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Procedural and In-Hospital Outcomes After Percutaneous Coronary Intervention for Chronic Total Occlusions of Coronary Arteries 2002 to 2008

Impact of Novel Guidewire Techniques

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The aim of this study was to examine the procedural success and in-hospital outcomes after percutaneous coronary intervention (PCI) for chronic total occlusions in the current era during contemporary practice. The technique of PCI has improved over time with the introduction of novel equipment and guidewire crossing techniques. However, there is limited data available from contemporary practice in the recent years. We evaluated the procedural and in-hospital outcomes in a consecutive series of 904 procedures performed at Toyohashi Heart Center for PCI of chronic total occlusions of >3 months in duration. Technical and procedural success was achieved in 87.5% and 86.2%, respectively. In-hospital major adverse cardiac events occurred in only 1.9% of the patients. Single antegrade wire was the predominant strategy for guidewire crossing; however, retrograde guidewire crossing was used in 7.2% of the cases and controlled antegrade and retrograde subintimal tracking in 9.9% of the cases as the final strategy. Logistic regression analysis identified severe tortuosity and moderate-to-severe calcification as significant predictors of procedural failure. This is the first reported large series of patients undergoing PCI for chronic total occlusion with improved wire crossing techniques. We have reported high success rates in recent years and very low complication rates despite the use of more aggressive devices and techniques. (J Am Coll Cardiol Intv 2009;2:489–97) © 2009 by the American College of Cardiology Foundation

Percutaneous coronary intervention (PCI) of chronic total occlusion (CTO) is considered a major frontier in interventional cardiology. Approximately one-third to one-half of patients with significant coronary artery disease on angiography have at least 1 CTO (1,2). However, they account for only 10% to 15% of all PCI activity (3), and the majority of the patients are treated with either coronary artery bypass grafting or medical therapy. The procedural success rate for CTO has improved over time, but is still low and is mainly due to the failure to cross the lesion with the guidewire (4–11). Recent development of dedicated guidewires, sophisticated technologies, and increasing clinical experience and skills have improved the procedural outcomes with CTO-PCI. Moreover, the novel methods of guidewire crossing particularly parallel wire, retrograde, and controlled antegrade and retrograde subintimal tracking (CART) techniques have given much hope for the treatment of chronically occluded arteries.

However, there is limited data on the procedural success rate and procedural complications with these techniques after PCI for CTO in contemporary practice. Several previous large studies have shown procedural success rates and outcomes after CTO-PCI, but they have also included the pa-

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tients with recent occlusions (10) and all occlusions of more than 1 month's duration (3,12,13).

The aim of our study is to analyze the procedural success rates, guidewire strategies, and in-hospital outcomes in the patients treated for CTO-PCI in contemporary practice.

Methods

Study design. Consecutive patients who underwent PCI of a chronic occluded artery were identified from the dedicated database at the Toyohashi Heart Center, Toyohashi, Japan, where data was entered prospectively. All procedures performed between January 2002 and July 2008 were included in this analysis. The database includes demographic, clinical, angiographic, and procedural data; guidewire strategies; and in-hospital outcomes.

Definitions. Our study defined CTO as a lesion showing Thrombolysis In Myocardial Infarction (TIMI) flow grades of 0 to 1 that were 3 months or more in duration. All patients included in this analysis had at least 1 occlusive lesion. Duration of occlusion was estimated on the basis of either history of angina or previous myocardial infarction (MI) in the same territory or proven by previous angiography.

Abbreviations and Acronyms

CABG = coronary artery bypass surgery

CART = controlled antegrade and retrograde tracking

CK = creatinine kinase

CTO = chronic total occlusion

IVUS = intravascular ultrasound

MACE = major adverse cardiac events

MI = myocardial infarction

PCI = percutaneous coronary intervention

TIMI = Thrombolysis In Myocardial Infarction

Major adverse cardiac events (MACE) were defined as death, Q-wave MI, or urgent revascularization during the same admission. Urgent revascularization was defined as target vessel repeat PCI within 24 h or urgent coronary artery bypass surgery (CABG).

Q-wave MI was defined as cardiac enzymes (creatinine kinase [CK]) elevation of more than 3 times the normal value with development of Q-wave following the PCI. Non–Q-wave MI was defined as elevation of CK greater than 3 times without development of Q-wave following the PCI.

Technical success was defined as successful guidewire and balloon crossing with residual stenosis >50% and TIMI flow grade 3. Procedural success was defined as residual stenosis >50% with TIMI flow grade 3 without MACE.

Acute occlusion is defined as target vessel occlusion needing repeat PCI within 24 h. Subacute occlusion is defined as target vessel occlusion needing repeat PCI within 7 days. Side branch compromise was defined as TIMI flow grades 0 to 1 in the side branch of >2.0 mm in size. Access-related complications were not included in this analysis.

Procedure time is defined as the time difference between the patient's entry and exit from the catheterization room. Fluoroscopy time and dosing data was available in only 350 patients. Type 1 coronary perforation was defined as discrete or localized extravasation of the contrast medium and Type 2 coronary perforation was defined as persistent visible extravasation of the contrast medium.

Interventional technique and guidewire crossing strategies. The operators performed the PCI procedure according to their practice at that time, and most of the procedures were performed via femoral route using 8-F guiding catheters. The technique has been modified over time by routine use of bilateral simultaneous coronary injections and dedicated stiff wires, including Xtreme (Asahi Intecc, Aichi, Japan), Fielder and Fielder FC (Asahi Intecc), Miracle 3-12 (Asahi Intecc), and stiff-tapered wires (Confianza Family, Asahi Intecc). Also, the uptake of micro catheters (Finecross MG, Terumo Corporation, Tokyo, Japan) and over-the-wire specialist devices has increased over time.

The guidewire strategies used were single wire technique, parallel (contact) wire technique, intravascular ultrasound (IVUS)-guided wiring technique, and retrograde wiring through collaterals and CART technique. These techniques have been described by our group in the past (14–18).

The sequence of these wiring techniques and selection of the guidewire is completely dependent on the operator's discretion and the patient's coronary anatomy. Generally the antegrade approach was started with a step up to different wiring strategies and stiffer wires depending on the progress.

Briefly, parallel wire (contact wire) technique involves 2 antegrade wires in which the first wire ends up in the false lumen. The shaft of second wire remains in contact with the first wire and the tip is deflected to gain entry into the true lumen.

Intravascular ultrasound guided wiring was used when the entry point of the CTO was not visible, therefore IVUS was used to localize the entry point. Second, IVUS was used to help find the true lumen in the event of guidewire entry into the false lumen.

Retrograde wiring was used when favorable collaterals were present and this technique involves manipulating and advancing the guidewire into CTO retrogradely to reach the proximal true lumen and achieve successful recanalization.

The CART technique involves simultaneously antegrade and retrograde guidewire manipulation using controlled antegrade and retrograde subintimal tracking to limit the extent of dissection to the CTO site and achieve successful recanalization.

All patients were treated with aspirin and thienopyridine (ticlopidine or clopidogrel) before the procedure and received heparin to achieve activated clotting time of around 250 s.

Statistical Analysis

Continuous data was presented as mean ± SD and differences were compared using the Student *t* test. Discrete variables were expressed as counts and percentages. These were assessed by Fisher exact test and chi-square test depending on the table size. All statistical tests were 2-tailed.

Logistic regression analysis was used to assess the relationship between baseline demographic, clinical, and angiographic characteristics and procedural failure. All analysis was performed using SPSS version 15 statistical software (SPSS Inc., Chicago, Illinois).

Results

Patient population. Between January 2002 and July 2008, 665 patients had 1 CTO lesion attempted (665 lesions), 88 patients had more than 1 CTO lesion (186 lesions) attempted, and 53 patients had same CTO lesion (53 lesions) attempted more than once. Therefore, we present a consecutive series of 904 CTO lesions in 806 patients.

Trends in successful revascularization. Overall technical successful revascularization was achieved in 791 (87.5%) lesions and the remaining 113 (12.5%) were unsuccessful. Successful revascularization has increased from around 80% in year 2002 up to 90% during more recent years. The procedural success rate was achieved in 780 (86.2%) lesions.

Guidewire techniques. Yearly uptake of different novel guidewire techniques and technical success rates are shown in Figure 1. There is a steady yearly increase in the usage of IVUS guidance, parallel wire technique, retrograde wiring techniques, and CART attempts ($p = 0.019$), and this increase in usage was associated with a nonsignificant increase in the procedural success rates ($p = 0.078$).

Baseline clinical characteristics. The baseline demographics for both CTO success and failure groups are shown in Table 1. Mean age, gender frequency, and risk factors were similar in both groups. The majority of patients had a history of previous MI (86%) and about one-quarter of the patients had previous PCI, which was similar in both groups. The CTO failure group had a higher incidence of multivessel disease and prior CABG.

Angiographic and anatomical characteristics. Table 2 summarizes the angiographic and anatomical characteristics. The CTO vessels were predominantly the right coronary arteries (38%), followed by the left anterior descending artery (29%) and left circumflex coronary artery (22%). The left main coronary artery was the CTO vessel in 5 cases. The CTO vessel was the branch artery in 8% of the procedures, and there was a significantly higher number of PCI procedures attempted on the branch artery in the CTO failure group. Significant side branch at the CTO site was seen in about 16% of the cases, and the incidence of side branch at the CTO site was higher in the successful group. Moderate-to-severe calcification was seen in around one-third of the cases with increased calcification seen in the CTO failure group. The majority of the CTO lesions (86%) were nonostial in location and 12 (0.2%) lesions were aorto-ostially located. The location of the CTO site was similar in both groups. In-stent restenosis was the cause of CTO in around 10% cases. The estimated CTO length was similar in success and failure groups.

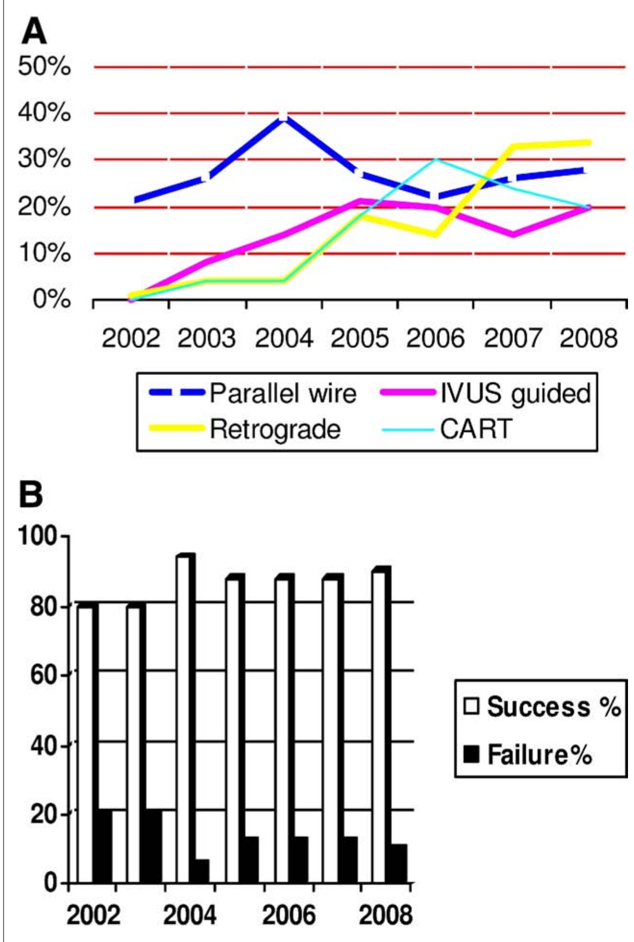

Figure 1. Yearly Utilization of Adjunctive Wiring Strategies and Procedural Success Rates

(A) Yearly increase in adjunctive wiring techniques ($p = 0.019$). **(B)** Procedural success rates in percutaneous coronary intervention for chronic total occlusion ($p = 0.078$), comparing success rates (2002 to 2004 vs. 2004 to 2008). CART = controlled antegrade and retrograde tracking; IVUS = intravascular ultrasound.

Patient characteristics stratified with guidewiring techniques. As shown in Table 3, the baseline demographics and angiographic features were similar in all 4 different wiring techniques. There were significantly more cases with severe tortuosity and calcification in the single wire failure, retrograde attempt, and CART success groups. There were also significantly more cases with CTO in the right coronary

Table 1. Baseline Patient Demographics and Vessel Characteristics for CTO Success and Failure Groups

Variables	CTO Success (n = 791)	CTO Failure (n = 113)	p Value
Age, yrs	65.42 ± 10.7	66.01 ± 11.2	0.587
Male	654 (82.2%)	94 (83.2%)	0.837
Diabetes mellitus	318 (40.2%)	42 (37.4%)	0.473
Hypertension	488 (61.7%)	74 (65.5%)	0.334
Hyperlipidemia	312 (39.5%)	45 (39.9%)	0.936
Family history of CAD	115 (14.6%)	18 (15.7%)	0.662
Smoking	219 (27.7%)	33 (29.1%)	0.728
Previous MI	679 (85.8%)	99 (87.6%)	0.571
Previous CABG	94 (11.9%)	20 (17.7%)	0.036
Previous PCI	220 (27.9%)	27 (24.1%)	0.293
Unstable angina	60 (7.7%)	15 (12.8%)	0.026
CCS class 3 to 4	52 (6.6%)	11 (9.3%)	0.187
Vessel disease			
1-vessel	102 (12.9%)	7 (6.4%)	0.005
2-vessel	258 (32.6%)	35 (31.03%)	NS
3-vessel	431 (54.5%)	70 (62.5%)	NS
Body weight, kg	63.50 ± 11.8	63.69 ± 12.1	0.873
Body surface area	1.67 ± 0.17	1.72 ± 0.59	0.057

Values are mean ± SD or n (%).

CABG = coronary artery bypass surgery; CAD = coronary artery disease; CCS = Canadian Cardiovascular Society; CTO = chronic total occlusion; MI = myocardial infarction; PCI = percutaneous coronary intervention.

Table 2. Angiographic and Treatment Factors of CTO Success and Failure Groups

Variables	CTO Success (n = 791)	CTO Failure (n = 113)	p Value
Target vessel			
LAD	239 (30.2%)	28 (24.6%)	NS
RCA	312 (39.3%)	43 (37.9%)	NS
LCX	182 (23.1%)	19 (17.2%)	NS
LMT	4 (0.4%)	1 (0.4%)	NS
Branch	52 (6.6%)	22 (19.7%)	<0.0001
RITA	1 (0.1%)	0	NS
SVG	1 (0.1%)	0	NS
Significant side branch at CTO site	144 (18.2%)	11 (9.8%)	0.03
Calcification			
None	240 (30.1%)	37 (31.5%)	NS
Mild	258 (32.3%)	32 (28.5%)	NS
Moderate	214 (26.9%)	22 (19.2%)	0.001
Severe	79 (9.9%)	22 (19.2%)	NS
Ostial location			0.294
Aorto-ostial	10 (1.2%)	2 (1.4%)	
Nonaorto-ostial	86 (10.9%)	17 (14.7%)	
Nonostial	695 (87.8%)	94 (83.7%)	
Tortuosity			
None	675 (85.1%)	85 (75.3%)	NS
Moderate	81 (10.5%)	16 (14.3%)	NS
Severe	35 (4.4%)	12 (10.3%)	0.001
In-stent restenosis	95 (12.1%)	9 (8.3%)	0.174
Lesion length	30.53 ± 13.68	24.72 ± 6.01	0.067

Values are mean ± SD or n (%).

CTO = chronic total occlusion; LAD = left anterior descending artery; LCX = left circumflex artery; LMT = left main trunk; RCA = right coronary artery; RITA = right internal thoracic artery; SVG = saphenous vein graft.

Table 3. Patients Baseline, Procedural Characteristics, and Outcomes Comparing Different Wiring Strategies

	Single Wire		Parallel Wire		Retrograde Attempt		CART		
	Success (n = 510)	Failure (n = 380)	Success (n = 150)	Failure (n = 125)	Success (n = 57)	Failure (n = 80)	Success (n = 78)	Failure (n = 5)	p Value*
Variables									
Age, yrs	66.2 ± 10.7	64.9 ± 10.9	64.7 ± 9.8	64.3 ± 12.1	63.0 ± 10.6	65.6 ± 10.6	64.4 ± 11.3	71.6 ± 6.8	NS
Diabetes	40.8	38.2	42.2	31.9	42.9	33.3	40.2	42.9	NS
Male	79.5	85.2	84.5	87.4	84.1	82.2	83.9	71.4	NS
Hypertension	62.4	59.5	59.6	62.2	71.4	65.6	67.8	71.4	NS
Hyperlipidemia	37.8	41.8	40.4	41.5	42.9	42.2	47.1	28.6	NS
Smoking	24.9	31.7	31.1	33.3	28.6	28.9	32.2	20.0	NS
Previous MI	83.3	89.1	88.8	88.9	95.2	94.4	93.1	100	0.005
Previous CABG	10.1	15.8	12.4	13.3	19.0	21.1	18.4	40	0.041
Unstable angina	8.5	9.1	6.2	9.6	9.5	6.7	9.2	0	NS
Vessel									
LAD	29.8	31.9	32.9	32.6	30.2	37.8	23	42.9	NS
RCA	35.9	43.4	38.5	48.9	50.8	51.1	65.5	51.1	<0.0001
LCX	26.6	19.0†	22.4	13.3†	14.3	10.0	9.2	0	0.003
Branch	7.2	5.5	5.6	5.2	1.1	1.6	0	0	0.024
LMT	0.4	0.3	0.6	0	1.6	0	2.3	0	NS
Others	0.2	0	0	0	1.6	0	0	0	NS
Previous PCI	25.8	29.6	23.6	30.4	44.4	21.0	39.1	42.9	<0.001
ISR	14.8	8.3†	6.8	8.1	11.1	7.8	8.0	0	0.028
Side branch	18.6	14.5	19.9	11.9	20.6	15.6	14.9	0	NS
Tortuosity									
Moderate	7.8	12.7†	9.9	12.6	19.0	24.4	20.7	28.6	0.018
Severe	2.5	9.1†	6.8	10.4	11.1	14.4	12.7	14.3	<0.0001
Calcification									
Moderate	24.3	27.8	33.5	23.7	19.0	32.2	34.5	14.3	0.0186
Severe	9.7	13.5	11.2	17.8	17.5	23.3	9.2	28.6	
CTO length	31.1 ± 13.7	27.8 ± 12.46	26.4 ± 13.4	36.5 ± 15.0	34.6 ± 14.5	27.3 ± 5.06	31.4 ± 11.8	N/A	NS
Outcomes									
Success rate	57.3%		54.5%		61.4%				NS
Dissection	10.9	10.9	17.3	13.6	3.1	10	7.6	20	0.0183
Perforation									
Type I	3.2	16.1†	9.9	20.7‡	7.9	30.0†	12.6	25	<0.001
Type II	2 (0.4)	1 (0.3)	0	0	1 (1.6)	0	1 (1.1)	0	
Non–Q-wave MI	11 (2.1)	11 (2.9)	5 (3.1)	3 (1.9)	1 (1.6)	0	3 (3.4)	1	NS
Q-wave MI	1 (0.2)	4 (1.0)	2 (1.2)	1 (0.7)	0	0	0	0	NS
Cardiac tamponade	1 (0.2)	5 (1.3)	3 (1.9)	1 (0.7)	0	1 (1.1)	1 (1.1)	0	NS
Emergency CABG	1 (0.2)	1 (0.3)	0	0	0	1 (1.1)	0	0	NS
Death	2 (0.4)	3 (1.0)	0	3 (2.2)	0	0	0	0	NS
Procedure time, hh:mm	2.13 ± 2.09	3.14 ± 2.41	3.07 ± 1.12	3.32 ± 2.59	3.24 ± 3.04	3.45 ± 2.38	3.56 ± 1.30	4.34 ± 1.21	<0.0001
Fluoroscopy time, mm:ss (n = 350)	59.57 ± 34.40	100.00 ± 49.03†	80.16 ± 40.32	114.00 ± 53.50†	101.60 ± 48.10	112.40 ± 48.71	112.96 ± 52.29	135.32 ± 26.29†	<0.0001
Fluoroscopy dose (frontal), Gy (n = 350)	7.65 ± 5.31	11.81 ± 8.39	10.17 ± 6.92	13.05 ± 10.84	12.25 ± 6.67	14.50 ± 8.55	12.65 ± 6.19	13.21 ± 15.23	<0.0001

Values are mean ± SD or %. Categorical variables presented as n (%) frequencies and continuous variables as mean ± SD. *p value compared between success in different groups; NS > 0.05 (chi-square and 1-way analysis of variance). †p < 0.05 intragroup.
ISR = in-stent restenosis; other abbreviations as in Tables 1 and 2.

artery in the retrograde technique success groups. However, the success rate with each wiring technique is similar, but overall, this increases the success rates cumulatively in some patients. Single wire usage was the predominant strategy used in 510 (64%) cases followed by parallel wire technique in 150 (19%) cases, retrograde guidewire crossing in 57 cases

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Table 4. In-Hospital Complications for CTO Success and Failure Groups

Variables	CTO Success (n = 791)	CTO Failure (n = 113)	p Value
Death	2 (0.25)	3 (2.6)	NS
Q-wave MI	4 (0.50)	1 (0.88)	NS
Non–Q-wave MI	20 (2.5)	2 (1.76)	NS
Urgent CABG	1 (0.10)	1 (0.88)	NS
MACE	12 (1.5)	5 (4.4)	0.027
Aortic dissection	1 (0.10)	1 (0.88)	NS
Arrhythmias	3 (0.40)	1 (0.88)	NS
Delayed tamponade	5 (0.6)	1 (0.88)	NS
Acute vessel occlusion	5 (0.6)	0 (0)	0.058
Subacute occlusion	2 (0.23)	0 (0)	1.00
Distal embolization	24 (3.0)	0 (0)	0.008
Spasm	2 (0.23)	0 (0)	1.00
Side branch compromise	35 (4.4)	1 (0.88)	0.008
Any dissection	110 (13.9)	25 (22)	0.006
Type 1 perforation	59 (7.0)	39 (19.2)	<0.01
Type 2 perforation	3 (0.4)	2 (1.0)	0.240

Values are n (%).
MACE = major adverse cardiovascular events; other abbreviations as in Table 1.

(7.2%), and CART wire crossing technique in 78 (9.9%) cases of the successful procedures. The IVUS guided wire crossing was performed at different stages of the procedure in 78 (10%) of the successful procedures.

Several different guidewires were used ranging from soft wires to intermediate wires and CTO dedicated wires along with various back up supporting catheters. The final guidewires used were stiff wires (60% of cases), polymer-coated hydrophilic wires (19%), and soft wires in (21%) of the cases.

The majority of the patients were treated with stents (74.3%) after successful recanalization and balloon angioplasty was the main device used in 18% of the cases. Several other adjunctive mechanical devices were used such as directional coronary atherectomy, cutting balloon angioplasty, and rotablation. However, cutting balloon angioplasty, rotablation, and directional coronary atherectomy were the primary treatment devices in 31 (4%), 22 (3%), and 6 (1%) cases, respectively.

In-hospital complications. The in-hospital complications for both success and failure groups are shown in Table 4. Total in-hospital MACE was low (1.9%) and was slightly higher in the CTO failure group (1.5% vs. 4.4%, $p = 0.02$). The in-hospital mortality was 0.25% and 2.6% in CTO success and failure groups, respectively. The Q-wave MI/non–Q-wave MI rate was 0.5%/2.5% and 0.8%/1.76% in CTO success and CTO failure groups, respectively. One patient in each group needed urgent CABG, and urgent repeat PCI due to acute vessel closure was seen in 5 (0.6%) cases. Delayed cardiac tamponade needing pericardiocentesis was seen in 6 (0.6%) cases. Aortic dissection was seen in 2 patients, 1 in each group, needing conservative treatment. Major side branch compromise was noted in 36 patients (3.9%), predominantly in the successful recanalization group. We identified 135 (14.9%) cases with different degrees of vessel dissection and that were similar in both groups. There were 98 patients (9.3%) identified with Type 1 coronary perforation, and the number was significantly higher in the failure group (19.2% vs. 7.0%; $p < 0.01$). Type 2 coronary perforations were seen in 5 cases (0.5%) and were similar in both groups.

Table 3 also shows stratification of in-hospital complications and MACE events according to the different wiring techniques utilized with the success and failure groups. There was no difference noted in the in-hospital MACE events in all groups; however, there were more Type 1 perforations seen in patients with single wire failure, parallel wire, and retrograde attempts. Procedure duration, fluoroscopy time, and fluoroscopy dose increased with more complex wiring techniques.

Determinants of procedural success. Results of the logistic regression model are shown in Table 5. There were no significant differences in the age, sex, history of hypertension, diabetes mellitus, hyperlipidemia, family history, smoking, previous MI, previous CABG, unstable angina, body surface area, previous PCI, in-stent restenosis, and significant side branch at CTO site in the successful and failure groups. Only severe tortuosity and moderate-to-severe calcification were associated with technical failure in this series.

Table 5. Logistic Regression Result for Unsuccessful CTO Procedures

Variables	Odds Ratio	95% Confidence Interval	p Value
Female	0.93	0.57–1.52	0.787
Age	0.98	0.97–1.0	0.164
Diabetes mellitus	1.08	0.78–1.51	0.628
Hypertension	0.88	0.63–1.24	0.499
Hyperlipidemia	0.93	0.67–1.30	0.695
Family history	0.89	0.57–1.40	0.637
Smoking	0.87	0.60–1.25	0.463
Previous MI	0.81	0.50–1.34	0.427
Previous CABG	0.74	0.43–1.05	0.195
Unstable angina	0.61	0.36–1.06	0.084
BSA	0.50	0.20–1.24	0.137
Previous PCI	1.17	0.75–1.83	0.472
In-stent restenosis	1.27	0.65–2.49	0.478
Absence of side branch	1.96	1.18–3.26	0.009
Severe tortuosity	2.30	1.26–4.18	0.006
Moderate calcification	1.95	1.19–3.21	0.008
Severe calcification	1.60	0.97–2.65	0.064
Nonaorto-ostial	0.70	0.44–1.11	0.132
Multivessel disease	1.20	0.85–1.69	0.283

BSA = body surface area; other abbreviations as in Table 1.

Discussion

Our study. The major findings of this study are that in an unselected population of patients undergoing PCI for CTO procedure of more than 3 months' duration: 1) the technical success rate in the current era is high around 87%; 2) the in-hospital MACE and other complications are low and comparable to other non–CTO-PCI data (19,20); and 3) the incidence of Type 1 coronary perforation was higher with the use of novel wiring techniques and high usage of stiff guidewires.

The procedural success rate for CTO-PCI has improved over the years with the uptake of new techniques (IVUS guided, retrograde, and CART) and available equipment. In our series, the success rates have increased from 80% to around 90% from the year 2004 onward, and this is associated with the introduction of retrograde wiring technique, CART procedure, and IVUS guided wiring techniques. This is the largest series describing the lesion morphology and guidewire crossing strategies and their influence on successful recanalization of the CTO lesions.

Several studies have looked at the in-hospital outcomes and complications following CTO-PCI. The majority of these studies have included patients with occlusion duration of 4 weeks or more as the definition for CTO lesion. Compared with these studies, our series included complex cases of CTO and showed the continuing high success rate with low complications.

Procedural success rates. Suero et al. (10) have reported an overall success rate of 69.9% in their cohort during the period of 1980 to 1999 with only 7% usage of stents. In the same era, Stone et al. (4) reported a success rate of 72%. More recently, Hoye et al. (3) and Olivari et al. (13) reported procedural success rates of 65.1% and 73.3%, respectively. Both these studies used 4 weeks' duration to define the CTO lesion and the stent use was high (around 80%). More recently, Prasad et al. (12) published the 25-year experience of their institution and showed a procedural success rate of around 70%, with not much improvement in success rate with widespread use of stent and with time. The predominant reason for the low success rate in the treatment of CTO is the failure to cross the lesion with the guidewire (4–11).

Our data suggest that advances in guidewire techniques, such as parallel wire technique, retrograde technique, CART technique, and IVUS guided wiring, have improved the success rate in CTO-PCI in this group of patients with complex lesion morphology.

In-hospital outcomes. The higher success rate in our series of patients is not associated with an increase in acute complications rates, despite high use of stiff wires and aggressive guidewire strategies. Major adverse cardiac events occurred in only 17 patients (1.8%) with the prevalence of Q-wave MI in 5 (0.5%) patients and non–Q-wave MI was seen in 22 (2.4%) of the patients. Cardiac tamponade, possibly due to the wire perforation, occurred in only 6 (0.66%) patients. These in-hospital complications are similar to those reported in the literature. Olivari et al. (13) reported MACE rates of 5.1% and MI rates of 4.25% in a multicenter registry. Hoye at al. (3) reported MACE rates of 3.5%, with high incidence in the failed group very similar to our study. Prasad et al. (12) reported reducing MACE rates and the need for urgent CABG over time with recent rates of around 3.5% and 0.7%, respectively. Our data are comparable to recently published literature for urgent CABG, MI, and MACE following contemporary coronary interventions.

There was a higher incidence of Type 1 coronary perforation in our series with higher usage of stiff guidewires and complex wiring techniques. However, they did not result in significant adverse events and were mostly managed conservatively by prolonged balloon inflation and reversing anticoagulation.

The procedure time, fluoroscopy time, and fluoroscopy dosage increased with increasing complexity of the cases and the wiring techniques. As expected, in some cases, a stepwise approach of different techniques results in accumulating time and radiation dosing.

The high success rate in our study is due to the combination of factors such as increased operator's experience, availability of dedicated CTO wires and microcatheters, and use of advanced guidewiring techniques. Interestingly, the high success rate was not associated with increased adverse events, despite the use of more aggressive devices and techniques.

Our results of in-hospital complications are similar to those shown in large databases with non–CTO-PCI (19,20).

Predictors of success. In the multivariate analysis, severe tortuosity and moderate-to-severe calcification are the only predictors shown to be significantly associated with procedural failure in our study. The other important observation from our study is that 22 patients (20%) in the failed group had CTO attempted to the branch artery. There were significant low success rate with branch CTO lesion (6.6% vs. 19.6%). This is merely a fact that it is technically difficult to recanalize the branch; also, more aggressive strategies could not be applied to the branch lesions. Multivessel disease and side branch at CTO site were not found to be related to procedural failure in our study.

Presence of multivessel disease, CTO length more than 15 mm, and moderate-to-severe calcifications were shown to be independent predictors of unsuccessful procedures in a study by Olivari et al. (13). Multivessel disease, previous MI, and previous CABG were also noted to occur with high frequency in the study by Prasad et al. (12). Side branch at the occlusion site has also been shown to be a negative predictor of success along with bridging collaterals and abrupt stump in some older studies (8,21). The majority of these predictors of unfavorable outcomes were observed with antegrade approach to recanalization of the CTO lesion, although, this was not observed in our study. Also, these differences can be explained by increasing use of retrograde and IVUS guided wiring techniques.

Our study has shown a high incidence of previous MI and previous CABG as reported in literature, but they are not significantly different in patients in the successful and failed PCI groups.

Comparison of predictors in different studies can be difficult, as most studies are small (6,8,11,22,23) and some large series are lacking in angiographic and morphological characteristics (4,5,12,13). Moreover, the definition of CTO varied greatly and the majority of studies including patients with 4 weeks' duration or longer as well as some reported studies have included patients of recent occlusions (4,5). This is very important because the results of CTO-PCI should be compared with identical patient subsets. Duration of occlusion still remains the important predictor of outcomes following CTO-PCI.

The CTO-PCI requires special devices, techniques, and different strategies. The procedural success mainly depends on the operator's techniques and combination of complex strategies. Stepwise utilization of different guidewire strategies is needed in some patients to achieve successful recanalization. However, there could be an increase in the radiation exposure and coronary artery perforation with use of complex wiring and dedicated CTO guidewires. Further refinement in procedural techniques and education is needed to reduce complications and increase recanalization rates in CTO-PCI.

Study limitations. The retrospective nature of the study is a major limitation, and although data was collected prospectively, there are limitations to such analysis. Second, the duration of occlusion cannot be ascertained with confidence in some cases. Third, the results of this study could be influenced by selection criteria, operator experience, and technique variation among the operators. Fourth, lack of follow-up data beyond hospital stay is a limitation.

Conclusions

These data represent a large series of consecutive patients treated with PCI of CTO in contemporary fashion involving dedicated CTO guidewires and novel guidewire crossing techniques. We have reported high overall success rates with low MACE events and other complication rates. We found that predictors of failed procedures are severe tortuosity and moderate-to-severe calcification of the occluded vessel. As previously reported, other angiographic features such as multivessel disease, previous CABG, and side branch at the site of occlusion were not found to be predictive of procedural failure in our study. Thus, we recommend that PCI should be considered as the preferred strategy for patients who are symptomatic with CTO of the coronary arteries.

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Key Words: chronic total occlusion ■ percutaneous coronary intervention ■ in-hospital major adverse cardiac events ■ procedural success ■ controlled antegrade and retrograde tracking.