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¹ Kandzari DE, Böhm M, Mahfoud F, et al. Effect of renal denervation on blood pressure in the presence of antihypertensive drugs: 6-month efficacy and safety results from the SPYRAL HTN-ON MED proof-of-concept randomised trial. *The Lancet*. 2018 Jun 9;391(10137):2346-2355.

² Mahfoud F, Mancia G, Schmieder R, et al. Renal Denervation in high-risk patients with hypertension. *Journal of the American College of Cardiology*. 2020; 75(23): 2879-2888.




ORIGINAL STUDIES

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EDITORIAL COMMENT: Expert Article Analysis for:

Chronic total occlusion percutaneous coronary intervention in prior coronary artery bypass graft surgery patients: Caveat Emptor!

Clinical outcomes of percutaneous coronary intervention for chronic total occlusion in prior coronary artery bypass grafting patients

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Abstract

Objective: To compare the clinical characteristics and outcomes in patients with stable angina who have undergone chronic total occlusion (CTO) percutaneous coronary intervention (PCI) in native arteries with or without prior coronary artery bypass grafting (CABG) surgery in a national cohort.

Background: There are limited data on outcomes of patients presenting with stable angina undergoing CTO PCI with previous CABG.

Methods: We identified 20,081 patients with stable angina who underwent CTO PCI between 2007–2014 in the British Cardiovascular Intervention Society database. Clinical, demographical, procedural and outcome data were analyzed in two groups; group 1-CTO PCI in native arteries without prior CABG ($n = 16,848$), group 2-CTO PCI in native arteries with prior CABG ($n = 3,233$).

Results: Patients in group 2 were older, had more comorbidities and higher prevalence of severe left ventricular systolic dysfunction. Following multivariable analysis, no significant difference in mortality was observed during index hospital admission (OR:1.33, CI 0.64–2.78, $p = .44$), at 30-days (OR: 1.28, CI 0.79–2.06, $p = .31$) and 1 year (OR:1.02, CI 0.87–1.29, $p = .87$). Odds of in-hospital major adverse cardiovascular events (MACE) (OR:1.01, CI 0.69–1.49, $p = .95$) and procedural complications (OR:1.02, CI 0.88–1.18, $p = .81$) were similar between two groups but procedural success rate was lower in group 2 (OR: 0.34, CI 0.31–0.39, $p < .001$). The adjusted risk of target vessel revascularization (TVR) remained similar between the two groups at 30-days (OR:0.68, CI 0.40–1.16, $P=0.16$) and at 1 year (OR:1.01, CI 0.83–1.22, $P=0.95$).

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Conclusion: Patients with prior CABG presenting with stable angina and treated with CTO PCI in native arteries had more co-morbid illnesses but once these differences were adjusted for, prior CABG did not independently confer additional risk of mortality, MACE or TVR.

KEYWORDS

chronic total occlusion, mortality, percutaneous coronary intervention, target vessel revascularization

1 | INTRODUCTION

Chronically occluded coronary arteries (CTO) are present in up to 20% of diagnostic angiograms and percutaneous coronary intervention (PCI) for chronic totally occluded (CTO) coronary arteries is rapidly evolving.¹ A significant proportion of these patients are managed with optimal medical therapy (OMT), and only a minority of these individuals receive percutaneous (10–22%) or surgical (22–26%) revascularisation.^{2,3} Clinical data has indicated the association between successful CTO revascularization and better clinical outcomes compared to unsuccessful CTO PCI procedures.^{4,5} These studies demonstrated significant symptom relief, and improved quality of life and exercise tolerance but did not show significant differences in mortality.

Patients with prior CABG surgery often have complex coronary anatomy due to more advanced atherosclerosis and calcification.⁶ These patients have very high prevalence of CTO lesions and approximately half of post CABG patients undergoing coronary angiography have a native CTO coronary artery.² In the Prague 4 trial, only one in four SVGs to CTOs remained patent 1 year after CABG surgery.⁷ Due to increased age, frailty and multiple comorbid illnesses, further bypass surgery is rarely performed, leaving PCI as the treatment of choice. Consequently, there is an increasing interest in treating such CTOs with PCI, even though CTO PCI in prior CABG patients is more challenging, associated with more procedural complexity and lower success rates than CTO PCI in patients without a prior history of CABG.⁸ This lesion subset remains the most technically challenging.

The long-term clinical outcomes of CTO PCI in patients with prior CABG have only received limited evaluation in large clinical studies, and it remains unclear whether higher procedural complexity encountered during CTO PCI in prior CABG patients is also translated into adverse outcomes on follow up.^{8,9} We therefore sought to describe the early and late clinical outcomes of CTO PCI in patients presenting with stable angina and had prior history of CABG in a large, unselected national cohort from the database of the British Cardiovascular Intervention Society (BCIS).

2 | MATERIALS AND METHODS

This study consists of national data for all patients who have undergone CTO PCI in native coronary arteries in England and Wales from January 2007 to December 2014. The British Cardiovascular

Intervention Society (BCIS) maintains data prospectively on PCI procedures throughout United Kingdom, and whole process is monitored by the National Institute of Cardiovascular Outcomes Research (NICOR). The data that supports findings of this study are available from NICOR. Restrictions apply to the availability of these data, which were used under license for this study. Data are available from the authors with the permission of NICOR. The protocol, governance and quality of these data have previously been validated and published.^{10,11} In 2014, approximately 98% of all PCI procedures performed in the National Health Service (NHS) hospital in England & Wales were recorded on this National database (www.bcis.org.uk/). The BCIS database consists of 113 clinical, demographical, procedural and outcomes variables with approximately 80,000 new entries supplemented each year.^{10,11} BCIS records are linked with Office of National Statistics (ONS) data for mortality tracking in all patients from England & Wales by using their unique National Health Service (NHS) numbers. Patients from Scotland and Northern Ireland were not included in this study due to the absence of the ONS-linked mortality data. All patients who received CTO PCI in the setting of an acute coronary syndrome (ACS), or if the data were missing for age, sex and mortality after discharge, were not included in this analysis (Figure 1). Data were collected around patients' clinical & demographical features, risk profile and comorbid conditions as well as aspects of interventional practice and adjunctive pharmacotherapy. All-cause mortality data were captured during index hospital admission, at 30-days and 1-year following the PCI procedure. We also analyzed in-hospital major adverse cardiovascular events (MACE; defined as a composite of in-hospital mortality, in-hospital myocardial infarction, and target vessel revascularization), procedural complications including coronary perforation, major in-hospital bleeding and in-hospital stroke. We defined in-hospital major bleeding as a composite of clinical tamponade after coronary perforation, intracerebral bleed, gastrointestinal bleed, blood or platelet transfusion, retroperitoneal hematoma, or an arterial access site hemorrhage. We also examined a composite endpoint of "any procedural complication" defined as including aortic dissection, coronary perforation, DC cardioversion, heart block requiring pacing, no flow/slow flow phenomenon, need ventilation or cardiogenic shock-following the procedure. We also assessed frequency of target vessel revascularization (TVR) at 30 days and 1 year. TVR was defined if patient underwent a second PCI procedure in same coronary artery. Furthermore, we analyzed temporal changes in interventional practice for these patients from 2007–2014.

Total patients received PCI in UK from 2007-2014: 669,279



Total patients received PCI in England & Wales from 2007-2014: 593,058



Patients with Stable PCI Procedures = 228,370



Patients with CTO PCI Procedures in patient with stable angina = 28,007



Patients with missing data about prior history of CABG are 7,398 & numbers after excluding them from further analysis = 20,609

No use of Patients with missing data for age n = 12, sex n = 38, Mortality data after discharge n = 478, n for further analysis = 20,081



Data for final analysis: n = 20,081

1. CTO PCI in CABG naïve patients = 16,848
2. CTO PCI in Prior CABG patients = 3,233

A CTO lesion was defined as complete occlusion with Thrombolysis in Myocardial Infarction (TIMI) flow grade 0 antegrade through the affected segment of >3 months duration as per previous analyses published from the BCIS dataset.^{12,13} We analyzed data by the number of enabling strategies (ES) used in the index procedure as a marker of procedural complexity as per our previous analyses.¹⁴ ES to facilitate CTO-PCI were described as one of the following: dual arterial access, rotational or laser atherectomy, intravascular ultrasound (IVUS), use of penetration catheters (recorded in the BCIS dataset as Fine cross, corsair, Tornus) or CrossBoss / Stingray balloon.

The PCI cohort was divided into two groups: (group 1) CTO PCI in patients without a history of CABG and (group 2) CTO PCI in patients with prior CABG. For descriptive statistical analysis, continuous variables were presented as median and interquartile ranges, whereas categorical variables were presented using frequencies and proportions. Chi-square tests were applied to evaluate group differences for categorical variables, while rank sum test were used for continuous variables. We applied multiple imputations with chained equations to impute data for all variables with missing records. We applied multivariable logistic regression analysis to assess the risk of adverse outcomes between two groups. In multivariable analysis, we adjusted age, gender, year of procedure, radial access, femoral access, Body Mass Index (BMI), angina class, New York Heart Association (NYHA) class shortness of breath, prior history of smoking, previous history of myocardial infarction, family history of coronary artery disease (CAD), ejection fraction, circulatory support, history of hypercholesterolemia, history of hypertension, history of peripheral vascular disease, history of cerebrovascular accident, history of diabetes mellitus, use of drug-eluting eluted stents (DES) and use of ES on imputed data.

FIGURE 1 Illustration of study inclusion & exclusion criteria: Consort diagram to show to show all participant inclusion and exclusion. CABG; coronary artery bypass grafts; CTO, chronic total occlusion; PCI, percutaneous coronary intervention [Color figure can be viewed at wileyonlinelibrary.com]

Furthermore, we applied propensity score matching (PSM) on imputed data to estimate the average treatment effect, adjusting for baseline differences between the two groups of interest. One to one matching with replacements was performed, followed by logistic regression analysis (the sole predictor being group membership) to gain the average treatment effect. We also performed Kaplan–Meier survival estimates for 30-days and 1-year mortality. Log-Rank test was applied to assess the difference between two groups. Stata 14.2 statistical package was used for all analyses. All statistical analyses were two-tailed, and an alpha of 5% used throughout.

3 | RESULTS

3.1 | Study cohort

Our study cohort consisted of 20,081 patients who received at least 1 CTO PCI procedure in native coronary arteries in England & Wales from January 2007 to December 2014. The inclusion and exclusion of the population for this analysis is presented in Figure 1. Out of 20,081 total patients in this cohort, 16,848 (84%) CTO PCI was performed in patients who had no prior history of CABG surgery whilst 3,233 (16%) procedures were performed in patients with prior CABG (Table 1). The median follow-up of the entire cohort was 3.84 (IQR 2–5.86) years. Temporal changes in practice from 2007–2014 are illustrated in Figure 2. The rate of CTO PCI in prior CABG patients of the total CTO PCI cohort ranged from 15% to 18% during study period.

TABLE 1 Clinical Characteristics

Variable	Missing data from total	CTO PCI in CABG Naïve (16,848)	CTO PCI in prior CABG (3,233)	p value
Median age (IQR)	0	63 (56–71)	68 (61–74)	<.001
Female sex (%)	0	3,393 (24%)	450 (14%)	<.001
Body mass index, median (IQR)	6,017	29 (26–32)	29 (29–32)	.73
CCS class, mean (SD)	1,211	3.2 (0.85)	3.4 (0.82)	<.001
NYHA class, mean (SD)	1,665	1.88 (0.75)	2.01 (0.78)	<.001
Smoking history (%)	1,784	9,928 (64%)	1,828/ (63%)	.19
Diabetes mellitus (%)	635	3,424/ (21%)	986 (32%)	<.001
Hypertension (%)	831	9,826 (61%)	2,122 (69%)	<.001
Hypercholesterolaemia (%)	831	10,570 (65%)	2,134 (69%)	<.001
Previous PCI (%)	167	5,574 (33%)	1,567 (50%)	<.001
Previous MI (%)	1,284	6,164 (39%)	1,755 (59%)	<.001
Previous CVA (%)	831	569 (4%)	152 (5%)	<.001
Peripheral vascular disease (%)	831	890 (6%)	302 (10%)	<.001
Previous renal disease (%)	845	132 (0.81%)	45 (1.49%)	<.001
Family history of heart disease	2,137	7,991 (53%)	1,595 (57%)	<.001
Left ventricular systolic function				
Good (LVEF >50%)	7,557	8,176 (77%)	1,200 (63%)	<.001
Moderate (LVEF 30–50%)		19,78 (19%)	555 (29%)	
Poor (LVEF <30%)		455 (4%)	142 (8%)	
Access site (AS)				
Femoral (%)	0	10,324 (61%)	2,383 (74%)	<.001
Radial (%)	0	7,590 (45%)	1,031 (32%)	<.001
Glycoprotein IIb/IIIa inhibitor	885	1,379 (9%)	224 (7%)	.04
Circulatory support	447	62 (0.38%)	15 (0.48%)	.38
DES use	543	11,450 (70%)	1,846 (59%)	<.001
IVUS use	0	882 (5%)	173 (5%)	.79
Number of stent use				
0	210	4,226 (25%)	1,117 (35%)	<.001
1		4,212 (25%)	697 (22%)	
2		3,880 (24%)	585 (18%)	
≥3		4,374 (26%)	780 (25%)	
Mechanical ventilator support (%)	1,698	44 (0.28%)	20 (0.73%)	<.001
Median follow up period in years (IQR)	0	3.86 (2.01–5.9)	3.72 (1.85–5.75)	.004
Enabling strategies (ES)				
No ES used	487	11,014 (67%)	1,911 (62%)	<.001
No of enabling Strategies ^a use = 1		4,108 (25%)	766 (25%)	
No of enabling Strategies ^a use = 2		1,064 (6%)	285 (9%)	
No of enabling Strategies ^a use = > 3		341/16,527 (2%)	105/3,067 (4%)	
RCA as a target artery	170	8,861 (53%)	1,357 (43%)	<.001
LCX as a target artery	170	3,842 (23%)	882 (28%)	<.001
LAD as a target artery	170	6,754 (40%)	545 (17%)	<.001
Multi vessel PCI	170	2,661 (16%)	623 (20%)	<.001
Successful PCI	0	12,303 (73%)	1,626 (50%)	<.001

Abbreviations: CCS, Canadian Cardiovascular Society; CTO, chronic total occlusion; CVA, cerebrovascular accident; DES, drugs eluted stents; IQR; inter quartile range; LVEF, left ventricle ejection fraction; MI, myocardial infarction; NYHA, New York heart association; PCI, percutaneous coronary intervention.

^aEnabling Strategies to facilitate CTO-PCI were defined as one of the following: dual arterial access, intravascular ultrasound, atherectomy (rotational or laser), penetration catheters (recorded in the BCIS database as Tornus, Asahi Intecc, Santa Ana, CA or Gopher Gold, Vascular Solutions, Minneapolis, MN), microcatheters, or CrossBoss/Stingray balloon.

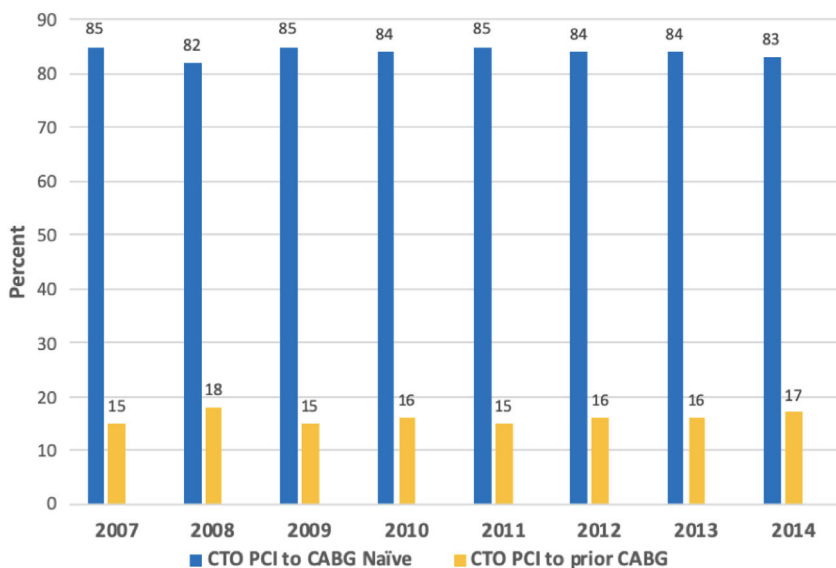


FIGURE 2 Yearly comparisons of CTO PCI in native arteries from 2007–2014 in patients with & without prior CABG: Temporal trends of CTO PCI in CABG naïve Patients vs CTO PCI in prior CABG patients. CABG; coronary artery bypass grafts; CTO, chronic total occlusion; PCI, percutaneous coronary intervention [Color figure can be viewed at wileyonlinelibrary.com]

3.2 | Clinical characteristics

Significant differences were observed in demographics, clinical and procedural characteristics between the two groups (Table 1). Patients who received CTO PCI and had prior history of CABG were older, more likely to be male, had a higher prevalence of DM, hypertension, hypercholesterolaemia, previous MI or PCI, peripheral vascular disease, family history of CAD, and worse angina, breathlessness and left ventricular systolic dysfunction (LVSD) as compared to those without CABG. Prior history of smoking, use of circulatory support and intra-vascular ultrasound during PCI were similar between the two groups.

Patients without CABG were more likely to receive drug eluting stents (DES) (70% vs. 59%, $p < .001$) and utilization of enabling strategies was higher when CTO PCI was performed in prior CABG patients (38% vs. 33% $p < .001$). More patients received PCI in left circumflex artery (28% vs. 23%, $p < .001$) & left main stem artery (13% vs. 1.45%) in prior CABG patients but lesser in right coronary artery (43% vs. 53, $p < .001$) and left anterior descending artery (17% vs. 40%, $p < .001$) compared to CABG naïve patients. Success of CTO PCI was higher in CABG naïve patients (73% vs. 50%, $p < .001$) compared to those who had previous CABG surgery.

3.3 | Unadjusted clinical outcomes

The unadjusted clinical outcomes are presented in Table 2. Crude mortality in group 2 was similar during index admission (0.34% vs. 0.18%, $p = .05$, higher at 30 days (0.80% vs. 0.43%, $p = .005$) and at 1 year (3% vs. 2%, $p < .001$) compared to group 1. In-hospital transfusion of blood products (group 1 = 0.23%, group 2 = 0.13%, $p = .22$), stroke (group 1 = 0.04%, group 2 = 0, $p = .25$) and MACE (group 1 = 0.91%, group 2 = 1.13%, $p = .24$) were similar between the two groups. Similarly, rates of procedural complications (8% vs. 9%, $P 0.26$) and coronary perforations (1.42% vs. 1.51%, $P 0.61$) were similar in both cohorts.

Finally, the crude rate TVR was similar (0.63% vs. 0.70%, $p = .68$) at 30 days, higher at 1 year (6% vs. 5%, $p = <.004$) and at any time during study follow up period (7% vs. 6%, $p = <.001$) in prior CABG CTO PCI patients compared to CABG naïve (Table 2).

Kaplan–Meier survival estimates at 30 days and 1 year are presented in Figure 3. In a separate subgroup clinical outcome analyses according to usage of ES are presented in Supplementary Tables 1–4.

3.4 | Adjusted clinical outcomes

The adjusted risk of procedural complications, short- and long-term mortality, in-hospital MACE and TVR are presented in Table 3. In the multivariable statistical analysis, the composite risk of any procedural complication (OR 1.02, CI 0.88–1.18, $P 0.81$) and coronary artery perforation (OR 0.89, CI 0.64–1.23, $P 0.48$) were similar between two groups. After adjustment of baseline characteristics, no significant differences in mortality were observed between the groups during index admission (OR 1.33, CI 0.64–2.78, $p = .44$), at 30 days (OR 1.28, CI 0.79–2.06, $p = .31$) and at 1 year of follow up (OR 1.02, CI 0.81–1.29, $p = .87$). In addition, no significant differences in in-hospital MACE were observed between the two cohorts (OR 1.01, CI 0.69–1.49, $p = .95$) after adjustment of baseline covariates. Finally, the risk of TVR was also similar between two groups at each study endpoints (anytime (OR: 1.05 CI 0.87–1.27, $P 0.6$), 30 days (OR: 0.68, CI 0.4–1.16, $P 0.16$) and 1 year (OR: 1.01, CI 0.83–1.22, $P 0.95$)).

3.5 | Analysis with propensity score-matching

In a propensity score matching analysis the adjusted composite risk of any procedural complication (OR 1.05, CI 0.83–1.28, $P 0.67$), coronary vessel perforation (OR 0.93, CI 0.49–1.38, $p = .77$) and in-hospital MACE (OR: 1.03, CI 0.45–1.62, $P = 0.91$) did not differ significantly when CTO PCI undertaken in either prior CABG or CABG naïve

TABLE 2 Unadjusted clinical outcomes

Outcome	Missing data from total	CTO PCI in CABG Naïve (16,848)	CTO PCI in prior CABG (3,233)	p value
Transfusions (%), n (%)	293	39 (0.23%)	4 (0.13%)	.22
In hospital major bleeding ^a , n (%)	292	189 (1.14%)	38 (1.19%)	.8
In-hospital mortality, n (%)	348	29 (0.18%)	11 (0.34%)	.05
30-day mortality, n (%)	0	72 (0.43%)	26 (0.80%)	.005
1-year mortality, n (%)	0	357 (2%)	105 (3%)	<.001
In-hospital MACE ^b	293	151 (0.91%)	36 (1.1%)	.24
In-hospital stroke	293	7 (0.04%)	0	.25
Procedural complications (%)				
Any procedural complications ^c	988	1,363 (8%)	278 (9%)	.26
Coronary perforation	988	228 (1.42%)	47 (1.54%)	.61
Retroperitoneal hemorrhage	551	20 (0.12%)	5 (0.16%)	.57
Renal failure/dialysis	293	7 (0.04%)	0	.25
TVR anytime	2,295	841 (6%)	198 (7%)	<.001
TVR during 30 days	2,295	105 (0.70%)	17 (0.63%)	.68
TVR during 365 days	2,295	740 (5%)	169 (6%)	.004

Note: +Emergency CABG or PCI.

Abbreviations: CTO, chronic total occlusion; MACE, major adverse cardiovascular events; PCI, percutaneous coronary intervention; TVR, target vessel revascularization.

^aMajor bleeding: Need blood or platelets transfusions, haemorrhagic stroke, tamponade, retroperitoneal hemorrhage.

^bMACE; Major adverse cardiovascular events (defined as a composite of in-hospital mortality, in-hospital myocardial reinfarction, and emergency target vessel revascularization).

^cAny procedural complication includes Aortic dissection, Coronary perforation, Heart block requiring pacing, DC cardioversion, no flow/slow flow phenomenon, need ventilation, Shock induced by procedure.

patients (Table 4). Similarly, the adjusted risk of mortality during index admission (OR 1.30, CI 0.31–2.30, $P = 0.55$), at 30 days (OR 1.24, CI 0.63–1.85, $P = 0.44$) and at 1 year of follow up (OR 1.03, CI 0.76–1.31, $p = .84$) were similar between the two groups.

We undertook sensitivity analyses to assess adverse clinical outcomes according to success of CTO PCI and the results are presented in supplement Tables 5–6. Adjusted risk of short- and long-term mortality & in-patient MACE were similar between the two groups whether the CTO PCI was successful or not.

We performed sensitivity analysis according to hospital volume of total CTO PCI procedures during study period by dividing data into four quartiles (75th percentile - 270 CTO PCI, 50th percentile - 116 CTO PCI, 25th percentile 37 CTO PCI) and results are presented in Supplement Tables 7–10. We observed no difference in short- or long-term adverse clinical outcomes in any of these quartiles either CTO PCI were attempted in prior CABG or CABG naïve patients. The adjusted risk of mortality during index admission (OR 1.99, CI 0.83–4.82, $P = 0.12$), at 30 days (OR 1.61, CI 0.91–2.87, $P = 0.10$) and at 1 year of follow up (OR 0.92, CI 0.655–1.30, $p = .64$) were similar between the two groups in most high-volume hospital quartile. Similar results were obtained when most high-volume quartile used $> = 1$ ES during CTO PCI (supplement Table 8).

We undertook another sensitivity analysis by consultant volume of total CTO procedures by dividing the data into four quartiles (75th percentile - 58 CTO PCI, 50th percentile 31 CTO PCI, 25th percentile - 19 CTO PCI) and results are presented in supplement Tables 11–14.

Similarly, the adjusted risk of mortality during index admission (OR 1.91, CI 0.67–5.4, $P = 0.23$), at 30 days (OR 1.43, CI 0.70–2.92, $P = .32$) and at 1 year of follow up (OR 0.92, CI 0.655–1.30, $p = .64$) were similar between the two groups in the most experienced operators' quartile. No difference in adverse clinical outcomes were observed when the most experienced consultant cohort used one or more ES (supplement Table 12).

Supplement Figure 1 is demonstrating adjusted spline analysis for ES use by the year of procedure. We observed lower probability of ES used during early years of study which gradually rise with time but notice little change during last 2 years of study (2013–14). We performed two further sensitivity analyses in view of spline analysis results, first by inclusion of patients who received CTO PCI in 2013–14 and second who received in 2011–2014. We again observed similar results and did not observe any difference in adverse clinical outcomes between two study cohorts (Supplement Tables 15–16).

In another multivariable sensitivity analysis, we assessed clinical outcomes in successful vs unsuccessful CTO PCI in both study cohorts separately (Supplement Tables 17–18). In CABG naïve patients, odds of any procedural complication were lower when CTO PCI was successful (OR: 0.71, 95% CI 0.61–0.83, $p < .001$) compared to unsuccessful procedures, while all other clinical outcomes were independent from procedure success (Supplement Table 17). In prior CABG patients, odds of 30-days mortality were lower when CTO PCI was successful (OR: 0.33, 95% CI 0.13–

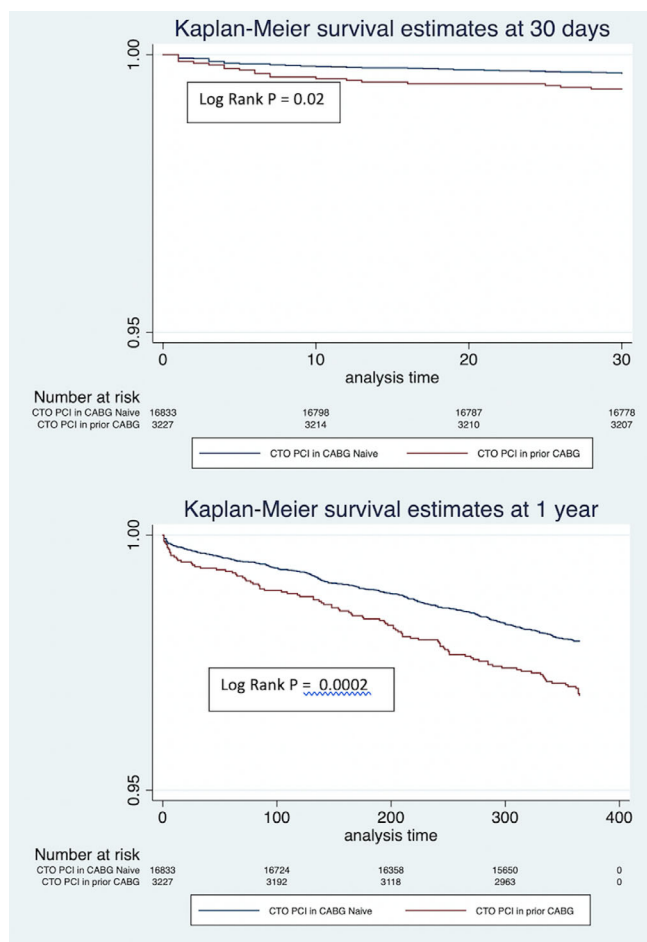


FIGURE 3 Comparison of Kaplan-Meier survival estimates of CTO PCI between study groups: KM survival estimates at 30 days and 1 year between two groups. CABG; coronary artery bypass grafts; CTO, chronic total occlusion; PCI, percutaneous coronary intervention [Color figure can be viewed at wileyonlinelibrary.com]

0.86, $p = .02$) compared to unsuccessful procedures, while all other clinical outcomes remain similar in both cohorts (Supplement Table 18).

Figure 4 provides a graphical overview of the main study findings.

4 | DISCUSSION

Our national real-world analysis suggests that patients with a prior history of CABG surgery who undergo CTO PCI are older, have more complex disease necessitating greater use of enabling strategies and have a greater burden of co-morbid illnesses compared to those who have never had CABG surgery. Following adjustment for these differences in baseline characteristics, there was similar adjusted risk of any procedural complications; vessel perforation, short- and long-term mortality, TVR and in-hospital MACE between the two groups and these results were independent of procedure success. To our knowledge, this is the first national analysis that compares and contrasts

clinical outcomes in prior CABG versus CABG naïve patients undergoing CTO PCI in native coronary arteries.

The relationship between CABG surgery and more aggressive progression of atherosclerosis in native coronary arteries is well reported in literature.^{15,16} Sakakura et al. demonstrated that CTO lesions in prior CABG patients had higher degree of calcification, moderate negative remodeling and higher prevalence of blunt stumps compared to CABG naïve.¹⁷ These angiographic features are also associated with challenging recanalization process and incorporated in risk scores to predict technical failure, for instance in the J-CTO and RECHARGE (Registry of CrossBoss and Hybrid procedures in France, the Netherlands, Belgium and United Kingdom) scores.^{18,19} In many other studies, prior CABG patients were found to be older, having more comorbid conditions compared to those without prior CABG, in line with our findings. Therefore, taking all these factors into account, it is perhaps not surprising that several studies have demonstrated that a previous history of CABG is a predictor of procedural failure of CTO PCI.^{8,20-22}

Nevertheless, clinical outcomes of CTO PCI according to CABG status have not been extensively studied. In a retrospective analysis of 470 CTO (Post CABG $n = 175$, CABG naïve $n = 295$) cases treated with PCI, the rate of in-hospital complications (death, type IV MI, stroke, tamponade, urgent surgery, major bleeding) was similar between patients with prior CABG and those without.²² However, at one-year, a prior history of CABG was associated with higher risk of MACE. Of course, the small sample size and the fact that this was a single center experience were limitations of this study. In another study of 2,058 CTO PCI patients (prior CABG $n = 401$, CABG naïve $n = 1,657$) by Azzalini et al., 24-month target vessel failure was higher in CTO PCI undertaken in CABG patients (16.1% vs. 9%, $p < .001$).¹⁵ This was an observational study conducted in seven specialist centers and involving highly experienced CTO PCI operators. Once again, there are important limitations to this work. Specifically, low event rates of major complications observed during in hospital admission (in-hospital death (0.34%), procedure related death (0.19%), stroke (0.39%), peri-procedural MI (0.78%), perforation (1.3%)) meant that there was insufficient statistical power to perform multivariable analyses. Secondly, although TVF was assessed in multi-variable analysis, individual endpoints were not reported probably due to small event rates at long term follow up (cardiac death (2%), target vessel MI (0.83%), TVR (6%)). There are a number of possible explanations that may contribute to the differences between our observations and these. Firstly, in the Azzalini study, their sample included 11% ACS patients, whereas our study population were comprised of stable angina patients only. Secondly, due to small overall numbers in their study, individual in-hospital clinical outcomes were underpowered (seven deaths and eight strokes in 2,058 patients) to assess real differences between the study cohorts. Thirdly, 14% of patients were lost to follow up in Azzalini study, compared to our study where we have followed up mortality data of all the participants included. Fourthly, different endpoints were studied. Azzalini & colleagues assess TVF (a composite endpoint of cardiac death, target vessel myocardial infarction, ischemia driven TVR), whereas we analyzed target vessel

TABLE 3 Risk of Adverse Outcomes following multivariate adjustments

Outcome	Adjusted OR ^a as compare to reference (CTO PCI in CABG naive)	p value	95% CI
Any procedural complications, n of observations = 19,914	OR 1.02	.81	0.88–1.18
Coronary artery perforation as procedural complication, n = 20,079	OR 0.89	.48	0.64–1.23
In-hospital mortality n of observations = 20,081	OR 1.33	.44	0.64–2.78
Procedural success, n = 20,077	OR: 0.34	<.001	0.31–0.38
30-day mortality n of observations = 20,079	OR 1.28	.31	0.79–2.06
1-year mortality, n of observations = 20,079	OR 1.02	.87	0.81–1.29
In-hospital MACE, n = 20,081	OR 1.01	.95	0.69–1.49
TVR anytime (n = 18,134)	OR 1.05	.6	0.87–1.27
TVR 30 days (n = 18,134)	OR 0.68	.16	CI 0.40–1.16
TVR 365 days (n = 18,134)	OR 1.01	.95	0.83–1.22

Note: OR, odds ratio and MACE, Major adverse cardiovascular events (defined as a composite of in-hospital mortality, in-hospital myocardial reinfarction, and emergency target vessel revascularization).

Abbreviations: CI, confidence interval; CTO, chronic total occlusion; MACE, major adverse cardiovascular events; n, number for analysis; OR, odds ratio; PCI, percutaneous coronary intervention; TVR, target vessel revascularization.

^aAdjusted for Age, gender, year of procedure, radial access, femoral access Body Mass Index, Angina class, NYHA class, prior history of (H/O) smoking, prior H/O Myocardial infarction, ejection fraction, family H/O coronary artery disease, circulatory support, prior H/O hypercholesterolemia, prior H/O hypertension, prior H/O peripheral vascular disease, prior H/O Cerebrovascular accident, prior H/O Diabetes Mellitus, year of procedure, use of Drug eluted stents & use of enabling strategies on imputed data.

TABLE 4 Propensity Score-Matched Analysis with Average Treatment Effects on imputed data

Outcome	Group	Coefficient ^a (95% CI)	Odds Ratio ^a (95% CI)	p value
Any procedural complications (n = 19,706)	group 1: CTO PCI in CABG naive	Reference		
	group 2: CTO PCI in prior CABG	0.0040216 (–0.0144907 to 0.022534)	1.05 (0.83–1.28)	.67
Perforation- complications (n = 19,704)	group 1: CTO PCI in CABG naive	Reference		
	group 2: CTO PCI in prior CABG	–0.0010099 (–0.0078223 to 0.0058024)	0.93 (0.49–1.38)	.77
In-hospital mortality (n = 19,706)	group 1: CTO PCI in CABG naive	Reference		
	group 2: CTO PCI in prior CABG	0.00102 (–0.0023474 to 0.0043874)	1.30 (0.31–2.30)	.55
30-day mortality (n = 19,704)	group 1: CTO PCI in CABG naive	Reference		
	group 2: CTO PCI in prior CABG	0.0018778 (–0.0029137 to 0.0066693)	1.24 (0.63–1.85)	.44
1-y mortality (n = 19,704)	group 1: CTO PCI in CABG naive	Reference		
	group 2: CTO PCI in prior CABG	0.0008425 (–0.0071284 to 0.0088133)	1.03 (0.76–1.31)	.84
In-hospital MACE (n = 19,706)	group 1: CTO PCI in CABG naive	Reference		
	group 2: CTO PCI in prior CABG	0.0003704 (–0.0061776 to 0.0069185)	1.03 (0.45–1.62)	.91

^aAdjusted for Age, gender, year of procedure, radial access, femoral access Body Mass Index, Angina class, NYHA class, prior history of (H/O) smoking, prior H/O Myocardial infarction, ejection fraction, family H/O coronary artery disease, circulatory support, prior H/O hypercholesterolemia, prior H/O hypertension, prior H/O peripheral vascular disease, year of procedure, prior H/O Cerebrovascular accident, prior H/O Diabetes Mellitus, use of Drug eluted stent & use of enabling strategies on imputed data.

revascularization and mortality as individual endpoints. Finally, the centers included in the analysis of Azzalini et al. were expert CTO centers and the complexity of CTO procedures may have been greater than the CTO procedures undertaken in a national analysis, a factor that may magnify any differences in outcomes between the two cohorts studied, particularly for more complex CTO cases.

Several observational studies have reported the association of successful CTO PCI with better clinical outcomes compared to non-successful CTO PCI. These studies demonstrated better symptoms control, improved self-reported quality of life, exercise tolerance and significant reduction in myocardial ischemia and modest positive effect on left ventricular function.^{4,5,23–25} Randomized control clinical trials like DECISION-CTO and EUROCTO tried to explore survival

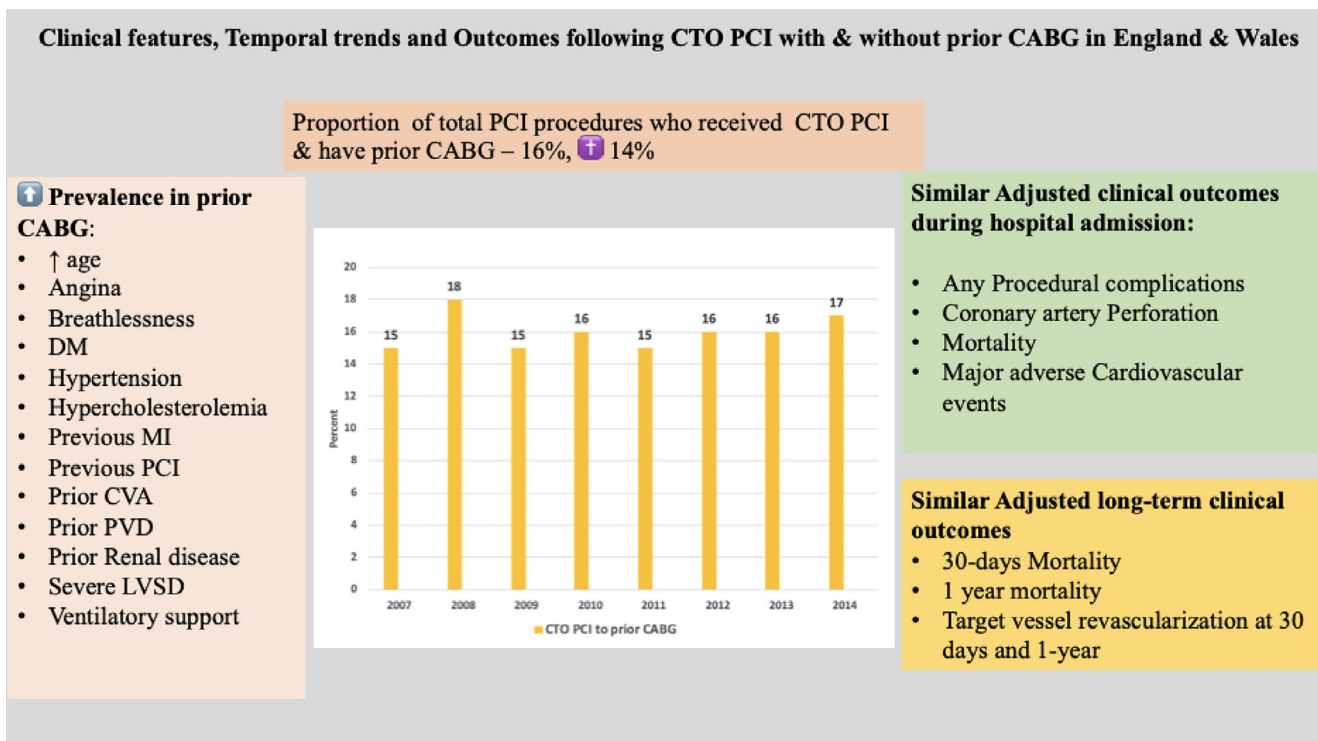


FIGURE 4 Central illustration Figure. Summary figure: CABG, coronary artery bypass grafts; CTO, chronic total occlusion; CVA, cerebrovascular accident; CVA, cerebrovascular accident; DM, diabetes mellitus; MI, myocardial infarction; PCI, percutaneous coronary intervention; PVD, peripheral vascular disease; LVSD, left ventricular systolic dysfunction [Color figure can be viewed at wileyonlinelibrary.com]

benefit of CTO PCI over optimum medical therapy (OMT). In the DECISION-CTO trial, the 3 years rate of composite endpoint of all cause death, stroke, MI and revascularization was similar between the PCI and OMT cohorts (20.6% vs. 19.6%).²⁶ In the EUROCTO trial, CTO PCI was associated with better symptoms control and improved quality of life but hard endpoints like cardiovascular death or MI were similar (5% in PCI arm, 2.9 in OMT, $p = .32$) between the two groups at 3 years of follow up.²⁷ In a recently published systematic review and meta-analysis of 17 studies and a total of 11,493 patients, a statistically significant association between CTO PCI and lower risk of all-cause mortality, cardiac death, MI, MACE was reported when compared to medical therapy.²⁸ However, this was predominantly driven by observation cohorts which would be limited by unmeasured confounders. The randomized trials considered in this meta-analysis showed no significant associations between CTO PCI and overall mortality, cardiac death, repeat revascularization and MACE.

One of the dominant drivers for increased CTO PCI in CABG patients is the perception that the outcome from SVG PCI is unsatisfactory as a medium- and long-term solution. Thus, many observational studies indicate that PCI to SVG is less efficacious than to native coronary arteries in CABG patients,^{29,30} being associated with lower success, higher complication rates and adverse long-term outcomes (mortality, myocardial infarction, and target vessel revascularization) as compared to PCI undertaken in native coronary arteries. Therefore, in contemporary interventional practice, it is increasingly believed that lesions in native coronary arteries should

be preferred target for PCI in the prior CABG patients, even if these are CTOs.²⁹

The current analysis adds to our current knowledge base about CTO PCI. Our analysis shows that after adjustment of baseline clinical differences, the risk of CTO PCI procedure-related complications, in-hospital MACE, stroke, short- and long-term mortality are not increased in those with a history of prior CABG presenting with stable angina. Based upon these findings, in present era of high success and acceptable complication rates, patient selection for CTO PCI should be focused on anticipated patient benefits instead of concern about perceived increased procedural complexity and procedural failure by virtue of prior CABG surgery. Our study confirms that prior CABG status does not affect complication rates in patients undergoing CTO PCI.

5 | LIMITATIONS

BCIS endeavors to record data about every PCI procedure undertaken in the UK and the nationwide participation from all NHS hospitals in the UK make it a national representation. This dataset also captures information from almost all patients received PCI in UK from a wide range of spectrum. Our large sample size gives us sufficient statistical power to capture differences in clinical outcomes between the patient groups studied. Moreover, majority of these patients are often excluded or under-represented in clinical trials, and so our data

represents important evidence in this context. However, due to inclusion of all the CTO procedures in this study, the overall cohort might be heterogenous where some CTO lesions are relatively low risk, or performed by non-CTO or less experienced operators, or in low volume hospitals. We tried to assess these potential limitations in our series of adjusted sensitivity analyses (Supplementary Tables 7–16) but did not find any significant difference in terms of adverse clinical outcomes between the two cohorts, neither in the high-volume centers nor by experience of CTO PCI operators.

However, our study has several other limitations. First, it is a retrospective analysis of prospectively collected national data and has all the inherent bias ascribed to this kind of study design. Secondly, though mortality tracking within England and Wales is well structured through ONS linkage, the cause of death is not available. Thirdly, all other clinical outcomes and post procedural complications are self-reported, without formal adjudication, and thus susceptible to reporting bias. Fourthly, apart from mortality and TVR, BCIS dataset does not record other post discharge clinical outcomes like readmission due to ACS or stroke. Fifth the BCIS dataset does not record the complexity of CTO lesions according to modern scoring systems (J-CTO or RECHARGE). Sixth, in pre-CABG cohort, the BCIS dataset does not capture information whether CTO PCI is attempted in a grafted or un-grafted vessel which may affect the overall complexity of procedure. Finally, the database does not collect data regarding procedural time, radiation dose and contrast volume during the CTO PCI procedures.

6 | CONCLUSION

Our study demonstrates that approximately one in six CTO PCI procedures were undertaken in patients with a prior history of CABG in England & Wales. These patients are a higher risk group that are older, have more comorbid conditions and have more complex disease. After adjustment of differences in baseline clinical and procedural characteristics, we report that clinical outcomes are not significantly different between patients who undergo CTO PCI with or without a prior history of CABG. These data indicate that history of CABG is not a risk factor for adverse outcome in CTO PCI.

CONFLICT OF INTEREST

None.

DATA AVAILABILITY STATEMENT

The data that supports findings of this study are available from NICOR. Restrictions apply to the availability of these data, which were used under license for this study. Data are available from the authors with the permission of NICOR.

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REFERENCES

1. Stone GW, Kandzari DE, Mehran R, et al. Percutaneous recanalization of chronically occluded coronary arteries: a consensus document: part I. *Circulation*. 2005;112(15):2364-2372.
2. Fefer P, Knudtson ML, Cheema AN, et al. Current perspectives on coronary chronic total occlusions: the Canadian multicenter chronic total occlusions registry. *J Am Coll Cardiol*. 2012;59(11):991-997.
3. Ramunddal T, Høebers LP, Henriques JP, et al. Chronic total occlusions in Sweden—a report from the Swedish coronary angiography and angioplasty registry (SCAAR). *PLoS One*. 2014;9(8):e103850.
4. Christakopoulos GE, Christopoulos G, Carlino M, et al. Meta-analysis of clinical outcomes of patients who underwent percutaneous coronary interventions for chronic total occlusions. *Am J Cardiol*. 2015; 115(10):1367-1375.
5. Safley DM, Grantham JA, Hatch J, Jones PG, Spertus JA. Quality of life benefits of percutaneous coronary intervention for chronic occlusions. *Catheter Cardiovasc Interv*. 2014;84(4):629-634.
6. Rupprecht HJ, Hamm C, Ischinger T, Dietz U, Reimers J, Meyer J. Angiographic follow-up results of a randomized study on angioplasty versus bypass surgery (GABI trial). *GABI Study Group Eur Heart J*. 1996;17(8):1192-1198.
7. Widimsky P, Straka Z, Stros P, et al. One-year coronary bypass graft patency: a randomized comparison between off-pump and on-pump surgery angiographic results of the PRAGUE-4 trial. *Circulation*. 2004; 110(22):3418-3423.
8. Michael TT, Karpaliotis D, Brilakis ES, et al. Impact of prior coronary artery bypass graft surgery on chronic total occlusion revascularisation: insights from a multicentre US registry. *Heart*. 2013;99(20):1515-1518.
9. Mehran R, Claessen BE, Godino C, et al. Long-term outcome of percutaneous coronary intervention for chronic total occlusions. *JACC Cardiovasc Interv*. 2011;4(9):952-961.
10. Rashid M, Ludman PF, Mamas MA. British cardiovascular intervention society registry framework: a quality improvement initiative on behalf of the National Institute of cardiovascular outcomes research (NICOR). *Eur Heart J Qual Care Clin Outcomes*. 2019;5(4):292-297.
11. Shoaib A, Kinnaird T, Curzen N, et al. Outcomes following percutaneous coronary intervention in non-ST-segment-elevation myocardial infarction patients with coronary artery bypass grafts. *Circ Cardiovasc Interv*. 2018;11(11):e006824.
12. Schumacher SP, Stuijtzand WJ, Opolski MP, van Rossum AC, Nap A, Knaapen P. Percutaneous coronary intervention of chronic Total occlusions: when and how to treat. *Cardiovasc Revasc Med*. 2019;20 (6):513-522.
13. Henriques JP, Høebers LP, Ramunddal T, et al. Percutaneous intervention for concurrent chronic total occlusions in patients with STEMI: the EXPLORE trial. *J Am Coll Cardiol*. 2016;68(15):1622-1632.
14. Kinnaird T, Gallagher S, Cockburn J, et al. Procedural success and outcomes with increasing use of enabling strategies for chronic Total occlusion intervention. *Circ Cardiovasc Interv*. 2018;11(10):e006436.
15. Azzalini L, Ojeda S, Karatasakis A, et al. Long-term outcomes of percutaneous coronary intervention for chronic Total occlusion in patients who have undergone coronary artery bypass grafting vs those who have not. *Can J Cardiol*. 2018;34(3):310-318.
16. Pereg D, Fefer P, Samuel M, et al. Native coronary artery patency after coronary artery bypass surgery. *JACC Cardiovasc Interv*. 2014;7 (7):761-767.
17. Sakakura K, Nakano M, Otsuka F, et al. Comparison of pathology of chronic total occlusion with and without coronary artery bypass graft. *Eur Heart J*. 2014;35(25):1683-1693.
18. Maeremans J, Spratt JC, Knaapen P, et al. Towards a contemporary, comprehensive scoring system for determining technical outcomes of hybrid percutaneous chronic total occlusion treatment: the RECHARGE score. *Catheter Cardiovasc Interv*. 2018;91(2):192-202.

19. Morino Y, Abe M, Morimoto T, et al. Predicting successful guidewire crossing through chronic total occlusion of native coronary lesions within 30 minutes: the J-CTO (multicenter CTO registry in Japan) score as a difficulty grading and time assessment tool. *JACC Cardiovasc Interv.* 2011;4(2):213-221.
20. Teramoto T, Tsuchikane E, Matsuo H, et al. Initial success rate of percutaneous coronary intervention for chronic total occlusion in a native coronary artery is decreased in patients who underwent previous coronary artery bypass graft surgery. *JACC Cardiovasc Interv.* 2014;7(1):39-46.
21. Christopoulos G, Menon RV, Karpaliotis D, et al. Application of the "hybrid approach" to chronic total occlusions in patients with previous coronary artery bypass graft surgery (from a contemporary multicenter US registry). *Am J Cardiol.* 2014;113(12):1990-1994.
22. Dautov R, Manh Nguyen C, Altisent O, Gibrat C, Rinfret S. Recanalization of chronic Total occlusions in patients with previous coronary bypass surgery and consideration of retrograde access via saphenous vein grafts. *Circ Cardiovasc Interv.* 2016;9(7):e003515.
23. Rossello X, Pujadas S, Serra A, et al. Assessment of inducible myocardial ischemia, quality of life, and functional status after successful percutaneous revascularization in patients with chronic Total coronary occlusion. *Am J Cardiol.* 2016;117(5):720-726.
24. Hoebbers LP, Claessen BE, Elias J, Dangas GD, Mehran R, Henriques JPS. Meta-analysis on the impact of percutaneous coronary intervention of chronic total occlusions on left ventricular function and clinical outcome. *Int J Cardiol.* 2015;187:90-96.
25. Wijnand JS, Biesbroek PS, Pieter GR, et al. Effects of successful percutaneous coronary intervention of chronic total occlusions on myocardial perfusion and left ventricular function. *EuroIntervention.* 2017;13(3):345-354.
26. Werner GS, Martin-Yuste V, Hildick-Smith D, et al. A randomized multicentre trial to compare revascularization with optimal medical therapy for the treatment of chronic total coronary occlusions. *Eur Heart J.* 2018;39(26):2484-2493.
27. Allahwala UK, Ward MR, Brieger D, Weaver JC, Bhindi R. Indications for percutaneous coronary intervention (PCI) in chronic Total occlusion (CTO): have we reached a DECISION or do we continue to EXPLORE after EURO-CTO? *Heart Lung Circ.* 2019;28(10):1484-1489.
28. Li KHC, Wong KHG, Gong M, et al. Percutaneous coronary intervention versus medical therapy for chronic Total occlusion of coronary arteries: a systematic review and meta-analysis. *Curr Atheroscler Rep.* 2019;21(10):42.
29. Brilakis ES, O'Donnell CI, Penny W, et al. Percutaneous coronary intervention in native coronary arteries versus bypass grafts in patients with prior coronary artery bypass graft surgery: insights from the veterans affairs clinical assessment, reporting, and tracking program. *JACC Cardiovasc Interv.* 2016;9(9):884-893.
30. Bundhoo SS, Kalla M, Anantharaman R, et al. Outcomes following PCI in patients with previous CABG: a multi Centre experience. *Catheter Cardiovasc Interv.* 2011;78(2):169-176.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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