JACC: CARDIOVASCULAR INTERVENTIONS VOL. 12, NO. 4, 2019

PUBLISHED BY ELSEVIER

Procedural Outcomes of Percutaneous Coronary Interventions for Chronic Total Occlusions Via the Radial Approach

Insights From an International Chronic Total Occlusion Registry

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ABSTRACT

OBJECTIVES This study examined the frequency and outcomes of radial access for chronic total occlusion (CTO) percutaneous coronary intervention (PCI).

BACKGROUND Radial access improves the safety of PCI, but its role in CTO PCI remains controversial.

METHODS We compared the clinical, angiographic, and procedural characteristics of 3,790 CTO interventions performed between 2012 and 2018 via radial-only access (RA) ($n = 747$) radial-femoral access (RFA) ($n = 844$) and femoral-only access ($n = 2{,}199$) access at 23 centers in the United States, Europe, and Russia.

RESULTS Patients' mean age was 65 ± 10 years, and 85% were men. Transradial access (RA and RFA) was used in 42% of CTO interventions and significantly increased over time from 11% in 2012 to 67% in 2018 ($p < 0.001$). RA patients were younger (age 62 ± 10 years vs. 64 ± 10 years and 65 ± 10 years; $p < 0.001$), less likely to have undergone prior coronary artery bypass graft surgery (18% vs. 39% and 35%; $p < 0.001$), and less likely to have undergone prior PCI (60% vs. 63% and 66%; $p = 0.005$) compared with those who underwent RFA and femoral-only access PCI. RA CTO PCI lesions had lower J-CTO (Multicenter CTO Registry in Japan) (2.1 ± 1.4 vs. 2.6 ± 1.3 and 2.5 ± 1.3; $p < 0.001$) and PROGRESS CTO (Prospective Global Registry for the Study of Chronic Total Occlusion Intervention) complication (2.3 ± 1.9 vs. 3.2 ± 2.0 and 3.2 ± 1.9; $p < 0.001$) scores. The mean sheath size was significantly smaller in the RA group (6.6 ± 0.7 vs. 7.0 ± 0.6 and 7.3 ± 0.8; $p < 0.0001$), although it increased with lesion complexity. Antegrade dissection re-entry (20% vs. 33% and 32%; $p < 0.001$) was less commonly used with RA, whereas use of retrograde techniques was highest with RFA (47%). The overall rates of technical success (89% vs. 88% vs. 86%; $p = 0.061$), procedural success (86% vs. 85% vs. 85%; $p = 0.528$), and in-hospital major complication (2.47% vs. 3.40% vs. 2.18%; $p = 0.830$) were similar in all 3 groups, whereas major bleeding was lower in the RA group (0.55% vs. 1.94% and 0.88%; $p = 0.013$).

CONCLUSIONS Transradial access is increasingly being used for CTO PCI and is associated with similar technical and procedural success and lower major bleeding rates compared with femoral-only access interventions. (Prospective Global Registry for the Study of Chronic Total Occlusion Intervention [PROGRESS CTO]; NCT02061436) (J Am Coll Cardiol Intv 2019;12:346–58) © 2019 by the American College of Cardiology Foundation.

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ISSN 1936-8798/$36.00 https://doi.org/10.1016/j.jcin.2018.11.019

The hybrid approach (1) to chronic total occlusion (CTO) percutaneous coronary intervention (PCI) is increasingly being used to achieve revascularization in this challenging lesion subset (2–4). Use of dual (and occasionally triple) arterial access is key for understanding the characteristics of the CTO, using retrograde crossing strategies, and improving the safety of the procedure. Since its description by Campeau (5), radial access has become the dominant approach for non-CTO PCI in most countries, but its use in CTO PCI has been low (6–10), possibly in part because of smaller sheath size (11,12). We examined the outcomes and temporal trends of transradial access use for CTO PCI in a large multicenter CTO PCI registry.

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METHODS

We analyzed the clinical, angiographic, and procedural characteristics of 3,790 CTO PCIs performed in 3,709 patients consecutively enrolled in the PROGRESS CTO (Prospective Global Registry for the Study of Chronic Total Occlusion Intervention; NCT02061436) registry between May 2012 and July 2018 at 21 U.S., 1 European, and 1 Russian center (Online Appendix). Some centers enrolled patients during only part of the study period because of participation in other studies. The study was approved by the Institutional Review Board of each center.

DEFINITIONS. Coronary CTO was defined as a coronary lesion with TIMI (Thrombolysis In Myocardial Infarction) flow grade 0 of at least 3 months' duration. Estimation of the duration of occlusion was clinical, on the basis of the first onset of angina, history of myocardial infarction (MI) in the target vessel territory, or comparison with a prior angiogram. Calcification was assessed by angiography as mild (spots), moderate (involving ≤50% of the reference lesion diameter), or severe (involving >50% of the reference lesion diameter). Moderate proximal vessel tortuosity was defined as the presence of at least 2 bends >70° or 1 bend >90° and severe tortuosity as 2 bends >90° or

ABBREVIATIONS AND ACRONYMS

CABG = coronary artery bypass graft

CTO = chronic total occlusion

FA = femoral-only access

MACE = major adverse cardiac event(s)

MI = myocardial infarction

PCI = percutaneous coronary intervention

RA = radial-only access

RFA = radial-femoral access

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Manuscript received September 12, 2018; revised manuscript received October 25, 2018, accepted November 15, 2018.

TABLE 1 Clinical Characteristics of the Study Patients Undergoing Radial-Only, Radial-Femoral, and Femoral-Only Chronic Total Occlusion Percutaneous Coronary Intervention

	Overall (N = 3,709)	Radial Only (n = 728)	Radial-Femoral (n = 824)	Femoral Only (n = 2,157)	p Value
Age (yrs)	64.6 ± 10.1	62.4 ± 9.8	64.3 ± 9.9	65.3 ± 10.2	<0.001
Men	84.6	84.5	84.8	84.6	0.985
BMI (kg/m^2)	30.6 ± 6.2	30.5 ± 6.1	30.9 ± 6.1	30.6 ± 6.3	0.527
Ad hoc CTO PCI	13.7	8.4	3.5	20.9	<0.001
Coronary artery disease presentation					<0.001
Acute coronary syndrome	25.5	27.8	28.9	23.1	
Stable angina	64.6	61.0	64.8	65.8	
Other	10.0	11.2	6.4	11.1	
CCS angina class					0.170
CCS <2	10.5	12.4	9.0	10.5	
CCS ≥2	89.5	87.6	91.0	89.5	
Diabetes mellitus	42.6	35.9	39.3	46.1	<0.001
Dyslipidemia	90.4	78.8	88.4	95.2	<0.001
Hypertension	90.4	88.4	89.1	91.6	0.023
Smoking (current)	26.1	29.6	20.9	27.0	0.001
LV ejection fraction (%)	50.0 ± 13.1	51.6 ± 11.6	50.0 ± 14.1	49.4 ± 13.2	0.002
Congestive heart failure	30.5	30.4	30.6	30.4	0.996
Prior MI	47.0	47.6	50.1	45.5	0.117
Prior CABG	32.2	17.5	38.6	34.9	<0.001
Prior PCI	64.3	59.8	63.2	66.4	0.005
Prior cerebrovascular disease	11.4	12.4	11.3	11.0	0.617
Peripheral artery disease	14.2	11.8	11.0	16.3	0.001
Currently on dialysis	2.6	0.2	0.9	4.1	<0.001
eGFR (1.73 ml/min/m^2)	72.7 ± 22.0	75.8 ± 19.8	73.6 ± 20.7	71.1 ± 23.2	<0.001
Baseline creatinine (mg/dl)	1.2 ± 0.9	1.1 ± 0.5	1.1 ± 0.5	1.3 ± 1.1	<0.001

Values are mean ± SD or %.

ACS = acute coronary syndrome(s); BMI = body mass index; CABG = coronary artery bypass graft; CAD = coronary artery disease; CCS = Canadian Cardiovascular Society; CTO = chronic total occlusion; eGFR = estimated glomerular filtration rate; LV = left ventricular; MI = myocardial infarction; PCI = percutaneous coronary intervention.

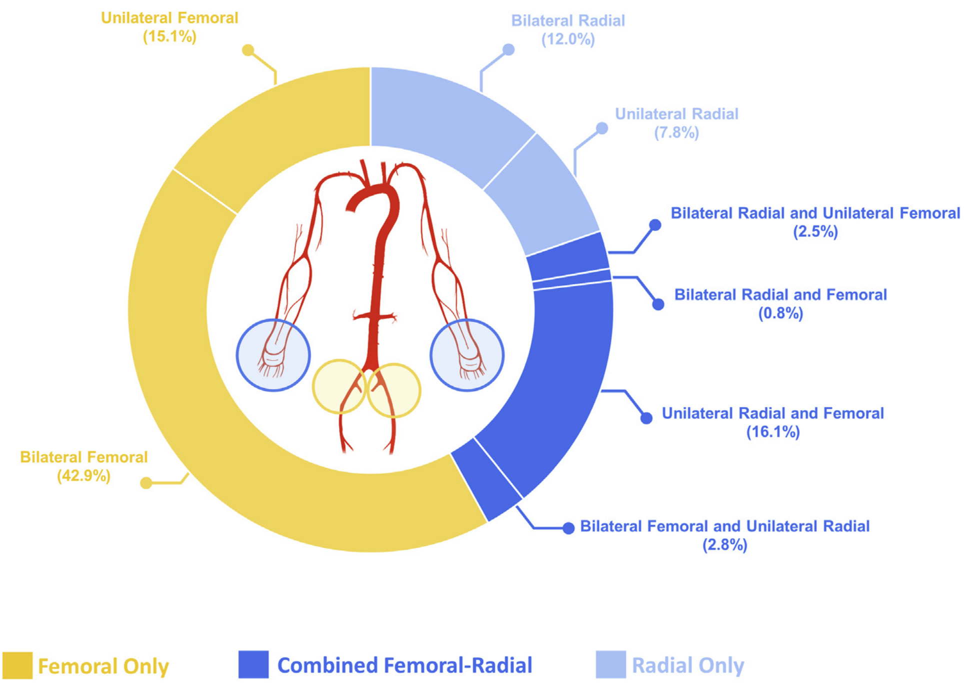
1 bend >120° in the CTO vessel. Blunt or no stump was defined as lack of tapering or lack of a funnel shape at the proximal cap. Interventional collateral vessels were defined as collateral vessels considered amenable to crossing by a guidewire and a microcatheter by the operator. Adequate distal landing zone was defined as a distal vessel segment with a diameter of larger than 2.0 mm and without diffuse disease. A procedure was defined as "retrograde" if an attempt was made to cross the lesion through a collateral vessel or bypass graft supplying the target vessel distal to the lesion; if not, the procedure was classified as "antegrade only." Antegrade dissection or re-entry was defined as antegrade PCI during which a guidewire was intentionally introduced into the subintimal space proximal to the lesion, or re-entry into the distal true lumen was attempted following intentional or inadvertent subintimal guidewire crossing. If at least 1 radial access was used, the case was classified as transradial CTO PCI (composite of radial-only access [RA] and radial-femoral access [RFA]), whereas transfemoral interventions involved femoral-only access (FA).

Technical success was defined as successful CTO revascularization with achievement of <30% residual diameter stenosis within the treated segment and restoration of TIMI grade 3 antegrade flow. Procedural success was defined as the achievement of technical success without any in-hospital complications. In-hospital major adverse cardiac events (MACE) included any of the following adverse events prior to hospital discharge: death, MI, recurrent symptoms requiring urgent repeat target vessel revascularization with PCI or coronary artery bypass graft (CABG) surgery, tamponade requiring either pericardiocentesis or surgery, and stroke. MI was defined using the third universal definition of MI (type 4a MI) (13). Major bleeding was defined as bleeding causing reduction in hemoglobin >3 g/dl or bleeding requiring transfusion or surgical intervention. The J-CTO (Multicenter CTO Registry in Japan) score was calculated as described by Morino et al. (14), the PROGRESS CTO score as described by Christopoulos et al. (15), and the PROGRESS CTO complications score as described by Danek et al. (16).

STATISTICAL ANALYSIS. Categorical variables were expressed as percentages and were compared using the Pearson chi-square test or Fisher exact test. Continuous variables are presented as mean ± SD or median (interquartile range) unless otherwise specified and were compared using the Student's *t*-test and 1-way analysis of variance for normally distributed variables; the Wilcoxon rank sum test and the Kruskal-Wallis test were applied for nonparametric continuous variables, as appropriate. The main comparison was among RA, RFA, and FA.

A generalized estimating equations approach with Poisson model (log-link), exchangeable correlation structure and robust sandwich errors was used to estimate relative likelihood of procedural success with respect to radial access size use in CTO PCI while accounting for intracenter dependencies; the events of interest included procedural success, in-hospital MACE, perforation, vascular access-site complications, and major bleeding. Similarly, continuous endpoints (i.e., procedure time, contrast volume, fluoroscopy time, and air kerma radiation dose), were analyzed on a log scale using generalized estimating equations with a Gaussian model and an identity link function.

FIGURE 1 Distribution of Access Sites Used in Chronic Total Occlusion Percutaneous Coronary Intervention



Femoral-only access **(yellow)** was used in most cases (58.0%). Radial access was used in 42.0% of cases, as follows: radial-only access **(light blue)** in 19.8% and combined radial-femoral access **(dark blue)** in 22.2%.

For multivariate analysis, the relative risks of procedural success associated with transradial CTO PCI (RA and RFA) versus FA were estimated using generalized estimating equations with a Poisson model adjusted for age, sex, height, body mass index, estimated glomerular filtration rate, peripheral artery disease, prior MI, prior congestive heart failure, prior CABG surgery, chronic pulmonary disease, hypertension, J-CTO score, occlusion length, moderate to severe proximal vessel tortuosity, moderate to severe calcification, proximal cap ambiguity, bifurcation at the distal cap, diseased distal target vessel, and presence of interventional collateral vessels. The estimates and their 95% confidence intervals are reported. A sequential analysis of deviance was performed to estimate the reduction in the residual deviance associated with the access strategy after adjusting for other risk factors; reported are a chi-square statistic and its p value.

All statistical analyses were performed with JMP version 13.0 (SAS Institute, Cary, North Carolina) and R version 3.4.1 in R-studio environment version 1.1.453 (R Foundation for Statistical Computing, Vienna, Austria). A 2-sided p value <0.05 was considered to indicate statistical significance.

RESULTS

CLINICAL AND ANGIOGRAPHIC CHARACTERISTICS. The baseline clinical characteristics of the study patients are shown in **Table 1**. Transradial access (RA [n = 747] and RFA [n = 844]) was used in 1,591 of 3,790 CTO interventions (42.0%) (**Figure 1**), with FA used in the rest (n = 2,199 [58.0%]).

Patients in the RA and RFA groups were younger and more likely to present with acute coronary syndromes (27.8% and 28.9% vs. 23.1%; $p < 0.001$). FA was more frequently used in ad hoc CTO PCIs (20.9% vs. 8.4% and 3.5%; $p < 0.001$). RA patients had fewer coronary risk factors (diabetes mellitus, dyslipidemia, and hypertension), prior PCI, prior CABG surgery, and peripheral arterial disease.

The angiographic characteristics of the study lesions are presented in **Table 2**. CTOs treated with RA had shorter length, larger vessel diameter, and were less likely to have diseased distal landing zones, moderate to severe calcification, and in-stent restenosis.

TECHNICAL CHARACTERISTICS AND THE HYBRID APPROACH. Crossing techniques used during CTO PCI are described in **Table 3 and Figures 1 and 2**. Bilateral angiography was performed in most cases

TABLE 2 Angiographic Characteristics Classified According to Chronic Total Occlusion Percutaneous Coronary Intervention With the Radial-Only, Radial-Femoral, and Femoral-Only Approaches

	Overall (N = 3,790)	Radial Only (n = 747)	Radial-Femoral (n = 844)	Femoral Only (n = 2,199)	p Value
Target vessel					0.038
RCA	55.1	53.9	59.3	54.1	
LCX	19.4	20.2	16.8	21.4	
LAD	24.0	25.9	23.9	24.4	
CTO length (mm)	32.9 ± 23.1	24.5 ± 16.8	33.9 ± 24.6	35.8 ± 23.9	<0.001
Vessel diameter (mm)	2.9 ± 0.5	3.0 ± 0.5	2.9 ± 0.5	2.8 ± 0.5	<0.001
Proximal cap ambiguity	35.6	30.9	42.5	34.3	<0.001
Side branch at proximal cap	51.6	52.1	51.8	51.3	0.946
Blunt stump/no stump	52.4	47.4	56.1	52.7	0.005
Interventional collateral vessels	57.1	54.9	65.3	53.9	<0.001
Distal cap at bifurcation	33.0	28.0	38.0	32.7	0.001
Good distal landing zone	67.9	73.3	67.1	65.9	0.003
Moderate/severe calcification	53.3	41.2	56.2	56.6	<0.001
Moderate/severe tortuosity	34.7	30.9	37.7	34.9	0.019
In-stent restenosis	16.6	12.9	15.2	18.6	0.001
Prior failed CTO PCI	20.6	19.7	24.7	19.2	0.004
J-CTO score	2.4 ± 1.3	2.1 ± 1.4	2.6 ± 1.3	2.5 ± 1.3	<0.001
PROGRESS CTO score	1.3 ± 1.0	1.3 ± 1.0	1.3 ± 1.0	1.3 ± 1.0	0.385
PROGRESS CTO complication score	3.0 ± 1.9	2.3 ± 1.9	3.2 ± 2.0	3.2 ± 1.9	<0.001

Values are % or mean ± SD.

CTO = chronic total occlusion; J-CTO = Multicenter CTO Registry in Japan; LAD = left anterior descending coronary artery; LCX = left circumflex coronary artery; PROGRESS CTO = Prospective Global Registry for the Study of Chronic Total Occlusion Intervention; RCA = right coronary artery.

(69.9%), albeit less commonly with RA (47.0% vs. 87.2% and 71.7%; p = 0.037). Antegrade wire escalation was used more often (92.6% vs. 81.6% and 81.3%; p < 0.001) and antegrade dissection re-entry less often (19.5% vs. 33.4% and 31.6%; p < 0.001) in RA cases compared with the RFA and FA groups. Compared with RA and FA cases, the retrograde approach was most frequently used with the combined approach (46.5% vs. 27.2% and 36.2%; p < 0.001) and was more often successful (29.1% vs. 19.3% and 21.8%; p < 0.001).

In the transradial group, a biradial approach was used in 453 CTO PCIs (28.5%), whereas a single-radial approach was used in 294 (18.5%) and a combined radial and femoral approach was used in 844 (53.0%). In the RFA group, the number of access sites was larger (2.0 ± 0.6 vs. 1.6 ± 0.5 and 1.7 ± 0.4; p < 0.001) compared with the RA and FA groups, whereas sheath size was smaller in the RA group (6.6 ± 0.7 vs. 7.0 ± 0.6 and 7.3 ± 0.8; p < 0.001). The mean access sizes increased with lesion complexity in RA (from 6.3 ± 0.5 [J-CTO score 0] to 7.2 ± 0.8 [J-CTO score 5]; p < 0.001), RFA (from 6.9 ± 0.6 [J-CTO score 0] to 7.2 ± 0.6 [J-CTO score 5]; p < 0.001), and FA (from 7.1 ± 0.9 [J-CTO score 0] to 7.8 ± 0.5 [J-CTO score 5]; p < 0.001) CTO interventions, as stratified by J-CTO score (Figure 2A), but not by the PROGRESS CTO score (Figure 2B).

PROCEDURAL OUTCOMES. The overall procedural outcomes are summarized in Table 3 and Figure 3. Technical and procedural success rates in the RA (89.3% and 86.4%) and RFA (86.5% and 84.5%) groups were similar to those in the FA group (85.9% and 84.8%) (p = 0.061 and p = 0.030). Overall technical success decreased with increasing lesion complexity in both transradial and transfemoral interventions (Figure 3, Online Figure 1).

The analysis of deviance for a multivariate model suggested no apparent association between the incidence of procedural success and access (chi-square = 3.6; p = 0.16). As compared with FA, the estimated relative risks for procedural success for RA and RFA were 1.010 (95% confidence interval: 0.929 to 1.098; p = 0.818) and 1.029 (95% confidence interval: 0.995 to 1.064; p = 0.098), respectively (Online Table 1).

IN-HOSPITAL COMPLICATIONS. The overall in-hospital MACE rate was 2.51% and was similar for RA, RFA, and FA interventions (2.47% vs. 3.40% vs. 2.18%; p = 0.830) (Online Table 2). In-hospital mortality was 0.51% (19 of 3,709 patients died). Only

TABLE 3 Technical and Procedural Characteristics of Chronic Total Occlusion Interventions With the Radial-Only, Radial-Femoral, and Femoral-Only Approaches

	Overall (N = 3,790)	Radial Only (n = 747)	Radial-Femoral (n = 844)	Femoral Only (n = 2,199)	p Value	Adjusted p Value*
Dual injection	69.9	47.0	87.2	71.7	<0.001	–
Crossing strategies used						
AWE	83.6	92.6	81.6	81.3	<0.001	–
ADR	29.6	19.5	33.4	31.6	<0.001	–
Retrograde	36.7	27.2	46.5	36.2	<0.001	–
First crossing strategy					<0.001	–
AWE	77.8	88.9	74.6	75.3		
ADR	7.5	2.6	7.6	9.1		
Retrograde	14.7	8.6	17.8	15.6		
Final crossing strategy					<0.001	–
AWE	48.2	61.8	40.4	46.5		
ADR	17.7	9.5	19.1	20.0		
Retrograde	22.9	19.3	29.1	21.8		
None	11.2	9.4	11.4	11.7		
Balloon-uncrossable lesions	12.2	7.1	10.3	16.2	<0.001	–
Balloon-undilatable lesions	10.8	6.3	9.3	15.9	<0.001	–
Number of access sites	1.8 ± 0.5	1.6 ± 0.5	2.3 ± 0.5	1.7 ± 0.4	<0.001	–
Sheath size	7.1 ± 0.8	6.6 ± 0.7	7.0 ± 0.6	7.3 ± 0.8	<0.001	–
Technical success	86.7	89.3	86.5	85.9	0.061	–
Non-CTO PCI	27.2	20.8	25.2	25.2	<0.001	–
	(N = 3,709)	(n = 728)	(n = 824)	(n = 2,157)		
Procedural success	85.0	86.4	84.5	84.8	0.528	0.030
Mechanical circulatory support	4.5	1.1	12.3	2.4	<0.001	<0.001
Planned	2.4	0.1	7.9	1.0	<0.001	<0.001
Urgent	0.8	0.6	2.2	0.4	<0.001	<0.001
Procedural time (min)	119 (75–180)	91 (61–137)	158 (113–229)	114 (72–175)	<0.001	<0.001
Fluoroscopy time (min)	45.7 (27.7–75.0)	37.1 (23.7–64.1)	60.3 (37.8–89.1)	43.3 (25.8–72.0)	<0.001	<0.001
Contrast volume (ml)	250 (190–350)	220 (160–300)	250 (190–334)	270 (200–370)	<0.001	<0.001
AK radiation (Gy)	2.8 (1.5–4.6)	2.6 (1.3–4.7)	2.8 (1.6–4.3)	2.8 (1.6–4.7)	0.357	0.440

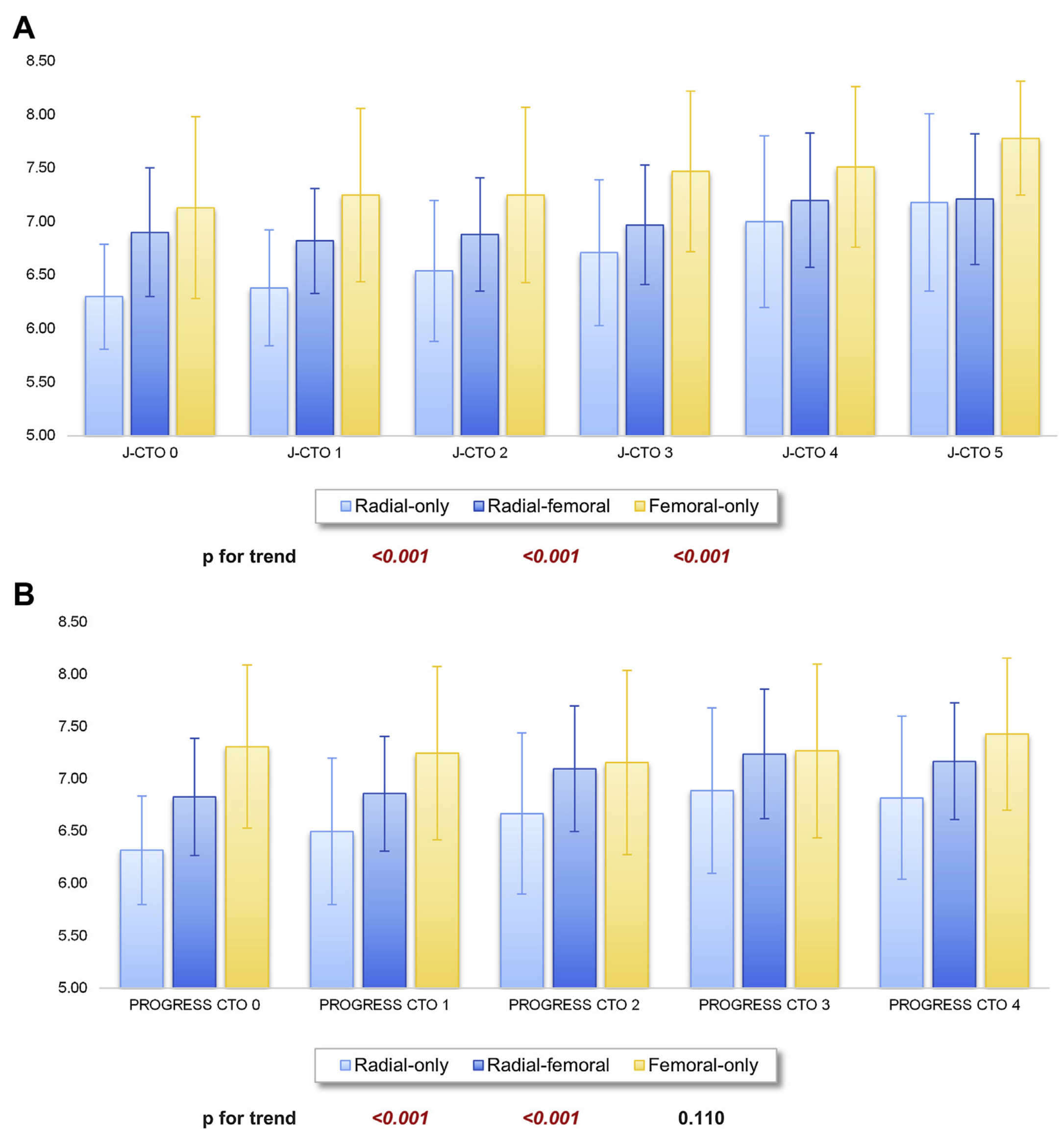
Values are %, mean ± SD, or median (interquartile range). *Analysis of deviance p value adjusted for intracenter dependency.
ADR = antegrade dissection and re-entry; AK = air kerma; AWE = antegrade wire escalation; other abbreviations as in Table 1.

2 patients died because of bleeding (1 post-CABG patient had left chest hemothorax caused by proximal right coronary artery perforation, and 1 patient developed hemorrhagic shock because of femoral access-site bleeding). The cause of death in the remaining cases was as follows: 9 patients had perforation with subsequent tamponade or cardiogenic shock, 2 patients had acute MI and cardiogenic shock, 2 patients developed cardiac arrhythmia and respiratory failure after successful CTO PCI, 1 patient had procedure-related hemorrhagic stroke, 1 patient had donor vessel dissection, and 1 patient had emergent repeat PCI and acute renal failure.

Major bleeding occurred in 39 patients, with a lower frequency in RA interventions (0.55% vs. 1.94% and 0.88%; p = 0.013) (Online Table 2). The location of the bleeding was the access site in 61.8%, retroperitoneal in 17.6%, hemothorax or mediastinal in 11.8%, gastrointestinal in 2.9%, genitourinary in 2.9%, and loculated ventricular bleeding in 2.9% (in a prior CABG patient). The majority of access-site bleeding complications occurred during RFA cases (61.9% of access-site bleedings), whereas one-third (33.3%) occurred with FA cases and only 4.8% with RA cases (p = 0.003), although left ventricular assist devices were used more frequently in the combined group (65.2%) compared with FA (18.9%) and RA cases (14.3%) (p = 0.007).

Fifty-nine patients had vascular access complications, which were numerically lower with RA (0.55% vs. 1.70% and 1.90%; p = 0.130). Most patients had access-site hematomas (59.2%), whereas pseudoaneurysm formation (16.3%), perforation (8.1%), and acute vessel closure (6.1%) were less common. Two patients had radial artery rupture that was treated percutaneously.

FIGURE 2 Size of Arterial Sheaths Used for Chronic Total Occlusion Percutaneous Coronary Intervention

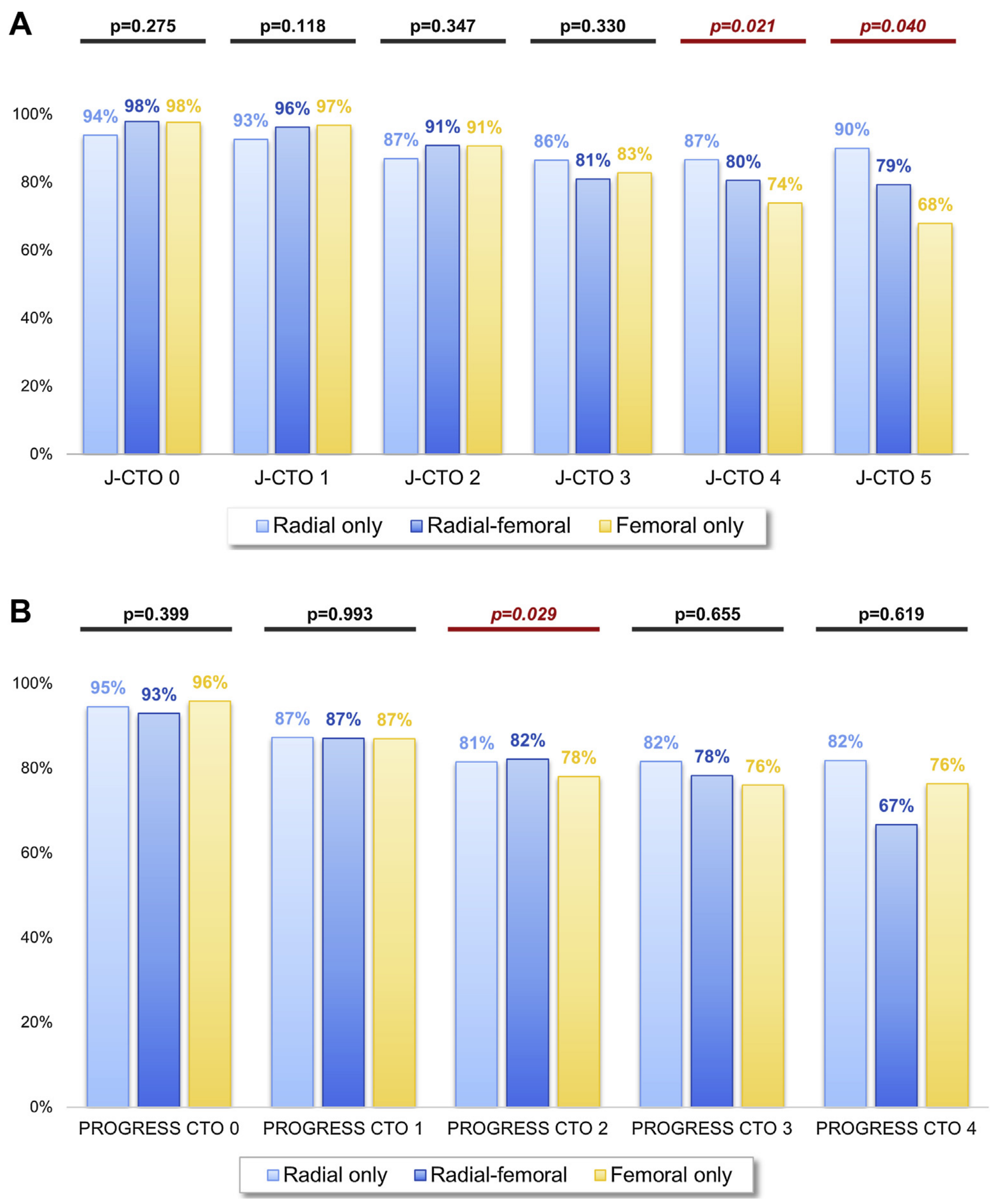


Sheath size (mean ± SD) used for radial-only **(light blue)**, radial-femoral **(dark blue)**, and femoral-only **(yellow)** chronic total occlusion percutaneous coronary intervention, classified according to J-CTO (Multicenter CTO Registry in Japan) **(A)** and PROGRESS CTO (Prospective Global Registry for the Study of Chronic Total Occlusion Intervention) **(B)** scores.

TEMPORAL TRENDS AND ACCESS-SITE COMBINATIONS. The frequency of transradial access (composite of RA and RFA) use increased significantly ($p < 0.001$) over time from 11% in 2012 to 67% in 2018 (Table 4, Figure 4). Technical and procedural success rates mildly decreased during the growth phase of radial CTO PCI (from 95% [2012] to 89% [2018]; $p = 0.045$, and from 95% [2012] to 89% [2018]; $p = 0.018$) (Figures 4A and 4B), whereas in-hospital MACE increased from 2012 to 2015 (from 0.00% to 4.9%) but decreased from 2016 to 2018 (from 4.3% to 0.7%) (Figure 4C). The overall procedure and fluoroscopy time, contrast volume, and air kerma radiation dose decreased significantly over time (Table 4).

BILATERAL RADIAL APPROACH IN CTO PCI. The efficacy of the biradial approach (n = 453) was compared with radial and femoral combined

FIGURE 3 Technical Success of Chronic Total Occlusion Percutaneous Coronary Intervention by Access Site and Lesion Complexity



Technical success of chronic total occlusion percutaneous coronary intervention via various arterial access sites (radial-only **[light blue]**, radial-femoral **[dark blue]**, and femoral-only **[yellow]**) stratified by J-CTO (Multicenter CTO Registry in Japan **(A)** and PROGRESS CTO (Prospective Global Registry for the Study of Chronic Total Occlusion Intervention) **(B)** scores.

(n = 844) and bifemoral (n = 1,626) cases (Table 5). The retrograde approach was used similarly (42.2% vs. 46.5% and 47.1%; p = 0.178), antegrade wire escalation was more frequent in the biradial group (88.7% vs. 81.6% and 76.9%; p < 0.001), and antegrade dissection and re-entry was less common (27.4% vs. 33.4% and 36.3%; p = 0.017). Technical and procedural success rates were higher in the biradial group (91.8% vs. 86.5% and 85.1%; p < 0.001, and 88.0% vs. 84.7% and 83.6%; p = 0.091) in comparison with the combined and bifemoral groups, but in-hospital MACE were numerically higher (3.64% vs. 3.40% and 2.51%; p = 0.300), while vascular access (0.91% vs. 1.71% and 2.26%; p = 0.165) and bleeding

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TABLE 4 Temporal Trends of Technical and Procedural Characteristics of Using the Transradial Approach (Composite of Radial-Only and Radial-Femoral Access) for Chronic Total Occlusion Percutaneous Coronary Intervention

	2012	2013	2014	2015	2016	2017	2018	p Value
Prevalence*	11	22	32	38	38	59	67	<0.001
J-CTO score*	3.2 ± 0.8	2.9 ± 1.1	2.4 ± 1.2	2.8 ± 1.3	2.6 ± 1.4	2.0 ± 1.4	2.3 ± 1.4	<0.001
PROGRESS CTO score*	1.6 ± 1.0	1.2 ± 1.0	1.3 ± 0.9	1.6 ± 1.0	1.4 ± 1.1	1.2 ± 1.0	1.2 ± 1.0	<0.001
Retrograde used*	49	53	43	47	43	30	31	<0.001
Successful crossing strategy*								<0.001
AWE	48.7	51.8	45.4	39.3	44.3	38.9	58.5	
ADR	12.8	15.7	18.5	23.6	18.1	10.3	11.6	
Retrograde	33.3	25.3	30.3	28.8	27.2	21.7	20.4	
None	5.1	7.2	5.9	8.4	10.4	13.5	9.5	
Sheath size*	6.1 ± 0.4	6.5 ± 0.5	6.8 ± 0.5	7.2 ± 0.6	7.1 ± 0.6	6.7 ± 0.6	6.6 ± 0.6	<0.001
Procedural time (min)	250 (200-385)	270 (185-340)	227 (175-300)	258 (200-375)	250 (200-320)	230 (170-310)	210 (150-280)	<0.001
Fluoroscopy time (min)	47.0 (26.6-78.1)	48.8 (30.0-95.6)	45.3 (27.3-85.5)	58.9 (35.0-96.4)	53.7 (33.7-80.6)	45.0 (28.3-76.4)	46.3 (26.5-71.0)	<0.001
Contrast volume (ml)	105 (83-181)	154 (88-214)	133 (92-214)	163 (122-247)	150 (103-209)	100 (65-156)	110 (69-160)	<0.001
AK radiation (Gy)	4.3 (2.5 6.2)	3.5 (2.0-6.7)	2.7 (2.0-4.8)	3.5 (2.1-5.0)	2.5 (1.5-3.8)	2.4 (1.2-4.1)	2.3 (1.2-4.3)	<0.001

Values are %, mean ± SD, or median (interquartile range). *Per lesion based.
Abbreviations as in Tables 2 and 3.

(0.91% vs. 1.94% and 1.00%; p = 0.201) complications were numerically lower in biradial cases.

DISCUSSION

This is the largest clinical study assessing arterial access during CTO PCI performed to date, showing that the use of transradial access has significantly increased in recent years. Radial access was associated with similar technical and procedural outcomes and in-hospital MACE as transfemoral-only interventions, with a lower rate of major bleeding.

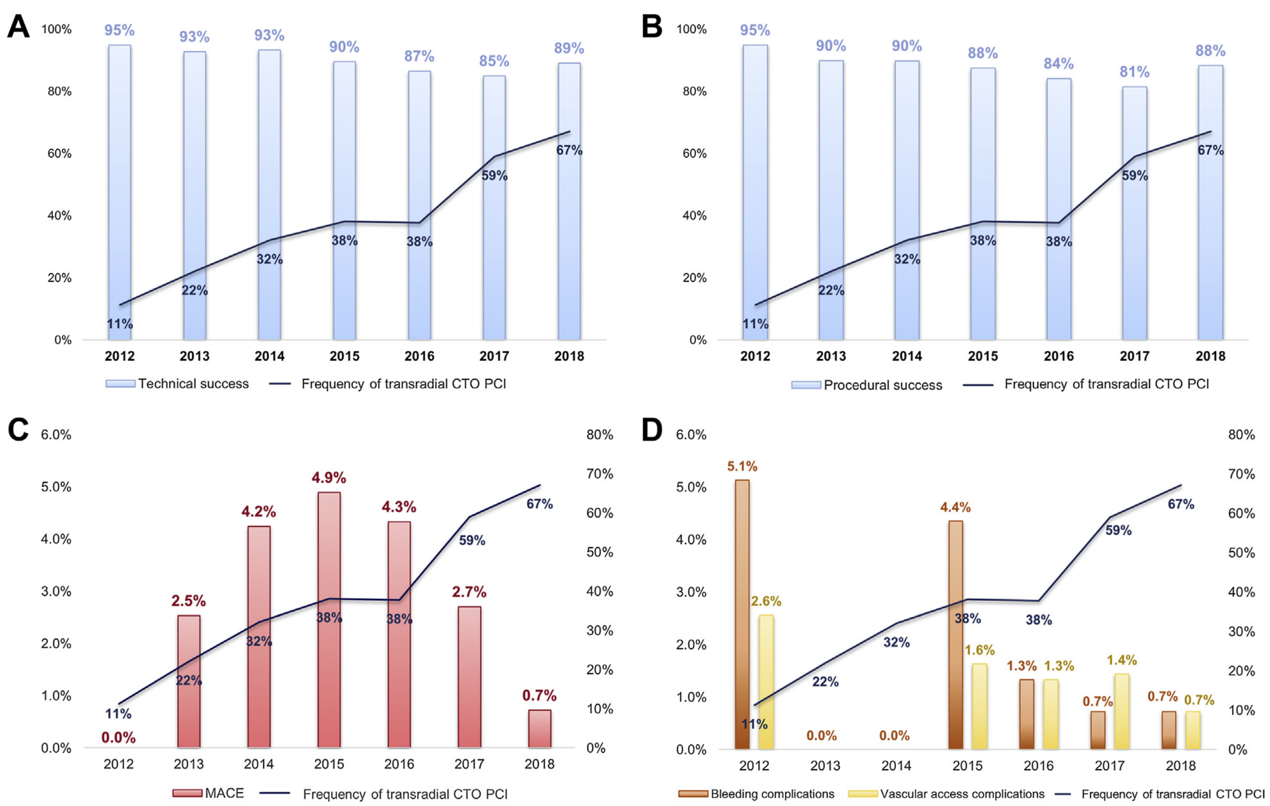
The access site in CTO PCI may have significant impact on both success and safety: femoral access could provide more support and allows larger guide catheters to be used, whereas radial access is associated with significantly lower risk for vascular access complications (17,18). Striking a balance between efficacy and safety could allow optimal access-site selection.

Our study shows a significant increase over time in the frequency of transradial access use in CTO PCI. In an early report from the PROGRESS CTO registry, transradial access was used in 17% (6), which has increased to 42% in the present cohort. This figure parallels increasing use of radial access for diagnostic catheterization and non-CTO PCI in the United States and may reflect increasing familiarity with transradial techniques and troubleshooting (19-22).

The high success achieved with transradial access in our study is likely related to increasing operator expertise in both CTO PCI and the use of radial access and increasing use of large guide catheters (7-F). It could also be related to better patient selection, with less complex cases being performed via transradial access (the mean J-CTO score for transradial cases was 3.2 in 2012 vs. 2.3 in 2018). Transradial CTO PCI success may have been enhanced by use of newer devices, such as guide catheter extensions (GuideLiner, TrapLiner [Teleflex, Wayne, Pennsylvania], and Guidezilla [Boston Scientific, Natick, Massachusetts]), sheathless guides and slender sheaths enabling larger radial guide catheters, and newer microcatheters and guidewires with improved handling characteristics, and decreasing size of CTO devices.

Several studies have examined the use of transradial access for CTO PCI (Online Table 3) (6,8-12,18,23). Tanaka et al. (11) compared transfemoral (n = 305) and transradial (n = 280) CTO interventions performed between 2005 and 2014 in a propensity-matched population (n = 187 pairs), demonstrating that technical success with the transradial approach was comparable with transfemoral CTO PCI in cases with low complexity (90% vs. 91%; p = 0.93 [J-CTO score 0]; 78% vs. 82%; p = 0.57 [J-CTO score 1]; and 71% vs. 71%; p = 0.95 [J-CTO score 2]) but not in complex interventions (36% vs. 58%; p = 0.04 [J-CTO score ≥3]) (11). In RECHARGE (Registry of CrossBoss and Hybrid Procedures in France, the Netherlands, Belgium and United Kingdom), Bakker et al. (9) showed that the procedural success rate of fully transradial (n = 306 [24%]) and transfemoral CTO interventions (n = 947 [76%]) remained comparable even with increasing lesion complexity

FIGURE 4 **Temporal Trends of Procedural Outcomes of Chronic Total Occlusion Interventions Using Transradial Approach (Radial-Only or Radial-Femoral) Between 2012 and 2018**



(A) Technical success (p = 0.045). **(B)** Procedural success (p = 0.019). **(C)** In-hospital major adverse cardiac events (MACE) (p = 0.82). **(D)** Vascular access and bleeding complications (p = 0.641 and p = 0.009). CTO = chronic total occlusion; PCI = percutaneous coronary intervention.

(100% vs. 99%; p = 0.99 [J-CTO score 0]; 97% vs. 94%; p = 0.52 [J-CTO score 1]; 85% vs. 88%; p = 0.47 [J-CTO score 2]; and 72% vs. 79%; p = 0.17 [J-CTO score ≥3]), although use of the retrograde approach was significantly lower in the transradial group (18% vs. 39%; p < 0.01). Rinfret et al. (7), in an early Canadian experience (n = 42), showed that retrograde CTO PCI is feasible with biradial access using mainly 6-F sheaths for antegrade and retrograde injections with high technical success (93%) (83% primary retrograde success) and no major in-hospital complications. In an earlier report (650 CTO PCIs vs. 3,790 in the present report) from PROGRESS CTO, Alaswad et al. (6) showed similar retrograde approach use in CTO PCI with transradial approach versus transfemoral cases (50% vs. 43%; p = 0.016). The retrograde approach was similarly used in our present cohort in transradial (composite of RA and RFA) and transfemoral cases (37% vs. 36%; p = 0.467), although it was more successful as a crossing technique with transradial access (25% vs. 22%; p < 0.001), even for lesions with high complexity (46% vs. 35%; p = 0.003 [J-CTO score 4]; 49% vs. 40%; p = 0.008 [J-CTO score 5]) in comparison with transfemoral cases (Online Figure 1). Antegrade dissection re-entry techniques were less frequently used in transradial interventions (27% vs. 32%; p = 0.002) and were less efficient in lesions with higher complexity (Online Figure 1). The limited efficacy of antegrade dissection re-entry with transradial access may be attributed to the smaller bore access size, as in dissection re-entry techniques likely more devices are used in a single catheter to facilitate wire maneuvering and re-entry; re-entry may also requires additional complex techniques, such as guide extension techniques ([mother-daughter [24], mother-daughter-granddaughter [25]), subintimal transcatheter withdrawal [26], anchoring techniques [27], the side-BASE technique [28], and so on. Kinnaird et al. (18) analyzed the procedural and in-hospital outcomes of CTO PCIs using the femoral approach using the British Cardiovascular

TABLE 5 Technical and Procedural Outcomes Comparing Biradial Chronic Total Occlusion Percutaneous Coronary Intervention With Radial-Femoral and Bifemoral Chronic Total Occlusion Interventions

	Bilateral Radial (n = 453)	Radial-Femoral (n = 844)	Bilateral Femoral (n = 1,626)	p Value
J-CTO score*	2.5 ± 1.3	2.6 ± 1.3	2.6 ± 1.2	0.549
PROGRESS CTO score*	1.4 ± 1.0	1.3 ± 1.0	1.2 ± 1.0	0.029
Crossing strategies used*				
Antegrade wire escalation*	88.7	81.6	76.9	<0.001
Antegrade dissection re-entry*	27.4	33.4	36.3	0.017
Retrograde technique*	42.2	46.5	47.1	0.178
Number of access sites*	2.0 ± 0.0	2.3 ± 0.5	2.0 ± 0.0	<0.001
Sheath size*	6.8 ± 0.7	7.0 ± 0.6	7.5 ± 0.7	<0.001
Technical success*	91.8	86.5	85.1	0.001
Non-CTO PCI*	21.0	26.1	25.3	0.102
LV assist device use	1.9	12.3	2.6	<0.001
Prophylactic	0.2	7.9	0.8	<0.001
Urgent	0.9	2.2	0.4	<0.001
Procedural success	88.0	84.7	83.6	0.091
Procedural time (min)	112 (78–169)	158 (114–229)	136 (96–199)	<0.001
Fluoroscopy time (min)	47.6 (29.4–77.8)	60.3 (37.8–89.1)	52.8 (33.0–79.8)	<0.001
Contrast volume (ml)	240 (171–307)	250 (190–334)	288 (200–400)	<0.001
AK radiation (Gy)	2.7 (1.4–4.9)	2.8 (1.6–4.2)	2.9 (1.6–4.8)	0.245
In-hospital MACE	3.64	3.40	2.51	0.300
Death	0.46	0.97	0.50	0.339
Acute MI	1.37	0.97	1.0	0.777
Repeat PCI	0.68	0.49	0.19	0.220
Stroke	0.23	0.49	0.25	0.583
Emergency CABG	0.23	0.12	0.06	0.631
Pericardiocentesis	1.59	0.97	0.82	0.342
Perforation	4.78	3.52	5.78	0.053
Vascular access complication	0.91	1.70	2.26	0.165
Bleeding	0.91	1.94	1.00	0.113

Values are mean ± SD, %, or median (interquartile range). *Per lesion based.
MACE = major adverse cardiac event(s); other abbreviations as in Tables 1 to 3.

Intervention Society database, demonstrating a significant decrease from 85% to 58% ($p < 0.0001$) in femoral access site use of 26,807 CTO interventions performed in the United Kingdom between 2006 and 2013. In-hospital major complications, such as death (0.2% vs. 0.1%; $p = 0.027$), acute MI (0.5% vs. 0.2%; $p = 0.037$), and major bleeding (0.8% vs. 0.1%; $p < 0.001$), were significantly higher in transfemoral cases, along with vascular access complications (1.5% vs. 0.5%; $p < 0.001$). Transradial CTO interventions ($n = 2,748$) were mostly performed with single arterial access site (95.9%), and dual angiography was rarely performed (4.1%).

In our study, overall in-hospital complications were similar between transradial and transfemoral groups, although vascular access complications were numerically lower with RA, and bleeding complications were significantly lower. Biradial interventions had a trend for lower access-site and bleeding complication rates compared with any femoral access (radial-femoral and bifemoral). The most common bleeding location was access-site bleeding, which occurred most frequently with combined radial and femoral interventions, in which mechanical circulatory support devices were used in almost two-thirds of cases involving hemorrhagic complications.

STUDY LIMITATIONS. First, we did not have long-term follow-up of the study patients. Second, our study had observational design without core laboratory assessment of the study angiograms or independent clinical event adjudication. Third, there was no follow-up assessment of radial artery patency in patients undergoing CTO PCI via transradial access; hence the incidence of post-procedural radial artery occlusion is not known. Fourth, study procedures were performed at dedicated, high-volume CTO centers by experienced operators, limiting the extrapolation to less experienced operators and lower volume centers. Fifth, selection of crossing strategy was made by each operator, likely reflecting local expertise and operator and patient preferences (Online Figure 2). However, the data are widely representative of an international contemporary practice of complex PCI techniques addressing CTO treatment. Sixth, we do not have information on the initially planned access strategy for each patient, so it is possible that planned access was different than achieved access in some of the study patients.

CONCLUSIONS

Transradial access is increasingly being used for CTO PCI with high procedural success rates and similarly low major in-hospital complication rates compared with FA cases.

ACKNOWLEDGMENTS Study data were collected and managed using Research Electronic Data Capture (REDCap) electronic data capture tools hosted at the Minneapolis Heart Institute Foundation. REDCap is a secure, Web-based application designed to support data capture for research studies, providing 1) an intuitive interface for validated data entry; 2) audit trails for tracking data manipulation and export procedures; 3) automated export procedures for seamless data downloads to common statistical packages; and 4) procedures for importing data from external sources.

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PERSPECTIVES

WHAT IS KNOWN? Radial access has become the dominant approach for non-CTO PCI in most countries around the world. However, the use of radial access in CTO PCI has been low, possibly because of concerns for lower technical success compared with femoral access.

WHAT IS NEW? Our study demonstrates that radial access use in CTO PCI has significantly increased between 2012 (11%) and 2018 (67%), while maintaining similar success and cardiac complication rates and achieving lower major bleeding complication rates compared with femoral access.

WHAT IS NEXT? Our findings support increasing use of radial access for CTO PCI in an attempt to further decrease complication rates. Further study is needed to determine which CTO lesion subsets may be best approached using femoral versus radial access.

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KEY WORDS chronic total occlusion, outcomes, percutaneous coronary intervention, radial approach

APPENDIX For a list of participating centers as well as supplemental tables and figures, please see the online version of this paper.