ORIGINAL ARTICLE

Chronic total occlusion- Percutaneous coronary intervention (CTO-PCI) experience in a single, multi-operator Tunisian center : A Five-Year Report

Angioplastie des occlusions totales chroniques : Rapport de cinq ans d'expérience dans un centre Tunisien multi-opérateurs

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Abstract

Introduction: In recent years, advancements in chronic total occlusion (CTO) percutaneous coronary intervention (PCI) have been notable, improving procedural techniques, imaging, and management of complications.
Aim: We sought to assess the performance and the practice of a high-volume Tunisian PCI center in treating patients with a CTO.
Methods: We retrospectively evaluated data from consecutive CTO patients who underwent percutaneous revascularization from October 2019 to January 2024 at the cardiology department of Habib Thameur Teaching Hospital, Tunisia. Operators' experience and CTO-PCI volume were also documented.
Results: The cohort consisted of 58 patients, predominantly male (86.2%), with an average age of 59.8±9.6 years. The right coronary artery was the most common CTO site (56.9%). The antegrade approach was adopted in 96.5% of the cases, with the antegrade wiring (AW) being the preferred technique (81%). Key procedural characteristics included the use of multiple access sites and dual coronary injection in 44.8% of the cases, multiple guidewires in 50%, additional support modality in 68.9% and drug-eluting stents in all instances. The procedural success rate was 75.9%, with an in-hospital adverse outcome rate of 13.8% and a major adverse cardiac event (MACE) rate of 3.4%. A significant impact of operator experience and volume on success rates (85.3% vs 62.5%, p=0.04) and adverse outcomes (25% vs 5.8%, p=0.03) was observed, with trained operators and higher-volume practitioners achieving better results.
Conclusion: In a single-center setting with a conservative CTO cohort, acceptable PCI success rates were achieved. We highlighted the positive impact of CTO training programs and PCI procedures volume on the overall outcomes.

Key words: Chronic total occlusion; Percutaneous coronary intervention; Experience; Tunisia

Résumé

Introduction: Ces dernières années, les avancées dans le domaine de l'angioplastie des occlusions totales chroniques (CTO) ont été remarquables, améliorant les techniques procédurales, l'imagerie et la prise en charge des complications.
Objectif: Évaluer la performance et la pratique d'un centre tunisien à haut volume d'angioplasties coronaires dans le traitement des patients ayant une CTO.
Méthodes: Nous avons évalué rétrospectivement les données de patients consécutifs ayant subi une revascularisation percutanée pour une CTO (définitive) entre octobre 2019 et janvier 2024 au département de cardiologie de l'Hôpital Universitaire Habib Thameur, en Tunisie. L'expérience des opérateurs ainsi que le volume d'angioplasties pour les CTO ont été également consignés.
Résultats: La cohorte comprenait 58 patients, majoritairement masculins (86,2 %), avec un âge moyen de 59,8 ± 9,6 ans. L'artère coronaire droite était le site de CTO le plus courant (56,9 %). L'approche antérograde a été adoptée dans 96,5 % des cas, le wiring antérograde (AW) étant la technique privilégiée (81 %). Parmi les caractéristiques procédurales clés figuraient : l'utilisation de multiples sites d'accès et l'injection coronaire controlatérale dans 44,8 % des cas, l'utilisation de multiples guides coronaires (>1) pour franchir l'occlusion dans 50 % des instances, le recours à une modalité de support additionnelle chez 68,9 % des patients et le déploiement des stents actifs dans 100% des cas. Le taux de succès procédural était de 75,9 %, avec un taux de complications intra-hospitalière de 13,8 % et un taux d'événements cardiaques majeurs (MACE) de 3,4 %. Un impact significatif et positif de l'expérience des opérateurs et du volume procédural sur les taux de succès (85.3% vs 62.5%, p=0.04) et les taux de complications (25% vs 5.8%, p=0.03) a été observé, en faveur des opérateurs formés en CTO et ceux réalisant un plus grand nombre d'interventions.
Conclusion: Dans un contexte monocentrique avec une cohorte conservatrice de CTO, des taux de succès acceptables d'angioplastie ont été atteints. Nous avons souligné l'impact positif des programmes de formation en CTO et du volume de procédures d'angioplastie sur les résultats globaux.

Mots clés: Occlusion totale chronique; Intervention coronaire percutanée ; Expérience ; Tunisie.

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Introduction

Coronary chronic total occlusion (CTO) is defined as the complete and persistent occlusion of a coronary artery, characterized by Thrombolysis In Myocardial Infarction (TIMI) grade 0 flow, for an estimated duration of more than 3 months (1). CTO represents an advanced stage of atherosclerotic coronary artery disease, currently observed in about one-fifth of patients undergoing diagnostic coronary angiography(2–5). Interestingly, an increasing amount of evidence indicates that revascularizing CTO can offer multiple clinical advantages, such as alleviating ischemic symptoms and enhancing the quality of life for patients(6–8). However, it is still unclear whether revascularization of CTO provides a survival benefit or long-term freedom from cardiac events, compared to receiving optimal medical therapy alone (7–9).

Despite the limited number of randomized and controlled trials available, remarkable progress has been achieved in CTO PCI recently, with refinement of the indications and technical aspects of the procedure, imaging, and complication management(5). CTO PCI procedural volumes have been increasing, and vary significantly across different regions, institutions, and based on the operators' expertise (5,10,11). Regarded as among the most complex procedures in contemporary endovascular therapy, the success rate of PCI for CTO has seen significant enhancements owing to advancements in techniques and equipment, CTO treatment algorithms, as well as the international exchange of knowledge and experience in major CTO conferences/ workshops and the development of expert consensus documents(10,12,13).

In view of these elements, and given the scarcity of published data on CTO PCI from Tunisia, this study aimed to evaluate the performance of a high-volume Tunisian PCI center in treating patients with CTO. It sought to report on the indications, procedural and technical aspects, in-hospital outcomes, and the impact of training programs on success rates.

Methods

Study design and population

This was a single-center, descriptive, and retrospective review of consecutive CTO patients who underwent percutaneous revascularization from October 2019 to January 2024 at the cardiology department of Habib Thameur Teaching Hospital, Tunisia. The inclusion criteria encompassed patients requiring non-emergency PCI for a definite CTO, as described subsequently. We excluded those with TIMI grade 1 antegrade flow through a severely stenosed but patent lumen or with occlusions known or suspected to be of less than three months duration.

Data collection

We analyzed our departmental database, hospital medical records, and individual angiograms to assess baseline characteristics of patients and lesions, procedural details, and outcomes during the procedure and hospital stay. All coronary angiograms were visually evaluated by at least two CTO operators who were blinded to patients' clinical information. Angiographic characteristics were obtained from comprehensive qualitative analyses of the lesions (Figure 1(14)), and the J-CTO score was calculated accordingly. Adjunctive modalities used to assist PCI recanalization, including intravascular imaging and coronary CT angiography (CTCA), were also recorded. Additional Support modalities included microcatheters and over the wire balloons. Information about the interventional cardiologists who carried out CTO PCI at our institution was collected, with a particular emphasis on their previous participation in training programs. This study was performed in accordance with the Declaration of Helsinki and good clinical practice.

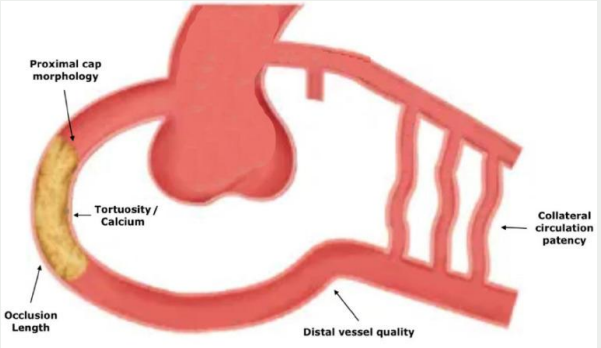

Figure 1. Angiographic characteristics of CTO lesion(14)

Definitions and Study Endpoints

All definitions adhered to the standards set by the Chronic Total Occlusion Academic Research Consortium (CTO-ARC), as outlined in their 2021 publication (1).

Chronic total occlusion

CTOs must have absent antegrade flow through the lesion (TIMI grade 0 flow). The typical appearance of a CTO involves the presence of angiographically evident mature collaterals and the lack of thrombus or staining at the proximal cap. However, precise information on the duration of occlusion is often unavailable. In view of these elements, CTOs should be classified as :

- *Definite* : CTO with typical appearance and definitive corroborating evidence of occlusion duration ≥3 months (e.g., prior angiogram demonstrating a total occlusion or acute myocardial infarction that is left untreated).
- *Probable* : CTO with typical appearance.

Lesion Crossing Strategies and nomenclature

CTO interventions can be categorized into two primary approaches: the antegrade approach (Figure 2(14), A and B), which involves accessing the occluded segment from its proximal end with the goal of penetrating the distal end to reach the true lumen, and the retrograde approach (Figure 2(14), C and D), where the occlusion is accessed from its distal end with the aim of reaching the proximal true lumen. Furthermore, these strategies

can be differentiated based on the employed technique, namely, the wiring technique (Figure 2(14), A and C) versus the dissection-reentry technique (Figure 2(14), B and D). For the reentry technique, it is advisable to refer to it as "wire-based reentry" when no specific reentry device is employed, and as "device-based reentry" when such a device is used, without detailing the exact method applied (Table 1). Furthermore, the Parallel Wire Technique (PWT) involves two antegrade wires in which the first wire has tracked into a false lumen and its tip is used as a landmark to redirect the second wire through the true lumen(15).

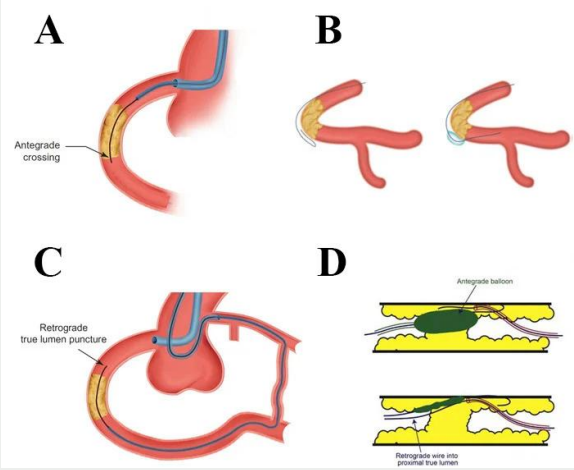

Figure 2. Lesion Crossing Strategies(14)

A : Antegrade wiring; **B** : Antegrade dissection and re-entry; **C** : Retrograde wiring; **D** : Retrograde dissection and re-entry

Table 1. Classification of CTO Strategies

Approach and crossing technique	Definition	Retrograde approach contribution
AW	Wire-based technique with the intention of traversing from the proximal vessel true lumen through the CTO to the distal vessel true lumen	No: AW-0 Yes: AW-R
ADR	Dissection technique (wire based or device based with a dedicated dissection device or equivalent) with the intention of passing from the proximal vessel lumen through a dissection plane followed by reentry into the distal vessel lumen at or beyond the distal cap of the occlusion	No: ADR-0 Yes: ADR-R
RW	Wire-based technique with the intention of traversing from the distal vessel true lumen to the proximal vessel true lumen	
RDR	Dissection technique (usually with knuckled wires) with the intention of connecting an antegrade dissection plane and a retrograde dissection plane, with wires advanced antegrade and/or retrograde	

ADR= Antegrade dissection re-entry; **AW**: Antegrade wiring; **CTO**: Chronic total occlusion; **RDR**: Retrograde dissection re-entry; **RW**: Retrograde wiring; **R**: Retrograde attempt; **0**: no retrograde attempt

Efficacy End Points

Crossing Success : CTO crossing success is determined by either angiographic or intravascular imaging evidence of the guide wire (or a related device) being positioned within the true lumen of the main vessel beyond the occluded segment.

Technical Success : Technical success is defined as achievement of TIMI grade 2 or greater antegrade flow in all ≥2.5-mm distal branches with <30% residual stenosis of the target CTO lesion at procedure end.

Procedural Success : is defined as technical success plus the absence of an in-hospital major adverse cardiovascular events (MACE).

Safety End Points

Cardiovascular death : is defined following to the ARC-2 criteria(16).

Stroke : we adopted the NeuroARC definition and classification (17).

Procedural Myocardial infarction (MI) : procedural MI was diagnosed in patients whose hs-cTn levels exceeded 70 times the upper reference limit within 48 hours post-procedure, accompanied by at least one of the following criteria: :1. TIMI grade 0–1 flow in a main epicardial vessel or in a sidebranch >2.0 mm in diameter that had TIMI grade 2–3 flow before PCI. 2. New pathological Q waves in ≥2 contiguous leads or new persistent left bundle branch block. 3. New wall motion abnormality related to the procedure.

In hospital MACE : included cardiovascular death, Myocardial infarction and emergency PCI or Coronary Artery Bypass Graft Surgery.

Stent Thrombosis: The ARC-2 criteria for stent thrombosis(16) were applied with modifications for CTO-PCI, broadening the definition to encompass symptomatic thrombosis in any segment of the target vessel treated during the initial procedure, not limited solely to the stented target lesion.

Additional secondary endpoints included: 1. coronary perforation requiring prolonged balloon inflation or other intervention; 2. cardiac tamponade requiring pericardiocentesis; 3. bleeding requiring a blood transfusion but not resulting in a hemodynamic compromise (GUSTO definition(18)); 4. acute kidney injury (AKI): according to the Valve ARC-2 criteria for AKI in Mitral Valve trials and registries(19); 5. access site vascular complications : hematoma >5 cm, pseudoaneurysm or retroperitoneal bleed;

CTO operators metrics :

We categorized operators based on their volume of CTO-PCI procedures and whether they had undergone specialized training in CTO techniques. The following definitions were adopted(20) : Low-volume operators (LVO: < 30 cases/year); medium-volume operators (MVO: 30-60 cases/year); and high-volume operators (HVO: > 60 cases/ year).

Statistical Analysis

The baseline clinical, lesion and procedural characteristics, angiographic and clinical outcomes were evaluated by descriptive statistics. For continuous variables, mean ± standard deviation (SD) or median and interquartile range (25th-75th percentile) levels were calculated, where appropriate. For categorical variables, count and percentages were determined. Normally distributed

continuous variables were compared by two tailed unpaired t-test and categorical variables were compared by chi-square test. A p-value of <0.05 was established as the level of statistical significance for all the tests. All statistical calculations were performed using the SPSS statistics version 25.0.

Results

Over nearly five years at our center, 9,119 patients underwent coronary angiography, with 8.9% (n=816) having a chronic total occlusion (CTO). Of the 4,633 patients who underwent percutaneous coronary intervention (PCI), 2% (n=96) involved CTO procedures. Of those with CTO, 11.7% attempted or completed PCI, 35.5% received Coronary Artery Bypass Graft Surgery, and 52.6% were managed medically. After reviewing angiograms and clinical data, 38 cases were excluded, leaving 58 patients (1.2% of all PCIs) with definite CTO included in the study.

Clinical and angiographic characteristics

The overall mean age was 59.8±9.6 years, with a majority being male (86.2%). Smoking emerged as the leading major cardiovascular risk factor, affecting 65.5% of the study participants, with diabetes mellitus coming in next at 58.6%. Among all participants, 60.3% (n=35) had a history of myocardial infarction, and 46.6% (n=27) had undergone previous PCI for non CTO lesions. The primary indication for CTO revascularization was the relief of ischemic symptoms (63.8 %). Noninvasive stress imaging and viability assessment were performed for only 1.7 % (n=1) and 3.4 % (n=2) of the study population, respectively. The baseline clinical characteristics of the study population are shown in detail in table 2.

Table 2. Population baseline clinical characteristics

Variable	Population (N=58)
Age (years)	59.8±9.6
Male	86.2 %
History of smoking	65.5 %
Diabetes mellitus	58.6 %
Dyslipidemia	31 %
Hypertension	39.7 %
Prior MI	60.3 %
Prior PCI	46.6 %
Prior CABG	0.0 %
Indication for CTO revascularization	
Ischemic symptoms relief	63.8 %
Complete myocardial revascularization in MVD patients	32.8 %
Improvement of severely impaired LV function	12.1 %
Proximal coronary vessels disease	1.7 %
Non-invasive stress imaging	1.7 %
Viability assessment	3.4 %
LV ejection fraction	
Median	54 (47.25-58)
Severely impaired	12.1 %
Median blood creatinine level (µmol/L)	79 (73-89)
Median hemoglobin level (g/dl)	14 (13-14.9)

Data are expressed as mean ± SD, median ± interquartile range and n (%)
CABG= coronary graft bypass surgery; **CTO**= Chronic total occlusion, **LV**= Left ventricle; **MI**= Myocardial infarction; **MVD**= Multi vessel disease; **PCI**= Percutaneous coronary intervention

In terms of lesion characteristics, multivessel disease (MVD) was noted in approximately two-thirds of the participants (69%). A significant portion of the patients presented with right coronary artery (RCA) CTO (56.9%, n=33), while intra-stent CTOs were found in 10 patients (17.2%). Concerning coronary collateral circulation, 69% of our cohort exhibited Rentrop grade 3 filling, while collateral connection (CC) grades 2 and 3 were noted in 43.1% and 37.9% of cases, respectively. J-CTO scores ranged from easy (20.7%) to very difficult (6.9%). Population coronary lesion characteristics are summarized in table 3.

Table 3. Population coronary lesion characteristics

Variable	Population (N=58)
Multivessel disease	69 %
Target vessel CTO	
Left anterior descending artery	32.8 %
Left circumflex artery	10.3 %
Right coronary artery	56.9 %
Intra-stent CTO	17.2 %
Rentrop classification	
Grade 0	3.4 %
Grade 1	10.3 %
Grade 2	17.2 %
Grade 3	69 %
Collateral connection grade	
CC 0	6.9 %
CC 1	12.1 %
CC 2	43.1 %
CC 3	37.9 %
Presence of antegrade bridging collaterals/ Microchannels	48.3 %
J-CTO SCORE	
0	20.7 %
1	37.9 %
2	34.5 %
3 or higher	6.9 %
Coronary CT angiography	1.7 %

Data are expressed as percentages (%)
CC= Collateral connection; **CT**= computerized tomography; **CTO**= Chronic total occlusion

Procedural characteristics and outcomes

Procedural details are presented in Table 4.
More than one arterial access site was secured in 44.8% of cases (n=26), accompanied by dual coronary injection in the same range. Radial access emerged as the preferred site, accounting for 46.6% of cases (n=27), with a combination of radial and femoral access trailing at 32.8% (n=19). Overall, 6 French catheters were the most commonly used (69%). Regarding the guidewire crossing approaches, the antegrade approach was adopted in 96.5% of the cases. Antegrade wiring was performed in 81% of the cases (n=47). The retrograde approach only accounted for 2 patients (3.4%). All re-entry techniques were wire-based. More than one coronary guidewire was used to cross the CTO in half of the cases. The median number of guidewires per case was 1.5 (range: 1-5). Lesion crossing was successfully achieved in 79.3% of cases (n=46). Of these, a workhorse guidewire was used in 28.2% of the cases and a polymer jacketed guidewire with intermediate gram force in 25.8%, followed by a tapered polymer jacketed guidewire in 19.5 % (Figure 3).

Table 4. Procedural details

Variable	Population (N=58)
Access site	
> 1	44.8 % (n=26)
Radial	46.6 % (n=27)
Femoral	8.6 % (n=5)
Radial + femoral	32.8 % (n=19)
Bi-radial	6.9 % (n=4)
Bi-femoral	5.2 % (n=3)
Dual injection	44.8 %
Catheter/sheath size	
6F	69 % (n=40)
7F	31 % (n=18)
8F	0.0 %
Guidewire crossing approaches	
Antegrade approach	96.6%
Antegrade Wiring	81.1 %
PWT	8.7 %
Antegrade dissection and re-entry	6.9 %
Retrograde approach	3.4%
Retrograde wiring	1.7 %
Retrograde dissection and re-entry	1.7 %
>1 guidewire to cross CTO	50 %
Median number of guidewires per case	1.5 (1-5)
Additional Support use	68.9 % (n=40)
Support modalities:	
Microcatheter	45 % (n=18)
Over the wire balloon	55% (n=22)
Guiding Catheter Extensions	0.0 %
Intravascular imaging	1.7 %
Drug-eluting stent usage	100 %
Stent length (mm)	74.8±32.9
Number of implanted stents per patient	1.85±0.6
Procedural outcomes	
Crossing Success	79.3% (n=46)
Technical Success	79.3% (n=46)
Procedural Success	75.9 % (n=44)
Procedural metrics	
Contrast volume (mL)	251.2±114.1
Median fluoroscopy time (min)	45.9 [30-64.8]
Median procedural time (min)	90 [63.5-134]

Data are expressed as mean ± SD, median ± interquartile range and n (%)
CTO= Chronic total occlusion; **F**=French; **PWT**= parallel wire technique

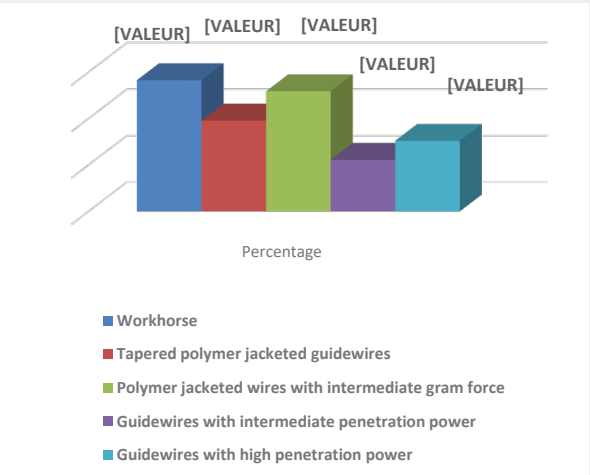

Figure 3. Categories of crossing guidewires

The ASAHI Gladius EX and the ASAHI Fielder series were the most successful crossing guidewires (Figure 4). Mostly, an additional support modality was used in 68.9% (n=40). Intravascular imaging was performed in only one patient. Drug-eluting stents were deployed in 100% of all cases. The average total stent length per target vessel was 74.8±32.9 mm and the mean number of stents per lesion was 1.85±0.6.

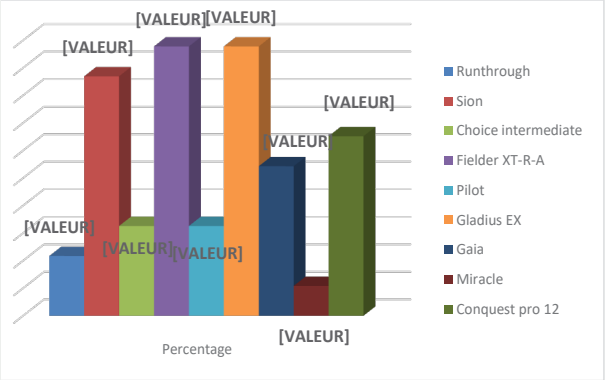

Figure 4. Wires used to finally cross

Procedural outcomes are also displayed in Table 4. Crossing success was achieved in 79.3% (46 cases), with each lesion adequately addressed, leading to a consistent technical success rate. Furthermore, overall procedural success rate reached 75.9% (n=44) across all cases. Procedural success rates according to J-CTO score were: 75 % (J-CTO Score of 0); 86.3% (score of 1); 70% (score of 2); 50% (score of 3 or above). Procedural metrics are listed below.

Six interventional cardiologists performed CTO-PCI in our center. The number of cases done by each operator varied from 5 to 22. Half of the operators boasted a decade or more of experience, and a similar portion had participated in specialized CTO training programs. These trained individuals were two MVOs and one HVO, with the remaining operators being LVOs. Of note, a statistically significant difference in procedural success rates was noted between operators who had undergone a CTO training program and those who had not (85.3% vs 62.5%, p=0.04). We did not observe significant differences in success rates for CTO-PCI based on: 1. the target vessel (p=0.75); 2. The Presence of antegrade bridging collaterals/Microchannels (71.4% vs 86.6%, p=0.15) and among: 3. those who had intrastent CTOs versus those with de novo CTO lesions (80% vs 79.1%, p=0.95); 4. those who had an additional support modality versus those who had none (80% vs 77.7%, p=0.84). However, in our study, the use of dual coronary injection was statistically associated with improved success rates for CTO-PCI (92.3% vs 68.7%, p=0.02).

In-hospital adverse outcomes

Eight patients (13.8%) exhibited adverse outcomes. Cardiovascular death occurred in 1.7% of the cases (n= 1). One more patient (1.7%) presented with a procedural MI. The overall frequencies of other adverse outcomes were: coronary perforation 5.2 % (n=3); cardiac tamponade 1.7% (n=1); bleeding requiring transfusion 1.7% (n=1); and acute kidney injury 3.4% (n=2). Notably, there were no cases of early stent thrombosis or emergency PCI/CABG. Furthermore, LVOs experienced a significantly higher rate of adverse outcomes compared to the combined rates of

MVOs and HVOs (25% vs 5.8%, p=0.03). Complication rates according to J-CTO score were 15% for score=0, 0.0% for score=1, 16.6% for score=2 and 75% (3 out of 4) for score ≥ 3. In terms of vascular complications, there were three reports (5.2%) of hematomas larger than 5 cm (Table 5).

Table 5. In-hospital adverse outcomes

Variable	Population (N=58)
Cardiovascular death	1.7%
Emergency PCI or CABG	0.0%
Procedural MI	1.7%
In hospital MACE	3.4%
Stent thrombosis	0.0%
Stroke	0.0%
Coronary perforation	5.2%
Cardiac tamponade	1.7%
Bleeding requiring transfusion	1.7%
Acute kidney injury	3.4%
Vascular complications	
Hematoma >5 cm	5.2%
Pseudoaneurysm	0.0%
Retroperitoneal bleed	0.0%

Data are expressed as percentages (%)
CABG= coronary graft bypass surgery; **MACE**= Major adverse cardiovascular events; **MI**= Myocardial infarction; **PCI**= Percutaneous coronary intervention

Discussion

This retrospective descriptive analysis, focusing on a high-volume PCI center in Tunisia, sought to assess our practice and performance in CTO-PCI. Its main findings are: 1. a clinically based indication for CTO revascularization with infrequent recourse to non-invasive stress testing and viability assessment; 2. a relatively conservative overall approach to tackling CTO-PCI : including the modest rate of dual injection and the low use of coronary CT angiography for optimal delineation of the CTO segment, the widespread adoption of the antegrade wiring technique, and limited usage of microcatheters, intravascular imaging or novel device-based lumen re-entry technologies; 3. Relatively acceptable success rates compared to contemporary standards in high volume international centers of excellence and the positive impact of CTO training programs and PCI volume on success rates.

Patient selection for CTO revascularization

The ESC guidelines on myocardial revascularization recommend that the selection of patients for CTO PCI should align with the criteria used for those requiring treatment for non-CTO lesions, highlighting that the clinical outcomes are comparable between these groups. Thus, the principles and decision-making criteria for revascularizing stable coronary artery disease are also applicable to CTO cases(21). According to the guidelines, patients may derive prognostic benefits from revascularization if they have significant lesion in the left main and/or left anterior descending artery (LAD), multi-vessel disease, or an ischemic territory that encompasses more than 10% of the left ventricle(21,22). Hence, they recommend the quantification of ischemia using non-invasive imaging techniques as a preliminary step prior to revascularization. For individuals with left ventricular dysfunction, the guidelines suggest performing viability assessment to detect stunned or hibernating myocardium associated with heart failure, which might have the potential for functional improvement(21,23). In our study, the infrequent use of non-invasive stress imaging and viability assessment can be attributed to logistical challenges and the high cost of these tests, which are not conducted on a regular basis. In the same vein, the 2021 American guidelines recently lowered the clinical recommendation for CTO PCI to a class II-b, evidence level B, reflecting the ambiguous results from randomized trials: “In patients with suitable anatomy who have refractory angina on medical therapy, after treatment of non-CTO lesions, the benefit of PCI of a CTO to improve symptoms is uncertain”. They also encourage CTO PCI after a shared decision-making process and consideration of the potential benefits(24).

Incidence of CTO-PCI : worldwide data

Our analysis is the first to report comprehensive data on CTO-PCI and its tendencies from a high volume Tunisian single center. During the nearly 5-year span of our study, only 2% of all PCI procedures were CTO-PCIs, and just 11% of patients with a CTO were recommended PCI as a treatment option. According to data from global CTO registries, less than 10% of all CTOs are treated with percutaneous techniques(25,26). Accordingly, discrepancies exist in reported CTO-PCI volumes among all performed PCIs, with the Polish national registry(27) and the American National Cardiovascular Data Registry (NCDR)(28) showing rates between 2.34% and 3.8%, while Dutch(11) and Swedish(29) nationwide registries report higher rates of 5.8% and 6.3%, respectively. Although there has been a noticeable increase in the last decade, the overall volume of CTO-PCI procedures remains relatively low worldwide(5).

Procedural characteristics and outcomes

Interestingly, in our study, the antegrade wiring technique was the primary approach used for CTO crossing, accounting for 81% of cases, while the use of retrograde and dissection-reentry strategies was considerably less common. We also observed a modest rate of dual coronary injection and low use of pre-procedural coronary CT angiography. In light of practical experience, Nearly 70% of CTO interventions can be successfully recanalized using antegrade wiring(30,31). In addition, a major breakthrough in CTO PCI has been the development of an algorithmic approach to CTO crossing. The first published algorithm was the hybrid algorithm(32), which advocates routine dual injection and systematic angiographic review to determine the initial CTO crossing strategy (33,34). The Asia-Pacific algorithm(35) suggests the use of pre-procedural CT angiography and the use of per procedural intravascular ultrasound to guide the proximal cap puncture. As for the Euro CTO Club, experts recommend

using the parallel wire technique or ADR, preferably with the Stingray system, if the antegrade wiring approach is unsuccessful(36). Another perspective is offered by a Japanese group of expert operators, who deliberately favor a direct retrograde approach for complex occlusions, while a primary antegrade approach is preferred for in-stent CTOs and occlusions with J-CTO scores of 0 and 1 (37), which is obviously the case of our study. Certain core principles are universally acknowledged. A global consortium of CTO experts from all five continents has distilled these into seven fundamental principles (Table 6), culminating in the creation of a comprehensive global CTO crossing algorithm that encapsulates the full spectrum of existing CTO PCI methodologies(38).

Table 6. Global Guiding Principles for CTO PCI

1. Improvement in ischemic symptoms is the primary indication for CTO PCI.
2. Dual coronary angiography and in-depth and structured review of the angiogram are key for planning the procedure.
3. Use of a microcatheter is essential for optimal guidewire manipulation and exchanges.
4. Antegrade wiring, antegrade dissection and re-entry, and the retrograde approach are all complementary and necessary crossing strategies; antegrade wiring is the most common initial technique, whereas retrograde and antegrade dissection and re-entry are often required for more complex CTOs.
5. If the initially selected crossing strategy fails, efficient change to an alternative crossing technique increases the likelihood of eventual PCI success and maximized procedural efficiency.
6. Specific CTO PCI expertise and volume and the availability of dedicated equipment will increase the likelihood of crossing success and facilitate prevention and management of complications.
7. Meticulous attention to lesion preparation and stenting technique (often requiring intracoronary imaging) is required to ensure optimal stent expansion and minimize the risk of long-term adverse events.

CTO= Chronic total occlusion; **PCI**= Percutaneous coronary intervention

We reported in our study a technical success rate of 79.3%, achieved at the cost of 3.4% MACE and 13.8% of overall adverse outcomes. These figures should be viewed with caution because of our small sample size. In addition, The J-CTO score has an excellent discriminative capacity for predicting successful guidewire crossing and overall CTO-PCI success rates(39), as indicated in our study. Nonetheless, real world data brings another facet. Over the past ten years, the success rate of CTO PCI procedures has seen a significant improvement, partly due to the adoption of state-of-the-art techniques for CTO PCI(5,38). Furthermore, major adverse cardiac event rates have remained stable worldwide despite the overall lesion complexity of CTO PCI having increased(5). In a recently published report on contemporary outcomes of chronic total occlusion percutaneous coronary intervention in Europe (ERCTO)(40), the authors documented an 89.2% technical success rate, , achieved at the cost of 1.7% MACE. Similarly, Werner et al, in the EuroCTO randomized controlled trial, showed a technical success rate of 86.6% and in-hospital complication rate of 2.9%(41). Data from the United States indicates technical success rates for CTO-PCI between 86.0% and 91.5%, with major in-hospital complications reported at 1.8% to 7.0%(3,42–44). Conversely, an Asian study showed technical success rates around 89.9% to 90.1%, with in-hospital MACE ranging from 1.5% to 1.7%(45). Of note, we reported comparable Procedural metrics (contrast volume, fluoroscopic time and procedural time) with different national registries(40).

Many studies have found a correlation between operator procedural volume and the success rate of CTO PCIs(28,46,47). In our cohort, a statistically significant difference in procedural success rates was noted between operators who had undergone a CTO training program (two MVOs and one HVO) and those who had not (LVOs). Moreover, LVOs experienced a significantly higher rate of adverse outcomes compared to the combined rates of MVOs and HVOs. In fact, Brilakis et al. demonstrated that operators with higher annual CTO PCI volumes achieve greater success rates without a corresponding rise in major complications(28). In contrast, Karacsonyi and colleagues, in a recent multicenter registry(20), found that HVOs achieved higher technical success rates (87.9% vs 86.9% vs 82.6%; p<0.001) and experienced greater incidences of periprocedural major adverse cardiac events compared to MVOs and LVOs (3.08% vs 2.71% vs 1.50%; p<0.01). The authors attributed these findings to the greater complexity of procedures undertaken by HVOs. However, setting different cutoffs (number of CTO cases per year) to categorize the expertise of operators introduces significant challenges in making comparisons between studies.

True facts and the need for a dedicated CTO program

This study delineates the experiences of a prominent Tunisian center in chronic total occlusion percutaneous coronary intervention (CTO-PCI), confronting the limitations posed by scarce resources and a small, dedicated specialist team. The center's initiative aims to transcend stagnant outcomes in CTO-PCI by instituting a specialized program intended to elevate Tunisian practices to the global forefront. This endeavor necessitates the incorporation of cutting-edge revascularization techniques. Notably, the radial approach has shown to reduce vascular complications compared to the transfemoral method (48), and the advent of dual lumen microcatheters offers a technological boon for complex CTO cases (49), often preferred in retrograde over antegrade strategies. Furthermore, guiding catheter extensions have been shown to streamline procedures and improve success rates, as evidenced by Kandzari et al. (50). The strategic application of intravascular ultrasound (IVUS) is also advocated for enhancing outcomes in intricate scenarios, such as cap ambiguity or wire navigation outside the plaque (5,51).

However, financial constraints can impede the adoption of these advancements. An illustrative case from Australia in 2013 (52) demonstrates the efficacy of a dedicated CTO revascularization program, driven by a trio of interventional cardiologists committed to ongoing CTO-PCI training, which included comprehensive educational sessions and on-site mentorship by a renowned CTO expert. The program's policy mandated dual operators for each case and allocated specific days for CTO procedures, regulated by the J-CTO Score, and established guidelines for contrast and radiation use, aligning with international norms. This example underscores the imperative of embracing global standards in CTO PCI to ensure optimal outcomes with minimal complications.

Study limitations

This study faces the usual constraints of being a retrospective and an observational analysis from a single center. Our work was notably hindered by a small sample size, though we aimed to systematically include patients undergoing CTO-PCI, prioritizing the clear indication for a definite CTO as a crucial selection criterion. There is a potential patient selection bias since the decision to enroll a patient is at the discretion of the operator and is not systematically followed by an oversight committee. In addition, independent core lab analysis of quantitative coronary (QCA) data was not performed. Furthermore, our examination was solely centered on patients undergoing PCI revascularization, omitting outcomes for those managed with medical therapy or surgical intervention for CTO lesions. Lastly, long-term outcome data were not included.

Conclusion

In a single-center setting with a conservative CTO cohort, we achieved acceptable PCI success rates. Yet, it's clear that the operator's experience significantly influences both the success of the procedure and the rate of complications. These findings highlight the critical need for Tunisian centers to embrace a coordinated and focused approach (a dedicated program) to CTO-PCI, in line with international best practices.

ABREVIATIONS LIST
ADR: Antegrade dissection and re-entry
ARC: Academic research consortium
AW: Antegrade wiring
CABG: Coronary artery bypass grafting
CTCA: Computed tomography coronary angiography
CTO: Chronic total occlusion
HVO: High volume operator
LV : Left ventricle
LVO: Low volume operator
MACE: Major adverse cardiovascular events
MI: Myocardial infarction
MVD: Multivessel disease
MVO: Medium volume operator
PCI: Percutaneous coronary intervention
PWT: Parallel wire technique
RDR: Retrograde dissection and re-entry
RW: Retrograde wiring
TIMI: Thrombolysis In Myocardial Infarction
TTE: Transthoracic echocardiography

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