



# CT Angiography-Derived RECHARGE Score Predicts Successful Percutaneous Coronary Intervention in Patients with Chronic Total Occlusion

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**Objective:** To investigate the feasibility and the accuracy of the coronary CT angiography (CCTA)-derived Registry of Crossboss and Hybrid procedures in France, the Netherlands, Belgium and United Kingdom (RECHARGE) score (RECHARGE<sub>CCTA</sub>) for the prediction of procedural success and 30-minutes guidewire crossing in percutaneous coronary intervention (PCI) for chronic total occlusion (CTO).

**Materials and Methods:** One hundred and twenty-four consecutive patients (mean age, 54 years; 79% male) with 131 CTO lesions who underwent CCTA before catheter angiography (CA) with CTO-PCI were retrospectively enrolled in this study. The RECHARGE<sub>CCTA</sub> scores were calculated and compared with RECHARGE<sub>CA</sub> and other CTA-based prediction scores, including Multicenter CTO Registry of Japan (J-CTO), CT Registry of CTO Revascularisation (CT-RECTOR), and Korean Multicenter CTO CT Registry (KCCT) scores.

**Results:** The procedural success rate of the CTO-PCI procedures was 72%, and 61% of cases achieved the 30-minutes wire crossing. No significant difference was observed between the RECHARGE<sub>CCTA</sub> score and the RECHARGE<sub>CA</sub> score for procedural success (median 2 vs. median 2,  $p = 0.084$ ). However, the RECHARGE<sub>CCTA</sub> score was higher than the RECHARGE<sub>CA</sub> score for the 30-minutes wire crossing (median 2 vs. median 1.5,  $p = 0.001$ ). The areas under the curve (AUCs) of the RECHARGE<sub>CCTA</sub> and RECHARGE<sub>CA</sub> scores for predicting procedural success showed no statistical significance (0.718 vs. 0.757,  $p = 0.655$ ). The sensitivity, specificity, positive predictive value, and the negative predictive value of the RECHARGE<sub>CCTA</sub> scores of  $\leq 2$  for predictive procedural success were 78%, 60%, 43%, and 87%, respectively. The RECHARGE<sub>CCTA</sub> score showed a discriminative performance that was comparable to those of the other CTA-based prediction scores (AUC = 0.718 vs. 0.665–0.717, all  $p > 0.05$ ).

**Conclusion:** The non-invasive RECHARGE<sub>CCTA</sub> score performs better than the invasive determination for the prediction of the 30-minutes wire crossing of CTO-PCI. However, the RECHARGE<sub>CCTA</sub> score may not replace other CTA-based prediction scores for predicting CTO-PCI success.

**Keywords:** Coronary artery disease; Coronary angiography; Percutaneous coronary intervention; Computed tomography angiography

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## INTRODUCTION

Coronary chronic total occlusion (CTO) percutaneous coronary intervention (PCI) is associated with lower procedural success (CTO vs. non-CTO, 55–80% vs. 90–99%) and higher complication rates (CTO vs. non-CTO, 1.6% vs. 0.8%) than non-CTO-PCI [1]. Compared with failed CTO-PCI, successful PCI has been associated with improvement in angina, left ventricular function, and increased survival [2, 3]. Procedural success is associated with several CTO lesion morphological characteristics and surgeon experience [1]. A pre-procedural evaluation of CTO lesion characteristics may facilitate better clinical decision making and procedural planning [4], which will increase the likelihood of overall success of CTO-PCI [5]. Some predictive scoring tools based on catheter angiography (CA) findings, such as the Multicenter CTO Registry of Japan (J-CTO) score [6, 7], clinical and lesion-related score (CL-score) [8], Prospective Global Registry for the study of Chronic Total Occlusion Intervention (PROGRESS) score [9], and Registry of Crossboss and Hybrid procedures in France, the Netherlands, Belgium and United Kingdom (RECHARGE) score [10], have been introduced to describe the complexity of the CTO lesion for appropriate patient selection and pre-procedural intervention planning of CTO-PCI. As the RECHARGE score is based on hybrid CTO procedures, it has demonstrated better capacity for predicting the technical outcomes and the feasibility of different levels of surgery than the J-CTO and PROGRESS scores [5, 10].

Coronary CT angiography (CCTA), a non-invasive imaging technique, can characterize the features of the CTO segment, which is a notable advantage over CA for the assessment of longer and more tortuous CTO lesions, as well as segments distal to a CTO lesion [11]. Moreover, it can provide prognostic information beyond CA [12–17], and it has been investigated as an alternative pre-procedural imaging method for CTO-PCI [18]. However, it is unclear whether the RECHARGE score can be calculated using CCTA data.

Thus, the aim of the present study was to investigate the feasibility and predictive value of the CCTA-derived RECHARGE score (RECHARGE<sub>CCTA</sub>) and compare it with CA (RECHARGE<sub>CA</sub>) and other pre-procedural tools for predicting procedural success and guidewire crossing within 30-minutes in CTO-PCI.

## MATERIALS AND METHODS

### Study Population

This single-center study was approved by the local Institutional Review Board, and written informed consent was obtained from each patient (IRB No. LS2018-001). The study was performed in compliance with the HIPAA regulations. One hundred and twenty-four patients (mean age, 54 years; 79% male, 131 CTO lesions) who underwent CCTA before elective interventional CTO recanalization at the institution were retrospectively enrolled in this study. CTO was defined as a native coronary artery occlusion (antegrade flow of the Thrombolysis in Myocardial Infarction [TIMI] = 0) that had lasted for  $\geq 3$  months. The exclusion criteria included previous reaction to iodine contrast media, renal failure (glomerular filtration rate  $< 30$  mL/min/1.73 m<sup>2</sup>), pregnancy, and previously implanted stents located at the occlusion site. Covariates, including cardiac risk factors and patient baseline characteristics, were obtained from the medical records.

### CCTA Acquisition Protocol

A dual-source CT scanner (Somatom Definition FLASH, Siemens Healthineers) or a 256-slice CT scanner (Revolution CT, GE Healthcare) was used for imaging. For the prospectively ECG-triggered CCTA, the patients with body mass index (BMI) of  $< 24$  kg/m<sup>2</sup> were scanned at 100 kV and those with BMIs of  $\geq 24$  kg/m<sup>2</sup> were scanned at 120 kV. The tube current was modulated by automatic exposure control. The acquisition window was performed within the 70% R-R interval for heart rates (HRs) of  $< 60$  bpm, 40–70% R-R interval for HRs of 60–80 bpm, or 30–40% R-R interval for HRs of  $> 80$  bpm. Bolus-tracking was performed with the region of interest placed in the root of the aorta, and image acquisition was automatically started 6 seconds after a predefined threshold of 100 Hounsfield units was reached. The scanning range was set from the tracheal bifurcation to 1 cm below the diaphragm. The contrast agent was injected with a dual-head power injector (Stellant D, Medrad) through an 18–20-gauge intravenous needle placed in the right antecubital vein. Fifty to seventy milliliters of contrast agent (Ultravist, iopromide 370 mg iodine/mL, Bayer AG) was injected, followed by 30 mL of saline as a bolus chaser with an injection rate of 4.5–5 mL/s for all the phases.

### CCTA Data Analysis and Assessment of RECHARGE Score

All the CCTA data showed diagnostic quality, and they

were included for further analysis. The image data were reconstructed using a dual-source CT (0.6 mm section thickness, 0.4 mm increment) and a 256-slice CT scanner (0.625 mm section thickness, 0.4 mm increment). Multi-planar reconstructions (MPRs), maximum intensity projections, and curved precision-recall (CPR) were obtained. CCTA post-processing was performed on a dedicated workstation (Vitrea, Canon). For all CTOs, the vessel lumen and vessel diameters were measured on orthogonal images, and the lengths were measured on CPR or MPRs.

For the CCTA-derived RECHARGE (RECHARGE<sub>CCTA</sub>) score, the following parameters were recorded: 1, a blunt stump; 2, severe calcification in the CTO segment, i.e., a calcified area of  $\geq 50\%$  of the vessel cross-sectional area [14, 17]; 3, tortuosity, defined as a bend of  $> 45^\circ$  within the CTO body; 4, occlusion length of  $\geq 20$  mm; 5, diseased distal landing zone, defined as the presence of significant coronary artery disease (lumen stenosis  $> 50\%$ ) distal to the occluded segment, and/or a distal lumen diameter of  $< 2$  mm; 6, previous bypass graft of CTO vessel [10]. Each variable was assigned one score point, which allowed the grading of CTO lesion complexity from 0 to 6 points. Two independent radiologists who were blinded to the CA results calculated the RECHARGE<sub>CCTA</sub> score, J-CTO<sub>CT</sub> score [12], CT-RECTOR [14], and KCCT scores [19]. Interobserver disagreements were resolved by consensus in a joint session.

### Catheter Angiography and Assessment of RECHARGE Score

CA and PCI were performed in all the 124 patients with 131 CTO lesions by interventional cardiologists with experience in the use of hybrid techniques who perform a mean number of  $\geq 70$  CTO procedures annually. A preoperative angiographic study was performed in each case to determine the CTO lesion complexity. In each case, the CTO lesion complexity was evaluated using the J-CTO scores. Hybrid strategies were applied: antegrade escalation and antegrade dissection and re-entry; retrograde escalation and retrograde dissection and re-entry. Two experienced cardiologists who were blinded to the RECHARGE<sub>CCTA</sub> score independently calculated the RECHARGE score using CA data, as previously described [10]. Interobserver disagreements were resolved by consensus. Procedural success was defined as successful CTO revascularization with the achievement of  $< 20\%$  residual diameter stenosis within the stented segment and

the restoration of a TIMI = 3.

### Statistical Analysis

All statistical analyses were performed using the MedCalc statistical software (MedCalc Software, version 15.8). Binary variables were presented as numbers with percentages (%), and continuous variables were presented as median with interquartile range (IQR) because of the non-normal distribution of the data. For comparisons of the RECHARGE<sub>CCTA</sub> and the RECHARGE<sub>CA</sub> scores, continuous variables were compared using both Mann-Whitney and Wilcoxon tests, and categorical variables were compared using the McNemar test. The prediction accuracies of the RECHARGE<sub>CCTA</sub>, RECHARGE<sub>CA</sub>, J-CTO<sub>CT</sub>, CT-RECTOR, and KCCT scores were evaluated using receiver operator characteristics (ROCs) curve analysis with the corresponding area under the curve (AUC). The method of DeLong et al. [20] was used to compare the ROC curves. The Optimal cut-off value of the RECHARGE<sub>CCTA</sub> score was determined using the Youden index for predicting procedural success. Statistical significance was set at a *p* value of  $\leq 0.05$ .

## RESULTS

### Patient Characteristics and Procedural Results

Of 124 patients, 33 (27%) had prior myocardial infarction and 13 (10%) had prior PCI. Further characteristics of the patients are presented in Table 1. Of the 131 lesions, final procedural success was obtained for 94 (72%), the 30-minutes wire crossing was achieved for 80 (61%), antegrade wire access was the preferred primary crossing

**Table 1. Baseline Data of Patients**

	Total
Age (years)	54 (43–60)
Sex (male/female)	98/26
Body mass index	26 (25–28)
Diabetes	32 (26)
Hypertension	78 (63)
Dyslipidemia	11 (9)
Prior MI	33 (27)
Prior PCI	13 (11)
Prior CABG	0 (0)
Current smoker	67 (54)
Echocardiographic LVEF%	62 (58–62)

Data presented as median with interquartile range or number (%). CABG = coronary artery bypass grafting, LVEF = left ventricular ejection fraction, MI = myocardial infarction, PCI = percutaneous coronary intervention

strategy in 92 (70%), and a hybrid approach was performed in 39 (30%). The median J-CTO score was 2 (IQR 2–2) for all the patients, and it was higher in the failure group (2 [IQR 2–3] vs. 1.5 [IQR 1–2],  $p < 0.05$ ). The median procedural time was 18 minutes (IQR 6–39 minutes) across the population. No severe complications occurred. Further characteristics of the CTO lesions and the procedural results are provided in Table 2.

### Comparison of RECHARGE Scores Derived From CCTA and CA in Procedural Results

Both scores were significantly different for procedural success and failure (median RECHARGE<sub>CA</sub> score: 2 vs. 3,  $p < 0.001$ ; median RECHARGE<sub>CCTA</sub> score: 2 vs. 3,  $p < 0.001$ ), the 30-minutes wire crossing (median RECHARGE<sub>CA</sub> score: 1.5 vs. 3,  $p = 0.001$ ; median RECHARGE<sub>CCTA</sub> score: 2 vs. 3,  $p = 0.001$ ), and the antegrade crossing (median RECHARGE<sub>CA</sub> score: 2 vs. 3,  $p = 0.044$ ; median RECHARGE<sub>CCTA</sub> score: 2 vs. 3,  $p = 0.040$ ), respectively (Table 3, Figs. 1, 2).

No significant difference was observed between the RECHARGE<sub>CCTA</sub> and RECHARGE<sub>CA</sub> scores (median score: 2 vs. 2,  $p = 0.084$ ) for procedural success. However, the RECHARGE<sub>CCTA</sub> score was higher than the RECHARGE<sub>CA</sub> score (median: 2 [IQR 1–3] vs. 1.5 [IQR 1–3],  $p = 0.001$ ) for predicting the 30-minutes wire crossing (Table 3). In terms of the final crossing strategy, no significant difference was observed between the RECHARGE<sub>CCTA</sub> and RECHARGE<sub>CA</sub> scores for success or failure during the antegrade crossing. For the prediction of the failed final retrograde crossing, the RECHARGE<sub>CCTA</sub> score was significantly higher than the

RECHARGE<sub>CA</sub> score (median: 2.5 [IQR 2–3] vs. 2 [IQR 1–3],  $p = 0.037$ ).

### Comparison of RECHARGE Scores Derived From CCTA and CA in CTO Lesions

The RECHARGE<sub>CCTA</sub> score described higher levels of CTO calcification than the RECHARGE<sub>CA</sub> score ( $p < 0.001$ ). However, no significant difference was observed between the two RECHARGE scores regarding other morphological parameters (Table 4).

**Table 3. Comparison of RECHARGE Scores Derived From CCTA and CA in Procedural Results**

	CA-Derived	CCTA-Derived	P
Procedural			
Success	2 (1–3)	2 (1–3)	0.084
Failure	3 (2–4)	3 (3–4)	0.429
<i>p</i>	< 0.001	< 0.001	
30-minutes crossing			
Success	1.5 (1–3)	2 (1–3)	0.001
Failure	3 (2–3)	3 (2–4)	0.336
<i>p</i>	0.001	0.001	
Antegrade crossing			
Success	2 (1–3)	2 (2–3)	0.099
Failure	3 (2–3)	3 (2–4)	0.149
<i>p</i>	0.044	0.040	
Retrograde crossing			
Success	2 (1–3)	2 (2–3)	0.146
Failure	2 (1–3)	2.5 (2–3)	0.037
<i>p</i>	0.677	0.275	

Data presented as median with interquartile range. CA = catheter angiography, CCTA = coronary CT angiography

**Table 2. Characteristics of CTO Lesions and Procedure Data**

Lesion Characteristics	Total	Procedural Results			Guidewire Crossing Time		
		Success n = 94	Fail n = 37	<i>P</i>	< 30 Minutes n = 80	> 30 Minutes n = 51	<i>P</i>
J-CTO score	2 (2–2)	1.5 (1–2)	2 (2–3)	0.033	2 (1–2)	2 (2–3)	0.159
Target vessel				0.979			0.430
RCA	61 (47)	43 (33)	18 (14)		35 (27)	26 (20)	
LAD	51 (39)	37 (28)	14 (11)		30 (23)	21 (16)	
LCX	17 (13)	12 (9)	5 (4)		13 (10)	4 (3)	
Previous failed lesion	14 (11)	9 (7)	5 (4)	0.352	6 (5)	8 (6)	0.756
Final crossing strategy	131 (100)	94 (72)	37 (28)	0.312	80 (61)	51 (39)	0.143
Antegrade*	116 (89)	86 (66)	30 (23)		74 (56)	42 (32)	
Retrograde	15 (11)	8 (6)	7 (5)		6 (5)	9 (7)	
Hybrid approach	39 (30)	22 (17)	17 (13)	0.428	15 (11)	24 (19)	0.113
Procedural time (minutes)	18 (6–39)	11.5 (4.75–26)	43.5 (34–62)	0.059	8 (4–15)	44 (36–65)	0.079

Data presented as median with interquartile range or number (%) of total 131 lesions (%). \*Antegrade approach includes antegrade wire escalation and dissection re-entry. CTO = chronic total occlusion, LAD = left anterior descending branch, LCX = left circumflex branch, RCA = right coronary artery



**Comparison of Prediction Accuracy between RECHARGE Scores Derived From CCTA and CA**

The AUC for the ROC curve analysis for determining procedural success was 0.718 (95% confidence interval [CI] 0.633–0.793) for RECHARGE<sub>CCTA</sub> and 0.757 (95% CI 0.661–0.840) for RECHARGE<sub>CA</sub>. Similar results were observed for the 30-minutes wire crossing with an AUC of 0.708 (95% CI 0.622–0.784) for RECHARGE<sub>CCTA</sub> and 0.705 (95% CI 0.603–0.793) for RECHARGE<sub>CA</sub>. Neither of the comparisons of the RECHARGE<sub>CCTA</sub> and RECHARGE<sub>CA</sub> scores for predicting procedural success and 30-minutes wire crossing showed a significant difference ( $p = 0.655$  and  $p = 0.984$ , respectively). The sensitivity, specificity, positive predictive value, and negative predictive value of the RECHARGE<sub>CCTA</sub> scores of  $\leq 2$  for predicting procedural success were 78%, 60%, 43%, and 87%, respectively.

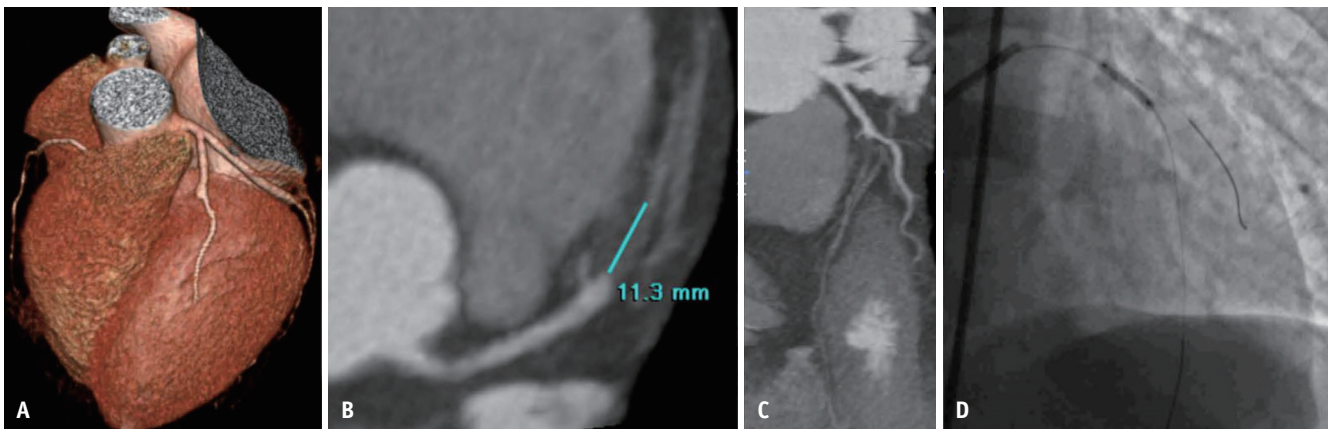
**Comparison of RECHARGE<sub>CCTA</sub> Score with Other Scores**

AUC at ROC curve analysis for determining procedural success was 0.704 (95% CI 0.618–0.780) for J-CTO<sub>CT</sub>, 0.665 (95% CI 0.577–0.745) for CT-RECTOR, and 0.717 (95% CI

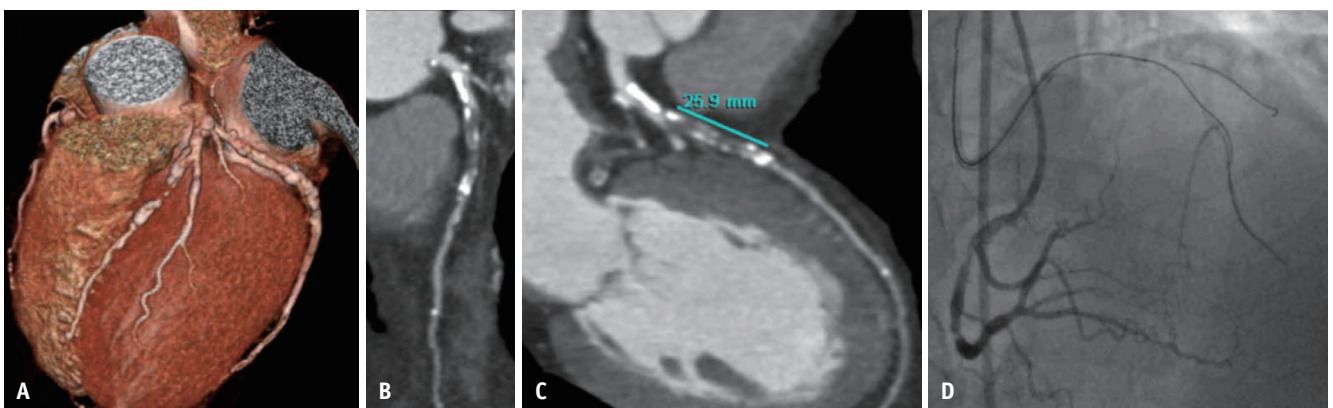
**Table 4. Comparison of RECHARGE Scores Derived from CCTA and Catheter Angiography in CTO Lesions**

	CA-Derived	CCTA-Derived	P
RECHARGE score	2 (1–3)	2 (1–3)	0.065
Blunt stump	82 (63)	85 (65)	0.838
CTO calcification	27 (21)	81 (62)	< 0.001
Tortuosity > 45°	34 (26)	39 (30)	0.523
CTO length (mm)	14.2 (10.1–31)	20 (9.3–29)	0.739
Diseased distal landing zone	50 (38)	51 (39)	0.938

Data presented as median with interquartile range or number (%). CA = catheter angiography, CCTA = Coronary CT angiography, CTO = chronic total occlusion

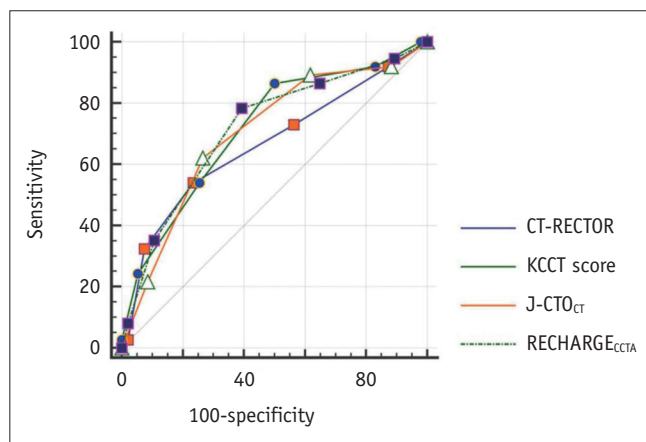


**Fig. 1. A short non-calcified CTO lesion with a blunt-entry site in the mid-segment of the LAD.**  
A-C. The RECHARGE<sub>CCTA</sub> score was 1. D. Invasive coronary angiography shows a successful recanalization of the LAD. CTO = chronic total occlusion, LAD = left anterior descending branch

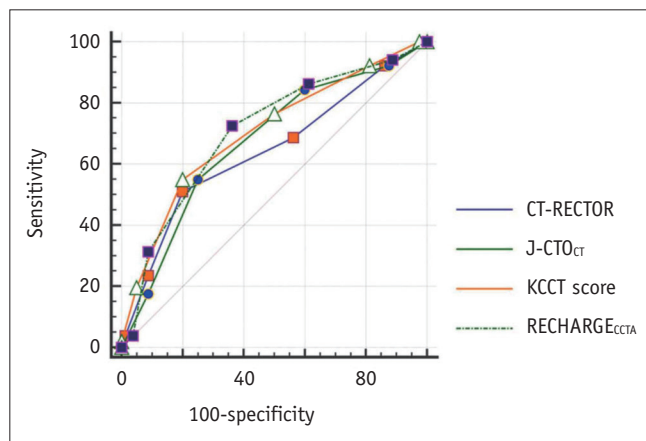


**Fig. 2. A long-calcified CTO lesion in the LAD with a blunt cap and non-relevant bending within the occlusion route and disease landing zone.**  
A-C. The RECHARGE<sub>CCTA</sub> score was 4. D. Invasive coronary angiography shows a failed attempt of guidewire penetration for entering a true lumen of the LAD and overall failure of the procedure. CTO = chronic total occlusion, LAD = left anterior descending branch

0.631–0.792) for KCCT scores, respectively. Similar results were observed for the 30-minutes wire crossing with an AUC of 0.673 (95% CI 0.586–0.752) for J-CTO<sub>CT</sub>, 0.643 (95% CI 0.544–0.724) for CT-RECTOR, and 0.703 (95% CI 0.617–0.780) for KCCT scores, respectively. There was no significant difference between the accuracies of the RECHARGE<sub>CCTA</sub> score and other scores (including CT-RECTOR and KCCT scores) for predicting procedural success and the 30-minutes wire crossing (all  $p > 0.05$ ) (Figs. 3, 4).



**Fig. 3. ROC curves of CTA-derived scores for the prediction of procedural success.** ROC curves with AUCs for predicting procedural success are illustrated: 0.718 (95% CI 0.633–0.793) for RECHARGE<sub>CCTA</sub> score, 0.704 (95% CI 0.618–0.780) for J-CTO<sub>CT</sub>, 0.665 (95% CI 0.577–0.745) for CT-RECTOR, and 0.717 (95% CI 0.631–0.792) for KCCT score. AUC = area under the curve, CI = confidence interval, CTA = CT angiography, ROC = receiver-operating characteristic



**Fig. 4. ROC curves of CTA-derived scores for the prediction of the < 30-minutes guidewire crossing.** ROC curves with AUCs for 30-minutes guidewire crossing are illustrated: 0.708 (95% CI 0.622–0.784) for RECHARGE<sub>CCTA</sub> score, 0.673 (95% CI 0.586–0.752) for J-CTO<sub>CT</sub>, 0.643 (95% CI 0.544–0.724) for CT-RECTOR, and 0.703 (95% CI 0.617–0.780) for KCCT score. AUC = area under the curve, CI = confidence interval, CTA = CT angiography, ROC = receiver-operating characteristic

## DISCUSSION

This study demonstrates that the prediction accuracy of the CCTA-derived RECHARGE score for CTO-PCI success and wire crossing within 30 minutes was similar to that of the CA-derived RECHARGE score and other CTA-based scores (including J-CTO<sub>CT</sub>, CT-RECTOR, and KCCT scores). The overall procedural success rate was 72% in this population, which was similar to previous findings [21].

The RECHARGE score, as a novel and easy-to-use scoring tool, was developed from hybrid CTO procedures incorporating objective clinical and morphological parameters [5, 10]. As the RECHARGE and J-CTO scores build on four common morphologic characteristics, their predictive powers were expected to be similar. Yet, compared with the J-CTO score, the “diseased distal landing zone” and “previous bypass graft on the CTO target vessel” are independent characteristics incorporated into the RECHARGE score, forming a 6-scale scoring tool. Maeremans et al. [10] demonstrated that the RECHARGE<sub>CA</sub> score was not only more accurate than the J-CTO score (AUC<sub>RECHARGE</sub> = 0.711 vs. AUC<sub>J-CTO</sub> = 0.676) in predicting overall procedural success; it was more suitable for different levels of surgery.

Several studies [12, 16] have validated CCTA as a valuable and non-invasive imaging method for assessing pre-procedural characterization of CTO lesions and established it as a useful alternative to invasive angiography for certain indications. Recent investigations [12, 22] concluded that the CCTA-derived J-CTO score has better predictive accuracy in predicting CTO-PCI success and the 30-minutes wire crossing, especially for complex cases. Similarly, the predictive accuracy of the RECHARGE<sub>CCTA</sub> and RECHARGE<sub>CA</sub> scores were compared in this study. Significantly higher RECHARGE scores (both CTA- and CA-derived) were observed for failed procedures, > 30-minutes guidewire crossing, and failure in final antegrade crossing, which indicates the predictive value of RECHARGE scores for procedural success and guidewire crossing within 30 minutes. However, the results also showed that the RECHARGE<sub>CCTA</sub> score, which was not significantly better, was fairly comparable to the RECHARGE<sub>CA</sub> score in predicting procedural success and the 30-minutes wire crossing. Furthermore, regarding that RECHARGE score focuses more on the “diseased distal landing zone,” the predictive performance of the CA- and CTA-derived scores were compared for the final retrograde crossing. The RECHARGE<sub>CCTA</sub> score was significantly higher than the RECHARGE<sub>CA</sub> for failed retrograde crossing. Yet,

neither scores were significantly different for successful and failed retrograde crossing, mostly due to the limitations of the sample used for retrograde crossing.

Currently, some novel CCTA-based prediction tools have been demonstrated to be more accurate in predicting time-efficient guidewire crossing [14, 19]. The CT-RECTOR score is a 6-variable predictive scoring system that exceeds the CA-based J-CTO score in prediction value [14, 23]. Another novel CCTA-based predictive algorithm, the KCCT score (Korean Multicenter CTO CT Registry), showed higher predictive power than the other pre-procedural tools, including the CA-based J-CTO, PROGRESS-CTO, CL-score, and CT-based CT-RECTOR (c-statistics = 0.78 vs. 0.65–0.72,  $p < 0.001$ , all) [19]. Moreover, these studies showed that with an increasing CT-RECTOR or KCCT score, procedural success or the guidewire crossing duration decreased. In this study, the comparisons of the ROC curves of the RECHARGE<sub>CCTA</sub> and other scores (J-CTO<sub>CT</sub>, CT-RECTOR, and KCCT scores) were not significantly different, indicating a similar predictive value of RECHARGE<sub>CCTA</sub> for procedural outcomes.

Identifying the morphologic characteristics of CTO, using pre-procedural CCTA, may assist in determining procedural strategy, which may facilitate an increase in the rate of successful CTO-PCIs. Luo et al. [16] reported that the predictors of failed antegrade PCIs (including negative remodeling, lesion lengths of  $> 31.89$  mm on CCTA, and ostial or bifurcation lesions on CA imaging) may prompt a switch to an early retrograde approach for appropriate patients and improve the chance of successful revascularization from 74% to 87%. Rolf et al. [17] reported that pre-procedural CCTA can significantly increase the success rate of CTO-PCI from 64% to 88%, although this was based on a relatively small patient cohort (30 patients with CCTA). Many CT-based studies consistently suggest the utility of severe calcification involving  $\geq 50\%$  of the vessel cross-sectional area for predicting CTO-PCI failure. In this study, the ability of CCTA to detect CTO calcification was significantly better than that of invasive angiograms (CCTA 62% vs. CA 21%,  $p < 0.001$ ), which was discordant with the fact that the AUC for procedural success was higher for RECHARGE<sub>CA</sub> (0.757 vs. 0.718), with similar AUC for the guidewire crossing time. In clinical practice, the success rate of the CTO intervention may be largely dependent on the surgeon's experience, but none of the RECHARGE scores incorporate procedure-related information. It may be one of the important reasons for this discordance.

Several limitations of this study need to be addressed.

First, this was a single-center, retrospective, observational study with a relatively small sample size (124 CTO patients with 131 CTO lesions). The predictive value of the RECHARGE<sub>CCTA</sub> score for procedural success and guidewire crossing within 30-minutes was found to be similar to those of other CTA-based scores; however, we did not analyze whether it was inferior to the other CTA-based scores due to the limitation of sample size. Our results also need to be further confirmed in a prospective multicenter study. Second, we only enrolled elective CTO-PCI patients who underwent CCTA before the procedure and had CTO lesions with intermediate complexity (median J-CTO score 2). The results of the current study require further validation before they can be generalized to patients with various lesions.

In conclusion, The predictive value of the RECHARGE<sub>CCTA</sub> score for CTO-PCI success and guidewire crossing within 30-minutes was similar to those of the RECHARGE<sub>CA</sub> score and other CTA-based scores. However, the RECHARGE<sub>CCTA</sub> score may not be a viable replacement for other CTA-based scores for predicting performance. CCTA may serve as an alternative non-invasive imaging tool for guiding procedural strategies and predicting procedural outcomes.

#### Conflicts of Interest

The authors of this manuscript declare relationships with the following companies: Dr. Schoepf receives research support from Astellas, Bayer AG, GE Healthcare, and Siemens Healthineers and is a consultant for Bayer, Guerbet, HeartFlow Inc., and Siemens. All authors have no conflicts of interest to disclose.

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