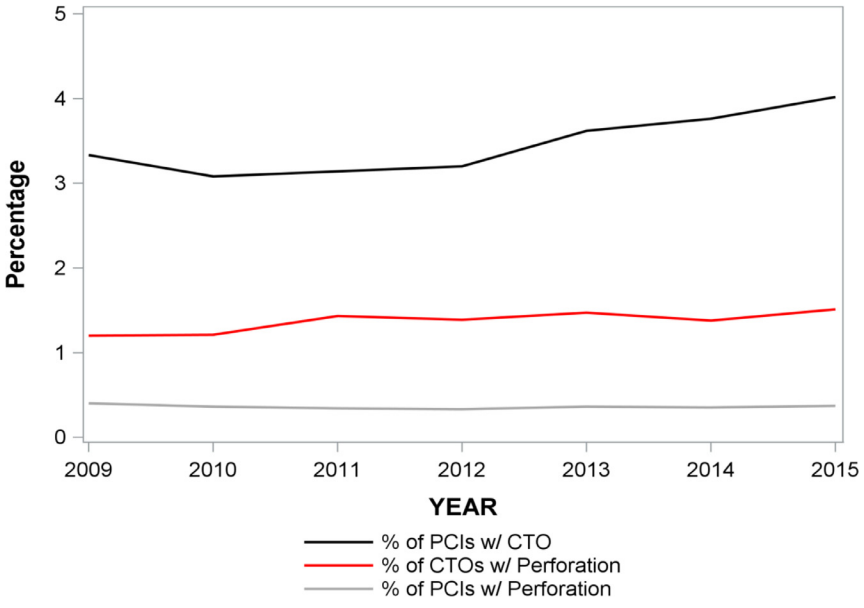

Figure 1. Trends in PCI with CTO, PCI with perforation and CTO with perforation.

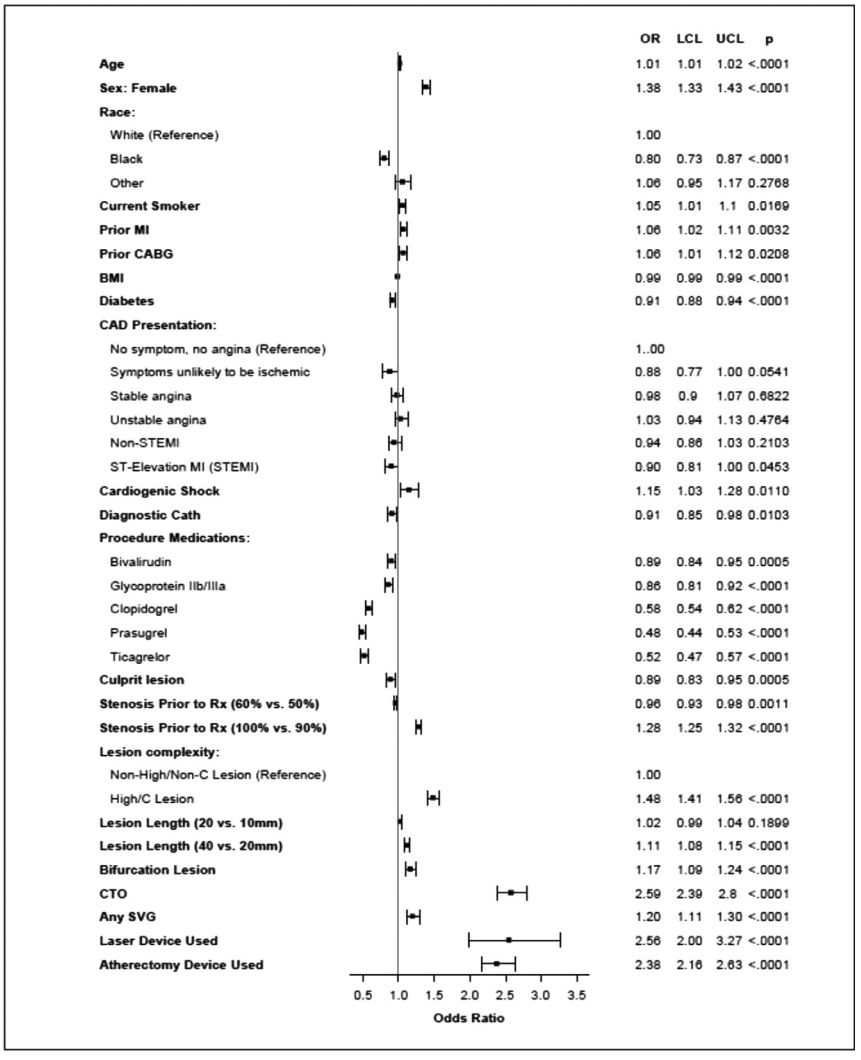

Figure 2. Forest plot of multivariable predictors of coronary perforation.

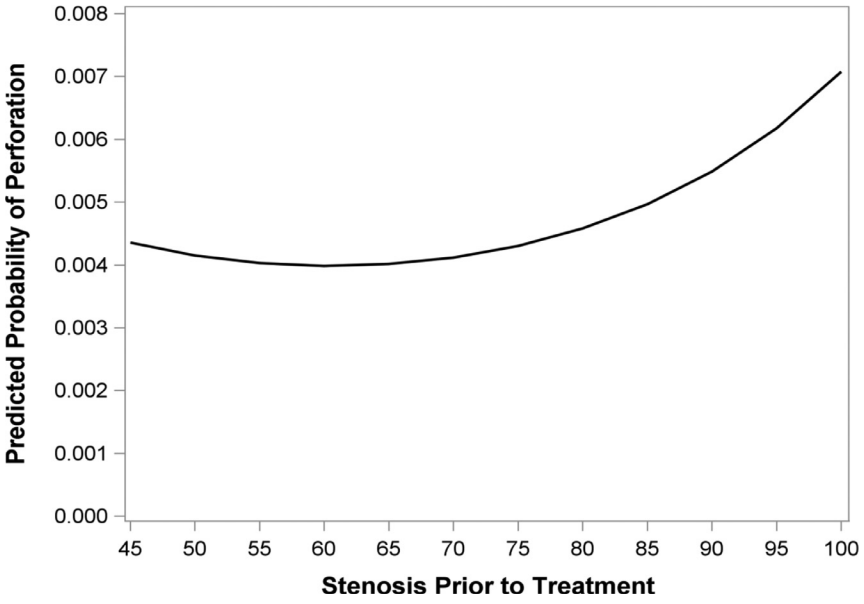

Figure 3. Relation of stenosis prior to treatment with predicted probability of perforation.

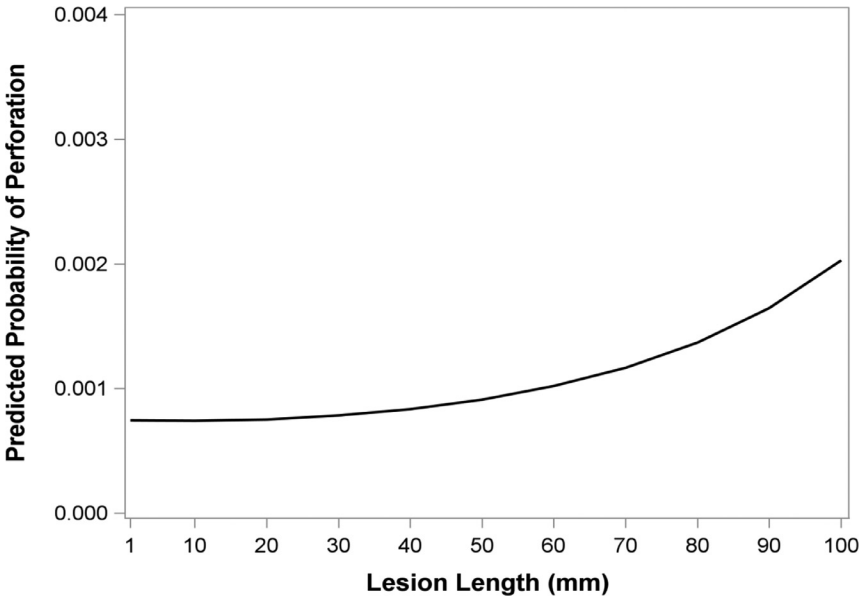

Figure 4. Relation of lesion length with predicted probability of perforation.

Similarly, patients with previous CABG who had CP had fewer adverse events compared with those without previous CABG (16.1% vs 24.7%) including lower rates of cardiogenic shock (6.9% vs 9.3%), tamponade (4.6% vs 11.6%), major bleeding (8.4% vs 11%), CABG (urgent, emergent, or salvage) (1.9% vs 6.7%), CABG due to PCI complication (1.4% vs 4.9%) and death (5.5% vs 7%) compared with non-CABG CP. (Supplementary table 6)

In the CP cohort, 1,303 patients received covered stent (9.45% incidence rate). CP who received covered stent had significantly higher rates of cardiogenic shock (23.6% vs 7.25%, p <0.001), tamponade (27.6% vs 8.3%, p <0.001), major bleeding (23.6% vs 9.3%, p <0.001), death (17.3% vs 5.7%, p <0.001) and any adverse event (47.2% vs 20.4%, p <0.001) compared with CP with no covered stent. This observation likely reflects the larger and more severe perforations that require covered stent use. No significant difference in rates of CABG (urgent, emergent, salvage) (5.37% vs 5.74%, p = 0.58) and CABG due to PCI complication (4.83% vs 4.13%, p = 0.22) were observed between CP with covered stent versus CP with no covered stent. (Supplementary table 7)

Discussion

In this largest report to date of a contemporaneous cohort of about 3.8 million patients who underwent PCI, the incidence of CP was 0.37% and did not change over time. Most

Table 3
In-hospital outcomes with coronary perforation versus no perforation

Outcome	Total		Perforation		No Perforation		Adjusted		p
							Perforation	No perforation	
Cardiogenic shock	43,141	1.1%	1,212	8.80%	41,929	1.12%	7.73%	1.02%	<.0001
CVA	9,275	0.25%	76	0.55%	9,199	0.25%	0.35%	0.17%	<.0001
Tamponade	3,360	0.09%	1,400	10.16%	1,960	0.05%	9.6%	0.05%	<.0001
Major bleed (blood transfusion, retroperitoneal bleed, hematoma > 10cm)	91,673	2.46%	1,472	10.68%	90,201	2.43%	5.9%	1.36%	<.0001
CABG (urgent, emergent, salvage)	37,841	1.01%	786	5.71%	37,055	0.99%	7.7%	1.22%	<.0001
CABG due to PCI Complication	5,023	0.13%	578	4.2%	4,445	0.12%	4.8%	0.13%	<.0001
Death	58,013	1.54%	939	6.81%	57,074	1.52%	4.8%	1.14%	<.0001

CVA = cerebrovascular accident; CABG = coronary artery bypass graft; PCI = percutaneous coronary intervention.
*adjusted for age, gender, diabetes, previous CABG, LVSD
†Rates are estimated for a mean aged male without diabetes, previous CABG, or LVSD

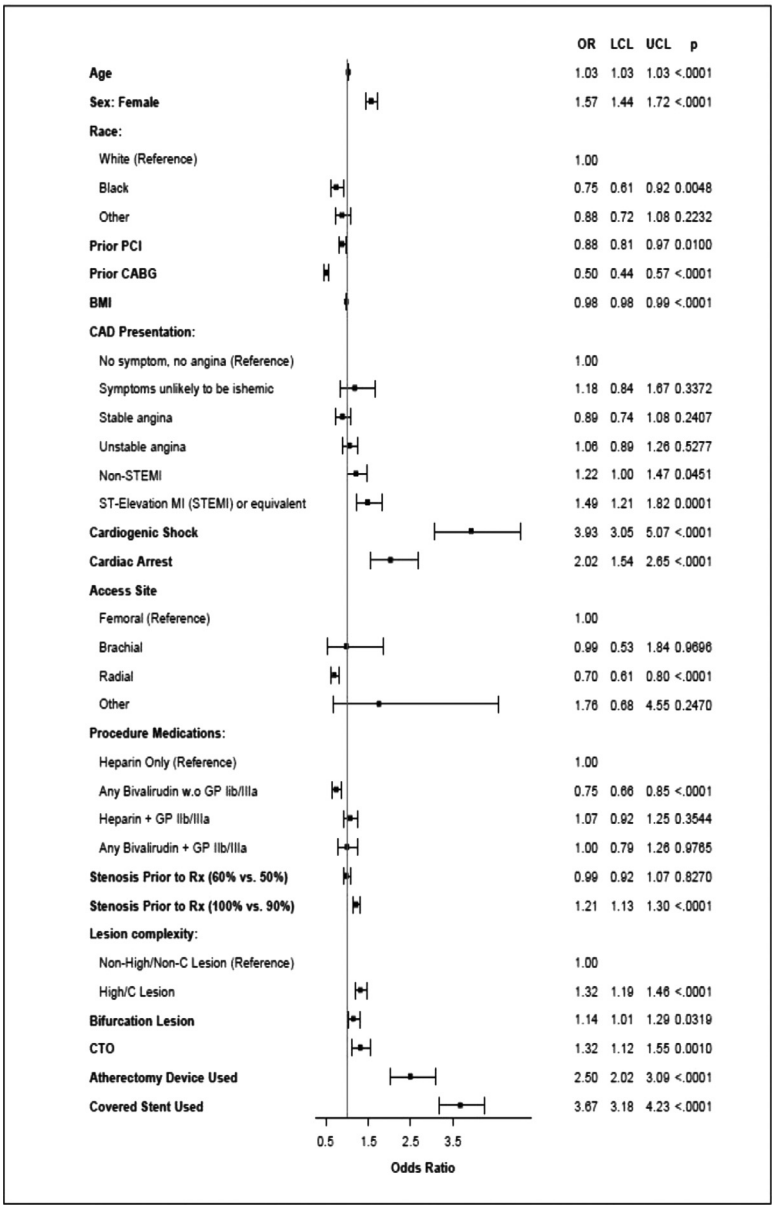

Figure 5. Forest plot of multivariable predictors of any adverse event with perforation.

Table 4
Adjusted rates of any adverse event in perforation patients

	Adjusted Rate*	test	p-values
Reference population	15.07		
Previous CABG	8.14	Yes v No	<.0001
CTO	18.94	Yes v No	0.0010
Covered Stent	39.41	Yes v No	<.0001
Heparin Only[1]	19.19	1 v 2	<.0001
Any Bivalirudin w.o GP Iib/IIIa[2]	15.07	2 v 3	<.0001
Heparin + GP IIb/IIIa[3]	20.30	3 v 4	0.5285
Any Bivalirudin + GP IIb/IIIa[4]	19.13		

CABG = coronary artery bypass graft; CTO = chronic total occlusion
* Adjusted rates are calculated as the probability of an adverse event if a patient from the reference population had the characteristic of interest for example if the reference has previous CABG their predicted risk of any AE would decrease from 15% to 8.1%.

cases did not require a covered stent (used in 9.4% of CP patients). Several clinical and procedural factors were associated with CP in both unadjusted and adjusted analyses. Patients with CP had a significantly higher rate of total in-hospital adverse events compared with those without CP including in-hospital death. An unexpected, hypothesis-generating observation was that the type of anticoagulation was related to in-hospital outcomes.

The incidence of CP of approximately 1.5% in the CTO patients, albeit significantly higher than in the non-CTO group, is lower than the 2.9% incidence rate reported previously in a large meta-analysis of 18,061 patients.[12] The reasons for the difference are not clear. This study also suggested that despite the increased risk of CP associated with CTO PCI, patient outcomes of CP might be similar in CTO and non-CTO PCI. CTO CP did have higher rates of tamponade, major bleeding and any adverse events; in contrast, non-CTO CP had higher rates of CABG (urgent, emergent, or salvage), CABG due to PCI complication and most importantly death.

This study confirms the notion that SVG CP produces fewer adverse outcomes, presumably due to an adherent pericardium from the previous bypass surgery. SVG CP was associated with lower risk of tamponade, major bleeding and any adverse event compared with non-SVG CP. No difference in cardiogenic shock and death observed between SVG CP and non-SVG CP. Similarly, patients with previous CABG who had CP had lower rates of tamponade, major bleeding, CABG due to PCI complication and death compared with non-CABG CP. CP in SVG should still be treated aggressively as it is not a benign complication, with serious consequences as highlighted in our results. In addition, there are multiple case reports of a loculated tamponade from CP, particularly in the posterior wall, associated with catastrophic outcomes, including death.[13]

An interesting and unexpected observation was the differential rate of adverse events amongst CP patients relative to the anticoagulation regimen. Our analysis associated bivalirudin with fewer CP and fewer adverse outcomes from CP compared with heparin, heparin plus GPI, or bivalirudin plus GPI. Previously, only 1 small study has examined the role of anticoagulation and outcomes in CP patients.[14] In 31 patients with CP who received either bivalirudin or unfractionated heparin in combination with GPI, the authors observed no difference in the composite of death, myocardial infarction or target vessel revascularization between either groups.[14] Despite the statistical adjustment for baseline and procedural differences amongst patients receiving various anticoagulants, it is important to note that patients who received heparin were more likely to be hypertensive, had previous MI and importantly had more complex lesions including CTO PCI (26.3% vs 6.9%) compared with patients who received bivalirudin. It is quite possible that use of heparin simply identifies the higher-risk PCI population, as it can be reversed with protamine and may have been favored by interventionists for that reason. The association of bivalirudin in patients with CP with lower odds for any adverse events in both non-CTO and in the high-risk CTO PCI is hypothesis generating and requires further study to verify this association.

Slightly less than 10% of CP patients (9.4%) received a covered stent. This group had the worst outcomes. It is likely that the use of covered stents is a surrogate for the worst (Ellis type 3) CP. The rate of cardiogenic shock was 23.6% similar to the 28.6% in the largest previous case series of Ellis class III CP.[6] They reported an in-hospital death rate of 17.9% similar to our analysis (in-hospital death rate 17.3%). Although the NCDR registry does not contain data regarding other treatment measures taken to treat CP, it would be fair to assume that covered stents were used in the extreme cases of large perforations that caused hemodynamic compromise. Despite the higher rate of death and complications in CP patients who received covered stents, the use of these salvage devices may have resulted in some benefit as evidenced by equal rates of CABG (urgent, emergent, or salvage) (5.37% vs 5.74%) and CABG due to PCI complication (4.83% vs 4.13%) in CP with vs without covered stents. In the largest report of covered stent usage for CP, Kawamoto and colleagues identified 57 CP patients who received covered stents. MACE rates were 16% at 6 months, 22% at 1 year and 38% at 3 years and all-cause mortality was 6% at 6 months, 11% at 2 years and 17% at 3 years. Most of the late events were target vessel revascularization.[15]

There are several limitations of this study. Despite the large sample size and the rigor and auditing of this carefully managed database, there is a lack of an independent core lab to review and validate CP coding as well as classify the perforation severity. Data collected does not include the cause of CP (wire, balloon, etc.) and does not mention types of treatment including prolonged balloon inflation, distal embolization, coiling, or other measures that can be undertaken to treat CP. Importantly, the data are limited to in-hospital outcomes. The NCDR dataset is an all-comer database and is not specifically designed to capture data of high risk PCIs and so may not be the best representative data of CTO PCI outcomes.

In conclusion, in the largest, contemporary coronary perforation report to date, several important clinical and procedural factors related to the risk of CP and adverse events were identified. CP was associated with a significantly higher risk of adverse events including in-hospital death. CP in patients with SVG PCI and previous CABG were associated with low adverse events compared with the reference group, although still had significant rates of adverse events associated with CP.

CRediT Author Statement

Ramez Nairooz _ conceptualization, writing draft/editing. Craig Parzynski- Data collection, statistical analysis; manuscript review and edits. Ed MCnulty, Jeptha Curtis, Amr Mohsen & Barry Uretsky- reviewing and editing. Abdul Hakeem- conceptualization, writing draft/editing, data analysis

Disclosures

The authors have no conflicts of interest to disclose.

Supplementary materials

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.amjcard.2020.06.014.

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