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Evaluation of success and complications scores for chronic total occlusion percutaneous coronary interventions: insights from the LATAM registry

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Running title: Success and complication scores for CTO PCI

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ABSTRACT

Chronic total occlusion (CTO) percutaneous coronary intervention is a complex procedure and is associated with considerable risk of complications. Several success and complication scores have been developed; however, data regarding their external validation in other populations such as Latin America are scarce. This study aimed to evaluate the accuracy of the main predictors of success and complications in a broad cohort of procedures in the Latin American (LATAM) CTO registry. From April 2008 to December 2023, 3706 consecutive procedures listed in the LATAM CTO Registry were screened. Of these, 2835 procedures had sufficient information to analyze the J-CTO, PROGRESS, ORA, CL-score, and CASTLE success scores. The complication scores were PROGRESS (MACE, Mortality, and Pericardiocentesis) and OPEN CLEAN. The J-CTO and CASTLE scores demonstrated the highest areas under the curve (AUC) of 0.718 and 0.703, respectively. The AUC value for the CL-score was 0.685, while the PROGRESS score had an AUC of 0.598 and the ORA AUC was 0.545. The level of agreement between scores was low; only 4% of the procedures were classified as difficult or very difficult by all scores and less than 1% were classified as easy by all 5 scores. Among the complication scores, PROGRESS Mortality (AUC 0.651) and PROGRESS MACE (AUC 0.588) showed the best performance, identifying groups with over 10% event rate. These results may improve the selection of revascularization techniques, especially for patient demographics that are historically underrepresented in CTO research.

Keywords: chronic total occlusion, coronary artery disease, scores, percutaneous coronary intervention

INTRODUCTION

Over the past decade, considerable progress has been made in the field of chronic total occlusion (CTO) revascularization. The development and validation of risk scores to predict success and complication rates was an important step forward to adequately apply these procedures in daily practice.¹⁻⁵. Since the primary indication for CTO revascularization is symptom control⁶, a comprehensive preprocedural evaluation is crucial to carefully determine the balance between risks and benefits. However, there is a lack of data regarding the accuracy of these scores in the context of middle and low-income countries, which may present significantly different realities than in cohorts where the scores were validated. This study aimed to evaluate the accuracy of the main predictors of success and complications in a cohort of patients treated by CTO PCI in Latin America to provide insights for clinical practice in this and other regions with similar socio-economic and cultural characteristics.

METHODS

The present work assessed data from the Latin American (LATAM) CTO registry which has been described elsewhere.⁷ The LATAM CTO registry is an ongoing international observational study from more than 70 centers in Latin America (Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, Mexico, and Puerto Rico). There is no specific requirement regarding CTO percutaneous coronary intervention (PCI) volume and operator's experience for entering data into the registry.

CTO PCI data was included in an online platform coordinated by the group of investigators, in partnership with the Brazilian Society of Interventional Cardiology, and managed by the Instituto de Cardiologia do Rio Grande do Sul, Brazil. Access to the database was available via research electronic data capture (REDCap)⁸, a secure and free-

access web application developed by Vanderbilt University that meets international standards and requirements from the National Agency for Sanitary Surveillance in our country. All investigators received standardized instructions for data entry in REDCap, and clinical, procedural, angiographic information, and postprocedural clinical outcomes were collected on the same platform. The centers received online support for questions regarding inclusion or completion of cases, and monthly feedback for missing data and discrepant values. All the variables required for the scores calculations were independently collected in the database. The scores results were generated automatically without manual interference during the filling process.

Moderate/severe calcification was defined as a >50% involvement of the vessel by angiography⁵, and moderate/severe tortuosity was the presence of at least two bends >70°, or one bend >90° in the proximal vessel⁵. Bending was defined as at least 1 bend of 45° assessed by angiography throughout the occluded segment divided into either CTO entry or CTO body.¹ The proximal cap was defined as tapered if the occluded segment ended in a funnel-shaped form.¹ Interventional collateral vessels were side branches considered amenable to crossing by a guidewire and a microcatheter, by the operator.⁴ The following strategies were generally considered for CTO PCI. Antegrade wire escalation consisted of a stepwise attempt to directly cross the occluded segment employing different guidewires. Antegrade dissection and re-entry was defined as an antegrade PCI, during which the operator intentionally used the sub adventitial space to, partially or totally, overcome the CTO segment with gears, reentering into the true lumen distally to the CTO. A retrograde procedure was defined as an attempt to cross the lesion through a collateral vessel supplying a segment distal to the target CTO. We defined technical success as successful CTO revascularization within the treated segment, restoration of Thrombolysis in Myocardial Infarction (TIMI) antegrade flow grade 3, and residual stenosis < 30%. Procedural success was the achievement of technical success without major adverse cardiac and cerebrovascular events (MACE). Outcomes In-hospital MACE before hospital discharge

included all-cause mortality, myocardial infarction (MI), and stroke. MI was defined using the universal definition of MI (type 4a MI)⁹. Stroke was defined as a new focal neurological deficit of sudden onset, of presumably cerebrovascular irreversible cause (or resulting in death) within 24 hours, and not caused by any other easily identifiable cause. Procedural complications included major bleeding, coronary perforation, cardiac tamponade, and urgent revascularization with PCI or coronary artery bypass graft (CABG). Major bleeding was defined as any bleeding causing a reduction in hemoglobin >3g/dL or bleeding requiring transfusion or surgical intervention. Coronary perforation was defined following Ellis's classification.¹⁰ Cardiac tamponade was defined as a hemodynamic compromise caused by an acute accumulation of blood in the pericardial space.

The investigated predictive success scores were the Multicenter CTO Registry in Japan (J-CTO, 2011¹), the Clinical and Lesion-related Score (CL-score, 2015²), the Ostial location, Rentrop grade, and Age (ORA, 2016³), the Prospective Global Registry for the Study of Chronic Total Occlusion Intervention (PROGRESS CTO, 2016⁴), and the EuroCTO Score (CASTLE, 2019⁵). For the purpose of comparison, technical success, as described in the article, was utilized as the target outcome for all scores. The grades of each score were categorized into easy, intermediate, difficult, and very difficult, as depicted in **Figure 1**. The cut-off points for these categories were derived from the original publications, except for the PROGRESS score, for which the cut-off points were defined by consensus among the authors of this article due to the lack of description in its original publication and no reference in the literature.

Additionally, we analyzed the OPEN-CLEAN perforation score¹¹, the PROGRESS-CTO MACE, the PROGRESS-CTO Mortality, and the PROGRESS-CTO Pericardiocentesis¹². The outcome for the comparison between OPEN-CLEAN and PROGRESS-CTO Pericardiocentesis was the occurrence of Ellis grade 3 perforation or tamponade. The performance of the PROGRESS-CTO MACE score was assessed for the composite outcome of death, MI, stroke, unplanned revascularization (percutaneous or

surgical), Ellis grade 3 perforation, or tamponade during the index hospitalization. Lastly, the PROGRESS-CTO Mortality score was evaluated based on the outcome of death from any cause during the index hospitalization.

Continuous variables were expressed as mean $\pm$ standard deviation (SD) or median (interquartile range), according to data normality. The normality of the distribution of each variable was assessed by the Shapiro-Wilk test. Categorical variables were expressed as relative and absolute frequencies. Continuous variables were compared using independent samples t-test or Mann-Whitney U test. Receiver-operating characteristic (ROC) curves were used to evaluate the discriminatory power of the different scores. Youden index analysis was performed to determine the best cutoff value for predicting clinical endpoints. The areas under the curve (AUCs) were compared with the De Long test. Sensitivity, specificity, and positive and negative predictive values were calculated for Youden index values. Hosmer-Lemeshow goodness-of-fit test was used to assess the calibration of the scores. Inter-rater reliability among multiple observers was assessed using the Intraclass Correlation Coefficient (ICC). Scores were categorized into different categories (Easy, Intermediate, Difficult, and Very Difficult) for direct comparison. ICC statistic was calculated based on a one-way random-effects model, treating the raters as a random factor. Statistical analysis was performed with MedCalc Statistical Software version 14.8.1 (MedCalc Software bvba, Ostend, Belgium) and IBM SPSS Statistics Version 29.0 (IBM Corporation, Chicago, Illinois). A 2-tailed p-value of <0.05 was considered statistically significant.

RESULTS

A total of 3706 procedures included in the LATAM CTO Registry from April 2008 to December 2023 were analyzed. Of these, 2835 procedures had sufficient information for analyzing the J-CTO, PROGRESS, ORA, CL-score, and CASTLE success scores. The distribution of cases among countries was as follows: Brazil 47.6%, Mexico 17.6%, Argentina 16.8%, Colombia 7.2%, Puerto Rico 6.2%, Chile 3.8%, Ecuador 0.25%, Bolivia

0.1%. The mean value of procedure per operator was 25; 89 (82%) operators had less than 10 procedures per year, and 83 (77%) operators had less than 5 procedures per year.

The overall success rate was 86%. Contralateral injection was used in 58% of the procedures and microcatheter in 85%. The main strategy for success was antegrade wire escalation (80%), followed by antegrade dissection reentry and retrograde techniques, with approximately 10% each. The percentage of retrograde technique use was 15%. The median fluoroscopy time was 34 minutes, and the average contrast volume was 245 ml. The access routes were: radial-femoral (30%), single radial (24%), femoral-femoral (20%), single femoral (17%), and radial-radial (6%). The main study sample baseline characteristics can be depicted in **Table 1**.

The incidence of MACE as defined by the LATAM CTO registry (myocardial infarction, stroke, or death) was reported at 3%. When MACE was calculated by the criteria in the PROGRESS MACE score (myocardial infarction, stroke, death, urgent revascularization, or significant perforation), the incidence was 5.5%. There was a mortality rate of 5.1% in cases of procedural failure, but no statistical difference in the rates of periprocedural myocardial infarction and stroke between successful and unsuccessful cases (**Table 2**).

In **Figure 1**, the technical success rates for CTO PCI in each score category are presented. The calibrations of the scores were: CASTLE=0.07; CL-score=0.8; ORA=0.2; PROGRESS=0.2; J-CTO=0.03. The J-CTO and CASTLE scores demonstrated the highest AUCs of 0.718 and 0.703, respectively, with no statistically significant difference between them according to the Delong test. The CL-Score is the third most accurate, with an AUC of 0.685, statistically outperforming the PROGRESS score, which had an AUC of 0.598. The score with the lowest performance was the ORA, presenting an AUC of 0.545 (**Figure 2 Central illustration and Table 3**).

Despite J-CTO and CASTLE scores presenting similarly high performances, there is still a significant reclassification in the complexity of procedures between them (**Figure 3**). Of all the procedures categorized as difficult or very difficult by J-CTO (2 or more points), 40%

were classified as intermediate and 10% as easy by the CASTLE score. However, there is a high agreement between these scores in low complexity cases, as 97% of the procedures classified as easy by J-CTO (0 points) continue to be classified as easy by CASTLE.

On the other hand, the PROGRESS score reclassified 20% of the procedures considered easy by J-CTO as difficult or very difficult, in contrast to the CL-Score, which reclassified less than 5% of these procedures as difficult and none as very difficult. The ORA score categorized 17% of the procedures assessed as easy by J-CTO as difficult or very difficult. Only 4% of the procedures were classified as difficult or very difficult by all scores and less than 1% were classified as easy by all 5 scores, highlighting significant differences in the complexity assessment between the scores.

In the temporal analysis (**Table 4**), there was no significant difference in the performance of the scores except for the CASTLE score in the comparison between the biennium 2018-2019 and biennium 2020-2021.

Among the complication scores, the one with the best performance in our sample was the PROGRESS Mortality with an AUC of 0.651, where the set of procedures with 0 points on this score showed a periprocedural mortality of 0.5%. In comparison, the group with 4 points showed a mortality of 12.2%. The second-best score was the PROGRESS MACE (AUC 0.588), with a difference in the incidence of death, myocardial infarction, stroke, unplanned revascularization, or significant perforation <5% in the lower-risk groups and >10% in the higher-risk groups (**Table 5**). The PROGRESS pericardiocentesis and OPEN CLEAN scores presented a modest performance in our sample (AUC 0.554 and 0.529), however, the numbers of Ellis 3 perforation events and cardiac tamponade were small.

DISCUSSION

The first CTO score developed was the J-CTO score, derived from the Japanese CTO registry in 2011, which still is the most widely used metric for assessing CTO difficulty level. In 2015, the French CL-score was introduced, incorporating clinical variables

alongside angiographic ones to predict procedural success, with variables weighted differently to classify lesion's success probabilities. The ORA score was developed in 2016 from a dataset of 1073 procedures performed in Europe by a single operator. In the same year, the PROGRESS group's score emerged from a large multicentric North American dataset, identifying four angiographic predictors of technical failure. Finally, in 2019 the EuroCTO Club's CASTLE score was published, combining clinical and angiographic factors to predict technical success. In 2021, the risk score for perforation in CTO PCI, OPEN-CLEAN, was derived and validated in a cohort of 1000 procedures from 12 North American centers, and in 2022, the PROGRESS group published a set of risk scores derived from a database with more than 10,000 procedures from 7 countries.

The present study sought to assess the accuracy and diagnostic performance of the abovementioned risk scores in a different context, the clinical practice of Latin America, which is characterized by many low and middle-income countries, differently from the reality where scores were developed. The importance of any risk stratification tool is to provide reliable information on potential difficulties to be encountered. Despite significant improvements in medical care delivery, Latin America continues to experience considerable variability in clinical practices, variations in proficiency among medical operators depending on their level of experience, and a shortage of state-of-the-art devices in several countries, particularly in specific regions. The availability of advanced devices has been demonstrated to enhance procedural success in the Latin American context.¹³ These aspects may influence the accuracy of a risk score formulated in developed regions, which is an important point to be investigated. Also, the more procedural difficulties are to be expected, an adequate risk stratification tool is even more important to guide physicians in which cases they may or may not engage. Despite facing financial constraints, which may limit access to the latest equipment and technologies, equivalent success and complication rates suggest that Latin American operators already present adequate expertise in these procedures. This indicates that the techniques and protocols used are effective, but there may be some selection bias in the presented data, with more challenging cases referred to centers with

more resources or specific expertise. In this context, we believe our study findings may offer valuable information on the usefulness of success and risk scores of CTO PCI in the context of a particular geographical and demographic region, which can help enhance the selection of treatment strategies for a group of patients who are not well-represented in the existing CTO literature. The application of these results to other regions with similar socio-economic characteristics, like some countries in Asia, Africa, and Eastern Europe, could also be a matter of further investigation.

The J-CTO score was designed to predict lesion crossing within 30 minutes¹, with subsequent validation for the success of the procedure.^{14,15} It was also derived from a cohort that solely utilized the antegrade technique and during a period in the past when the options for dedicated devices for CTO recanalization were much more limited than they are currently. Despite losing some of the accuracy shown in the original developing cohort, the J-CTO score displayed the best AUC in our sample, which was also demonstrated in other studies.^{16,17} The fact that most procedures in our sample were performed by the antegrade approach may be involved in this good performance. Also, several operators in Latin America use the J-CTO score as the main risk score to plan CTO PCI procedures, which also can help explain these findings.

The CL-score was derived from a cohort of 1143 patients in a single center in France and used 2 clinical variables (previous CABG and previous MI), in addition to 4 angiographic variables (severe calcification, length of occlusion, coronary location of the CTO, and type of proximal stump)⁴. Unlike the J-CTO score, the CL-score assigned different weights to some variables: severe calcification, 2 points; length equal to or greater than 20mm, 1.5 points; previous CABG, 1.5 points, with the others being 1 point each. Despite demonstrating a good diagnostic performance in our analysis (AUC 0.685) and in other publications^{17,18}, its greater complexity than other scores has limited its broader use.

On the other end of the complexity spectrum, the ORA score, with only 3 variables, demonstrated the lowest performance in our sample, achieving an AUC of 0.545. This outcome is significantly lower than the result reported in its publication in 2016³, which had

an AUC of 0.772. The discrepancy in performance may be attributed to the fact that the score was derived from a single-operator experience, with greater utilization of the retrograde technique than our sample (27% vs 15%).

The low use of the retrograde approach in the LATAM CTO Registry may also justify the modest performance of the PROGRESS score (AUC 0.598) in the present study. In addition to being derived from a cohort with high use of the hybrid approach^{4,19}, this score includes the presence of interventional collaterals in its calculation. Also, the use of the retrograde approach in our study was not associated with technical success, which may be related to operators in the learning curve or the limited availability of dedicated equipment to perform these techniques. Besides, more than 60% of CTO PCIs using retrograde techniques target the RCA²⁰. While the circumflex artery was a variable assigned one point in the PROGRESS score, in our sample, CTO PCIs in the right coronary artery were associated with failure.

The CASTLE score is the most recent of the scores examined and demonstrated similar accuracy with the older J-CTO score while exhibiting improved calibration. This score was derived and validated using a sample of 20,000 patients, with a representative utilization of the retrograde technique (accounting for 20% of the procedures)⁵, and it has shown good performance in previous studies.^{16,17} The CASTLE score consists of two clinical and four angiographic variables, all of which are given equal weight in the model: previous CABG, age 70 years or older, blunt proximal cap, severe tortuosity, length of occlusion equal to or greater than 20mm, and severe calcification. While there is some overlap between the variables used in the CASTLE and J-CTO scores, there is significant reclassification between them, particularly in the high-complexity strata. In the temporal analysis, the CASTLE score was the only score to show a statistically significant difference, demonstrating better performance in the 2020-2021 biennium compared to the 2018-2019 biennium. This difference could potentially be attributed to pandemic-related case selection bias, although the reasons for this are unclear and the possibility of chance cannot be ruled out.

Despite the inability to generate the PROGRESS-CTO ACUTE MI score due to the absence of the key variable - previous atrial fibrillation - in the Latam CTO Registry database, the findings from current research indicate that the PROGRESS-CTO complication risk models have the potential to enhance risk assessment and facilitate the evaluation of risks and benefits in CTO PCI procedures in Latin America. Although the area under the curve (AUC) is relatively modest, the models demonstrate an effective ability to identify a high-risk group within the CTO PCI patient population. These results suggest that the PROGRESS-CTO complication risk models can be a useful asset in CTO PCI risk management.

This study presents several limitations worth noting. Firstly, the data were self-reported by the participating centers without on-site auditing or monitoring, relying on a detailed manual sent to standardize inclusion and minimize variability. Despite periodic checks of the database for outliers and asymmetries to enhance data quality, the non-consecutive inclusion of patients by each center might have introduced selection bias. Furthermore, angiographic and procedural characteristics were not evaluated by an independent core lab, and the assessment of scoring systems was contingent on whether dual angiography was performed—its use in merely half of the cases might have led to overestimated scores. Clinical outcomes were not adjudicated by a central events committee, although standardized definitions were provided. Additionally, long-term outcomes were not discussed in this paper, with plans for future analysis.

In conclusion, our study provides valuable insights into the effectiveness of various CTO PCI scores, particularly within the unique socio-economic and medical landscape of Latin America. It highlights the diagnostic significance of the J-CTO and CASTLE scores, which are particularly suited to the antegrade approach predominant in our analysis, and introduces the PROGRESS-CTO complication risk models as crucial tools for identifying high-risk patients and refining procedural strategies. This comprehensive evaluation underscores the potential to enhance the selection of treatment strategies, especially for patient demographics historically underrepresented in CTO research.

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Figures legends

Figure 1. Scores Categories and Technical Success Rates in LATAM CTO Registry

Figure 2. Central Illustration - Scores characteristics and AUCs Comparison between validation and LATAM CTO Registry

Figure 3. Reclassification J-CTO/CASTLE

J-CTO	Points	Success
Easy	0	96%
Intermediate	1	96%
Difficult	2	87%
Very Difficult	≥ 3	74%

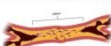


CL-score	Points	Success
Easy	≤ 1	95%
Intermediate	$> 1 < 3$	90%
Difficult	$\geq 3 < 5$	83%
Very Difficult	≥ 5	70%

ORA	Points	Success
Easy	0	88%
Intermediate	1	87%
Difficult	2	83%
Very Difficult	≥ 3	73%

PROGRESS	Points	Success
Easy	0	91%
Intermediate	1	86%
Difficult	2	81%
Very Difficult	≥ 3	79%

CASTLE	Points	Success
Easy	≤ 1	94%
Intermediate	2	85%
Difficult	3	75%
Very Difficult	≥ 4	65%

	J-CTO	CL-score	PROGRESS	ORA	CASTLE
Original Validation AUC	0.760 	0.680 	0.720 	0.772 	0.680 
LATAM CTO Registry AUC	0.718 	0.685 	0.598 	0.545 	0.703 
Clinical and Angiographic characteristics					
Age 				≥75 years (+1)	≥70 years (+1)
Clinical History 	Prior attempt (+1)	-Prior CABG (+1.5) -Prior MI (+1)			Prior CABG (+1)
Proximal cap 	Blunt (+1)	Blunt (+1)	Ambiguity (+1)		Blunt or invisible (+1)
Occlusion Length 	≥ 20 mm (+1)	≥ 20 mm (+1.5)			≥ 20 mm (+1)
Calcification 	Any (+1)	Severe (+2)			Severe (+1)
Tortuosity 	Bending > 45° (+1)		Moderate or severe (+1)		Severe (+1)
Target Vessel 		Non-LAD (+1)	Circumflex (+1)	Ostial lesion (+1)	
Collaterals 			Lack of Interventional collaterals (+1)	Rentrop < 2 filling (+2)	

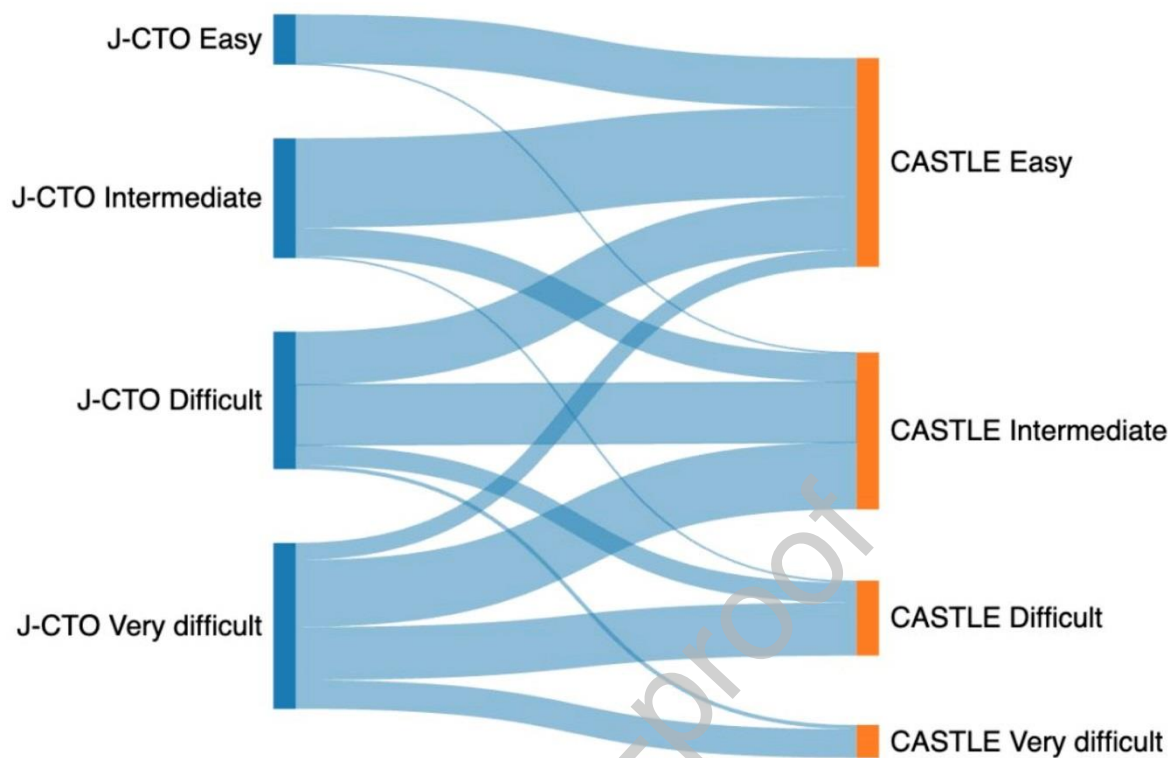


Table 1 - Baseline Characteristics

	Overall n = 2834	Failure n = 387	Success n = 2447	p-value
Age	63.7 ($\pm$ 10.5)	65.8 ($\pm$ 10.8)	63.4 ($\pm$ 10.5)	<0.001
Male Sex	2204 (77.8)	297 (76.7)	1907 (77.9)	0.601
BMI	27.8 ($\pm$ 4.1)	27.7 ($\pm$ 4.0)	27.8($\pm$ 4.1)	0.421
LVEF	52 ($\pm$ 12.3)	52($\pm$ 12.9)	53 ($\pm$ 12.2)	0.327
CHF	452 (16.0)	57 (14.7)	395 (16.2)	0.472
Prior CABG	386 (13.6)	78 (20.2)	308 (12.6)	<0.001
Prior MI	1326(46.8)	191 (49.4)	1135 (46.4)	0.273
Prior PCI	1295 (45.8)	203 (52.6)	1092 (44.7)	0.004
Diabetes	1148 (40.6)	154 (40)	994(40.7)	0.794
PVD	272 (9.7)	41 (10.7)	231 (9.6)	0.496
CKD	217 (7.7)	27 (7.0)	190 (7.8)	0.580

Current Smoking	549 (19.6)	73 (19.1)	476 (19.7)	0.792
Target vessel				
-LAD	1066 (37.6)	117 (30.2)	949 (38.8)	0.001
-RCA	1146 (40.4)	181 (46.8)	959 (39.4)	0.006
-LCX	608 (21.4)	85 (22.0)	523 (21.4)	0.789
Ostial lesion	525 (18.5)	86 (22.2)	439 (17.9)	0.044
Occlusion Length	20 [15-30]	25 [20-30]	20 [15-28]	<0.001
Blunt Proximal cap	1292 (45.6)	273 (70.5)	1019 (41.6)	<0.001
Moderate or severe calcification	1279 (45.1)	229 (59.2)	1050 (42.9)	<0.001
Proximal cap ambiguity	903(31.9)	212 (54.8)	691 (28.2)	<0.001
Moderate or severe tortuosity	482 (17.0)	95 (24.5)	387 (15.8)	<0.001
No interventional collaterals	1084 (38.2)	140 (36.2)	944 (38.6)	0.112
Collaterals	0.917			
-No continuous connections	597 (21.1)	83 (21.4)	514 (21.0)	
-Continuous threadlike connections	1496 (52.8)	206 (53.2)	1290 (52.7)	
-Side branch like collateral	742 (26.2)	98 (25.3)	644(26.3)	
In-stent restenosis	348 (12.3)	43 (11.1)	305(12.5)	0.435
Prior attempt	377 (13.3)	77 (19.9)	300(12.3)	<0.001
Retrograde procedure	420 (15.6)	150 (34.4)	270 (12.0)	<0.001
Success Scores				
J-CTO	2[1-3]	3[2-4]	2[1-3]	<0.001
Castle	2[1-2]	2[2-3]	2[1-2]	<0.001
Progress	1[0-2]	1[1-2]	1[0-2]	<0.001
ORA	1[1-1]	1[1-2]	1[1-1]	0.001
CL-SCORE	2.5 [2-3.5]	3.5 [2.5-5]	2.5[1.5-3.5]	<0.001

Complication Scores				
Progress MACE	2[1-3]	3 [2-4]	2 [1-3]	<0.001
Progress Pericardiocentesis	1[1-2]	2 [1-3]	1 [1-2]	<0.001
Progress Mortality	1 [1-2]	1 [2-3]	1 [1-2]	<0.001
OPEN-CLEAN	2 [2-3]	3 [2-4]	2 [2-3]	<0.001

Values are expressed as mean (SD), median [IQR], or n (%)

BMI - Body Mass index; CABG - Coronary artery bypass graft; CHF - Chronic heart failure; CKD - Chronic Kidney diseases; LAD - left anterior Descending artery; LCX - left circumflex artery; LVEF - Left Ventricular ejection fraction; MI - Myocardial infarction; PCI - Percutaneous coronary intervention; PVD - peripheral vascular disease; RCA - right coronary artery;

Table 2 - Clinical Outcomes

	Overall n = 2834	Failure n = 387	Success n = 2447	p-value
MACE	84 (3.0)	25 (6.5)	59 (2.4)	<0.001
MACE PROGRESS	146 (5.5)	49 (13.3)	97 (4.2)	<0.001
Death	51 (1.9)	19 (5.1)	32 (1.4)	<0.001
MI	35 (1.3)	6 (1.6)	29 (1.3)	0.555
Stroke	7 (0.3)	2 (0.5)	5 (0.2)	0.256
Tamponade	21 (0.7)	7 (1.8)	14 (0.6)	0.008
Ellis 3 perforation	22 (0.8)	8(2.1)	14 (0.6)	0.002
Unplanned PCI	46 (1.7)	13 (3.5)	33 (1.4)	0.004
Unplanned CABG	6 (0.2)	5 (1.3)	1 (0.0)	<0.001

CABG - Coronary artery bypass graft; MACE - all-cause mortality, myocardial infarction, and stroke; MACE PROGRESS - death, MI, stroke, unplanned revascularization (percutaneous or surgical), Ellis grade 3 perforation, or tamponade; MI - myocardial infarction; PCI - Percutaneous coronary intervention

Table 3 - Younden index, area under the curve, sensitivity, specificity, positive predictive value, negative predictive value of Scores

Score	J-CTO*	ORA*†	CL*†¶	PROGRESS*†¶‡	CASTLE†‡
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Youden Index	≤2	≤1	≤3	≤1	≤1
AUC	0.718 (0.701-0.734)	0.545 (0.526-0.563)	0.685 (0.668-0.703)	0.598 (0.598-0.616)	0.703 (0.686-0.720)
Sensitivity	69.73	76.35	63.85	71.16	48.1
Specificity	65.37	31.27	63.82	43.15	81.40
PPV	92.7	87.5	91.8	88.8	94.2
NPV	25.5	17.3	21.8	19.1	19.9
Intra-class coefficient correlation = 0.615 (0.592 to 0.637)					

AUC area under the curve, **PPV** positive predictive value , **NPV** negative predictive value.

(†, *, ‡, ¶) DeLong test comparisons with p <0.05

Table 4: Temporal Comparison of Scores AUC Values

	<2018	2018-2019	2020-2021	2022-2023	p-value
J-CTO	0.723	0.693	0.751	0.718	>0.05 for all
CASTLE	0.705	0.673*	0.771*	0.685	*0.01
PROGRESS	0.605	0.572	0.609	0.654	>0.05 for all
ORA	0.501	0.537	0.593	0.599	>0.05 for all
CL	0.653	0.684	0.704	0.666	>0.05 for all

Table 5.CTO PCI Complications Scores AUC and event rates by score point

	Open-Clean	Progress Pericardiocentesis	Progress Mortality	Progress MACE
AUC	0.529	0.554	0.651	0.588
Score points	Event rate			
0	0.0%	0.4%	0.5%	2.7%
1	0.6%	1.2%	1.5%	4.7%
2	1.4%	1.2%	2.6%	4.7%
3	1.0%	1.4%	2.4%	5.6%
4	1.4%	2.2%	12.2%	5.5%
5	0.9%	0.0%	-	11.1%

6	0.0%	-	-	7.5%
7	0.0%	-	-	12.5%

Declaration of interests

☐ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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