CASTLE score versus J-CTO score for the prediction of technical success in chronic total occlusion percutaneous revascularisation

Andreas S. Kalogeropoulos[1], MD, PhD; Osama Alsanjari[2,3], MBBS;
Thomas R. Keeble[2,3], MBBS, MD; Kare H. Tang[2], BM, FHKAM; Klio Konstantinou[2,3], MBBS;
Athanasios Katsikis[2], MD, PhD; Rohan Jagathesan[2], MBBS, MD;
Rajesh K. Aggarwal[2], MBChB, MD; Gerald J. Clesham[2,3], BMBCh, PhD;
Paul A. Kelly[2], MBChB, MD; Gerald S. Werner[4], MD, PhD; David Hildick-Smith[1], MB, BChir, MD;
John R. Davies[2,3], MBBS, PhD; Grigoris V. Karamasis[2,3]*, MD

1. Department of Cardiology, Royal Sussex County Hospital, Brighton, United Kingdom; 2. Department of Cardiology, Essex Cardiothoracic Centre, Basildon, United Kingdom; 3. School of Medicine, Faculty of Medical Science, Anglia Ruskin University, Cambridge and Chelmsford, United Kingdom; 4. Medizinische Klinik I (Cardiology & Intensive Care), Klinikum Darmstadt GmbH, Darmstadt, Germany

This paper also includes supplementary data published online at: https://eurointervention.pcronline.com/doi/10.4244/EIJ-D-19-00352

Abstract

Aims: We sought to compare the efficiency of the novel EuroCTO (CASTLE) score with the commonly used Multicentre CTO Registry in Japan (J-CTO) score in predicting procedural success of percutaneous coronary intervention (PCI) for coronary chronic total occlusions (CTOs).

Methods and results: We evaluated 660 consecutive CTO PCIs (mean age 66±11 years, 84% male). The mean J-CTO and EuroCTO (CASTLE) scores were 1.86±1.2 and 1.74±1.2, respectively. Antegrade wire escalation, antegrade dissection re-entry and retrograde approach were used in 82%, 14% and 37% of cases, respectively. Receiver operating characteristic analysis demonstrated equal overall discriminatory capacity between the two scores (AUC 0.698, 95% CI: 0.653-0.742, p<0.001 for J-CTO vs AUC 0.676, 95% CI: 0.627-0.725, p<0.001 for EuroCTO; AUC difference: 0.022, p=0.5). However, for more complex procedures (J-CTO ≥3 or EuroCTO [CASTLE] ≥4), the predictive capacity of the EuroCTO (CASTLE) score appeared superior (AUC 0.588, 95% CI: 0.509-0.668, p=0.03 for EuroCTO [CASTLE] score vs AUC 0.473, 95% CI: 0.393-0.553, p=NS for the J-CTO score, AUC difference: 0.115, p=0.04).

Conclusions: In this study, the novel EuroCTO (CASTLE) score was comparable to the J-CTO score in predicting CTO PCI outcome with a superior discriminatory capacity for the more complex cases.

*Corresponding author: Essex Cardiothoracic Centre, Basildon and Thurrock University Hospitals NHS Foundation Trust, Basildon, SS16 5NL, United Kingdom. E-mail: grigoris.karamasis@gmail.com

Abbreviations

ADR   antegrade dissection and re-entry
AUC   area under the curve
AWE   antegrade wire escalation
CABG   coronary artery bypass graft
CART   controlled antegrade and retrograde subintimal tracking
CTO   chronic total occlusion(s)
HL   Hosmer-Lemeshow goodness-of-fit
J-CTO   Multicentre CTO Registry in Japan
PCI   percutaneous coronary intervention
RA   retrograde approach
RCA   right coronary artery
ROC   receiver operating characteristic
RWE   retrograde wire escalation
TIMI   Thrombolysis In Myocardial Infarction

Introduction

Coronary chronic total occlusions (CTOs), defined as coronary lesions with Thrombolysis In Myocardial Infarction (TIMI) grade 0 flow of at least three months duration, are a common finding in patients undergoing invasive diagnostic angiography[1-3]. Over the last decade, the advent of novel techniques and the utilisation of more advanced equipment has resulted in high procedural success rates and an upsurge in the number of CTO percutaneous coronary interventions (PCIs) performed[4,5]. However, the success of CTO interventions can still vary significantly, especially in unselected populations[6] and, apart from lesion complexity and operator experience, it is also liable to several additional factors including patients' clinical characteristics.

Preprocedural preparation, involving careful identification of various clinical risk factors and meticulous assessment of the diagnostic coronary angiogram to evaluate lesion complexity and plan the procedural strategy, is important to achieve successful outcomes in CTO PCI[7]. Success prediction scores are valuable in this regard, as they provide a quantitative evaluation of procedural difficulty and the likelihood of recanalisation success and thus facilitate case selection, procedural planning and clinical decision making[7]. The novel EuroCTO (CASTLE) scoring system has recently been derived and validated from the large multicentre EuroCTO registry including more than 20,000 patients. It comprises two clinical factors (age ≥70 years and previous coronary artery bypass graft [CABG] surgery) and four angiographic factors (blunt or invisible proximal cap, severe tortuosity, severe calcification and lesion length ≥20 mm) with one point for each factor, resulting in a minimum score of 0 to a maximum score of 6[8]. We sought to compare the technical success predictive efficacy of the novel EuroCTO (CASTLE) score with the widely adopted Multicentre CTO Registry in Japan score[9].

Editorial, see page 1564

Methods

We analysed 660 consecutive CTO PCI cases performed in a tertiary cardiac centre with a dedicated CTO programme (Essex Cardiothoracic Centre, Basildon, United Kingdom). All cases performed since the onset of the programme in June 2012 up to November 2018 were included in the analysis. As part of the programme and for auditing purposes, clinical, angiographic and procedural characteristics of the CTO cases were prospectively recorded in a dedicated CTO database. The J-CTO and EuroCTO (CASTLE) scores were calculated according to the algorithms described by Morino et al[9] and Szijgyarto et al[8], respectively. The EuroCTO (CASTLE) score analysis took place retrospectively as the score was introduced only recently. The definitions of the EuroCTO and J-CTO score variables and the different recanalisation techniques can be found in **Supplementary Appendix 1-Supplementary Appendix 3** and **Supplementary Table 1**.

Technical success of CTO PCI was defined as successful CTO revascularisation resulting in <30% residual vessel diameter stenosis within the treated segment and restoration of TIMI grade 3 antegrade flow.

STATISTICAL ANALYSIS

All quantitative variables were tested for normal distribution according to the Kolmogorov-Smirnov test. Continuous variables are reported as mean and SD values. Categorical variables are expressed as frequency and proportion. Normally distributed continuous variables were compared using the Student's t-test, whilst the Mann-Whitney U test was used to compare non-normally distributed continuous variables. Categorical data were compared using the Pearson chi-squared test. To evaluate the trend of efficiency metrics amongst different prediction score strata, the Jonckheere-Terpstra statistical test was applied. The association between prediction scores and technical outcome was evaluated using the univariate logistic regression analysis and their efficiency as independent factors for predicting successful outcomes in CTO PCI was evaluated using a multivariate logistic regression model accounting for various potential confounding factors. Odds ratios for every one-point increase of the J-CTO and the EuroCTO (CASTLE) scores with their respective 95% confidence intervals were calculated. The Hosmer-Lemeshow goodness-of-fit (HL) test was used to assess calibration of both scores in our study population. The HL test analyses the observed versus the predicted outcomes; theoretically, there should not be any statistically significant difference between the expected and observed counts and thus, based on χ^2 distribution, an HL statistic with a p-value >0.05 should be consistent with a good model fit[10]. The discriminatory performance of the predictive scores was evaluated by comparing the two scores using the receiver operating characteristic (ROC) curve and area under the curve (AUC) analysis. Differences in AUC between ROC curves were tested as described by Hanley & McNeil[11]. Statistical analysis was performed with SPSS, Version 24.0 (IBM Corp., Armonk, NY, USA). A two-tailed p-value of <0.05 was considered statistically significant.

Results

The study included 660 CTO PCIs (mean age 65.8±10.6 years, 83.8% male). **Table 1** shows the clinical, angiographic and

**Table 1. Clinical, angiographic and procedural characteristics.**

	N=660
Clinical characteristics	
Age, years (mean±SD)	65.8±10.6
Age >70 years, n (%)	236 (35.8)
Male, n (%)	553 (83.8)
BMI, mean±SD	30.5±5.6
Hypertension, n (%)	453 (68.6)
Hyperlipidaemia, n (%)	512 (77.6)
Smoking, n (%)	162 (24.5)
Diabetes, n (%)	145 (22.0)
Previous MI, n (%)	328 (49.7)
Previous PCI, n (%)	307 (46.5)
Previous CABG, n (%)	128 (19.4)
Previous CVA, n (%)	36 (5.5)
Peripheral vascular disease, n (%)	48 (7.3)
Chronic kidney disease, n (%)	139 (21)
Left ventricular systolic function, n (%)	
Good (EF >50%)	425 (71.1)
Moderate (EF: 35-50%)	152 (25.4)
Severe (EF <35%)	21 (3.5)
CCS, mean±SD	2.2±1.0
NYHA, mean±SD	1.8±0.8
Previous failed target vessel CTO PCI, n (%)	113 (17.1)
Angiographic characteristics	
Target CTO vessel, n (%)	
RCA	432 (65.5)
LAD	163 (24.3)
LCx	65 (9.8)
CTO length >20 mm, n (%)	363 (55.0)
Blunt proximal cap, n (%)	288 (43.6)
Calcification, n (%)	310 (47.0)
Severe calcification, n (%)	124 (18.8)
Tortuosity, n (%)	154 (23.3)
Severe tortuosity, n (%)	19 (2.9)
Procedural characteristics	
Procedural time, minutes (mean±SD)	131.3±59.1
Fluoroscopy time, minutes (mean±SD)	42.4±25.1
Contrast volume, ml (mean±SD)	259.8±92.9
Radiation DAP, mGy (mean±SD)	22,019.3±28,946.6
Number of implanted stents, mean±SD	2.1±1.4
Overall stent length, mm (mean±SD)	47.9±34.2
Prediction scores	
J-CTO score, mean±SD	1.9±1.2
EuroCTO (CASTLE) score, mean±SD	1.8±1.2

BMI: body mass index; CABG: coronary artery bypass graft surgery; CCS: Canadian Cardiovascular Society angina pectoris grading; CTO: chronic total occlusion; CVA: cerebrovascular accident; DAP: dose area product; LAD: left anterior descending artery; LCx: left circumflex artery; MI: myocardial infarction; NYHA: New York Heart Association functional classification; PCI: percutaneous coronary intervention; RCA: right coronary artery

procedural characteristics of the study cases. The indication for CTO PCI was stable angina pectoris in all cases; the most common target PCI vessel was the right coronary artery (66%). More than 30% of the study participants were ≥70 years old and 19% had a history of previous CABG. An antegrade wire escalation (AWE) approach was the most frequent recanalisation approach: it was applied as an initial strategy in 73.9% of cases followed by the retrograde approach (RA) in 20.4% of cases and antegrade dissection and re-entry (ADR) in 5.8% of cases. The overall prevalence of AWE, RA and ADR was 82%, 37% and 14%, respectively. Successful CTO recanalisation was achieved in 516 cases (78%). Amongst cases with successful CTO PCI, AWE was the successful recanalisation strategy used in 67% of cases, RA was used in 22% of cases and ADR in 11% of cases. The mean EuroCTO and J-CTO scores were 1.8±1.2 and 1.9±1.2, respectively. Failed cases had significantly higher EuroCTO (CASTLE) and J-CTO scores compared to cases with successful CTO PCI (2.4±1.2 vs 1.6±1.2, p<0.001, and 2.5±1.0 vs 1.7±1.2, p<0.001, respectively).

The EuroCTO (CASTLE) score exhibited superior calibration compared to the J-CTO score in our sample analysis: EuroCTO (CASTLE) score HL χ^2=0.765, p=0.858, and J-CTO score HL χ^2=17.397, p=0.001. In the multivariate logistic regression analysis, both the EuroCTO (CASTLE) and J-CTO scores were the only independent predictors of successful CTO PCI. For each unit increase of the EuroCTO (CASTLE) and J-CTO scores, there was a 28% and 36% odds reduction for successful recanalisation, respectively **(Table 2)**. Technical success was significantly lower for higher values of both scores **(Figure 1A, Figure 1B)**; the probability of successful PCI was inversely correlated with both score strata **(Figure 1C, Figure 1D)**. The most

Table 2. Multivariate logistic regression analysis for prediction of CTO PCI technical outcome including the two scoring systems and potential confounders.

	OR	95% CI	*p*-value
EuroCTO (CASTLE) score	0.698	0.532-0.916	0.009
J-CTO score	0.683	0.516-0.909	0.008
Male gender	0.803	0.392-1.647	0.6
BMI	0.985	0.941-1.032	0.5
Chronic kidney disease	0.760	0.405-1.426	0.4
Previous MI	1.168	0.679-2.012	0.6
Previous PCI	1.021	0.600-1.736	0.9
Diabetes	1.181	0.657-2.123	0.6
Peripheral vascular disease	1.371	0.622-3.022	0.434
Target CTO vessel LAD	0.357	0.125-1.018	0.06
Target CTO vessel RCA	0.635	0.240-1.683	0.4
Left ventricular function good	2.280	0.521-9.985	0.3
Left ventricular function moderate	2.451	0.538-11.160	0.2

BMI: body mass index; CI: confidence interval; CTO: chronic total occlusion; LAD: left anterior descending artery; MI: myocardial infarction; OR: odds ratio; PCI: percutaneous coronary intervention; RCA: right coronary artery
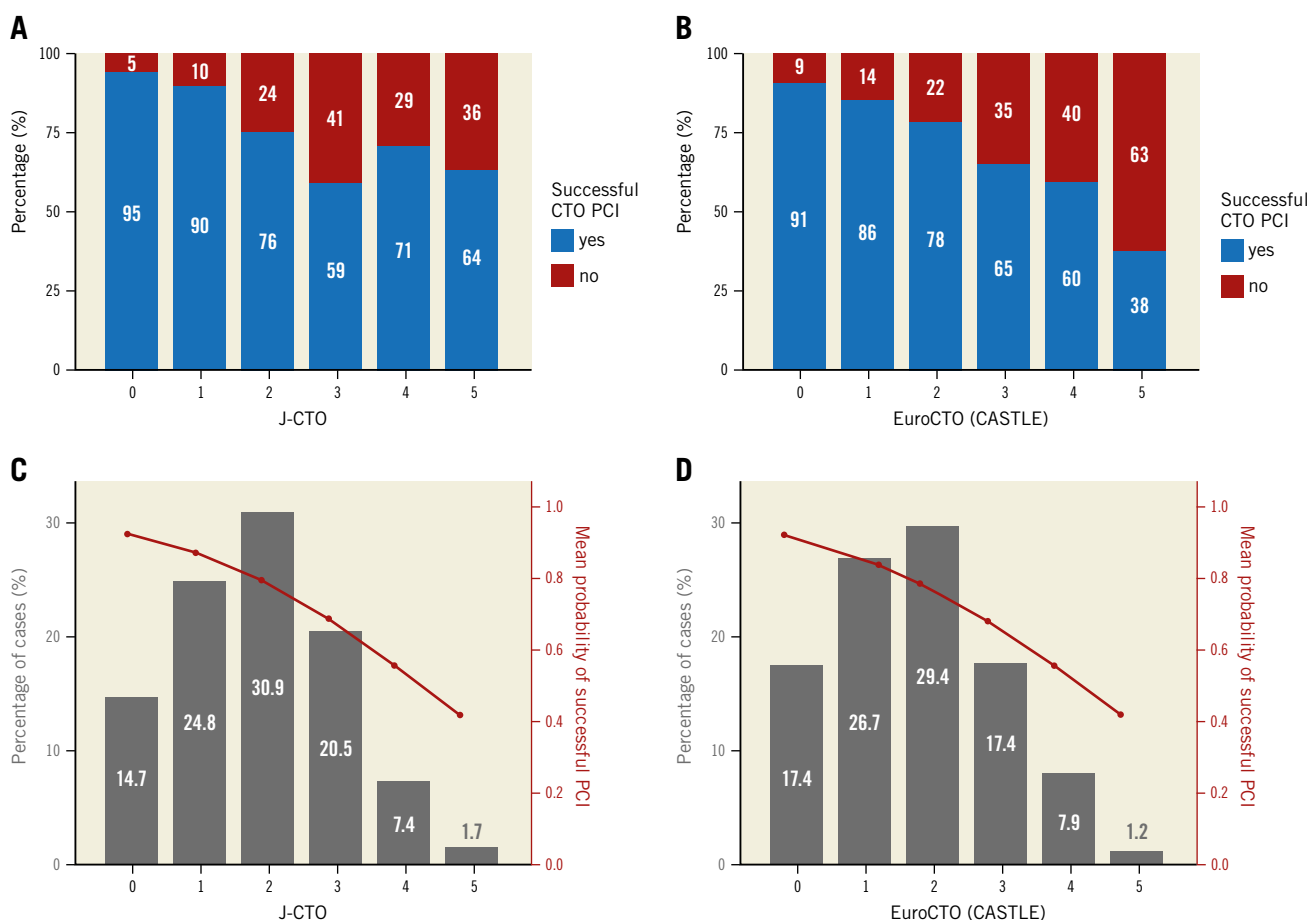
Figure 1. *Rates of technical success and J-CTO and EuroCTO (CASTLE) scores strata. A) Observed rates of technical success of CTO PCI across J-CTO score strata. B) Observed rates of technical success of CTO PCI across EuroCTO (CASTLE) score strata. C) Distribution of J-CTO score strata across study cases. The red line demonstrates the predictive mean probability of successful CTO PCI according to the J-CTO score stratification. There is an evident discrepancy between the observed (panel A) and predicted success rates (red line) in the more complex cases with a J-CTO score of ≥3. D) Distribution of EuroCTO (CASTLE) score strata across study cases. The red line demonstrates the predictive mean probability of successful CTO PCI according to the EuroCTO (CASTLE) score stratification. The EuroCTO (CASTLE) score depicts a good agreement between the observed (panel B) and the predicted success rates (red line) across all score strata.*

pronounced difference in success rates of approximately 54% between the lowest scoring grade (least complex cases) and the highest scoring grade (most complex cases) was observed in the EuroCTO (CASTLE) score **(Figure 1B)**. The J-CTO score was associated with an overestimation of case complexity compared to the EuroCTO (CASTLE) score as a J-CTO score ≥3 was observed in 30% and a EuroCTO (CASTLE) score ≥4 in 9% of cases **(Figure 1C, Figure 1D)**.

The discriminatory performance of the two scoring systems in predicting the technical outcome of CTO PCI was evaluated using the ROC curve analysis. Both scores demonstrated equal overall discriminatory capacity: for the EuroCTO (CASTLE) score, AUC 0.674, 95% CI: 0.625-0.724, p<0.001, for the J-CTO score, AUC 0.694, 95% CI: 0.649-0.739, p<0.001, AUC difference: 0.02, p=NS **(Figure 2A)**. However, for the more complex procedures (EuroCTO [CASTLE] score ≥4 or J-CTO score ≥3), the discriminatory capacity of the EuroCTO (CASTLE) score to predict

procedural success appeared superior compared to the J-CTO score (AUC 0.588, 95% CI: 0.509-0.668, p=0.03 for EuroCTO [CASTLE] score vs AUC 0.473, 95% CI: 0.393-0.553, p=NS for J-CTO score, AUC difference: 0.115, p=0.04) **(Figure 2B)**. In the univariate logistic regression analysis, both scores appeared to have better predictive efficacy for the less complex cases with a J-CTO score of <3 and EuroCTO (CASTLE) score <4 **(Table 3)**. We analysed the discriminatory capacity of the two scoring systems across the very early (2012-13) and very late (2017-18) periods of time of our study. The EuroCTO (CASTLE) and J-CTO scores demonstrated a consistent and satisfactory discriminatory capacity over time (AUC 0.740, 95% CI: 0.657-0.882, p<0.001 vs AUC 0.733, 95% CI: 0.579-0.886, p=0.007, and AUC 0.723, 95% CI: 0.641-0.805, p<0.001 vs AUC 0.699, 95% CI: 0.564-0.834, p=0.021, respectively) **(Figure 3)**.

Successful recanalisation with an AWE approach was predominant in the lower strata of both scores, whereas in more complex
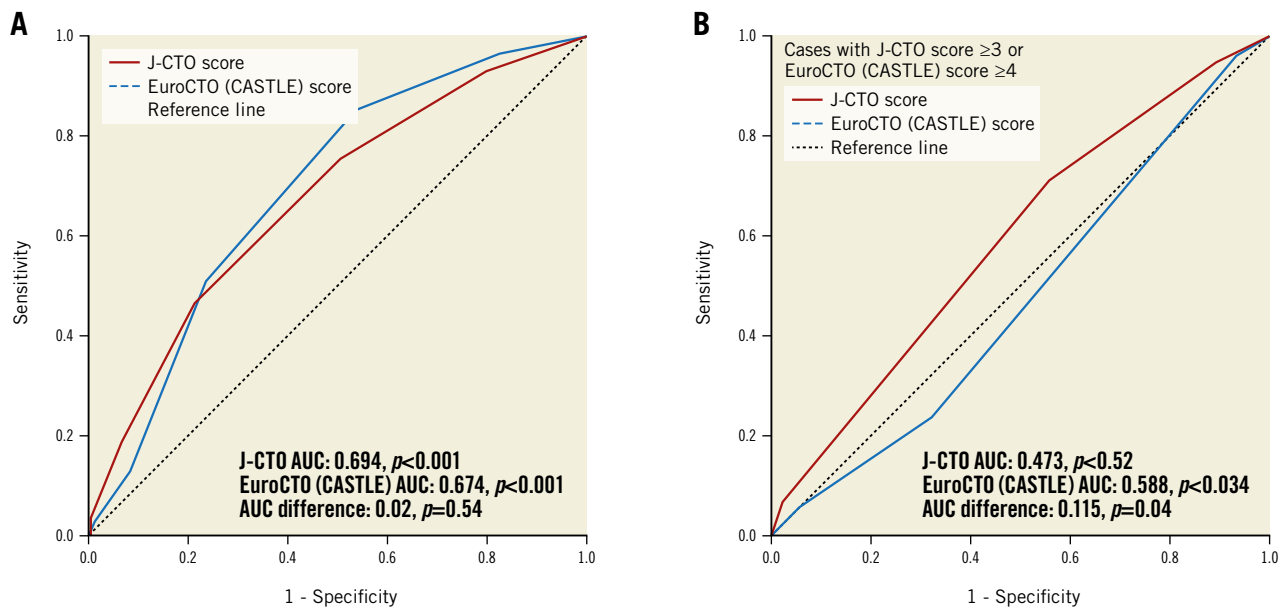
Figure 2. *ROC curves for success prediction for the J-CTO and the EuroCTO (CASTLE) scores. A) In the whole study cohort. B) In the more complex cases with J-CTO score ≥3 or EuroCTO (CASTLE) score of ≥4. ROC: receiver operating characteristic*

Table 3. Univariate logistic regression analysis of the capacity of both scoring systems to predict a successful technical outcome of CTO PCI across the different scoring strata.

		OR	95% CI	*p*-value
J-CTO score	1	10.5	2.3-48.2	0.002
	2	5.3	1.4-20.0	0.014
	3	1.8	0.5-6.4	NS
	4	0.831	0.2-3.0	NS
	5	1.4	0.4-5.7	NS
EuroCTO (CASTLE) score	1	17.5	3.6-84.2	<0.001
	2	10.1	2.3-44.8	0.002
	3	6.0	1.4-26.3	0.017
	4	3.1	0.7-13.8	NS
	5	2.5	0.5-11.4	NS
CI: confidence interval; OR: odds ratio

cases successful recanalisation through the RA or ADR approach was more frequently observed **(Figure 4)**. Moreover, there was significantly higher radiation dose area product, contrast volume administration, overall procedural time and fluoroscopy time amongst the higher strata of both scores according to the trend analysis **(Figure 5)**.

Discussion

The present study compared the efficiency of the novel EuroCTO (CASTLE) score with the widely adopted J-CTO score to predict the technical outcome of CTO PCIs in an unselected cohort of patients treated with contemporary CTO techniques. Our results showed that the EuroCTO (CASTLE) score demonstrated an overall equal predictive performance with the J-CTO score. However, the EuroCTO (CASTLE) score appeared superior in predicting the technical outcome in the more complex cases.

The ability to appraise case complexity and predict outcomes reliably is a favourable concept that can facilitate CTO PCI in various ways. Firstly, it could ease the process of determining the appropriateness of CTO PCI by evaluating the overall risk-benefit ratio of the procedure[12]. Secondly, it could help interventional cardiologists during the early stages of their training in CTO PCI to select simpler cases and either refer the more complex cases to more experienced operators or perform these with proctor support. Furthermore, objective quantification of lesion complexity allows careful procedural planning, which is an essential step before attempting CTO recanalisation both for experienced and for non-experienced CTO PCI operators. Finally, determining case complexity, technical outcomes and efficiency metrics could help to evaluate the overall performance of a dedicated CTO programme, identify pitfalls and help to improve performance and quality measures further.

So far, various predicting scoring systems have been developed[9,13-16]. These scores have been derived from registries that predominantly included a relatively modest number of patients. Additionally, across the different registries there was great variance regarding the adopted recanalisation techniques, CTO PCI success rates, patients' clinical characteristics, case complexity and operator skills, making these scores unattractive for more generalised adoption. The most commonly used score – the J-CTO score – was derived from a cohort of 465 patients treated exclusively with the antegrade approach between 2006 and 2007[9]. The endpoint in that study was successful guidewire crossing within 30 minutes, which was achieved in 48% of the cases.
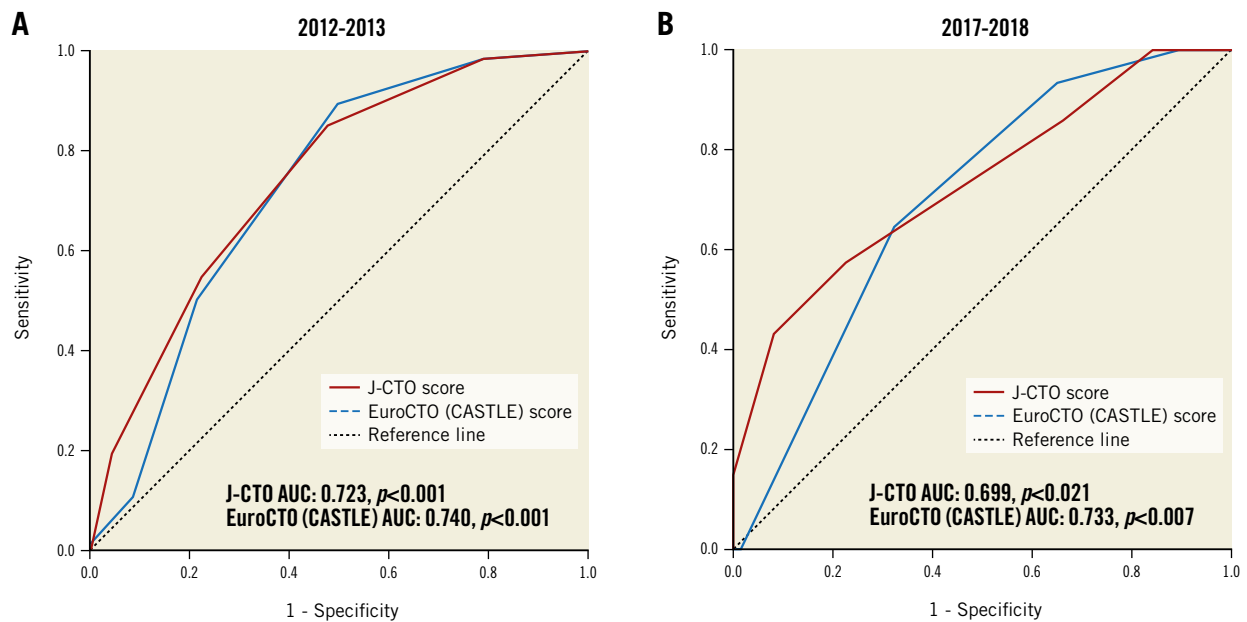
Figure 3. *ROC curves for success prediction for the J-CTO and the EuroCTO (CASTLE) scores in the study cohort between the years 2012 and 2013, and 2017 and 2018. A) 2012-2013. B) 2017-2018. ROC: receiver operating characteristic*

The EuroCTO group recently reported the development and validation of a novel CTO PCI success prediction scoring system, the EuroCTO (CASTLE) score. The potential advantages of this prediction score are the large derivation and validation cohort consisting of an unselected and contemporary population of more than 20,000 cases, the homogeneous distribution of operator experience with the majority of the operators performing >50 CTO PCIs/year and the utilisation of a broad spectrum of contemporary CTO PCI techniques and equipment. In our study, we compared the EuroCTO (CASTLE) score with the J-CTO score, as the latter is the score most commonly used to assess the complexity of CTO PCIs. The EuroCTO (CASTLE) score demonstrated an overall equal discriminatory capacity with the J-CTO score. However, the EuroCTO

(CASTLE) score showed superior calibration and had better predictive performance than the J-CTO score in the more complex cases. The noticeably large number of patients who were included in the original derivation cohort of the EuroCTO (CASTLE) score and the inclusion of additional objective clinical features such as prior history of CABG and patients' age potentially improved the ability of the EuroCTO (CASTLE) score to predict the technical outcome in more complex CTO PCIs. Elderly patients and those with a prior history of CABG are likely to have more comorbidities and diffuse and complex atherosclerotic disease that can increase case complexity and thus result in a higher likelihood of unsuccessful outcomes[17,18]. In contrast to the J-CTO score, in the EuroCTO (CASTLE) score a previously failed attempt was not
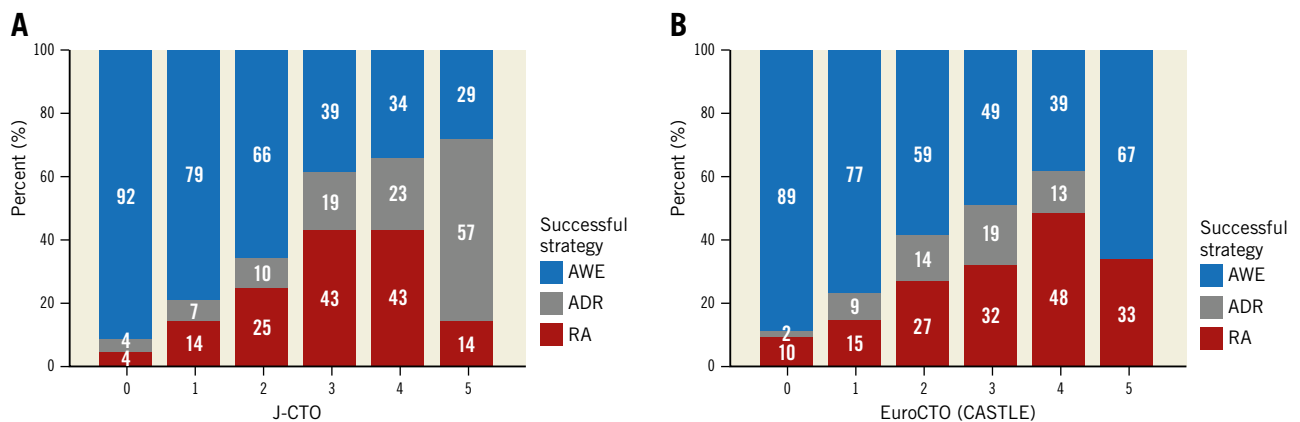
Figure 4. *Rates of successful techniques across J-CTO and EuroCTO (CASTLE) score strata. A) J-CTO score strata. B) EuroCTO (CASTLE) score strata.*
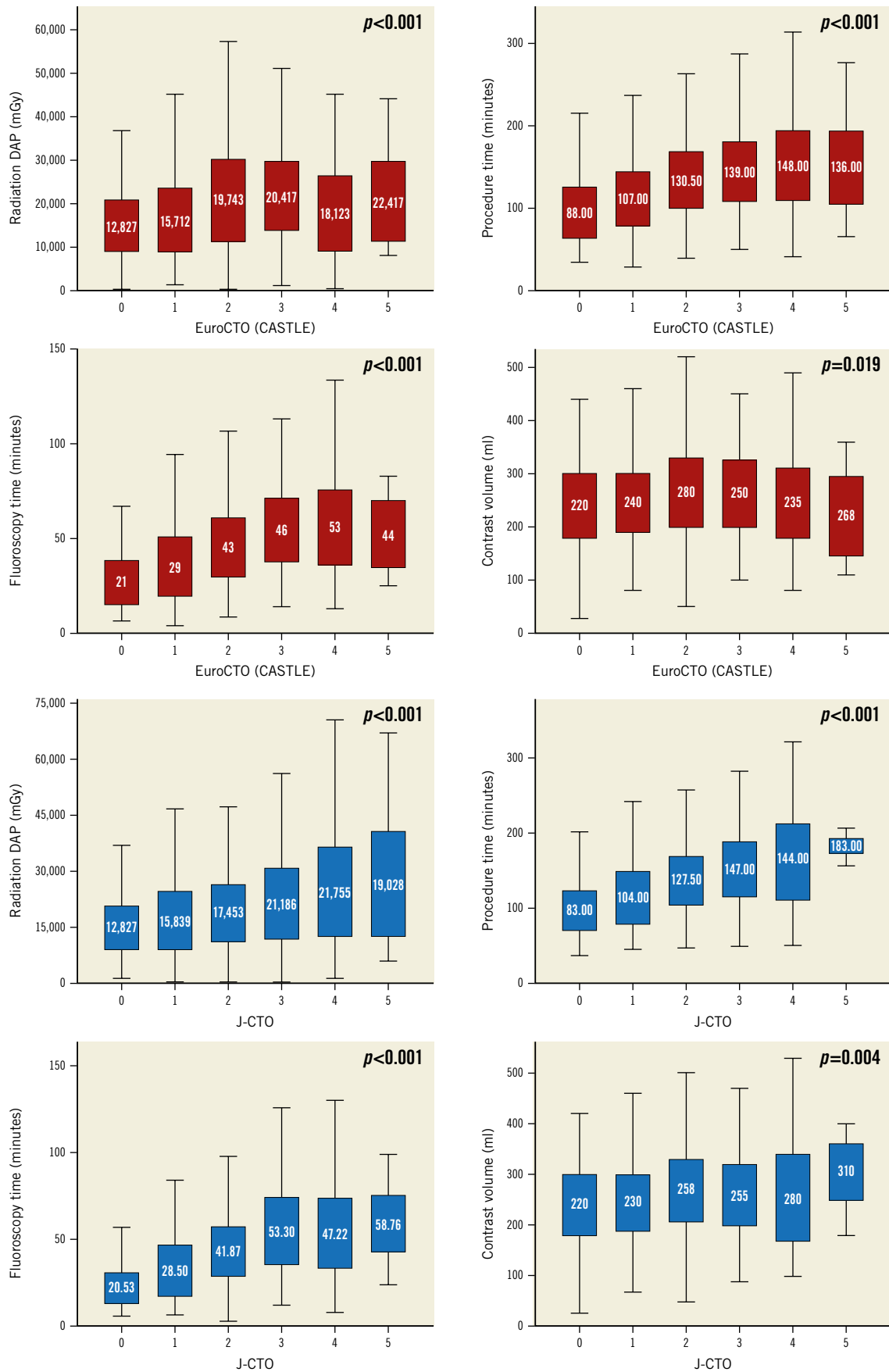
Figure 5. *CTO PCI efficiency metrics including contrast volume, radiation dose area product, fluoroscopy and procedural time across the J-CTO score and EuroCTO (CASTLE) score strata.*

incorporated in the final prediction model. This parameter is subject to the operator's technical expertise. Less experienced operators are more likely to fail, simply because they do not master all recanalisation techniques and thus have limited options to tackle more difficult CTOs, whilst a more experienced operator might have succeeded at the first attempt. Therefore, for an operator with a good level of CTO PCI experience, a previously failed attempt does not necessarily translate into a more complex procedure or increased chances of failure. In addition, the utilisation of the currently expanded armamentarium of dedicated CTO equipment and the implementation of more advanced recanalisation techniques compared to those used in the derivation cohort of the J-CTO score might have blunted the impact of CTO complexity assessed by the J-CTO score and could at least in part explain the inconsistency that we observed in the predictive efficiency in the more complex cases. Finally, although the discriminatory capacity of the EuroCTO (CASTLE) score was superior in the higher complexity subgroup, it was reduced compared to the overall population (AUC 0.588 vs 0.674, respectively).

In our study, the EuroCTO (CASTLE) score demonstrated an almost identical discriminatory capacity with that of the original derivation cohort from the EuroCTO registry (AUC of 0.67 and 0.66, respectively). In our analysis, we included consecutive CTO cases from day 1 of a dedicated CTO PCI programme, thus incorporating all stages of a contemporary CTO PCI learning curve. Therefore, we provide evidence that the EuroCTO (CASTLE) score is generalisable, with excellent reproducibility in different CTO populations and across variable CTO PCI expertise and contemporary CTO PCI modalities.

Higher grades of both scores were associated with significantly higher levels of several procedural efficiency metrics such as radiation exposure, contrast volumes, procedural and fluoroscopy times, in keeping with findings of previous studies[19]. Beyond the actual predictive ability of technical success, the CTO PCI scoring systems might be advantageous by assisting angiographic review, estimating procedure and lesion complexity and evaluating efficiency metrics, all of which can be valuable components of a comprehensive and universal approach to clinical decision making. Given the higher potential for complications, the decision to proceed with CTO revascularisation must be based on a meticulous risk-benefit assessment and an uncluttered discussion with both the patient and the Heart Team.

Limitations
A few limitations of this study warrant further discussion. The study is limited by its observational design and, even though the population was unselected with enrolment of consecutive patients undergoing CTO PCI, it could be subject to operators' case selection bias especially during the early stages of the dedicated CTO programme. However, the inclusion of cases from the early stages of the programme, when the operators' experience was more limited, enhances the capacity of extrapolating the study results to other populations that encompass a broad spectrum of case difficulty

and operator technical experience. Angiographic parameters were assessed by the operators without adjudication from a core laboratory, although we think it is unlikely that the major findings would have been any different as all operators were participating in a dedicated CTO programme and have substantial theoretical and practical knowledge regarding all aspects of CTOs. Finally, it is worth mentioning a limitation not of our study, but of any outcome predicting score. Predicting scores are useful for estimating lesion complexity and planning procedural strategy and use of equipment, but it is impossible to generate a flawless model with a perfect predictive capacity. Clinical judgement and operator experience cannot be substituted by any prediction model and are the most important factors for determining a successful and uneventful procedure.

Conclusions
In conclusion, the EuroCTO (CASTLE) score demonstrated similar performance to the J-CTO score in predicting the success of CTO PCI with potentially better discriminatory capacity in more complex cases. Both scores were associated with higher values of procedural efficiency measures and could thus assist with preprocedural planning and risk-benefit assessment.

Impact on daily practice
Percutaneous revascularisation of chronic total occlusions represents the most challenging procedure in the field of coronary interventions. In this setting, technical outcome prediction scores are useful in preprocedural planning of CTO percutaneous revascularisation. The novel EuroCTO (CASTLE) score, derived from the large EuroCTO registry, could be used as an alternative to the commonly applied J-CTO score, as it shows similar overall capacity in predicting CTO PCI success rates with a superior discriminatory capacity for the more complex cases.

Conflict of interest statement
The authors have no conflicts of interest to declare.

References
1. Di Mario C, Werner GS, Sianos G, Galassi AR, Buttner J, Dudek D, Chevalier B, Lefevre T, Schofer J, Koolen J, Sievert H, Reimers B, Fajadet J, Colombo A, Gershlick A, Serruys PW, Reifart N. European perspective in the recanalisation of Chronic Total Occlusions (CTO): consensus document from the EuroCTO Club. *EuroIntervention.* 2007;3:30-43.

2. Sianos G, Werner GS, Galassi AR, Papafaklis MI, Escaned J, Hildick-Smith D, Christiansen EH, Gershlick A, Carlino M, Karlas A, Konstantinidis NV, Tomasello SD, Di Mario C, Reifart N; EuroCTO Club. Recanalisation of chronic total coronary occlusions: 2012 consensus document from the EuroCTO club. *EuroIntervention.* 2012;8:139-45.

3. Fefer P, Knudtson ML, Cheema AN, Galbraith PD, Osherov AB, Yalonetsky S, Gannot S, Samuel M, Weisbrod M, Bierstone D, Sparkes JD, Wright GA, Strauss BH. Current perspectives on coronary chronic total occlusions: the Canadian Multicenter Chronic Total Occlusions Registry. *J Am Coll Cardiol.* 2012;59:991-7.

4. Konstantinidis NV, Werner GS, Deftereos S, Di Mario C, Galassi AR, Buettner JH, Avran A, Reifart N, Goktekin O, Garbo R, Bufe A, Mashayekhi K,

Boudou N, Meyer-Gessner M, Lauer B, Elhadad S, Christiansen EH, Escaned J, Hildick-Smith D, Carlino M, Louvard Y, Lefèvre T, Angelis L, Giannopoulos G, Sianos G; Euro CTO Club. Temporal Trends in Chronic Total Occlusion Interventions in Europe. *Circ Cardiovasc Interv.* 2018;11:e006229.

5. Suzuki Y, Tsuchikane E, Katoh O, Muramatsu T, Muto M, Kishi K, Hamazaki Y, Oikawa Y, Kawasaki T, Okamura A. Outcomes of Percutaneous Coronary Interventions for Chronic Total Occlusion Performed by Highly Experienced Japanese Specialists: The First Report From the Japanese CTO-PCI Expert Registry. *JACC Cardiovasc Interv.* 2017;10:2144-54.

6. Brilakis ES, Banerjee S, Karmpaliotis D, Lombardi WL, Tsai TT, Shunk KA, Kennedy KF, Spertus JA, Holmes DR Jr, Grantham JA. Procedural outcomes of chronic total occlusion percutaneous coronary intervention: a report from the NCDR (National Cardiovascular Data Registry). *JACC Cardiovasc Interv.* 2015;8:245-53.

7. Galassi AR, Werner GS, Boukhris M, Azzalini L, Mashayekhi K, Carlino M, Avran A, Konstantinidis NV, Grancini L, Bryniarski L, Garbo R, Bozinovic N, Gershlick AH, Rathore S, Di Mario C, Louvard Y, Reifart N, Sianos G. Percutaneous recanalisation of chronic total occlusions: 2019 consensus document from the EuroCTO Club. *EuroIntervention.* 2019;15:198-208.

8. Szijgyarto Z, Rampat R, Werner GS, Ho C, Reifart N, Lefevre T, Louvard Y, Avran A, Kambis M, Buettner HJ, Di Mario C, Gershlick A, Escaned J, Sianos G, Galassi A, Garbo R, Goktekin O, Meyer-Gessner M, Lauer B, Elhadad S, Bufe A, Boudou N, Sievert H, Martin-Yuste V, Thuesen L, Erglis A, Christiansen E, Spratt J, Bryniarski L, Clayton T, Hildick-Smith D. Derivation and Validation of a Chronic Total Coronary Occlusion Intervention Procedural Success Score From the 20,000-Patient EuroCTO Registry: The EuroCTO (CASTLE) Score. *JACC Cardiovasc Interv.* 2019;12:335-42.

9. Morino Y, Abe M, Morimoto T, Kimura T, Hayashi Y, Muramatsu T, Ochiai M, Noguchi Y, Kato K, Shibata Y, Hiasa Y, Doi O, Yamashita T, Hinohara T, Tanaka H, Mitsudo K; J-CTO Registry Investigators. Predicting successful guidewire crossing through chronic total occlusion of native coronary lesions within 30 minutes: the J-CTO (Multicenter CTO Registry in Japan) score as a difficulty grading and time assessment tool. *JACC Cardiovasc Interv.* 2011;4:213-21.

10. Lemeshow S, Hosmer DW Jr. A review of goodness of fit statistics for use in the development of logistic regression models. *Am J Epidemiol.* 1982;115:92-106.

11. McNeil BJ, Hanley JA. Statistical approaches to the analysis of receiver operating characteristic (ROC) curves. *Med Decis Making.* 1984;4:137-50.

12. Galassi AR, Brilakis ES, Boukhris M, Tomasello SD, Sianos G, Karmpaliotis D, Di Mario C, Strauss BH, Rinfret S, Yamane M, Katoh O, Werner GS, Reifart N. Appropriateness of percutaneous revascularization of coronary chronic total occlusions: an overview. *Eur Heart J.* 2016;37:2692-700.

13. Galassi AR, Boukhris M, Azzarelli S, Castaing M, Marza F, Tomasello SD. Percutaneous Coronary Revascularization for Chronic Total Occlusions: A Novel Predictive Score of Technical Failure Using Advanced Technologies. *JACC Cardiovasc Interv.* 2016;9:911-22.

14. Christopoulos G, Kandzari DE, Yeh RW, Jaffer FA, Karmpaliotis D, Wyman MR, Alaswad K, Lombardi W, Grantham JA, Moses J, Christakopoulos G, Tarar MNJ, Rangan BV, Lembo N, Garcia S, Cipher D,

Thompson CA, Banerjee S, Brilakis ES. Development and Validation of a Novel Scoring System for Predicting Technical Success of Chronic Total Occlusion Percutaneous Coronary Interventions: The PROGRESS CTO (Prospective Global Registry for the Study of Chronic Total Occlusion Intervention) Score. *JACC Cardiovasc Interv.* 2016;9:1-9.

15. Alessandrino G, Chevalier B, Lefèvre T, Sanguineti F, Garot P, Unterseeh T, Hovasse T, Morice MC, Louvard Y. A Clinical and Angiographic Scoring System to Predict the Probability of Successful First-Attempt Percutaneous Coronary Intervention in Patients With Total Chronic Coronary Occlusion. *JACC Cardiovasc Interv.* 2015;8:1540-8.

16. Maeremans J, Spratt JC, Knaapen P, Walsh S, Agostoni P, Wilson W, Avran A, Faurie B, Bressollette E, Kayaert P, Bagnall AJ, Smith D, McEntegart MB, Smith WHT, Kelly P, Irving J, Smith EJ, Strange JW, Dens J. Towards a contemporary, comprehensive scoring system for determining technical outcomes of hybrid percutaneous chronic total occlusion treatment: The RECHARGE score. *Catheter Cardiovasc Interv.* 2018;91:192-202.

17. Michael TT, Karmpaliotis D, Brilakis ES, Abdullah SM, Kirkland BL, Mishoe KL, Lembo N, Kalynych A, Carlson H, Banerjee S, Lombardi W, Kandzari DE. Impact of prior coronary artery bypass graft surgery on chronic total occlusion revascularisation: insights from a multicentre US registry. *Heart.* 2013;99:1515-8.

18. Teramoto T, Tsuchikane E, Matsuo H, Suzuki Y, Ito T, Ito T, Habara M, Nasu K, Kimura M, Kinoshita Y, Terashima M, Asakura Y, Matsubara T, Suzuki T. Initial success rate of percutaneous coronary intervention for chronic total occlusion in a native coronary artery is decreased in patients who underwent previous coronary artery bypass graft surgery. *JACC Cardiovasc Interv.* 2014;7:39-46.

19. Karatasakis A, Danek BA, Karmpaliotis D, Alaswad K, Jaffer FA, Yeh RW, Patel M, Bahadorani JN, Lombardi WL, Wyman RM, Grantham JA, Kandzari DE, Lembo NJ, Doing AH, Toma C, Moses JW, Kirtane AJ, Parikh MA, Ali ZA, Garcia S, Kalsaria P, Karacsonyi J, Alame AJ, Thompson CA, Banerjee S, Brilakis ES. Comparison of various scores for predicting success of chronic total occlusion percutaneous coronary intervention. *Int J Cardiol.* 2016;224:50-6.

Supplementary data

Supplementary Appendix 1. Definitions of the EuroCTO and J-CTO variables.
Supplementary Appendix 2. Recanalisation techniques.
Supplementary Appendix 3. Additional multicollinearity analysis.
Supplementary Table 1. Collinearity statistics including tolerance and variance inflation factor (VIF) for all the variables incorporated in the final multivariate regression analysis for the identification of potential independent predictors for successful CTO PCI.

The supplementary data are published online at:
https://eurointervention.pcronline.com/
doi/10.4244/EIJ-D-19-00352

Supplementary data

Supplementary Appendix 1. Definitions of the EuroCTO and J-CTO variables

The angiographic morphology of the proximal cap was classified as tapered if the occluded segment ended proximally in a funnel-shaped form, blunt if it did not and invisible or ambiguous if the guidewire target was not angiographically apparent. The presence of calcification was assessed by angiographic criteria as mild (spots), moderate (involving $\leq 50\%$ of the reference vessel diameter) and severe (involving >50% of the reference vessel diameter). Mild tortuosity was defined as the presence of one bend $>45^{\circ}$ and $<90^{\circ}$, moderate tortuosity was defined as a segment containing either two bends $>70^{\circ}$ or a single bend $>90^{\circ}$ and severe tortuosity was defined as the presence of two bends $>90^{\circ}$ or one bend $>120^{\circ}$. Vessel tortuosity involved either the proximal segment of the vessel adjacent to the CTO lesion or the occlusive segment. For the EuroCTO (CASTLE) score calculation, the presence of tortuosity was confined only to the pre-occlusive segments of the CTO vessel. Occlusion length was measured from the beginning of the occluded segment to the distal vessel filling from collateral connections using bilateral contrast injections.

Supplementary Appendix 2. Recanalisation techniques

The techniques used for vessel recanalisation were categorised into antegrade wire escalation (AWE), antegrade dissection and re-entry (ADR) and retrograde approach (RA). The latter group included the retrograde wiring (RW) and reverse controlled antegrade and retrograde subintimal tracking (CART) techniques. The approach was defined as RA if a guidewire was introduced into a collateral channel that was supplying the distal target vessel and AWE if the recanalisation attempt involved an

antegrade guidewire tracking through the proximal cap without introducing a guidewire into a collateral channel. In antegrade cases, where a wire or a device-based vessel dissection was implemented to achieve successful recanalisation either primarily or as a bail-out strategy, the procedure was defined as ADR. In RA cases, the RWE technique, the reverse CART or both strategies were used to cross the lesion successfully and achieve entry to the proximal true lumen of the vessel.

Supplementary Appendix 3. Additional multicollinearity analysis

We performed additional multicollinearity analysis to test for potential multicollinearity between the two scoring systems in the regression model analysis. There was a statistically significant correlation in the bivariate correlation analysis between the two variables (r=0.688, p<0.001). However, the performed collinearity diagnostics did not demonstrate any significant collinearity, as is shown in **Supplementary Table 1** below with a good variance inflation factor of <3 for both variables. Moreover, after performing the multivariate logistic regression analysis with only one of the scoring systems included in each model, both scores still remained the only independent predictors of successful CTO PCI outcome (OR 0.568, 95% CI: 0.460-0.700, p<0.001 for the EuroCTO [CASTLE] score; OR 0.572, 95% CI: 0.464-0.707, p<0.001 for the J-CTO score).

Supplementary Table 1. Collinearity statistics including tolerance and variance inflation factor (VIF) for all the variables incorporated in the final multivariate regression analysis for the identification of potential independent predictors for successful CTO PCI.

Coefficients

Model	Collinearity statistics	
	Tolerance	VIF
Gender	0.952	1.051
Diabetes	0.937	1.067
Target CTO vessel	0.963	1.038
J-CTO score	0.494	2.024
CASTLE score	0.494	2.023
Previous MI	0.821	1.218
Previous PCI	0.872	1.147
LV function	0.853	1.173
PVD	0.958	1.044
CKD stage	0.896	1.115
BMI	0.944	1.059