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Derivation and Validation of a Chronic Total Coronary Occlusion Intervention Procedural Success Score From the 20,000-Patient EuroCTO Registry

The EuroCTO (CASTLE) Score

Zsolt Szijgyarto, PhD,[a] Rajiv Rampat, MD,[b] Gerald S. Werner, MD, PhD,[c] Claudius Ho, MBBS,[b] Nicolaus Reifart, MD, PhD,[d] Thierry Lefevre, MD,[e] Yves Louvard, MD,[e] Alexandre Avran, MD,[f] Mashayekhi Kambis, MD,[g] Heinz-Joachim Buettner, MD,[g] Carlo Di Mario, MD, PhD,[h] Anthony Gershlick, MD, PhD,[i] Javier Escaned, MD, PhD,[j] George Sianos, MD, PhD,[k] Alfredo Galassi, MD,[l] Roberto Garbo, MD,[m] Omer Goktekin, MD,[n] Marcus Meyer-Gessner, MD,[o] Bernward Lauer, MD,[p] Simon Elhadad, MD,[q] Alexander Bufe, MD,[r] Nicolas Boudou, MD,[s] Horst Sievert, MD,[t] Victoria Martin-Yuste, MD,[u] Leif Thuesen, MD, DMSc,[v] Andrejs Erglis, MD,[w] Evald Christiansen, MD, PhD,[x] James Spratt, MD,[y] Lesciak Bryniarski, MD, PhD,[z] Tim Clayton, PhD,[a] David Hildick-Smith, MD[b]

ABSTRACT

OBJECTIVES The aim was to establish a contemporary scoring system to predict the outcome of chronic total occlusion coronary angioplasty.

BACKGROUND Interventional treatment of chronic total coronary occlusions (CTOs) is a developing subspecialty. Predictors of technical success or failure have been derived from datasets of modest size. A robust scoring tool could facilitate case selection and inform decision making.

METHODS The study analyzed data from the EuroCTO registry. This prospective database was set up in 2008 and includes >20,000 cases submitted by CTO expert operators (>50 cases/year). Derivation (n = 14,882) and validation (n = 5,745) datasets were created to develop a risk score for predicting technical failure.

RESULTS There were 14,882 patients in the derivation dataset (with 2,356 [15.5%] failures) and 5,745 in the validation dataset (with 703 [12.2%] failures). A total of 20.2% of cases were done retrogradely, and dissection re-entry was performed in 9.3% of cases. We identified 6 predictors of technical failure, collectively forming the CASTLE score (Coronary artery bypass graft history, Age (≥70 years), Stump anatomy [blunt or invisible], Tortuosity degree [severe or unseen], Length of occlusion [≥20 mm], and Extent of calcification [severe]). When each parameter was assigned a value of 1, technical failure was seen to increase from 8% with a CASTLE score of 0 to 1, to 35% with a score ≥4. The area under the curve (AUC) was similar in both the derivation (AUC: 0.66) and validation (AUC: 0.68) datasets.

CONCLUSIONS The EuroCTO (CASTLE) score is derived from the largest database of CTO cases to date and offers a useful tool for predicting procedural outcome. (J Am Coll Cardiol Intv 2019;12:335–42) © 2019 by the American College of Cardiology Foundation.

From the [a]London School of Hygiene and Tropical Medicine, London, United Kingdom; [b]Sussex Cardiac Centre, Brighton and Sussex University Hospitals, Brighton, United Kingdom; [c]Department of Cardiology & Intensive Care, Klinikum Darmstadt, Darmstadt, Germany; [d]Department of Cardiology, Main Taunus Heart Institute, Frankfurt am Main, Germany; [e]Department of Cardiology, Institut Cardiovasculaire Paris Sud, Paris, France; [f]Department of Cardiology, Arnault Tzanck Institut, Saint Laurent du Var, France; [g]Division of Cardiology and Angiology II, University Heart Center Freiburg, Freiburg, Germany; [h]Structural Interventional Cardiology, Careggi University Hospital, Florence, Italy; [i]Department of Cardiovascular Sciences, University of Leicester, Leicester, United Kingdom; [j]Hospital Clinico San Carlos IDISSC and Complutense, Madrid, Spain; [k]1st Department of Cardiology, AHEPA University Hospital, Thessaloniki, Greece; [l]Department of Experimental and Clinical Medicine, University of Catania, Catania, Italy; [m]Interventional Cardiology Unit, San Giovanni Bosco Hospital, Torino, Italy; [n]Department of Cardiology, Istanbul Memorial Hospital, Istanbul, Turkey; [o]Department of Cardiology, Augusta Krankenhaus, Düsseldorf, Germany; [p]Department of Cardiology, Kardiologie Zentralklinik, Bad Berka, Germany; [q]Department of Cardiology, Centre

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ABBREVIATIONS AND ACRONYMS

AUC = area under the curve

CABG = coronary artery bypass graft

CTO = chronic total occlusion

PCI = percutaneous coronary intervention

Chronic total occlusions (CTOs) are present in approximately one-fifth of patients undergoing coronary angiography (1). Historically, these lesions have often been managed either with medical therapy or coronary artery bypass graft (CABG) in suitable candidates because of their complexity and low interventional success rates. Percutaneous coronary intervention (PCI) of CTOs has become more widely accepted in the last decade, with increasing success rates related to operator experience, guidewire technology, and microcatheter sophistication (2). Despite these improvements, procedural success rates remain lower than those achieved with nonocclusive lesions (3). A simple and accurate scoring tool to grade the difficulty of cases would be valuable for appropriate case selection and planning. Attempts have been made to classify procedures according to their likelihood of success based on patient, lesion, and procedural features (4,5). However, these have been derived from a relatively modest number of patients, and consequently their predictive ability has not been uniformly consistent (6). Additionally, some have focused purely on the antegrade approach, to the exclusion of retrograde possibilities (7). Using the EuroCTO registry, we analyzed the factors influencing technical success and derived and validated a simple model to predict successful percutaneous treatment of CTOs.

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METHODS

PATIENT POPULATION. The EuroCTO club is a collaborative effort among high-volume CTO operators in Europe aimed at sharing experiences and outcomes data. Since 2008, patient characteristics and procedural data have been prospectively recorded in a dedicated registry by individual members. In this database, multiple variables are recorded for every patient regarding preprocedural demographic and anatomical characteristics, procedural details, and postprocedural outcomes. The data for this analysis relate to patients in whom CTO recanalization was attempted between 2008 and 2016 in 55 European centers. The aim of the analysis was to develop a scoring system to predict the likelihood of success of CTO PCI.

DEFINITIONS. Coronary CTOs were defined as occlusions of >3 months duration with Thrombolysis In Myocardial Infarction flow grade 0 intralesional coronary flow (8). The length of coronary occlusions was estimated from angiographic projections visually with single- or dual-contrast injections. The degree of calcification was visually estimated on fluoroscopy—moderate calcification was considered to be present if one-half of the total CTO segment had visible residues; extension of calcification to >50% of the segment was considered to be severe. The CTO was defined as straight if the pre-occlusive segment contained a bend of <70°. Moderate tortuosity was defined as a segment containing either 2 bends >70° or 1 bend >90°. A severely tortuous CTO vessel contained either 2 or more pre-occlusive bends of >90° or at least 1 bend of >120°. The morphology of the vessel stump was classified as tapered, blunt, or unseen depending on its appearance on fluoroscopy. The angiographic assessment of collateral connections was made according to the Werner classification (9). Opacification beyond the occlusion was classified into either none, faint, or good. Good distal visibility was defined as distal opacification comparable to the proximal segment. Technical success was defined as a residual stenosis of<10% at the end of the procedure with TIMI flow grade 3 antegrade flow.

STATISTICAL METHODS. Predictive model development. The aim was to develop an accurate predictive model from a large number of potential risk factors to provide robust prediction of success or

Hospitalier de Marne-la-vallée, Jossigny, France; [r]Helios Heart Center Krefeld, University Witten/Herdecke, Witten, Germany; [s]Cardiology Department, Rangueil University Hospital, Toulouse, France; [t]Department of Cardiology, Cardiovascular Center Frankfurt, Frankfurt am Main, Germany; [u]Department of Cardiology, Hospital Clínic Barcelona, Barcelona, Spain; [v]Department of Cardiology, Aalborg University Hospital, Aalborg, Denmark; [w]Pauls Stradins Clinical University Hospital, University of Latvia, Riga, Latvia; [x]Department of Cardiology B, Aarhus University Hospital, Aarhus, Denmark; [y]Department of Cardiology, St. George's University NHS Trust, London, United Kingdom; and the [z]Department of Cardiology, Interventional Electrocardiology and Hypertension Institute of Cardiology, Jagiellonian University Medical College, Kraków, Poland. Dr. Sievert has received study honoraria, travel expenses, and consulting fees from 4tech Cardio, Abbott, Ablative Solutions, Ancora Heart, Bavaria Medizin Technologie GmbH, Bioventrix, Boston Scientific, Carag, Cardiac Dimensions, Celonova, Comed BV, Contego, CVRx, Edwards, Endologix, Hemoteq, Lifetech, Maquet Getinge Group, Medtronic, Mitralign, Nuomao Medtech, Occlutech, pfm Medical, Recor, Renal Guard, Rox Medical, Terumo, Vascular Dynamics, and Vivasure Medical. Dr. Hildick-Smith has served on the advisory board for Abbott, Terumo, Boston Scientific, and Medtronic. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

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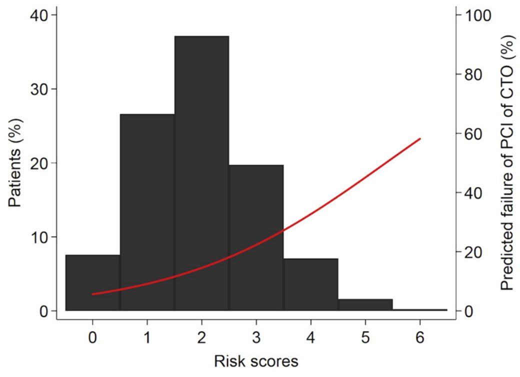
FIGURE 1 Risk Scores and Predicted Probabilities of Failure of Percutaneous Coronary Intervention for Patients in the EuroCTO Registry Derivation Dataset From 2008 to 2014



The graph represents the distribution of total risk scores of 14,882 patients with chronic total occlusion (CTO). The **red line** shows the predicted procedural failures.

TABLE 1 Distribution of Patient Demographics, Medical History and Lesion Characteristics in EuroCTO Cohort and Their Association With the Failure of Percutaneous Coronary Intervention Estimated With Univariate Logistic Regression Analyses

	Overall (N = 14,882)	Success (n = 12,526, 84.2%)	Failure (n = 2,356, 15.8%)	Univariate Analyses OR (95% CI)	p Value
Previous CABG					
No	12,489	10,678 (85.5)	1,811 (14.5)	1.00	
Yes	1,942	1,516 (78.1)	426 (21.9)	1.66 (1.47–1.87)	<0.001
Missing	451	332 (73.6)	119 (26.4)	-	
Age					
<55 yrs	3,128	2,723 (87.1)	405 (12.9)	1.00	<0.001
55 yrs	2,269	1,925 (84.8)	344 (15.2)	1.20 (1.03–1.40)	
60 yrs	2,517	2,118 (84.1)	399 (15.9)	1.27 (1.09–1.47)	
65 yrs	2,307	1,937 (84.0)	370 (16.0)	1.28 (1.10–1.50)	
70 yrs	2,262	1,860 (82.2)	402 (17.8)	1.45 (1.25–1.69)	
75 yrs	1,468	1,201 (81.8)	267 (18.2)	1.49 (1.26–1.77)	
80 yrs	907	744 (82.0)	163 (18.0)	1.47 (1.21–1.80)	
Missing	24	18 (75.0)	6 (25.0)	-	
Tortuosity					
Straight/slight	9,411	8,224 (87.4)	1,187 (12.6)	1.00	<0.001
Moderate	3,355	2,810 (83.8)	545 (16.2)	1.34 (1.20–1.50)	
Severe/unseen	1,639	1,160 (70.8)	479 (29.2)	2.86 (2.53–3.23)	
Missing	477	332 (69.6)	145 (30.4)	-	
Calcification					
None/mild	8,327	7,330 (88.0)	997 (12.0)	1.00	<0.001
Moderate	4,062	3,425 (84.3)	637 (15.7)	1.37 (1.23–1.52)	
Severe	1,973	1,394 (70.7)	579 (29.3)	3.05 (2.72–3.43)	
Missing	520	377 (72.5)	143 (27.5)	-	
Stump					
No	1,796	1,331 (74.1)	465 (25.9)	1.00	
Blunt	5,809	4,772 (82.1)	1,037 (17.9)	2.00 (1.79–2.22)	<0.001
Tapered	6,315	5,695 (90.2)	620 (9.8)	3.21 (2.81–3.67)	<0.001
Missing	962	728 (75.7)	234 (24.3)	-	
Length of CTO					
<20 mm	3,740	3,363 (89.9)	377 (10.1)	1.00	<0.001
20 mm	2,581	2,232 (86.5)	349 (13.5)	1.40 (1.19–1.63)	
25 mm	1,580	1,358 (85.9)	222 (14.1)	1.46 (1.22–1.74)	
30 mm	2,034	1,701 (83.6)	333 (16.4)	1.75 (1.49–2.05)	
35 mm	4,053	3,300 (81.4)	753 (18.6)	2.04 (1.78–2.32)	
Missing	894	572 (64.0)	322 (36.0)	-	

Values are n (%), unless otherwise indicated. The p values for the binary variable correspond to the Wald test, otherwise to the trend test across groups.

CABG = coronary artery bypass graft; CI = confidence interval; CTO = chronic total occlusion; OR = odds ratio.

failure of CTO PCI. Potential predictive factors strongly associated with the failure of the procedure were selected from candidate variables with univariate logistic regression analysis. These variables included patient characteristics and medical history, baseline measurements, and lesion characteristics. Given the large number of patients and outcomes, important independent clinical predictors were identified using a stepwise approach with $p < 0.01$ as the inclusion criterion. Using multiple imputed data to account for missing values, patients' demographic data and medical history variables were first entered into the logistic regression model. Baseline measurements and lesion characteristics were then added to the model and evaluated using the pre-set p value of <0.01 for variable retention. In the final stage variables initially excluded were sequentially re-entered into the model and were re-assessed using the pre-set inclusion criteria.

Multiple imputations. There were no missing values for the outcome of the CTO procedure, but data were missing for potential predictor variables (<10% for each variable). To adjust for these missing data, multiple imputation techniques with chained equations were used, assuming missingness is at random, with 20 imputations using all covariates showing an association ($p < 0.01$) including the outcome variable of technical success, smoking status, gender, CTO location, and collateral circulation (10). The variables included in the final model were also imputed on the validation set using the same multiple imputation techniques.

Risk score analyses. The 2008 to 2014 cohort was available initially to develop the risk score. The 2015 to 2016 cohort was used for the validation of the model when these data became available and also to help establish whether success rates had improved over time. The coefficients in the final logistic model can be used to develop a detailed risk score to predict the probability of failure for each patient. However, the aim of our analysis was to develop and present a simplified, easy-to-use risk score for predicting failure. The multivariable predictive model was converted into a simple risk score by allocating a 0 or 1 score for each variable in the model depending on the value of that variable for each individual. For each

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TABLE 2 Multivariable Logistic Regression Analysis for Failure of Percutaneous Coronary Intervention by the EuroCTO CASTLE Model and the Assignment of Risk Scores to the Risk Factors on the Imputed Derivation Set

	EuroCTO CASTLE Model			
Risk Factor	**OR (95% CI)**	**p Value**	**Log(OR)**	**Robust Scoring**
Previous CABG				
No	1.00		0	0
Yes	1.42 (1.25–1.61)	<0.0001*	0.35	1
Age				
<55 yrs	1.00	<0.001	0	0
55 yrs	1.18 (1.01–1.38)		0.17	0
60 yrs	1.18 (1.01–1.37)		0.16	0
65 yrs	1.15 (0.98–1.35)		0.14	0
70 yrs	1.28 (1.09–1.49)		0.24	1
75 yrs	1.29 (1.08–1.54)		0.25	1
80 yrs	1.34 (1.09–1.66)		0.30	1
Tortuosity				
Straight/slight	1.00	<0.001	0	0
Moderate	1.15 (1.02–1.28)		0.14	0
Severe/unseen	2.28 (2.00–2.60)		0.82	1
Calcification				
None/mild	1.00	<0.001	0	0
Moderate	1.15 (1.03–1.28)		0.14	0
Severe	2.18 (1.92–2.47)		0.78	1
Stump				
Tapered	1.00	<0.001	0	0
Blunt	1.64 (1.47–1.84)		0.50	1
No	2.74 (2.39–3.14)		1.01	1
Length of CTO				
<20 mm	1.00	<0.001	0	0
20 mm	1.43 (1.23–1.67)		0.36	1
25 mm	1.49 (1.24–1.79)		0.40	1
30 mm	1.60 (1.36–1.89)		0.47	1
35 mm	1.78 (1.55–2.04)		0.58	1

Multiple imputation = 20, observations = 14,882; due to nonresponse the average relative variance increase, was 0.048 and the largest fraction of missing information was 0.124. *The p value corresponding to the Wald test otherwise to the trend test across groups.

CASTLE = coronary artery bypass graft history, ≥70 yrs of age, stump anatomy (blunt or invisible), tortuosity degree (severe or unseen), length of occlusion (≥20 mm), and extent of calcification (severe); other abbreviations as in Table 1.

risk factor the category with the lowest predicted risk (i.e., the most beneficial group) was allocated a score of 0 together with any categories with a coefficient <0.20 in the model. A score of 1 was assigned to categories in which the coefficient was ≥0.20 from the multivariable logistic regression model (which equates to an odds ratio of 1.22). The total risk score for each individual in the cohort was then computed by adding up the assigned scores for each factor. The distribution of the patients' total risk scores was split into 4 risk groups for comparison of observed and predicted probabilities of failure to ensure a reasonable number of events in each risk group. On the validation set, the same scoring systems were applied as on the derivation set to classify the patients into different levels of risk categories (Figure 1).

Model performance. The model performance was inspected on the imputed data with the Hosmer-Lemeshow statistic comparing the observed and predicted probabilities of the patients in groups defined by their predicted probabilities and with the area under the curve (AUC) quantifying the ability of the model to discriminate patients at high risk from patients at low risk. Overall model performance on the validation set was assessed with the Brier score (11).

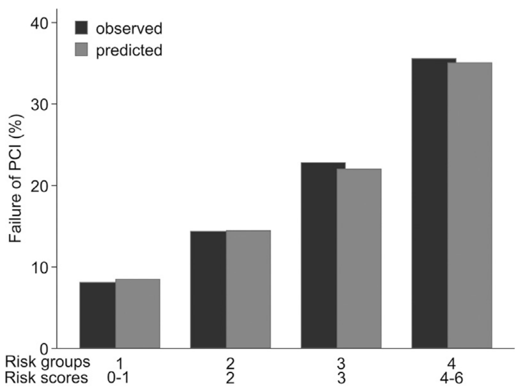
The regression coefficients from the derivation dataset from the logistic model containing the 0 to 6 patient risk score were applied to compute the predicted risk of failure of PCI for patients in the validation set. To correct for the improvement in success rates in the 2015 to 2016 cohort compared with the 2008 to 2014 cohort, an adjustment was made by including the year of operation as a covariate into the model. This allowed for an assessment of the validity of the risk score while presenting better current estimates of actual predicted risks of failure. Risk scores for the validation dataset were calculated in exactly the same way as for the derivation dataset (i.e., by allocating a score of 0 or 1 for each of the 6 variables in the model and summing across variables).

Comparison with J-CTO scoring system. We explored the discriminative capacity of the commonly utilized J-CTO (Japanese Multicenter CTO Registry) score (4) in our dataset. Score of 1 was first allocated to J-CTO variables of previously failed lesion, blunt or no stump, bending, severe calcification, and occlusion length ≥20mm. The total risk scores were then obtained on both the derivation and validation sets. The discriminative performance of J-CTO scoring system was assessed using receiver-operating characteristic curves within both the derivation and validation datasets.

RESULTS

PROCEDURAL CHARACTERISTICS. In 76.1% of cases, PCI CTO was attempted for the first time while 3.7% of cases had had more than 2 previous failed attempts. Contralateral injection was used in one-half of the cases. The majority of the cases were done using either 6-F (42.8%) or 7-F guide catheters (44.5%). Intravascular imaging with intravascular ultrasound was performed in 7.4% of cases. The antegrade approach was attempted in 86.1% of cases and was successful in 82.7% of those cases. The single-wire technique was commonly successful in recanalization being used in over 75.7% of cases. This was followed by the parallel wire technique (16.8% of successful cases). Dissection re-entry techniques were used in a minority of antegrade cases (2.1%). A retrograde strategy was utilized in 20.2% in our cohort, with this approach being used a priori in

FIGURE 2 Model Calibration in EuroCTO Registry Derivation Dataset From 2008 to 2014 (n = 14,882)



Comparison of the observed and predicted probabilities of failure of percutaneous coronary intervention (PCI) across the 4 risk groups.

13.9%. Touching wire was most commonly used (37.6%), followed by retrograde wire crossing (30.8%), reverse controlled antegrade and retrograde tracking and dissection (24.6%), and controlled antegrade and retrograde tracking and dissection (7.0%). The overall success rate of the retrograde approach (including both upfront and bailout after failed antegrade technique) was 67.3%.

DERIVATION OF THE EURO-CTO CASTLE RISK ANALYSIS TOOL. Of 14,882 patients in the derivation dataset (2008 to 2014), 2,356 (15.8%) had unsuccessful CTO PCI. In the validation dataset (2015 to 2016), there were 5,745 patients, with 703 (12.2%) who had an unsuccessful CTO PCI. Demographic and clinical variables were explored using the derivation dataset for their association with an unsuccessful CTO procedure (Table 1, Online Tables 1 to 3).

The derivation dataset had 10,760 patients with no missing values and 4,122 patients with at least 1 missing value for the predictor variables, which were imputed as described previously. On multivariable analysis of 21 variables associated on univariable analysis, 6 were identified on the imputed dataset as strong independent predictors of failure of CTO PCI, collectively forming the CASTLE (CABG, age, stump anatomy, tortuosity, length of CTO, and extent of calcification) model. The estimated odds ratios of the association between these variables and the failure of PCI are shown in Table 2. Previous CABG, blunt or no stump, severe tortuosity, high level of calcification, occlusion >20 mm, and age above 70 years were all independently associated with an increased risk of failure of the intervention.

TABLE 3 Observed and Predicted Risks on the Derivation Dataset

Risk Scores	Procedures	Failures	Mean Predicted Risk (%)
0	1,129	68	5.8
1	3,959	347	9.3
2	5,530	797	14.5
3	2,936	671	22.1
4	1,056	345	32.3
5	238	110	44.7
6	34	18	56.5
Total	14,882	2,356	15.8

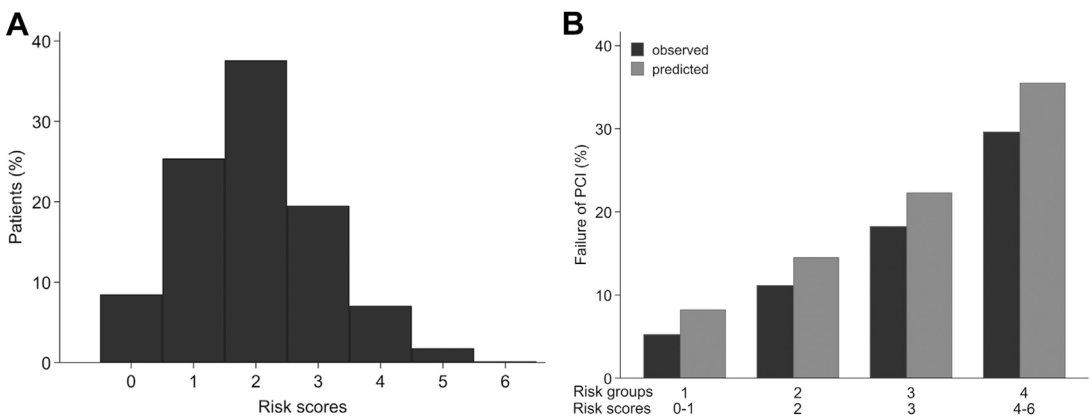
To develop an easy to use scoring system able to identify patients at highest risk of CTO PCI failure, a robust risk score was developed, allocating 0 or 1 for each variable depending on which category a patient was in (Table 2, Online Table 4). The risk score was calculated by the simple addition across all variables.

To compare the observed and predicted risk for the simple risk score, the total scores were grouped into 4 categories (Figure 2 and Table 3). The total risk scores and risk categories showed good separation of the failure rates across the risk groups. There were 18 unsuccessful PCI procedures in 34 patients with total risk score of 6 (52.9%) compared with 68 unsuccessful procedures in 1,129 patients (6.0%) with risk score of 0, an 8-fold increase in risk. Overall, a good agreement was found between the observed and predicted risks within each group (Table 3, Figure 2), demonstrating good model calibration.

Using the CASTLE model with the identified predictive factors (Table 1) Hosmer-Lemeshow goodness-of-fit test revealed good agreement between the predicted and observed probabilities of failure of PCI (chi-square test value with degrees of freedom of 13 = 18.79; p = 0.10 for any imputed dataset), demonstrating that the model was well calibrated. The discriminating ability of the CASTLE model based on the robust scoring defined by the AUC of the total risk scores (AUC: 0.66) was reasonable to distinguish patients at low and high risk.

VALIDATION OF THE EURO-CTO CASTLE RISK ANALYSIS TOOL. The distribution of the identified predictive variables by the outcome of the procedure on the validation Euro-CTO dataset from years 2015 and 2016 is shown in Online Table 5. The validation dataset had 5,258 patients with no missing values and 487 patients with at least 1 missing value for the predictor. The distribution of the total risk scores of patients in the imputed validation set (Figure 3A) was very similar to that on the derivation set (Figure 1). Although the model seems to overestimate the

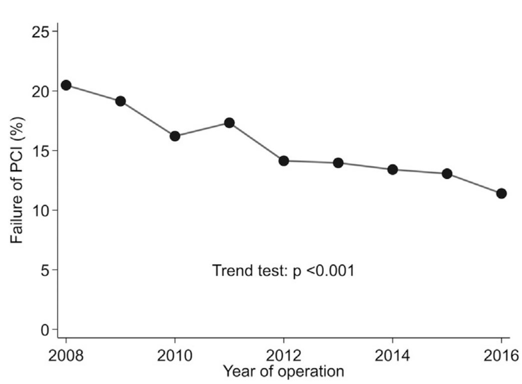
FIGURE 3 Risk Scores and Calibration of the CASTLE Model in the EuroCTO Registry Validation Dataset From 2015 and 2016



(A) Distribution of the risk scores of 5,745 patients with chronic total occlusion. **(B)** Comparison of the observed and predicted probabilities of failure of percutaneous coronary intervention computed by the EuroCTO CASTLE (coronary artery bypass graft history, age, stump anatomy, tortuosity degree, length of occlusion, and extent of calcification) model across the 4 risk groups.

likelihood of failure of PCI to some extent (Figure 3B, Online Tables 6 and 7), this can largely be explained by the improved success rate over time. The overall rate of the observed failure of PCI on the derivation set (15.8%, 2,356 of 14,482) was higher by 3.5% than that on the validation set (12.2%, 703 of 5,745). A decreasing trend year on year in the observed annual failure rates from years 2008 to 2016 was also revealed ($p < 0.001$) (Figure 4). Adjusting the CASTLE model for year of operation indeed proved that this improvement in the success of PCI helps to explain small discrepancies between the observed and predicted failure rates computed by the CASTLE algorithm on the validation set (Figure 5, Online Table 8). The overall model performance on the validation set quantified by the Brier score (0.103 and 0.102 without and with the adjustment of the CASTLE model for year of operation, respectively) was reasonable. The concordance probability measured by the AUC was actually higher on the validation set (AUC for both unadjusted and adjusted models: 0.68) when compared with the derivation set (AUC: 0.66).

FIGURE 4 Annual Failure Rates of PCI of CTO From 2008 to 2016



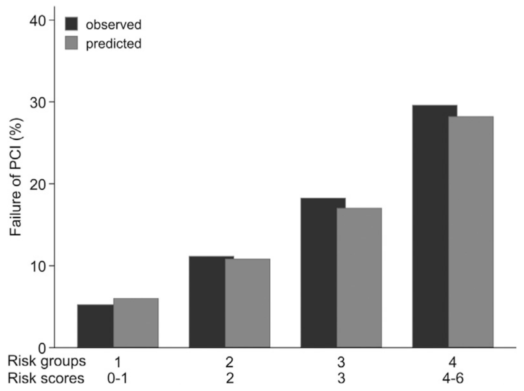
The decreasing trend year on year in the observed annual failure rates was statistically evaluated with trend test ($p < 0.001$). Abbreviations as in Figures 1 and 2.

COMPARISON WITH J-CTO SCORE. The AUC of J-CTO scoring tool was 0.63 and 0.64 within the training and validation sets, respectively. In comparison, our AUC showed a higher discriminatory capacity for both datasets (AUC for the derivation set: 0.66; AUC for the validation set: 0.68).

DISCUSSION

We present a simple scoring system to predict technical success when performing CTO PCI. Despite technical advances, CTO PCI remains one of the most difficult areas of interventional cardiology and the one most likely to fail. Therefore, being able to predict in advance the likelihood of success will help cardiologists choose wisely, in a number of important ways. First, it will help guide interventionalists during their learning phase as CTO operators in terms of case selection. Second, it will aid Heart Team discussions regarding the likelihood of complete revascularization with PCI or CABG. Third, it will aid comprehensive informed consent for patients regarding the likelihood of CTO PCI success.

FIGURE 5 Comparison of the Observed Risk Scores and the Adjusted Predicted Risk Scores on the EuroCTO Registry Validation Dataset From 2015 and 2016 (n = 5,745)



The CASTLE (coronary artery bypass graft history, age, stump anatomy, tortuosity degree, length of occlusion, and extent of calcification) model was adjusted for the effect of time on failure rate before computing the predicted failure rate of percutaneous coronary intervention (PCI).

A number of scoring systems have been developed over the years to predict successful PCI. Morino et al. (4) published the J-CTO score in 2011, derived from 400 CTO cases. This study identified 5 characteristics associated with failure to pass an antegrade guidewire across the occlusion within 30 min (4). The characteristics included a previous failed attempt and did not include previous CABG (widely recognized to be an adverse feature). While procedural failure has been shown to be associated with higher lesion scores in some studies, this relationship has not been observed consistently (6).

Alessandrino et al. (7) published the single-center CL-score that identified independent predictors of procedural failure in patients undergoing CTO-PCI for the first time. Two clinical variables (history of CABG and previous myocardial infarction) and 4 lesion-specific characteristics (blunt stump, lesion calcification, non-left anterior descending artery CTO, and lesion length >20 mm) were found to be associated with an unsuccessful procedure.

The PROGRESS CTO (Prospective Global Registry for the Study of Chronic Total Occlusion Intervention) complications score developed by Christopoulos et al. (12) estimated the likelihood of success in CTO treated using a hybrid approach. Four lesion characteristics—proximal cap ambiguity, moderate-to-severe tortuosity, circumflex artery CTO, and absence of retrograde collaterals—were found to determine technical success.

Maeremans et al. (13) recently published the RECHARGE Registry (Registry of CrossBoss and Hybrid Procedures in France, the Netherlands, Belgium and United Kingdom). Six factors associated with technical failure were identified: a blunt stump, lesion calcification, in-lesion tortuosity ≥45°, lesion length >20 mm, a diseased distal landing zone, and previous bypass graft on the CTO vessel. However, this score was derived from 880 patients undergoing a particular approach to CTO treatment using the CrossBoss or Hybrid techniques, used relatively rarely in the EuroCTO database. However, it is reassuring to see that some negative predictors remain consistent.

The strength of the EuroCTO CASTLE score rests on the large and varied volume of patients from which it is derived and validated. Some of the prior scoring systems were from a single institution, based on the antegrade technique alone or on relatively modest numbers of patients. This study uses patient numbers an order of magnitude greater, with cases undertaken by a large number of different operators across Europe and should therefore reflect more accurately global practice and offer greater contemporary relevance. Previous scores have provided valuable insight into the predictors of failure. However, some of these are no longer contemporary, and our study demonstrates the importance of adjusting for improved success rates over time in predicting actual failure rates. Despite this change over time, the score performs well both in identifying predictors of procedural failure and demonstrating their persisting relevance.

Our scoring system has a greater discriminative capacity compared with the widely used J-CTO score. The EuroCTO CASTLE score incorporates 4 factors that are included in the other 2 main general scoring systems—stump anatomy (J-CTO score); tortuosity (J-CTO [in-lesion] and PROGRESS scores), length of occlusion (J-CTO and PROGRESS scores), and extent of calcification (J-CTO). Importantly, however, it also includes 2 additional variables—previous CABG and age, both of which are objective and not open to operator interpretation. This enhances the functional integrity of the score. It is also noteworthy that the incidence of previous CABG was lower at 6% to 9% in the previous main scoring systems but was 13% in the EuroCTO registry. This relatively higher prevalence helps justify why previous CABG merits consideration as an important variable. Although our score is broadly similar to published ones, our study confirms the importance of previously identified predictors of CTO PCI success using contemporary data from a multitude of operators. To facilitate usage and uptake, we deliberately simplified the scoring system using a point-based approach. We will also be creating a more precise model using the original coefficients of the model, which will be available in App form.

STUDY LIMITATIONS. Our analysis was performed on registry data in the absence of independent verification by core laboratory. Lack of external validation is a limiting factor in our analysis. In addition, while procedural outcome was obtained in all cases, data collection on variables was incomplete. However, the amount of missing data did not exceed 10% for any variable. Angiographic data were obtained by visual assessment rather than by quantitative coronary analysis. Thus, we cannot eliminate operator-related bias. Data were collected from high-volume centers with highly skilled operators at CTO PCI. Our model may not apply to centers where operator experience is lower. The failure rate for CTO PCI fell gradually during the course of the study, and therefore the predictive failure rates are marginally higher than those seen in the final year of the Registry.

CONCLUSIONS

The EuroCTO (CASTLE) prediction score is a multicenter-derived scoring system to predict technical failure in the percutaneous treatment of CTO. Previous CABG, over 70 years of age, a blunt stump, severe tortuosity, length of the occlusion, and extent of calcification were strongly associated with unsuccessful CTO-PCI.

ADDRESS FOR CORRESPONDENCE: Dr. David Hildick-Smith, Sussex Cardiac Centre, Eastern Road, Brighton, United Kingdom. E-mail: david.hildick-smith@bsuh.nhs.uk.

PERSPECTIVES

WHAT IS KNOWN? Interventional treatment of CTOs is a developing subspecialty. Demographic and anatomical criteria that can predict outcome have been derived from relatively modest sample sizes and not been subject to extensive contemporary data analysis.

WHAT IS NEW? We examined data from the EuroCTO Registry of 20,000 prospectively entered cases from dedicated CTO operators and created a simple integer scoring system to predict technical outcome. The following factors were found to be of greatest importance—coronary artery bypass graft history, age, stump anatomy, tortuosity degree, length of occlusion, and extent of calcification. Technical failure rates range from 8% (CASTLE score 0 to 1) to 35% (CASTLE score ≥4).

WHAT IS NEXT? The predictive ability of our model needs to be validated in future studies.

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KEY WORDS coronary artery disease, chronic total occlusion, percutaneous coronary intervention, scoring system

APPENDIX For supplemental tables, please see the online version of this paper.