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CLINICAL RESEARCH

CORONARY

Procedural Outcomes of Chronic Total Occlusion Percutaneous Coronary Intervention

A Report From the NCDR (National Cardiovascular Data Registry)

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ABSTRACT

OBJECTIVES The aim of this study was to describe contemporary frequency, predictors, and outcomes of chronic total occlusion (CTO) percutaneous coronary intervention (PCI) in the United States.

BACKGROUND CTO PCI can provide significant clinical benefits, yet there is limited information on its success and safety in unselected patient populations.

METHODS We analyzed the frequency and outcomes of CTO PCI compared with non-CTO PCI in elective patients, and of successful versus failed CTO PCI between July 1, 2009, and March 31, 2013, in the National Cardiovascular Data Registry CathPCI Registry. Generalized estimating equations logistic regression modeling was used to generate independent variables associated with procedural success and procedural complications.

RESULTS During the study period, CTO PCI represented 3.8% of the total PCI volume for stable coronary artery disease (22,365 of 594,510). Overall, patients undergoing CTO PCI required greater contrast volume and longer fluoroscopy time and had lower procedural success (59% vs. 96%, $p < 0.001$) and higher major adverse cardiac event (1.6% vs. 0.8%, $p < 0.001$) rates than non-CTO PCI patients. On multivariable analysis, several parameters (including older age, current smoking, previous myocardial infarction, previous coronary artery bypass graft, previous peripheral arterial disease, previous cardiac arrest, right coronary artery CTO target vessel, and less operator experience) were associated with a lower likelihood of CTO PCI procedural success, whereas operators' annual CTO PCI volume was associated with improved success without a significant increase in major complications.

CONCLUSIONS CTO PCI is currently performed infrequently in the United States for stable coronary artery disease and is associated with lower procedural success and higher complication rates compared with non-CTO PCI. Procedural success was associated with several patient factors and operator experience. (J Am Coll Cardiol Intv 2015;8:245–53)

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ABBREVIATIONS AND ACRONYMS

CABG = coronary artery bypass graft

CAD = coronary artery disease

CTO = chronic total occlusion

MACE = major adverse cardiac event(s)

MI = myocardial infarction

NCDR = National Cardiovascular Data Registry

PCI = percutaneous coronary intervention

Chronic total occlusions (CTOs) are encountered in 18.4% to 52% of patients with coronary artery disease (CAD) undergoing coronary angiography (1–4). Although no randomized, controlled trial of CTO percutaneous coronary intervention (PCI) has been performed, observational studies suggest that successful CTO PCI can provide significant clinical benefit to patients, including symptom relief, improved left ventricular function, reduced risk of arrhythmias, and better tolerance of an acute coronary syndrome (5). By contrast, failed CTO PCI has been associated with an increased risk of death and angina compared with successful recanalization (6). In recent years, important advances have occurred in CTO PCI techniques, including the introduction and dissemination of the retrograde approach (7–9), antegrade dissection/re-entry techniques (10), and a systematic algorithmic "hybrid" approach (11). As a result, some centers in Europe (12), Japan (13), the United States (9,14–17), and Canada (18) now consistently achieve technical success rates >80%. Despite this progress, there is an ongoing controversy on the relative value and risks of CTO PCI, with this procedure being given a Class IIa indication in the American Heart Association/American College of Cardiology PCI guidelines (19) and patients with CTOs being given lower ratings in 5 of the 18 categories described in the PCI appropriateness use criteria (20). This study sought to describe contemporary risks and success of CTO PCI and to compare these with non-CTO PCI to provide an evidence-based foundation with which to better evaluate the appropriateness of CTO PCI and document opportunities to improve safety and use of this potentially beneficial procedure. We hypothesized that CTO PCI is performed infrequently and has different success and complication rates compared with non-CTO PCI.

SEE PAGE 254

METHODS

PATIENT POPULATION. The National Cardiovascular Data Registry (NCDR) CathPCI Registry is an initiative of the American College of Cardiology Foundation and the Society for Cardiovascular Angiography and Interventions. The registry receives data from more than 1,000 participating U.S. hospitals, and catalogs in-hospital data regarding patient characteristics, clinical features, angiographic and procedural details, and in-hospital outcomes for patients undergoing diagnostic catheterizations and PCI. The registry uses a standard dataset with pre-specified definitions supplemented with data abstractor training, uniform data entry and transmission requirements, and data quality checks, although there is no core laboratory adjudication of the angiographic parameters (21). Details on the data collection process and the variable definitions were published previously (21,22). For the purpose of this study, we examined CathPCI Registry patients with stable CAD undergoing PCI from July 1, 2009, to March 31, 2013.

DEFINITIONS OF CTO AND OUTCOMES. Since 2009, an explicit, operator-defined indication for attempting CTO PCI has been implemented in NCDR CathPCI Registry version 4. This was used to identify patients undergoing CTO PCI. The primary outcome of this study was procedural success, defined as <50% angiographic stenosis with Thrombolysis In Myocardial Infarction flow grade 3 after the procedure without any major adverse cardiac event (MACE). A MACE was defined as the composite of death, urgent coronary artery bypass graft (CABG) surgery, stroke, or tamponade.

STATISTICAL ANALYSIS. Continuous variables are presented as mean ± SD, and categorical

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variables were reported as percentages. The baseline characteristics, PCI procedural findings, and in-hospital outcomes were compared between patients with stable CAD who underwent CTO versus non-CTO PCI. A second set of comparisons was performed among the CTO procedures and compared the characteristics of successful versus failed CTO PCI. Comparisons between groups were performed using Pearson chi-square tests for all categorical variables and Wilcoxon tests for all continuous variables.

Hierarchical multivariable logistic regression analyses were performed to determine variables associated with procedural success and complications of CTO PCI. The following parameters from the NCDR data collection forms were entered into the model: age, sex, Caucasian race, body mass index, no medical insurance, glomerular filtration rate calculated using the Modification of Diet in Renal Disease study equation, smoking, hypertension, dyslipidemia, family history of CAD, previous myocardial infarction (MI), previous heart failure, previous valve surgery, previous CABG surgery, currently on dialysis, previous cardiovascular disease, previous peripheral arterial disease, chronic liver disease, diabetes mellitus, heart failure within the previous 2 weeks, previous cardiogenic shock, previous cardiac arrest, CTO target vessel (left main coronary artery, left anterior descending coronary artery, left circumflex coronary artery) average CTO PCI volume during the previous year, and average elective PCI volume during the previous year.

All tests were 2-sided, and $p < 0.05$ was considered statistically significant. All analyses were performed using SAS software (version 9.2, SAS Institute, Cary, North Carolina) by Saint Luke's Mid America Heart Institute (Kansas City, Missouri). The authors had full access to the data and take responsibility for its integrity. All authors have read and agree to the paper as written.

TABLE 1 Comparison of Patients With Stable Coronary Artery Disease Undergoing CTO PCI Versus Those Undergoing Non-CTO PCI

Variable	All Patients (N = 594,510)	CTO PCI (n = 22,365)	Non-CTO PCI (n = 572,145)	p Value
Demographic characteristics				
Age, yrs	66.3 ± 11.0	64.0 ± 10.9	66.4 ± 11.0	<0.001
Male	69	78	69	<0.001
White race	88	87	88	<0.001
Comorbidities				
Hypertension	86	86	86	0.015
Dyslipidemia	85	88	85	<0.001
Diabetes mellitus	39	39	39	0.08
Current smoking	21	23	20	<0.001
Previous MI	31	38	31	<0.001
Previous PCI	46	48	46	<0.001
Previous CABG surgery	20	19	20	0.213
Cerebrovascular disease	13	11	13	<0.001
Peripheral arterial disease	14	14	14	0.034
Glomerular filtration rate, ml/min/1.73 m^2	71.3 ± 17.8	72.9 ± 17.1	71.3 ± 17.8	<0.001
Chronic lung disease	15	13	15	<0.001
Body mass index, kg/m^2	30.3 ± 15.0	30.5 ± 13.9	30.3 ± 15.0	0.035
CAD presentation				
Symptoms				<0.001
No angina	30	29	30	
Atypical chest pain	9	7	10	
Stable angina	61	64	60	
Congestive heart failure within 2 weeks	9	10	9	<0.001
PCI outcomes				
Procedural success	94	59	96	<0.001
MACE	0.8	1.6	0.8	<0.001
Death	0.3	0.4	0.3	<0.001
Urgent CABG surgery	0.4	0.8	0.4	<0.001
Stroke	0.1	0.1	0.1	0.045
Tamponade	0.1	0.3	0.1	<0.001
MI	1.9	2.7	1.9	<0.001
RBC transfusion	1.9	2.7	1.9	<0.001
Contrast volume	189.1 ± 92.3	243.8 ± 124.7	187.0 ± 90.1	<0.001
Fluoroscopy time	15.0 ± 12.4	29.9 ± 20.8	14.5 ± 11.6	<0.001

Values are mean ± SD or %.

CABG = coronary artery bypass graft; CAD = coronary artery disease; CTO PCI = chronic total occlusion percutaneous coronary intervention; MACE = major adverse cardiac event(s); MI = myocardial infarction; PCI = percutaneous coronary intervention; RBC = red blood cell.

RESULTS

PATIENT AND PROCEDURAL CHARACTERISTICS OF CTO PCI IN STABLE CAD. During the study period,

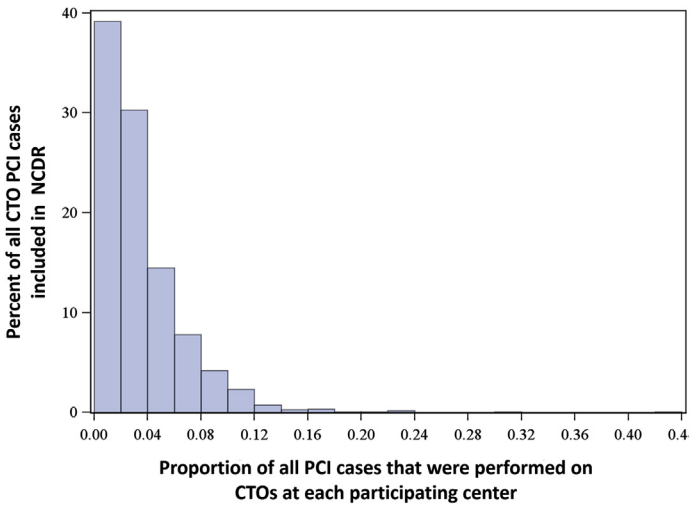
TABLE 2 Success and MACE Rates of CTO PCI Over Time

Outcome	Total (N = 22,365)	2009 (n = 2,695)	2010 (n = 6,373)	2011 (n = 6,161)	2012 (n = 5,650)	2013 (n = 1,486)	p Value
CTO PCI as percentage of total PCI volume	22,365 of 594,510 (3.8)	2,695 of 84,483 (3.2)	6,373 of 183,649 (3.5)	6,161 of 160,072 (3.8)	5,650 of 135,331 (4.2)	1,486 of 30,975 (4.8)	<0.001
Procedural success	13,077 (58.5)	1,495 (55.5)	3,637 (57.1)	3,645 (59.2)	3,380 (59.8%)	920 (61.9)	<0.001
MACE	357 (1.6)	50 (1.9)	103 (1.6)	104 (1.7)	81 (1.4)	19 (1.3)	0.108

Values are n (%).

Abbreviations as in Table 1.

FIGURE 1 Relative Frequency of CTO PCI

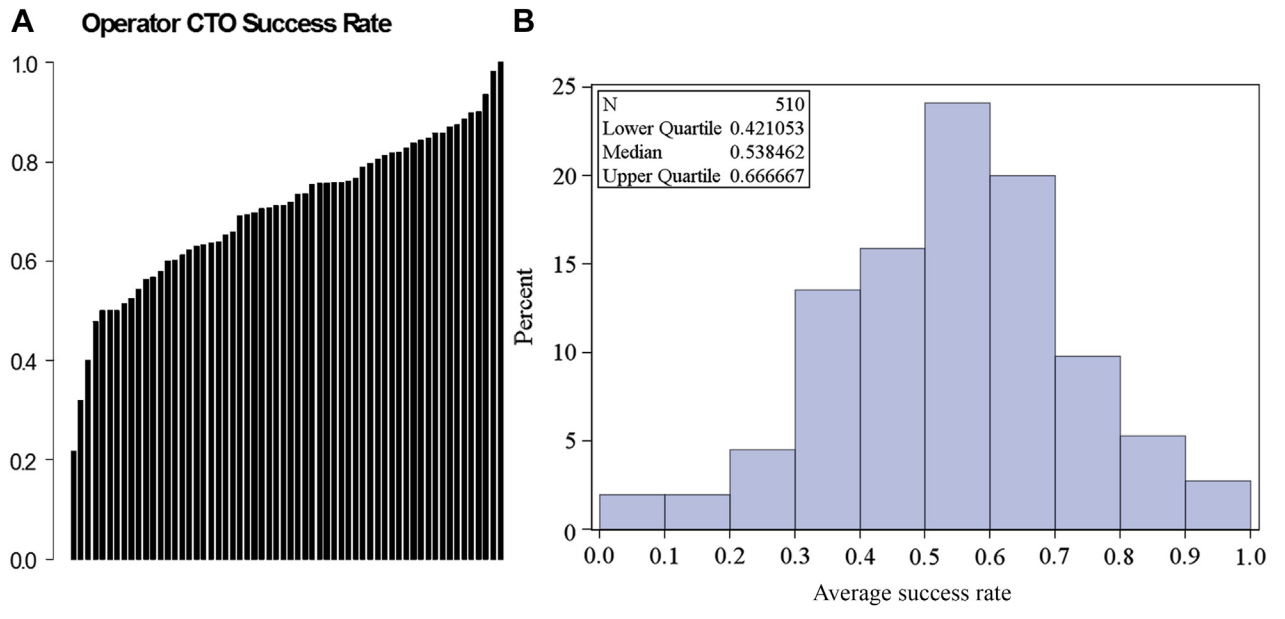


Proportion of chronic total occlusion percutaneous coronary intervention (CTO PCI) cases among centers participating in the NCDR (National Cardiovascular Data Registry).

CTO PCI represented 3.8% of the total PCI volume for stable CAD (22,365 of 594,510), with marked variation in use across centers (0% to 44%; interquartile range 1.2% to 4.5%) (Tables 1 and 2, Figure 1). At 1,387 sites included in the analysis, CTO PCI was never attempted at 234 (17%). Marked variation was also noted among operators (interquartile range 0.3% to 4.9%). CTO PCI represented a low but increasing proportion of the total PCI volume for stable coronary artery disease, from 3.2% in 2009 to 4.8% in 2013 (Table 2), in stable CAD PCI procedures. Compared with patients undergoing non-CTO PCI, those undergoing CTO PCI were younger and more likely to be men, to have had a previous MI or PCI or left ventricular dysfunction, and to undergo staged PCI. They were less likely to have cerebrovascular disease, chronic lung disease, and peripheral arterial disease (Table 1).

CTO PCI PROCEDURAL SUCCESS. Patients undergoing CTO PCI had lower procedural success compared with non-CTO PCI (59% vs. 96%, $p < 0.001$), with marked variability across centers and operators (Figure 2). Procedural success among operators performing <5, 5 to 10, and >10 CTO PCI procedures per year was 53%, 62%, and 75%, respectively ($p < 0.001$) (Table 3). Procedural success for the 8 high-volume operators was 81%. Patients undergoing CTO PCI also required higher contrast volume and longer fluoroscopy time (Table 1). Procedural success significantly increased over time from 55.5% in 2009 to 61.9% in 2013 ($p < 0.001$) (Table 2).

FIGURE 2 CTO PCI Success Rates



Proportion of chronic total occlusion percutaneous coronary intervention (CTO PCI) cases among operators performing more than 10 CTO PCI procedures per year (n = 60) **(A)** and sites at which at least 30 CTO PCI procedures were performed during the study period **(B)**.

Compared with patients in whom CTO PCI failed, those in whom CTO PCI was successful were younger and more likely to be current smokers and to have left anterior descending artery CTO. They were less likely to have had a previous MI, diabetes, cerebrovascular or peripheral arterial disease, chronic lung disease, and previous CABG (Table 4). Successful CTO PCI cases required more contrast administration but had similar fluoroscopy time. On multivariable analysis, several parameters (older age, current smoking, previous MI, previous CABG, previous peripheral arterial disease, previous cardiac arrest, right coronary artery CTO target vessel, and less operator experience) were associated with a lower likelihood of CTO PCI procedural success (Figure 3). Larger operator annual volume in CTO PCI was associated with higher procedural success rates (Figure 4, Table 3). However, only 8 operators performed 50 or more CTO PCI per year.

CTO PCI COMPLICATIONS. Patients undergoing CTO PCI had higher MACE rates compared with non-CTO PCI procedures (1.6% vs. 0.8%, $p < 0.001$) (Table 1), with a trend toward a decreased MACE rate over time (Table 2). Among operators performing more than 10 CTO PCIs per year (n = 60), the median MACE rate was 1% (interquartile range: 0% to 2%). At sites where more than 30 CTO PCIs were performed during the study period (n = 510), the median MACE rate was 0% (interquartile range, 0% to 3%). Compared with patients in whom CTO PCI was complicated by a MACE, those in whom CTO PCI did not result in a MACE were younger, more likely to have had previous PCI and previous CABG surgery, and less likely to have a history of cerebrovascular disease or chronic lung disease (Table 5). Higher CTO PCI operator volume was associated with lower MACE rates (Figure 4). On multivariable analysis, several parameters (but not operator CTO PCI annual volume [Figure 4]) were associated with higher likelihood of MACE (Figure 5).

DISCUSSION

To the best of our knowledge, this is the largest study performed to date, from a prospective PCI database providing detailed information on the frequency and outcomes of contemporary CTO PCI. Analyses of the CathPCI Registry demonstrate that CTO PCI is infrequently performed in the United States, although its frequency has been increasing over time; is associated with lower procedural success and higher complication rates compared with non-CTO PCI for stable CAD; and procedural success and MACE are associated with both patient factors and operator experience.

TABLE 3 Procedural Success and MACE Rates as a Function of Annual CTO PCI Volume

Outcome	Total (N = 22,225)	<5 CTO PCI per Year (n = 14,934)	5–10 CTO PCI per Year (n = 2,881)	>10 CTO PCI per Year (n = 4,410)	p Value
Procedural success	13,010 (58.5)	7,934 (53.1)	1,788 (62.1)	3,288 (74.6)	<0.001
MACE	356 (1.6)	260 (1.7)	34 (1.2)	62 (1.4)	0.050

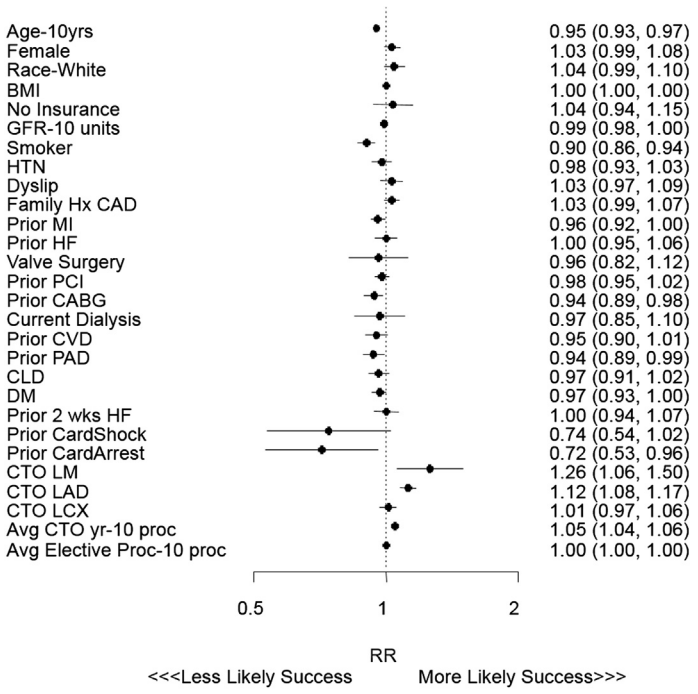
Values are n (%).
Abbreviations as in Table 1.

TABLE 4 Comparison of Successful Versus Failed CTO PCI Cases

Variable	Successful CTO PCI (n = 13,077)	Failed CTO PCI (n = 9,288)	p Value
Demographic characteristics			
Age, yrs	63.6 ± 11.0	64.7 ± 10.8	<0.001
Male	78	78	0.685
White race	87	86	0.053
Comorbidities			
Hypertension	85	86	0.009
Dyslipidemia	88	88	0.206
Diabetes mellitus	38	40	<0.001
Current smoking	21	25	<0.001
Previous MI	37	40	<0.001
Previous PCI	48	49	0.397
Previous CABG surgery	18	20	<0.001
Cerebrovascular disease	11	13	<0.001
Peripheral arterial disease	13	16	<0.001
Glomerular filtration rate, ml/min/1.73 m^2	73.0 ± 17.1	72.8 ± 17.2	0.355
Chronic lung disease	12	15	<0.001
Body mass index, kg/m^2	30.4 ± 16.5	30.6 ± 9.0	0.459
CAD presentation			
Symptoms			<0.001
No angina	28	30	
Atypical chest pain	6	9	
Stable angina	66	61	
Congestive heart failure within 2 weeks	10	11	0.015
CTO target vessel			
Right coronary artery	44	47	<0.001
Left main artery	1	0.5	<0.001
Left anterior descending artery	33	27	<0.001
Left circumflex artery	24	26	<0.001
PCI outcomes			
Procedural success	100	0	<0.001
In-hospital MACE	0	3.8	<0.001
Death	0	1.1	<0.001
Urgent CABG surgery	0	1.9	<0.001
Stroke	0	0.3	<0.001
Tamponade	0	0.8	<0.001
MI	2.8	2.5	0.212
RBC transfusion	1.2	2.2	<0.001
Contrast volume, ml	258.1 ± 124.8	223.5 ± 121.9	<0.001
Fluoroscopy time, min	30.1 ± 21.1	29.6 ± 20.5	<0.001

Values are mean ± SD or %.
Abbreviations as in Table 1.

FIGURE 3 Factors Associated With CTO PCI Success



Forest plot of variables associated with chronic total occlusion percutaneous coronary intervention (CTO PCI) success. Avg = average; BMI = body mass index; CABG = coronary artery bypass graft; CAD = coronary artery disease; CardShock = cardiac shock; CLD = chronic liver disease; CVD = cardiovascular disease; DM = diabetes mellitus; Dyslip = dyslipidemia; GFR = glomerular filtration rate; HF = heart failure; HTN = hypertension; Hx = history; LAD = left anterior descending artery; LCX = left circumflex artery; LM = left main; MI = myocardial infarction; PAD = peripheral arterial disease; proc = procedure; RR = relative risk.

FREQUENCY OF CTO PCI. Our study demonstrates that CTO PCI accounts for a small proportion of PCIs for stable CAD currently performed in the United States (3.8%), although its frequency has been increasing slightly over time (it represented 3.2% of all PCIs in 2009 vs. 4.8% in 2013). Although early reports of CTO prevalence from the NCDR suggested that it was present in only 5.5% of cases (23), prospective registries that explicitly examined the prevalence of CTOs documented rates of 18.4% to 52% (1–4).

Similar to previous studies (1), there is wide variability in the proportion of CTO PCIs (**Figures 1 and 2**) performed at various centers. Given the high prevalence of CTOs, the overall proportion of CTO PCI is very low. Potential explanations for the disparity between the prevalence and treatment of CTOs with PCI include the following: 1) CTOs are often associated with extensive CAD, necessitating CABG surgery referral in many patients; 2) variation in local expertise and comfort with performing CTO PCI; and 3) limited evidence on the risk/benefit ratio of CTO PCI leading to frequent treatment with medical therapy alone in many patients with CTOs.

Comparison of CTO PCI and non-CTO PCI. We found important differences in the outcomes of CTO compared with non-CTO PCI: CTO PCI was associated with significantly lower procedural success and higher complication rates (although the overall rate of MACE was relatively low [1.6%] in patients undergoing CTO PCI). This marked discrepancy in outcomes is likely related to the higher technical difficulty of CTO PCI, higher CAD burden of patients with CTOs, and limited local expertise with the procedure. However, the alternative revascularization strategy to CTO PCI in many patients is CABG surgery, which may also carry increased procedural risk in patients with CTOs (24). Moreover, many patients undergoing CTO PCI may not be good candidates for CABG surgery; for example, patients with a previous CABG represented ~20% of the NCDR CTO PCI cohort and 37% of a contemporary U.S. CTO PCI registry (14). Given the high rates of saphenous vein graft failure (25) and the increased risk of redo CABG surgery (26), CTO PCI may be the preferred revascularization modality in the majority of patients who have had a previous CABG.

CTO PCI procedural success. Several factors were associated with procedural success in our study, related to both the patient (age, smoking, previous MI, previous CABG, previous peripheral arterial disease, previous cardiac arrest, CTO target vessel), and the operator (CTO PCI volume). Although the overall success rate remained low during the study period, significant improvement occurred between the first (2009, 55.5%) and last (2013, 61.9%) years of the study (**Table 2**).

Older age is likely associated with more advanced coronary atherosclerosis and greater coronary artery calcification. Previous CABG surgery has been associated with lower procedural success rates (27), likely due to more extensive calcification and negative remodeling (28) and possible distortion of the native coronary artery anatomy from the graft anastomoses. Of 1,363 patients in a multicenter CTO registry, 37% had previous CABG surgery and those patients were older, had more comorbidities, were treated more frequently with the retrograde approach (46.7% vs. 27.1%, $p < 0.001$), and had lower technical success rates (79.7% vs. 88.3%, $p = 0.015$), but similar major complication rates (2.1% vs. 1.5%, $p = 0.392$) compared with patients without previous CABG (27).

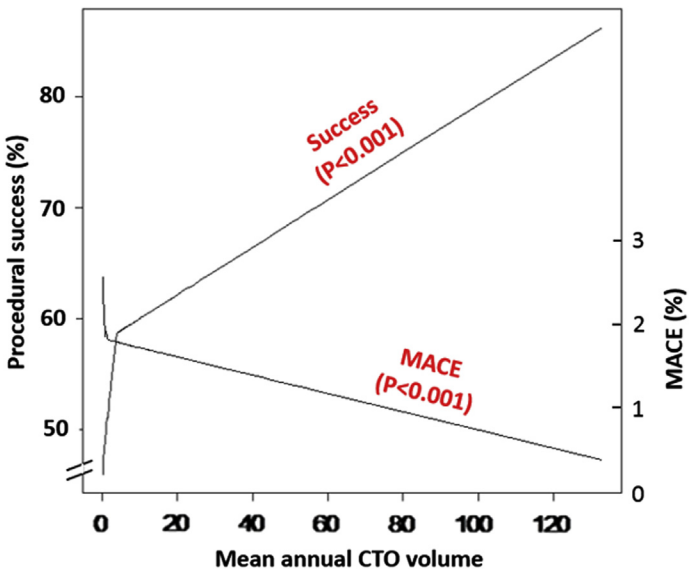
The significant increase in CTO PCI success rates with increasing CTO PCI volume (**Figure 4**) supports

performing CTO PCI by experienced operators at centers with high CTO PCI volume, where a 5% increase in success for each 10 CTO PCI procedures performed per year was observed. Of note, the overall PCI volume was not associated with success in CTO PCI (**Figure 3**), suggesting that performing large numbers of non-CTO PCIs is not associated with more success in performing CTO PCI. This is not surprising, given that CTO PCI is a fundamentally different procedure, requiring different techniques and skills compared with non-CTO PCI. Both subintimal crossing techniques (10,29) and the retrograde approach (7,29) are not used in non-CTO PCI, and require time and practice to learn and master. Improved training pathways in CTO PCI could reduce the marked variation in procedural outcomes. Moreover, operator experience with CTO PCI can result, not only in higher success rates, but also in lower fluoroscopy and contrast use (30). There appeared to be no upper limit in CTO PCI success rates with increased CTO PCI volume (**Figure 4**), suggesting that continuous improvement is possible, even among high-volume CTO PCI operators.

CTO PCI COMPLICATIONS. A recent systematic review of published studies reported low and decreasing rates of CTO PCI complications over time, despite increasing success rates (31). In our study, the risk of complications with CTO PCI was higher than with non-CTO PCI, which was in part related to higher baseline risk profiles of CTO patients and the use of advanced CTO crossing techniques. Previous PCI and previous CABG surgery were associated with lower risks of complications; however, comorbidities (e.g., history of cerebrovascular disease or chronic lung disease) were associated with higher risk. Operator CTO PCI volume was not associated with lower complication rates on multivariable analysis, possibly because high-volume CTO operators may perform more complex CTO PCI procedures, which could not be well characterized in this cohort, given the absence of detailed angiographic descriptions of CTOs in the NCDR Registry. This stable complication rate in the spectrum of various procedural volumes still supports the performance of CTO PCI among high-volume operators and centers, because procedural success was higher in those centers without incurring a penalty in terms of procedural complications (i.e., the risk/benefit ratio was higher).

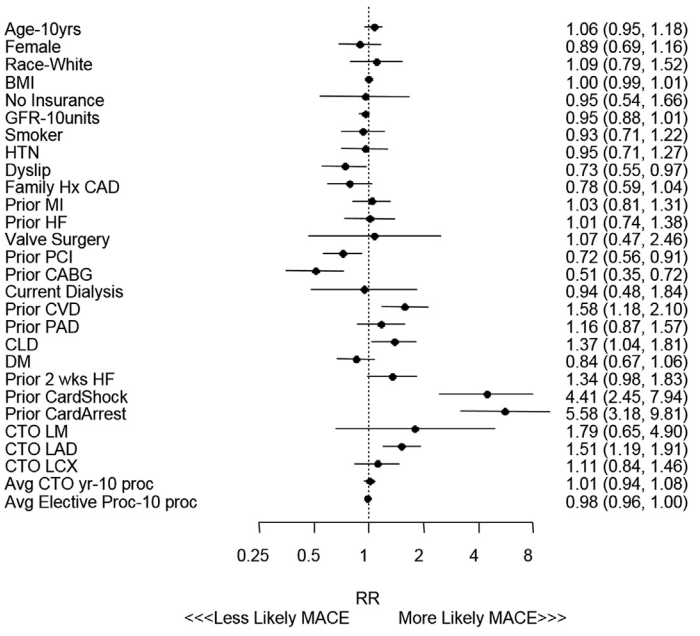
STUDY IMPLICATIONS. Our study suggests that CTO PCI may be underused, because it is infrequently performed (only 3.8% of all PCI cases in the United States were CTO PCI during the study period), despite

FIGURE 4 Operator CTO PCI Volume Association With Procedural Success and Complications



Procedural success and major adverse cardiac event (MACE) rates as a function of annual operator chronic total occlusion percutaneous coronary (CTO PCI) volume.

FIGURE 5 Factors Associated With CTO PCI Complications



Forest plot of variables associated with MACE. Abbreviations as in **Figures 3 and 4**.

TABLE 5 Comparison of CTO PCI Cases With and Without Periprocedural Complications

Variable	Periprocedural Complications (n = 357)	No Periprocedural Complications (n = 22,008)	p Value
Demographic characteristics			
Age, yrs	65.6 ± 11.6	64.0 ± 10.9	0.006
Male	78	78	0.893
White race	88	87	0.446
Comorbidities			
Hypertension	82	86	0.087
Dyslipidemia	80	88	<0.001
Diabetes mellitus	35	39	0.114
Current smoking	23	23	0.779
Previous MI	35	38	0.186
Previous PCI	35	49	<0.001
Previous CABG	11	19	<0.001
Cerebrovascular disease	17	11	<0.001
Peripheral arterial disease	17	14	0.056
Glomerular filtration rate, ml/min/1.73 m^2	69.7 ± 18.9	73.0 ± 17.1	<0.001
Chronic lung disease	19	13	<0.001
Body mass index, kg/m^2	30.2 ± 9.0	30.5 ± 14.0	0.689
CAD presentation			
Symptoms			<0.001
No angina	41	29	
Atypical chest pain	11	7	
Stable angina	48	64	
Congestive heart failure within 2 weeks	18	10	<0.001
PCI outcomes			
Procedural success	0	59	<0.001
MACE			
Death	28	0	<0.001
Urgent CABG	51	0	<0.001
Stroke	9	0	<0.001
Tamponade	20	0	<0.001
Myocardial infarction	9.3	2.6	<0.001
RBC transfusion	26.3	1.2	<0.001
Contrast volume, ml	252.7 ± 148.2	243.6 ± 124.3	0.171
Fluoroscopy time, min	34.7 ± 29.2	29.8 ± 20.7	<0.001

Values are mean ± SD or %.
Abbreviations as in Table 1.

the high prevalence of coronary CTOs (1–4). Our study also suggests that CTO PCI is currently associated with lower success and higher complication rates than non-CTO PCI, emphasizing the importance of dedicated CTO PCI training. Given the association of higher CTO PCI volume with higher success rates, it may be worthwhile, from a societal perspective, to concentrate CTO PCI at high-volume centers and in operators committed to developing and maintaining CTO PCI programs. Such programs would provide operators with the necessary equipment and support that are critical for achieving high success rates while maximizing safety (29,32).

STUDY LIMITATIONS. Our findings should be interpreted in the context of several potential limitations. Participation in the CathPCI Registry is voluntary, and therefore, the results may not be representative of the entire U.S. population, although the number of participating sites is large. In the CathPCI Registry, there is no core laboratory assessment of the patients' angiograms and composite assessments of the coronary anatomy, such as the SYNTAX (Synergy between PCI with Taxus and Cardiac Surgery) score, proximal cap ambiguity, lesion length, tortuosity and calcification, quality of the distal vessel, and the presence and quality of collateral circulation, which were not available. CathPCI Registry data are collected for in-hospital stay only; as such, differences in long-term outcomes of patients who underwent CTO versus those who underwent non-CTO PCI could not be assessed. Moreover, the long-term outcomes after use of the novel CTO crossing techniques (such as limited antegrade dissection/re-entry and the retrograde approach) have had limited study (33). Also prospective, randomized, controlled clinical trials are needed to accurately assess the risks and benefits of CTO PCI compared with optimal medical therapy alone. It is not known what initiated the decision to intervene in a CTO; therefore, unmeasured confounding variables could be responsible for some of the variability in in-hospital outcomes (success and MACE rates) after CTO PCI.

CONCLUSIONS

CTO PCI is currently infrequently performed and has lower success and higher complication rates compared with non-CTO PCI. However, higher operator experience was associated with higher success rates. Addressing the gap between what can be achieved in experienced CTO PCI centers and less experienced centers holds great promise for improving outcomes in this complex patient and lesion group.

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