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Association of Operator and Hospital Experience With Procedural Success Rates and Outcomes in Patients Undergoing Percutaneous Coronary Interventions for Chronic Total Occlusions: Insights From the Blue Cross Blue Shield of Michigan Cardiovascular Consortium

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ORIGINAL ARTICLE

Association of Operator and Hospital Experience With Procedural Success Rates and Outcomes in Patients Undergoing Percutaneous Coronary Interventions for Chronic Total Occlusions

Insights From the Blue Cross Blue Shield of Michigan Cardiovascular Consortium

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BACKGROUND: An inverse relationship has been described between procedural success and outcomes of all major cardiovascular procedures. However, this relationship has not been studied for percutaneous coronary intervention (PCI) of chronic total occlusion (CTO).

METHODS: We analyzed the data on patients enrolled in Blue Cross Blue Shield of Michigan Cardiovascular Consortium registry in Michigan (January 1, 2010 to March 31, 2018) to evaluate the association of operator and hospital experience with procedural success and outcomes of patients undergoing CTO-PCI. CTO-PCI was defined as intervention of a 100% occluded coronary artery presumed to be ≥3 months old.

RESULTS: Among 210 172 patients enrolled in the registry, 7389 (3.5%) CTO-PCIs were attempted with a success rate of 53%. CTO-PCI success increased with operator experience (45% and 65% in the lowest and highest experience tertiles) and was the highest for highly experienced operators at higher experience centers and the lowest for inexperienced operators at low experience hospitals. Multivariable logistic regression models (with spline transformed prior operator and institutional experience) demonstrated a positive relationship between prior operator and site experience and procedural success rates (likelihood ratio test=141.12, df=15, $P<0.001$) but no relationship between operator and site experience and major adverse cardiac event (likelihood ratio test=19.12, df=15, $P=0.208$).

CONCLUSIONS: Operator and hospital CTO-PCI experiences were directly related to procedural success but were not related to major adverse cardiac event among patients undergoing CTO-PCIs. Inexperienced operators at high experience centers had significantly higher success but not major adverse cardiac event rates compared with inexperienced operators at low experience centers. These data suggested that CTO-PCI safety and success could potentially be improved by selective referral of these procedures to experienced operators working at highly experienced centers.

GRAPHIC ABSTRACT: A graphic abstract is available for this article.

Key Words: Japan ■ length of stay ■ logistic models ■ percutaneous coronary intervention ■ publication

See Editorial by Kaul and Kandzari

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WHAT IS KNOWN

- Chronic total occlusion (CTO)-percutaneous coronary intervention (PCI) is challenging and complex as demonstrated by its lower success rate and worse outcomes compared with non-CTO-PCI.

WHAT THE STUDY ADDS

- A real-world insight on CTO-PCI experience of everyday operators in the state of Michigan.
- Operator and hospital CTO-PCI experiences were directly related to procedural success but were not related to major adverse cardiac event among patients undergoing CTO-PCIs.
- Compared with lesser experienced CTO operators, more experienced operators performed CTO PCI on those with baseline characteristics associated with much higher risk of adverse outcomes.
- Low experience operators at high experience centers had higher procedure success.

Nonstandard Abbreviations and Acronyms

BMC2	Blue Cross Blue Shield of Michigan Cardiovascular Consortium
CTO	chronic total occlusion
MACE	major adverse cardiac event
PCI	percutaneous coronary intervention

Many studies have evaluated the relationship between procedural volume of operators and hospitals with outcomes for many invasive procedures supporting the "practice makes perfect" belief.[1–5] These investigations have demonstrated lower rates of in-hospital complications including mortality and shorter length of stay of these procedures when performed at high volume centers.[1–5] The inverse relationship between volume and adverse outcome has been more pronounced particularly for patients with high-predicted risk for a given procedure and among those undergoing more complex procedures.[1–7]

The proportion of patients undergoing percutaneous coronary intervention (PCI) of chronic total occlusions (CTO) has been increasing over the last decade.[8] CTO-PCI continues to be challenging and complex as evidenced by its lower success rate and worse outcomes compared with non-CTO-PCI.[8–10] More careful patient selection, technological improvements, and evolving techniques have all contributed to improving procedure success rates and reduced complications.[11] A recent publication of the Japanese CTO-PCI expert registry reported that 41 most experienced operators had a very high overall technical success rate of 89.9% almost mirroring those observed among patients undergoing non-CTO-PCIs suggesting that success rates and outcomes are likely to be better in experienced hands.[12] This has led some experts to think that the path to attaining proficiency in CTO interventions is lengthy and may need up to 300 such procedures.[13,14] Although operator and institutional volume for this procedure varies in community centers, the majority of operators and hospitals in United States perform very few CTO-PCIs per year.[1] Thus, the association of operator and hospital experience of CTO-PCI with procedural success and outcomes in contemporary clinical practice remains of great interest, albeit poorly studied. The purpose of this investigation is to study the relationship of operator and hospital experience with procedural success rates and outcomes of CTO-PCI using data on patients enrolled in the in Blue Cross Blue Shield of Michigan Cardiovascular Consortium (BMC2) registry in Michigan.[15]

METHODS

Study Population and Data Collection

The study population consisted of consecutive patients who underwent PCI between January 1, 2010 and March 2018 at all nonfederal hospitals in Michigan that participate in the quality improvement registry, the BMC2. Details of BMC2 registry have been previously described.[15] All patients who underwent PCI and whose data were collected in the registry during the study time frame were included in this analysis. Patients were excluded if they underwent PCI for ST-segment–elevation myocardial infarction or in cases where a valid National Provider Identifier number was not recorded for the operator. Data were collected by onsite registered nurse coordinators on demographic and clinical characteristics, procedural details and outcomes of patients undergoing PCI procedures and submitted electronically to the registry. Data quality and the inclusion of consecutive procedures were ensured by ad hoc queries, random chart reviews, and a series of diagnostic routines included in the database.[15] The registry has been approved or the need for approval waived by the institutional review board of each participating hospital. The authors are unable to share the data due to the nature of contractual obligations with participating hospitals; the analysis code is available on request from Milan Seth (mcseth@med.umich.edu).

Data Definitions and Outcome Measures

CTO was defined as 100% luminal diameter stenosis with the absence of antegrade flow, with the duration being known or assumed to be ≥3 months. Procedural success was defined as <50% angiographic stenosis with Thrombolysis in Myocardial Infarction flow grade 3 after the procedure without any major adverse cardiac event (MACE). MACE was defined as the composite of death, urgent coronary artery bypass graft surgery, stroke, or tamponade. Bleeding was defined as any bleeding associated with one of the following: hemoglobin drops of ≥3 g/dL, transfusion of whole blood or packed red blood cells or procedural intervention/surgery at the bleeding site to reverse, stop or correct the bleeding. Vascular complication was defined

as any of the following: pseudoaneurysm, arteriovenous fistula, femoral neuropathy, retroperitoneal hematoma, hematoma at the access site requiring transfusion/prolonged hospital stay or causing a drop-in hemoglobin ≥3.0 g/dL, or any access site complication requiring surgical repair. In-hospital mortality was defined as all-cause death from either cardiac or noncardiac etiology. Contrast-induced nephropathy was defined as impairment in renal function resulting in 0.5 mg/dL absolute increase in serum creatinine from baseline.[16]

Statistical Methods

For display purposes, patients were divided into 3 tertiles based on operator CTO-PCI experience. For each procedure, the number of prior procedures performed by the operator occurring previously in the registry was calculated. Tertiles were then determined based on these prior procedure counts, and procedures were grouped by the prior experience of the operator at that point in time, so that the same operator could have (and likely will have) performed procedures in all 3 tertiles. Demographics baseline characteristics, treatments, cardiac catheterization and PCI procedural details, and in-hospital outcomes were compared among these groups using Pearson χ^2 test for categorical variables and ANOVA for continuous variables. Missing data were not defaulted to negative and denominators reflect cases reported. As of the date of each CTO-PCI procedure, the total number of CTO cases performed (1) at the hospital where the PCI was performed and (2) by the operator performing PCI between January 1, 2010 and the date of the procedure was determined. These values for site and operator experience at the time of each case were then used for regression modeling to determine the relationship between experience and outcomes and to partition cases into tertiles of site and operator experience. Multivariable logistic regression analyses were performed to adjust for patient risk factors including CAD presentation, PCI status, age, sex, and baseline BMC2 predicted risks of death and transfusion[17] while evaluating the impact of basis spline transformed hospital and operator experiences and their interactions upon procedural success rates and outcomes. As a sensitivity analysis, simplified regression models adjusting only for baseline predicted risk and operator prior CTO experience were fitted to the data. Mean predicted baseline risk estimates, procedural success, and in-hospital mortality was aggregated by prior CTO operator experience, and weighted spline linear regression models were fitted to these data. Model predicted outcome rates by prior CTO experience were then plotted to assess potential threshold values for operator experience associated with performance. Operator and institutional prior experience variables were transformed using a basis matrix representing the family of cubic piecewise polynomials. The results of these models are provided graphically in 3-dimensional perspective plots. Likelihood ratio tests were utilized to assess if prior operator and institutional CTO experience (and their interactions) were independently associated with procedural success and in-hospital death and MACE after adjustment for baseline clinical and demographic variables. All tests were 2-sided, and $P<0.05$ was considered statistically significant. All analyses were performed using R software (version 3.4.1, R Core Team [2017]. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/) by the University of Michigan (Ann Arbor, MI).

RESULTS

Baseline Demographics, History, Clinical Presentation, and Laboratory Features in 3 Tertiles Based on Experience of Operator CTO Procedures

During the 8-year study period, a total of 7389 CTO-PCI (3.4%) were recorded among a total of 210 172 PCI procedures at 46 sites with the proportion of CTO-PCI among all PCI procedures increasing over the study period (2.7% in 2010 to 4.5% in 2017; Table 1). Operator experiences in the 3 tertiles were divided <12, 12 to 33, and 34 or more previous CTO-PCI at the time of CTO-PCI. Operator experience ranged widely over the study period (median [interquartile range]: 12 (5–23), min=1, max=334) with few operators performing >50 CTO procedures during the study period (n=30/337, 8.9%) and most operators performing 20 to 50 (n=83/337, 24.6%) and <20 (n=224/337, 66.5%) CTO procedures during the study period. Similarly, few institutions performed >50 CTO PCI/y (n=4; 8.7%) with most institutions performing 20 to 50 CTO-PCIs per year (n=10, 21.7%) or <20 PCIs per year (n=32, 69.6%). Proportion of institutions performing >50 CTO per year was 8.7% in 2010 and 13.0% in 2017. Compared with patients in the lower operator experience tertiles, those in the highest tertile group were at high-risk with older age and greater prevalence of history of hypertension, diabetes mellitus, myocardial infarction, congestive heart failure, coronary artery bypass graft, or PCI, peripheral vascular disease as well as lower glomerular filtration rate at presentation.

Pre- and Intraprocedural Treatments in 3 Tertiles Based on Experience of Operator CTO Procedures

The operators with the most experience were more likely to perform CTO-PCI in patients with stable symptoms compared with the lower operator experience tertiles (29% versus 18%; Table 2). Stress testing before CTO-PCI was performed in similar proportion of patients in the 3-operator experience tertiles cohorts.

Procedural Details in 3 Tertiles Based on Experience of Operator CTO Procedures

The highest experience tertile operated most frequently on the right coronary artery along with the left anterior descending coronary artery (Table 3). The average fluoroscopy time was longest in the highest operator experience tertile and paralleled higher amount of contrast

Table 1. Demographics, Medical History, and Laboratory Features in 3 Tertiles Based on Operator CTO-PCI Experience

Variables	First Tertile N=2336 (<12 CTO-PCI)	Second Tertile N=2144 (12-33 CTO-PCI)	Third tertile N=2178 (>34 CTO-PCI)	T1 vs T2 (*P*-Value)	T1 vs T3 (*P*-Value)	T2 vs T3 (*P*-Value)
Demographic characteristics						
Age, y	62.9±11.4	63.7±11.2	64.3±10.9	*P*=0.030	*P*<0.001	*P*=0.061
Male	72.6%	73.4%	75.0%	*P*=0.563	*P*=0.075	*P*=0.240
White race	81.8%	83.7%	82.4%	*P*=0.091	*P*=0.596	*P*=0.253
Medical history						
Body mass index, kg/m^2	31.1±7.6	31.3±6.9	31.2±6.7	*P*=0.339	*P*=0.673	*P*=0.572
Hypertension	86.1%	88.9%	91.0%	*P*=0.005	*P*<0.001	*P*=0.019
Dyslipidemia	86.1%	88.9%	91.0%	*P*=0.125	*P*<0.001	*P*<0.001
Diabetes mellitus	40.6%	41.9%	46.0%	*P*=0.369	*P*<0.001	*P*=0.007
Current smoking	31.6%	29.3%	26.8%	*P*=0.097	*P*<0.001	*P*=0.065
Previous MI	40.5%	41.8%	52.0%	*P*=0.379	*P*<0.001	*P*<0.001
Prior percutaneous coronary intervention	45.5%	53.6%	67.4%	*P*<0.001	*P*<0.001	*P*<0.001
Prior coronary artery bypass	13.0%	16.1%	24.7%	*P*=0.004	*P*<0.001	*P*<0.001
Cerebrovascular disease	13.5%	13.7%	16.8%	*P*=0.859	*P*=0.002	*P*=0.004
Peripheral arterial disease	14.7%	16.6%	21.1%	*P*=0.077	*P*<0.001	*P*<0.001
Chronic lung disease	18.8%	22.1%	20.2%	*P*=0.005	*P*=0.233	*P*=0.116
Prior heart failure	18.8%	21.2%	31.5%	*P*=0.043	*P*<0.001	*P*<0.001
Laboratory						
Hemoglobin, gm/dL	13.5±1.9	13.5±1.9	13.4±1.9	*P*=0.601	*P*=0.032	*P*=0.111
Glomerular filtration rate ml/min per 1.73^2	76.8±24.7	76.9±24.2	74.2±24.9	*P*=0.907	*P*<0.001	*P*<0.001

Value presented as percentages unless specified otherwise. CTO indicates chronic total occlusion; MI, myocardial infarction; and PCI, percutaneous coronary intervention.

use and radiation dose compared with those in the lower operator experience tertiles.

Procedural Outcomes

Overall procedural success improved from 45% in 2010 to 55% to 2017 (Table 4; Figures 1 through 3). Procedural success for CTO-PCI was significantly higher when performed by high-compared with low experience operators (Tertile 3: 65%, Tertile 2: 54.5%, Tertile 1: 44.9%, *P*<0.0001; Figure 1). A similar relationship was also observed between institutional experience and the success rates for CTO-PCI. The success rates of CTO-PCI among low experience operators at highly experienced centers were higher than those performed by low experience operators at low experience centers (Figure 1). The highest success rates were observed for highly experienced operators at high-experience centers and lowest for low experience operators at low experience centers.

Observed major adverse events and death were higher in low experience compared with intermediate experience operators tertile (4.0% versus 2.9%) but similar to that seen in the highest experience tertile operators (MACE 4.0% versus 3.2%). In-hospital mortality showed a similar pattern (1.8%, 0.8%, and 1.7% low, intermediate and highly experienced tertiles, *P*=0.0039 and 0.8081 for low versus intermediate and high experience operator tertiles, respectively). In the periprocedural period, the highest experience tertile operators had the lowest risk of need for coronary artery bypass graft and repeat PCI, whereas the incidence of cardiac tamponade, major bleeding, need for transfusion, myocardial infarction, cardiogenic shock, and stroke were significantly higher in this group compared with the lowest and mid experience tertiles. Mechanical circulatory support devices were used more frequently in the highest experience tertile operators. Length of hospitalization was the highest in the low experienced operators compared with intermediate and high experienced operators (2.74±3.66, 2.58±3.68, and 2.52 ±3.66 days, respectively). The overall rate of MACE did not change over the study period.

Multivariable Logistic Regression Models

Multivariable logistic regression models (with spline transformed prior operator and institutional experience) displayed a positive relationship indicating inexperienced operators at high experience centers had significantly higher success (likelihood ratio test=141.12, df=15, *P*<0.001; Figure 1) and an inverse relationship between operator and site experience and mortality (likelihood ratio test=27.69, df=15, *P*=0.023; Figure 2).

Table 2. Preprocedural Presentation and Intraprocedural Treatments in 3 Tertiles Based on Operator CTO-PCI Experience

Presentation and Preprocedural Testing	First Tertile (<12 CTO-PCI)	Second Tertile (12–33 CTO-PCI)	Third Tertile (>34 CTO-PCI)	T1 vs T2 (*P* Value)	T1 vs T3 (*P* Value)	T2 vs T3 (*P* Value)
Patient symptom presentation						
Symptom unlikely to be ischemic	2.8%	3.3%	3.1%	*P*=0.345	*P*=0.500	*P*=0.789
Stable angina	18.7%	20.8%	29.1%	*P*=0.085	*P*<0.001	*P*<0.001
Unstable angina	44.0%	49.0%	48.9%	*P*=0.001	*P*=0.001	*P*=0.960
Non–ST-segment–elevation myocardial infarction	28.3%	21.6%	13.4%	*P*<0.001	*P*<0.001	*P*<0.001
Anginal classification within 2 wks						
No symptoms	6.1%	5.4%	5.5%	*P*=0.277	*P*=0.345	*P*=0.885
Canadian cardiovascular society I	2.6%	2.5%	1.5%	*P*=0.909	*P*=0.013	*P*=0.019
Canadian cardiovascular society II	13.6%	12.9%	11.6%	*P*=0.535	*P*=0.046	*P*=0.178
Canadian cardiovascular society III	46.3%	51.0%	58.6%	*P*=0.002	*P*<0.001	*P*<0.001
Canadian cardiovascular society IV	27.0%	24.3%	18.8%	*P*=0.038	*P*<0.001	*P*<0.001
Cardiomyopathy or left ventricular systolic dysfunction	15.4%	16.5%	20.3%	*P*=0.316	*P*<0.001	*P*=0.001
Preoperative evaluation						
Stress or imaging studies	47.1%	46.1%	45.7%	*P*=0.500	*P*=0.343	*P*=0.791
Diagnostic cath	86.3%	80.8%	70.8%	*P*<0.001	*P*<0.001	*P*<0.001
Procedural medications						
Bivalirudin	24.9%	18.7%	2.7%	*P*<0.0001	*P*<0.0001	*P*<10.000
Aspirin (any)	97.5%	98.7%	99.6%	*P*=0.0020	*P*<0.0001	*P*=0.0022
GP IIb/IIIa (any)	21.2%	15.2%	8.6%	*P*<0.0001	*P*<0.0001	*P*<0.0001
Low molecular weight heparin (any)	3.3%	2.24%	0.7%	*P*=0.0259	*P*<0.0001	*P*<0.0001
Prasugrel	11.6%	10.5%	6.3%	*P*=0.2508	*P*<0.0001	*P*<0.0001
Clopidogrel	58.5%	59%	67.7%	*P*=0.7499	*P*<0.0001	*P*<0.0001
Unfractionated heparin (any)	85.5%	89.1%	98.6%	*P*=0.0003	*P*<0.0001	*P*<0.0001
Ticagrelor	13.3%	19.6%	20.5%	*P*<0.0001	*P*<0.0001	*P*=0.4725

These findings exclude patients with documented contraindications to the medications listed, where medication use was blinded as part of a clinical trial, or at time-points where the medication was not an option available to the abstractor (eg, Ticagrelor was not added to the registry treatment list until after approval in Q1 2012). Value presented as percentages unless specified otherwise. CTO indicates chronic total occlusion; and PCI, percutaneous coronary intervention.

In contrast, no statistically significant independent relationship was observed between operator and site experience with MACE (likelihood ratio test=19.12, df=15, *P*=0.208; Figure 3). (The regression models are further described in the Data Supplement with additional figures [Figures I and II in the Data Supplement] for predicted procedural success and predicted in-hospital mortality based on operator CTO experience, respectively.)

DISCUSSION

Our study of contemporary clinical practice in Michigan showed that CTO-PCI experience varied widely by operator and across institutions. Few institutions or operators performed >50 CTO-PCIs per year. Our analysis showed that procedural success for CTO-PCI was directly related to procedural experience both at operator and institutional levels with higher experience associated with greater procedural success. Additionally, more experienced operators were more likely to perform CTO-PCI in higher-risk and thus had higher incidence of in-hospital complications including higher incidence of cardiac tamponade, major bleeding, need for transfusion, myocardial infarction, cardiogenic shock, and stroke. Nonetheless, the need to repeat revascularization with either PCI or coronary artery bypass graft was lower in the experienced operators. Observed in-hospital mortality was similar with highly experienced compared with less experienced operators but demonstrated statistically significant (but clinically marginal) inverse relationship with operator experience once adjusted for baseline confounders. A statistically significant (but clinically marginal) inverse relationship was also demonstrated for individual site experience where more experienced sites had lower adjusted in-hospital death compared with inexperienced institutions. Additionally, in-hospital rates of death for CTO-PCI were the lowest among high experience operators at high-experienced centers and highest for low experience operators at inexperienced centers. Low experience operators at highly experienced centers have lower death rates compared with

Table 3. Vessel Statistics and Procedural Details in 3 Tertiles Based on Experience of Operator CTO Experience

	First Tertile (<12 CTO-PCI)	Second Tertile (12–33 CTO-PCI)	Third Tertile (>34 CTO-PCI)	T1 vs T2 (*P* Value)	T1 vs T3 (*P* Value)	T2 vs T3 (*P* Value)
Percutaneous coronary intervention target vessel						
Left main	0.81%	0.65%	1.88%	*P*=0.5306	*P*=0.0017	*P*=0.0003
Left anterior descending	30.4%	29.7%	28.3%	*P*=0.5967	*P*=0.1204	*P*=0.3168
Left circumflex	27%	25%	23.1%	*P*=0.1158	*P*=0.0030	*P*=0.1741
Right coronary artery	42.3%	45.6%	50.7%	*P*=0.0251	*P*<0.001	*P*=0.0009
Lesion location data missing	0.9%	0.42%	0.69%	*P*=0.0495	*P*=0.4274	*P*=0.2342
Coronary arteries with stenosis >50%						
1 vessel	39.8%	41.3%	43.1%	*P*=0.3179	*P*=0.0265	*P*=0.2337
2 vessels	32.2%	32.7%	29.9%	*P*=0.6941	*P*=0.1090	*P*=0.0504
3 vessels	28.0%	25.9%	26.9%	*P*=0.1289	*P*=0.4319	*P*=0.4690
Pre-PCI TIMI flow						
TIMI–0	89.2%	90.7%	91.1%	*P*=0.1052	*P*=0.0344	*P*=0.6306
TIMI–1	4.5%	3.9%	3.8%	*P*=0.3038	*P*=0.2231	*P*=0.8551
TIMI–2	1.5%	1.6%	2.2%	*P*=0.7175	*P*=0.0779	*P*=0.1712
TIMI–3	2.6%	2.6%	1.7%	*P*=0.9989	*P*=0.0355	*P*=0.0386
Not available	2.2%	1.3%	1.8%	*P*=0.0202	*P*=0.3548	*P*=0.1611
Post-PCI TIMI flow						
TIMI–0	8.0%	8.5%	7.1%	*P*=0.5195	*P*=0.2352	*P*=0.0726
TIMI–1	1.3%	1.2%	0.8%	*P*=0.8295	*P*=0.1340	*P*=0.2060
TIMI–2	1.8%	1.6%	2.6%	*P*=0.7508	*P*=0.0471	*P*=0.0249
TIMI–3	47.8%	57.9%	68.3%	*P*<0.0001	*P*<0.0001	*P*<0.0001
NA (primarily due to unsuccessful guidewire crossing)	41.5%	31.4%	22.7%	*P*<0.0001	*P*<0.0001	*P*<0.0001
Fluoroscopy time, min	26.5±18.1	30.8±23.2	43.2±31.11	*P*<0.001	*P*<0.001	*P*<0.001
Radiation dose, mGy	2476±2364.5	2463.9±1801.4	2918±2104.9	*P*=0.923	*P*<0.001	*P*<0.001
Contrast volume, mL	207.7±91.5	206.2±97.5	212.4±98.4	*P*=0.617	*P*=0.096	*P*=0.040
Access site						
Femoral	72.6%	69.9%	72.1%	*P*=0.046	*P*=0.697	*P*=0.114
Brachial	0.2%	0.3%	0.1%	*P*=0.656	*P*=0.297	*P*=0.150
Radial	27.2%	29.8%	27.7%	*P*=0.055	*P*=0.680	*P*=0.139

Value presented as percentages unless specified otherwise. CTO indicates chronic total occlusion; PCI, percutaneous coronary intervention; and TIMI, Thrombolysis in Myocardial Infarction.

low experience operators at low experience centers. No independent relationship was observed for operator and site experience with adjusted MACE.

Few studies have focused specifically on examining the volume outcomes relationship for CTO-PCI.[18,19] Thompson et al[18] evaluated 636 patients between 2005 and 2008 undergoing CTO-PCI and showed that procedural success rate was higher among high volume operators (defined as >75 antegrade and >20 retrograde CTOs) than low volume operators (59.8% versus 75.2%, *P*<0.0001). No differences were observed in the 2 groups in the in-hospital adverse event rates. Brilakis et al[8] examined outcomes of CTO-PCI among 22 365 patients with stable angina enrolled in National Cardiovascular Data Registry between 2009 and 2013. Procedural success rates were significantly higher in operators performing >10 CTO-PCI per year (74.5%) compared with those performing 5 to 10 (62.1%) and <5 (58.5%) CTO-PCI per year (*P*<0.001).

Our data were consistent with the findings of the above studies confirming the direct relationship of CTO-operator and site procedural experience with success rate of PCI. Furthermore, our study provided insights into the relationship for CTO-PCI experiences with outcomes at both operator and institutional levels reaffirming that similar inverse relationship existed at both these levels and the highest procedural success rates and lowest mortality were observed when CTO-PCI were performed by high experience operators and highly experienced institutions.

More importantly, our investigation further revealed that low experience operators at highly experienced centers had significantly better outcomes than low experience operators at low experience hospitals. Thus, the

Table 4. Procedural Outcomes in 3 Tertiles Based on Operator CTO-PCI Experience

Variable	First Tertile (<12 CTO-PCI)	Second Tertile (12–33 CTO-PCI)	Third Tertile (>34 CTO-PCI)	T1 vs T2 (*P* Value)	T1 vs T3 (*P* Value)	T2 vs T3 (*P* Value)
Procedural success	44.9%	54.5%	64.5%	*P*<0.0001	*P*<0.0001	*P*<0.0001
Major adverse cardiac event	4%	2.9%	3.2%	*P*=0.0369	*P*=0.1666	*P*=0.4795
Death	1.8%	0.8%	1.7%	*P*=0.0039	*P*=0.8081	*P*=0.0085
Urgent coronary artery bypass surgery	1.8%	1.6%	0.3%	*P*=0.6590	*P*<0.0001	*P*<0.0001
Stroke	0.4%	0.2%	0.6%	*P*=0.2168	*P*=0.3082	*P*=0.0313
Tamponade	0.3%	0.3%	1%	*P*=0.6650	*P*=0.0021	*P*=0.0090
Myocardial infarction	1.7%	2.2%	3.5%	*P*=0.2035	*P*<0.0001	*P*=0.0082
Repeat percutaneous coronary intervention	1.1%	0.5%	0.3%	*P*=0.0425	*P*=0.0049	*P*=0.3476
Bleeding	2.9%	4%	7.3%	*P*=0.0353	*P*<0.0001	*P*<0.0001
Transfusion	2.2%	2.9%	4.1%	*P*=0.1326	*P*=0.0003	*P*=0.0408
Contrast-induced nephropathy	3.4%	2.9%	3.7%	*P*=0.3953	*P*=0.5717	*P*=0.1630
Intraaortic balloon pump	2.0%	1.3%	1.9%	*P*=0.082	*P*=0.919	*P*=0.105
Other mechanical ventricular support	1.4%	1.5%	5.7%	*P*=0.727	*P*<0.001	*P*<0.001
Cardiogenic shock w/in 24 h	1.9%	1.4%	2.8%	*P*=0.097	*P*=0.999	*P*=0.102
Cardiac arrest w/in 24 h	1.5%	0.5%	0.5%	*P*=0.001	*P*<0.001	*P*=0.971
Hospital length of stay	2.74±3.66 d	2.58±3.68 d	2.52±3.66 d	*P*=0.0008	*P*<0.0001	*P*=0.1127

CTO indicates chronic total occlusion; and PCI, percutaneous coronary intervention.

highest success rates and lowest incidence of death were observed among patients undergoing CTO-PCI by highly experienced operators at highly experienced centers and lowest success rates and highest death for those undergoing CTO-PCI by least experienced operators at low experience centers. These findings are comparable to those observed in a study by Fanaroff et al[1] who examined volume relationship for patients undergoing any PCI using data from the ACC National Cardiovascular Data Registry.

The higher incidence of in-hospital complications among patients treated by experienced operators and sites is probably related to both, a greater likelihood of attempting higher risk cases and to use more aggressive techniques, thus resulting in more MIs and/or more bleeding and tamponade secondary to coronary perforation. However, the fact that more experienced operators had less emergent open-heart surgeries, repeat PCIs, as well as the lowest length of hospital stay and lower risk adjusted mortality suggests that these complications were managed expeditiously and more effectively by these operators, perhaps accounting for lower in-hospital death rates despite higher MACE rates. Needless to say, these data highlight that CTO-PCI even in the most experienced hands is associated with higher risk of adverse events and the decision to proceed needs to be

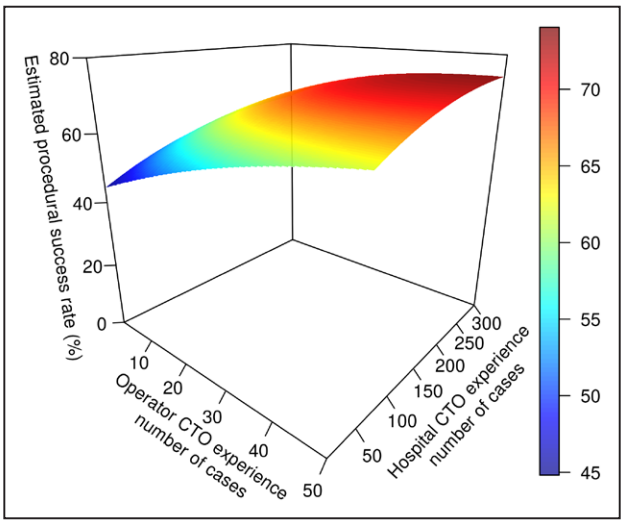

Figure 1. Association of operator and hospital chronic total occlusion (CTO)-percutaneous coronary intervention (PCI) experience with CTO-PCI procedural success rates.

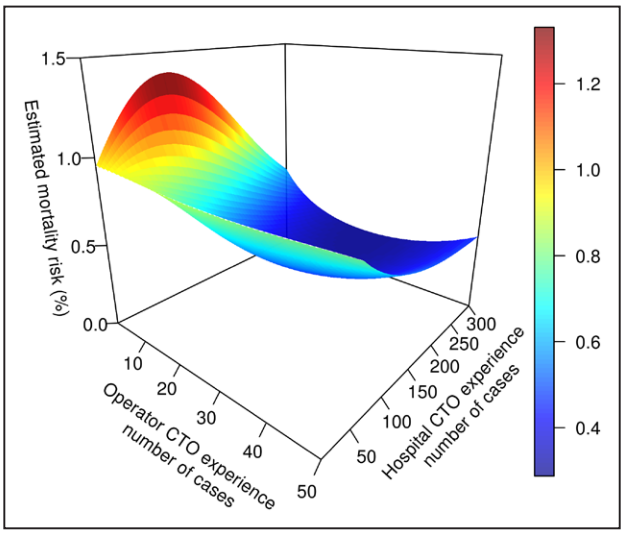

Figure 2. Association of operator and hospital experience with in-hospital mortality after chronic total occlusion (CTO)-percutaneous coronary intervention.

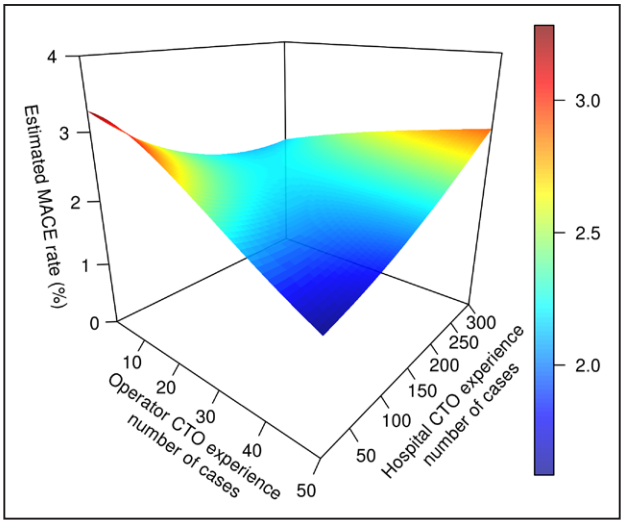

Figure 3. Association of operator and hospital experience with in-hospital major adverse cardiac event (MACE) after chronic total occlusion (CTO)-percutaneous coronary intervention.
Multivariable logistic regression failed to identify any statistically significant relationship between operator and hospital experience with in-hospital MACE.

individualized for each patient after careful discussion of risks versus benefits.

Programs specializing in treating chronic total occlusions are growing rapidly across the globe resulting in exponential growth in the number of interventional cardiologists tackling these lesions and in the number of CTO-PCI. However, CTO-PCI is challenging both in terms of complexities requiring availability of technology specific to CTO-PCI as well as commitment both at operator and institutional levels for improving procedural success. The lower success rates and associated worse outcomes for CTO-PCI by low experience operators or at low experience sites calls for understanding of the reasons behind such inferior outcomes. Potentially remedial factors include adequate formal training for the procedure (including that for retrograde approach) and recognition and management of its complications as well as institutional commitment to provide technology that aid in performing these procedures successfully and safely. The availability of CTO-PCI enabling technology[20] and use of retrograde approach for recanalization of CTO[18] have been shown to improve procedural success. The findings of previous investigators and our study further suggest that procedural success is likely greater when CTO-PCI is performed by more experienced operators at high experience centers. This would support regionalization of CTO-PCI to few highly experienced operators at highly experienced sites, but this approach may be impractical for many US health care segments given local referring and practice patterns.

The finding in our study that inexperienced operators at high experience sites had better outcomes than those at inexperienced centers may suggest that oversight of CTO-PCI performed by inexperienced operators by more experienced operators may have the potential for improving procedural success and outcomes. This hypothesis is supported by a study by Eggebrecht et al[21] that used data from the German Quality Assurance Registry on Aortic Valve Replacement showed that supervision by a Heart team from centers with on-site cardiac surgery of TAVR procedures at low experienced sites without cardiac surgery resulted in similar rates of deaths and stroke at these sites compared with that observed at highly experienced institutions with on-site cardiac surgery programs.

Limitations

Some limitations should be considered when interpreting the current study. Given observational nonrandomized nature of this analysis, caution needs to be exercised when inferring causality. As in all observational analyses, influence of unmeasured confounders on study results cannot be ascertained. Given minority of patients getting functional studies before an intervention on a CTO, whether the procedures were appropriate or underutilized could not be determined. Specifically, we are unable to provide insight into the proportion of patients who were on optimal guideline-based medical therapy before CTO-PCI, reasons for performing (or not) stress test in patients and its results (positive or negative) including the extent of ischemia that went into decision making. The definition of CTO was based on the operator's perception of whether or not the occlusion was >3 months older or not. We cannot ascertain the differences across operators or institutions in specific differences in anatomic adversities in patient undergoing CTO interventions such as coronary anatomy (for example, calcification or side branch at the site of occlusion or the Castle score[22]) or use of limited technique (such as antegrade approach rather than additional attempts using a retrograde approach). The registry collects data on in-hospital outcomes only and precluding us from providing any insight into the association of CTO-interventions with improvement of quality of life.

Conclusions

Operator and hospital CTO-PCI experiences were directly related to procedural success but were not related to MACE among patients undergoing CTO-PCIs. Low experience operators at high experience centers had significantly higher procedure success but not MACE rates compared with low experience operators at inexperienced centers.

ARTICLE INFORMATION

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