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Comparison of CT-RECTOR and J-CTO scores to predict chronic total occlusion difficulty for percutaneous coronary intervention

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ABSTRACT

Background: We sought to evaluate the ability of the CT-RECTOR and J-CTO scores to predict time-efficient guidewire (GW) crossing through a chronic total occlusion (CTO) and final procedure success.
Methods: Data from 191 consecutive CTO lesions with pre-procedural coronary computed tomography angiography (CCTA) from our center were analyzed retrospectively. The difficulty of the procedure was classified as easy, intermediate, difficult, or very difficult according to CT-RECTOR and J-CTO scores. A successful GW crossing within 30 min was set as the first endpoint. Final success of the procedure was set as the second endpoint. Receiver operating characteristic curves and net reclassification improvement (NRI) were used to compare the performance of both scores in predicting both endpoints.
Results: The first and second endpoints were achieved in 55% and 76% of lesions, respectively. The NRI for prediction for both endpoints were 30.21% and 28.94%, respectively. Use of the CT-RECTOR score demonstrated a positive NRI for both the first ($p = 0.0027$) and second ($p = 0.0190$) endpoints. Compared with the J-CTO score (area under the curve: 0.76), the CT-RECTOR score (area under the curve: 0.85) yielded a higher predictive value for successful GW crossing within 30 min ($p = 0.0018$).
Conclusions: Compared with J-CTO, the CT-RECTOR scoring system provides a more accurate noninvasive tool for predicting time-efficient GW crossing and final procedure success. This scoring system, which is based on CCTA, may aid in the identification of very difficult CTO lesions and downstream management.

1. Introduction

A chronic total occlusion (CTO) is common in patients with obstructive coronary artery disease, and successful percutaneous coronary intervention (PCI) for CTO is associated with an improvement in clinical outcomes [1–3]. However, uncertainty regarding the success of the procedure and procedural time remains the strongest barrier to PCI in CTO [4]. Therefore, a useful prediction rule for procedural time and success is of high clinical relevance. The Multicenter Chronic Total Occlusion Registry of Japan (J-CTO) scoring system is based on invasive coronary angiography (ICA) and is commonly used to grade the difficulty of crossing a CTO within 30 min and the overall success rate; however, it provides a limited accurate visualization of the CTO, such as trajectory and morphology of the occluded lesion [4]. The Computed Tomography Registry of Chronic Total Occlusion Revascularization (CT-RECTOR) score is a new and accurate noninvasive tool for predicting time-efficient guidewire (GW) crossing [5]. However, it has never been tested outside of the original study setting, and its validity has not been established in a Chinese population. The purpose of this study was to evaluate the performance of the CT-RECTOR score in predicting procedural complexity, defined as GW crossing through a CTO within 30 min, and the final success rate in a Chinese CTO cohort and to compare its predictive value with that of the J-CTO score.

2. Materials and methods

2.1. Patient population

In this retrospective study, 191 consecutive patients who underwent CCTA before an attempted PCI of a CTO between April 2012 and December 2015 at our center were

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enrolled. The inclusion criteria were as follows: patients with 1) an ICA-confirmed CTO lesion ≥ 2.5 mm and 2) who underwent further ICA and PCI within a 1-month interval after CCTA. The exclusion criteria were as follows: 1) uninterpretable CCTA due to poor image quality, 2) did not undergo ICA within a 1-month interval, 3) the occurrence of major adverse cardiac events (MACEs) between CCTA and ICA, and 4) previously implanted stents located at the entry or exit occlusion sites. The study was carried out in accordance with the code of Ethics of the World Medical Association (Declaration of Helsinki). All relevant protocols were approved by the ethics committee of the Chinese PLA General Hospital.

CTO was defined as obstruction of a coronary artery with antegrade Thrombolysis in Myocardial Infarction (TIMI) grade 0 flow that was confirmed or presumed to be >3 months old [6]. For each CTO lesion, the complexity was assessed by both the J-CTO and CT-RECTOR scoring systems.

The primary endpoint was defined as successful GW crossing through the CTO within 30 min of the procedure time. The procedure time, that is, the time from initial insertion of the GW into the vessel to the time it was successfully crossed through the lesion or was pulled out of the vessel because of unsuccessful GW crossing [4]. This was viewed as the most objective parameter that reflects the level of difficulty intrinsic to the CTO and minimizes the operator-related bias associated with the final PCI outcome.

The secondary endpoint was defined as successful CTO revascularization with achievement of <30% residual diameter stenosis within the treated segment at any time and restoration of antegrade TIMI grade 3 flow [5].

In-hospital complications, including cardiac tamponade, emergent PCI, emergent coronary artery bypass grafting, blood transfusion, contrast-induced nephropathy (CIN), radiation dermatitis, and in-hospital adverse outcomes were also assessed [7]. CIN was defined as a peak increase in the serum creatinine concentration over the baseline value of at least 0.5 mg/dL during the initial 72 h post-procedure [8]. In-hospital adverse outcomes were documented. Myocardial infarction was defined as a post-procedural creatine kinase elevation of ≥3-fold the normal value. Stent thrombosis was verified based on emergent PCI [7].

2.2. CCTA protocols and image reconstruction

All examinations were performed on a second-generation dual-source CT scanner (Definition Flash, Siemens Healthineers, Forchheim, Germany). CCTA images were acquired using the same machine for every subject. Data acquisition was performed using a 2 mm × 64 mm × 0.6 mm detector collimation, *z*-axis flying focal spot and gantry rotation of 280 ms. Patients with a body mass index (BMI) ≥ 25 mg/m^2 were examined using a tube voltage of 120 kVp, whereas those with a BMI < 25 mg/m^2 were examined using a tube voltage of 100 kVp. All patients received sublingual nitroglycerin (Nitroglycerin Aerosol; Jewim Pharma, Shandong, China) 3 min before scanning. For the contrast agent, 60–80 mL (scaled to body weight) Ultravist (370 mgI/mL, Shering AG, Guangzhou, China), or Omniapaque (350 mgI/mL, GE Healthcare Limited, Shanghai, China) was administered by intravenous injection followed by a saline chaser (40 mL) at a rate of 4.5–5.0 mL/s (scaled to venous condition) using a dual-head injector (Medrad Stellant CT Injector System, Indianola, PA, USA) [9].

Based on heart rates, different scanning protocols such as a prospectively ECG-triggered high-pitch spiral double scan, step-and-shot prospective or retrospective helical scan were applied as appropriate.

The reconstructed CCTA image data were transferred to a computer workstation for post-processing (MMWP 2011A, Siemens). Contrast enhanced CT images were reconstructed using a B26f kernel, slice thickness of 0.75 mm, increment of 0.5 mm for visualization of native arteries or using a B46f kernel, slice thickness of 0.6 mm, and increment of 0.4 mm for visualization of stents.

2.3. CCTA analysis

Data were transferred to an offline workstation (Syngo, Siemens Healthcare, Forchheim, Germany) for further analysis. The assessment was blinded to the angiographic data after confirmation of the CTO vessel in which PCI was attempted. The CCTA data were evaluated using three dimensional volume rendering, multiplanar reformatting and maximum intensity projections. The CT-RECTOR system is a 6-point scoring system combining baseline clinical and CCTA parameters to assess the difficulty of GW crossing through the CTO. One point is given for each of the following factors associated with a lower probability of successful GW crossing within 30 min: Multiple occlusions, absence of any tapered stump at the entry or exit site, the presence of any calcium involving >50% of the vessel cross-sectional area at any site in the occlusion route, bending > 45° at any site in the occlusion route, a previously failed PCI at the CTO, and a CTO duration > 12 months or unknown. In our study, the duration of the CTO was estimated using clinical or previous angiography findings and was calculated as the time from the first cardiac event or the first invasive angiogram verifying a CTO to the date of the CCTA examination. In addition, some CT imaging parameters such as focal calcification, negative remodeling and intra-occlusion linear enhancement were considered for estimation of the occlusion duration [10]. All lesions were categorized into the following four groups: 1) easy (score of 0), 2) intermediate (score of 1), 3) difficult (score 2), and 4) very difficult (score ≥ 3) [5]. Two experienced radiologists or cardiologist independently analyzed the lesions and calculated the points based on the CT-RECTOR. Any disagreement between the two observers was resolved by a consensus.

2.4. Angiographic analysis

Coronary angiography analyses were performed using commercial software (QAngio XA 3D Research Edition 1.0, Medis Specials, B.V., Leiden, The Netherlands) by two experienced interventional cardiologists initially blinded to the CCTA results. For each CTO segment, the J-CTO score was calculated based on the ICA findings following the criteria of the J-CTO scoring sheet. The J-CTO system is an angiography-based 5-point scoring system used to assess the difficulty of CTO crossing. One point is given for each of the following factors associated with a lower probability of successful GW crossing within 30 min: a blunt stump at the entry site, any evident calcification detected within the CTO segment, within lesion bending > 45°, an occlusion length > 20 mm and a prior failed attempt to revascularize the CTO. All lesions were categorized into the following four groups: 1) easy (score of 0), 2) intermediate (score of 1), 3) difficult (score 2), and 4) very difficult (score ≥ 3) [4].

2.5. Statistical analysis

Data are presented as mean ± standard deviation (SD) for continuous variables and as frequencies for categorical variables. Continuous variables were compared using Student's *t*-test or the Mann Whitney *U* test. Categorical variables are expressed as the frequencies and percentages. Differences in categorical data were analyzed by chi-square or Fisher's exact test, as appropriate. To compare the discriminatory power of the J-CTO and CT-RECTOR scores, the areas under the receiver operating characteristic (ROC) curves were compared. The proportion of patients reclassified using the CT-RECTOR score instead of the J-CTO score was determined by constructing a reclassification table showing the number of patients assigned to a different category of complexity. We also estimated net reclassification improvement (NRI) using the method previously described by Pencina et al. [11]. To examine the contribution to the NRI of the subgroups with and without successful GW crossing within 30 min or a final successful procedure, reclassification tables were constructed for patients with and without successful GW crossing within 30 min or a final successful procedure. Data analysis was performed using SPSS 22.0 (IBM corporation, Armonk, NY, USA) and Stata IC, version 10.0 (StataCorp, College Station, TX, USA). Any p value < 0.05 (two-tailed) was considered significant.

3. Results

3.1. Clinical characteristics

The baseline characteristics of the 191 consecutive patients (71% male) referred for CCTA and ICA are listed in Table 1. Successful GW crossing within 30 min was achieved for 54.97% of lesions. The clinical characteristics were similar between the successful and failed GW crossing groups, except for frequency of previous coronary artery bypass grafting.

3.2. CCTA and angiographic characteristics

Based on the CT-RECTOR scoring system, the group with failed GW crossing was more likely to have an occlusion length ≥ 20 mm, multiple

Table 1
Clinical characteristics.

	Total (n = 191)	SGW (n = 105)	FGW (n = 86)	p Value
Age (years)	61 ± 11	61 ± 11	61 ± 11	0.656
Male	135 (70.7)	77 (73.3)	58 (67.4)	0.426
BMI (kg/m^2)	25.9 ± 3.4	25.5 ± 3.6	26.3 ± 3.1	0.097
LVEF (%)	57 ± 8	57 ± 9	58 ± 7	0.697
Diabetes mellitus	56 (29.3)	28 (26.7)	28 (32.6)	0.426
Hypertension	119 (62.3)	63 (60.0)	56 (65.1)	0.549
Hyperlipidemia	64 (33.5)	28 (26.7)	36 (41.9)	0.031
Current smoker	77 (40.3)	45 (42.9)	32 (37.2)	0.461
Family history of CAD	52 (27.2)	28 (26.7)	24 (27.9)	0.871
Previous coronary stenting	95 (49.7)	50 (47.6)	45 (52.3)	0.562
Previous coronary artery bypass grafting	21 (11.0)	6 (5.7)	15 (17.4)	0.018*
Previous MI	55 (28.8)	39 (37.1)	31 (36.0)	0.881
Stable angina pectoris	133	76 (72.4)	57 (66.3)	0.429
Atypical chest pain	58	29 (27.6)	29 (33.7)	0.429

Values are mean ± SD or n (%).
SGW: successful guidewire crossing <30 min.
FGW: failure for guidewire to cross < 30 min.
* $p < 0.05$.

Table 2
Coronary computed tomographic angiographic characteristics.

	Total (n = 191)	SGW (n = 105)	FGW (n = 86)	p Value
Overall characteristics				
Occlusion length, mm	27.0 ± 21.5	23.2 ± 20.2	31.7 ± 22.1	0.000*
Occlusion length ≥ 20 mm	103 (53.9)	47 (44.8)	56 (65.1)	0.006*
Multiple occlusion	40 (20.9)	11 (10.5%)	29 (33.7)	0.000*
Proximal reference vessel diameter	3.5 ± 1.0	3.5 ± 1.0	3.5 ± 0.8	0.648
Distal reference vessel diameter	2.3 ± 0.8	2.3 ± 0.8	2.3 ± 0.9	0.625
Overall(entry + occlusion route + exit site)				
Blunt stump, any	114 (59.7)	42 (40.0)	72 (83.7)	0.000*
Side branch, any	76 (39.8)	38 (36.2)	38 (44.2)	0.299
Bending > 45, any	68 (35.6)	22 (21.0)	46 (53.5)	0.000*
Calcium, any	91 (47.6)	46 (43.8)	45 (52.3)	0.248
Calcium ≥ 50% CSA, any	40 (20.9)	14 (13.3)	26 (30.2)	0.007*

Values are mean ± SD or *n* (%).
SGW: successful guidewire crossing < 30 min.
FGW: failure for guidewire to cross < 30 min.
CSA = cross-sectional area.
* $p < 0.05$.

occlusions, a blunt stump, bending > 45° and calcification involving ≥50% of the cross-sectional area in any route of the CTO lesion, as determined by CCTA (Table 2).

Most CTOs were attempted for the first time (92%) by an antegrade approach (84%), and the overall final procedure success rate was 76%. Angiographic CTO characteristics based on the J-CTO scoring system were summarized in Table 3. The group with failed GW crossing showed a higher prevalence of multiple occlusions, a blunt stump at the entry, heavy calcification, bending >45°, an occlusion length > 20 mm, and reattempt of a failed CTO PCI.

3.3. Diagnostic performance of the CT-RECTOR score with reference to the ICA-based J-CTO score

The area under the ROC curve for the CT-RECTOR score in predicting successful GW crossing within 30 min was significantly higher than that for the J-CTO score (0.8462 vs. 0.7592, respectively, $p = 0.0018$) (Fig. 1). To determine an improvement in the classification of time-efficient GW crossing using the CT-RECTOR compared with the J-CTO score, NRI was calculated (Table 4). The NRI values were 20.95% and 51.16% in patients with and those without successful GW crossing within 30 min, respectively. Therefore, total NRI was 30.21% ($p = 0.0027$). Compared with the J-CTO score, the difficulty of procedure was classified more accurately using the CT-RECTOR score ($p = 0.0027$) (Table 4, Fig. 2). The area under the ROC curve for predicting final procedure success was significantly higher for the CT-RECTOR score than the J-CTO score (0.7754 vs. 0.6894, respectively, $p = 0.0025$) (Fig. 3). Among patients with final procedure success, the NRI was 27.58% and, among those without final procedure success, it was 56.52%. Therefore, total NRI was 28.94% ($p = 0.0190$) (Table 5, Fig. 4).

Table 3
Coronary angiographic characteristics.

	Total (n = 191)	SGW (n = 105)	FGW (n = 86)	p Value
Target vessel				
LAD	53 (27.7)	33 (31.4)	20 (23.3)	0.259
LCX	46 (24.1)	28 (26.7)	18 (20.9)	0.398
RCA	92 (48.2)	44 (41.9)	48 (55.8)	0.06
Occlusion time > 12 months or unknown	127 (66.5)	60 (57.1)	67 (77.9)	0.003*
Multiple occlusion	23 (12.0)	4 (3.8)	19 (22.1)	0.000*
Blunt stump at entry	65 (34.0)	21 (20.0)	44 (51.2)	0.000*
Side branch at entry	76 (39.8)	38 (36.2)	38 (44.2)	0.299
Ostial location	19 (9.9)	9 (8.6)	10 (11.6)	0.628
Calcium, any	59 (30.9)	27 (25.7)	32 (37.2)	0.115
Heavy calcium	36 (18.8)	14 (13.3)	22 (25.6)	0.040*
Bending > 45	72 (37.7)	24 (22.9)	48 (55.8)	0.000*
Occlusion length > 20 mm	96 (50.3)	45 (42.9)	54 (62.8)	0.009*
Bridging collaterals	44 (23.0)	21 (20.0)	23 (26.7)	0.303
Retrograde collaterals, grade > 3	147 (77.0)	85 (81.0)	62 (72.1)	0.169
Retrograde wiring approach	30 (15.7)	8 (7.6)	22 (25.6)	0.001*
Reattempt of failed CTO PCI	16 (8.4)	2 (1.9)	14 (16.3)	0.000*

Values are mean ± SD or *n* (%).
LAD = left anterior descending artery; LCX = left circumflex; RCA = right coronary artery.
SGW: successful guidewire crossing < 30 min.
FGW: failure for guidewire to cross < 30 min.
* $p < 0.05$.

3.4. In-hospital complications

Table 6 summarizes observed in-hospital complications. Significant adverse events were rarely observed in this study. Cardiac tamponade that resulted in death was observed in only 0.5% of cases and only one patient had a Q-wave MI (0.5%) that arose from stent thrombosis, followed by emergent PCI. Among the 191 patients analyzed, CIN was observed in five cases during their in-hospital observation period.

4. Discussion

To our knowledge, this study is the first to validate the use of the CT-RECTOR score for predicting time-efficient PCI in CTO lesions outside of the setting of the original study. The original study emphasized the importance of evaluating its applicability in other populations [5]. This study demonstrates that the CT-RECTOR score improves discrimination and reclassification of GW crossing within 30 min and final procedure success compared with the J-CTO score. Reclassification of the difficulty grading in nearly half of all CTO lesions using the CT-RECTOR score resulted in enhanced prediction of the first and second endpoints and, in particular, better identification of very difficult CTO lesions, consistent with the original study on the CT-RECTOR score [5]. However, our study is novel in that it also assessed reclassification of difficult CTO lesions and final procedure success using NRI. These findings suggest that assessing the CTO difficulty before PCI using the CT-RECTOR score may help determine downstream recanalization strategies, resource utilization and treatment scheduling, particularly in complex CTO lesions.

The availability of detailed anatomical information on CTO lesions to alleviate uncertainty concerning the success rate before PCI is essential. Angiography-based J-CTO scoring is useful in the procedural planning of CTOs [4]. Our study assessed the ability of the J-CTO score to predict successful GW crossing within 30 min by ROC analysis, similar to prior series [12,13]. However, our study included a further analysis of the relationship between the J-CTO score and final procedure success rate. We found that the J-CTO score can be applied to estimate the overall procedure success rate; however, its ability to do so is modest (area under the curve 0.6894), consistent with a previous Canadian study [12]. The limitations of ICA account for this observation, because some morphological features that influence the success rate of PCI are not readily seen on ICA [14]. The CT-RECTOR score was developed as a non-invasive prediction tool with improved discriminatory performance, compared with the J-CTO score, in predicting GW crossing within 30 min and final procedure success using ROC analysis and NRI, similar to the original CT-RECTOR study [5].

The findings presented herein support that the CT-RECTOR score is more accurate in CTO lesion categorization compared with the J-CTO score. We found that 46.1% of lesions were reclassified into different difficulty categories using the CT-RECTOR score; this was particularly true for the group with failed GW crossing within 30 min, in which over half (53.49%) of lesions were reclassified as more difficult lesions. For the group with successful GW crossing within 30 min, 8.57% of lesions were reclassified as less difficult lesions. The use of NRI was intended to demonstrate better lesion classification based on the CT-RECTOR score instead of the J-CTO score, which relies on the assumption that

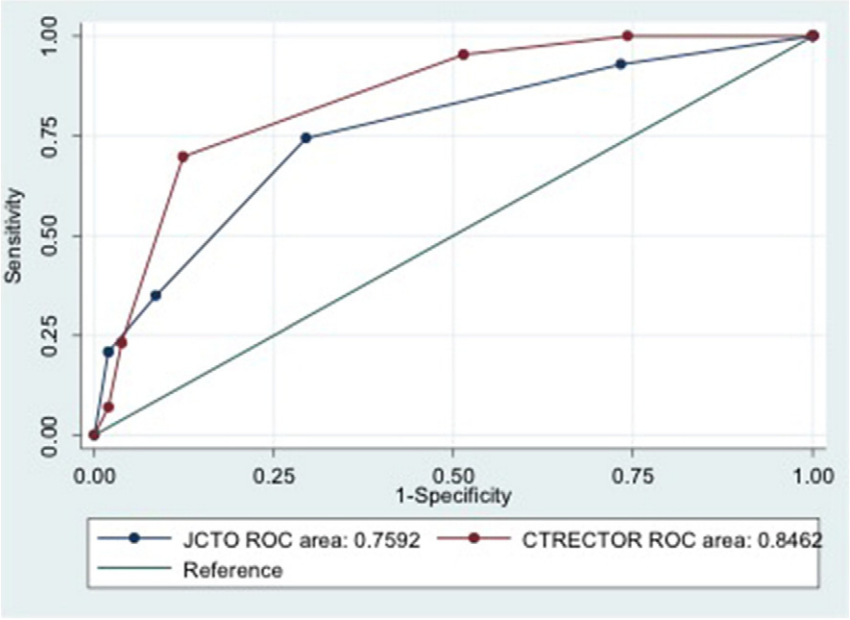

Fig. 1. ROC curves for prediction of GW success ≤ 30 min. Receiver-operating characteristic (ROC) curves for the probability of successful guidewire (GW) crossing within 30 min. The area under the curve was 0.7592 for the J-CTO score and 0.8462 for CT-rector score. $^{*}p = 0.0018$. J-CTO: Multicenter CTO Registry of Japan score. CT-RECTOR: Computed Tomography Registry of Chronic Total Occlusion Revascularization.

each category of difficulty is associated with different downstream management procedures. A high rate of successful recanalization is ensured for easy or intermediate difficulty occlusions, which could be useful for training purposes among less-skilled interventional cardiologists. For difficult and very difficult lesions, additional advanced techniques and complex retrograde approaches are most often used in clinical practice. In our study, with an increasing CT-RECTOR score, the likelihood of successful GW crossing within 30 min decreased, ranging from 100% for a score of 0 to 18% for a score > 2. The appropriate classification could help interventional cardiologist better prepare before PCI.

Of the multiple potential explanations for the NRI results, the following two emerge as particularly strong candidates. The different imaging findings between CCTA versus ICA were used to assess anatomical and morphological features of CTO lesions. Firstly, while the J-CTO score considers only the blunt shape at the entry site, more comprehensive considerations regarding the blunt stump at the exit site were added to the CT-RECTOR score. In our work, a blunt stump was detected at the entry site by ICA in 65 patients. However, when both the entry and exit sites along the occluded lesion were considered, a blunt stump was detected by CCTA in 114 patients. Therefore, many patients were assigned an additional point based on the CT-RECTOR score. Secondly, the different performance for detection and classification of calcification between CCTA and ICA is another important factor that may reveal significant differences in NRI. For example, using the CT-RECTOR scoring system, because the calcification did not involve ≥50% of the vessel cross-sectional area, 19 patients were not assigned a point; conversely, in the J-CTO scoring system, one point was assigned when any calcification was detected, regardless of how severe the calcium burden was. The accurate cut-off value for calcification has been debated; however, most studies consistently suggest that severe calcification involving ≥50% of the vessel cross-sectional area is a practical threshold for prediction of PCI failure in CTOs [5,15,16]. Furthermore, the occluded lesion length > 20 mm variable incorporated in the J-CTO score was

Table 4
Reclassification table using CT-RECTOR for prediction of guidewire crossing.

J-CTO	CT-RECTOR					Reclassification		NRI	*p* Value for NRI
	Easy	Intermediate	Difficult	Very difficult	Total	Up	Down		
SGW						29.52%	8.57%	30.21%	$p = 0.0027^{*}$
Easy	20	2	4	2	28				
Intermediate	5	22	19	0	46				
Difficult	2	0	16	4	22				
Very difficult	0	0	2	7	9				
Total	27	24	41	13	105				
FGW						53.49%	2.33%		
Easy	0	0	4	2	6				
Intermediate	0	2	12	2	16				
Difficult	0	2	6	26	34				
Very difficult	0	0	0	30	30				
Total	0	4	22	60	86				

NRI = net reclassification improvement;
J-CTO: Multicenter CTO Registry of Japan score.
CT-RECTOR: Computed Tomography Registry of Chronic Total Occlusion Revascularization.
SGW: successful guidewire crossing < 30 min.
FGW: failure for guidewire to cross < 30 min.
Patients were reclassified by CT-RECTOR and were compared to J-CTO.
NRI = †NRI = [P(Up|Positive) − P(Down|Positive)] − [P(Up|Negative) − P(Down|Negative)].

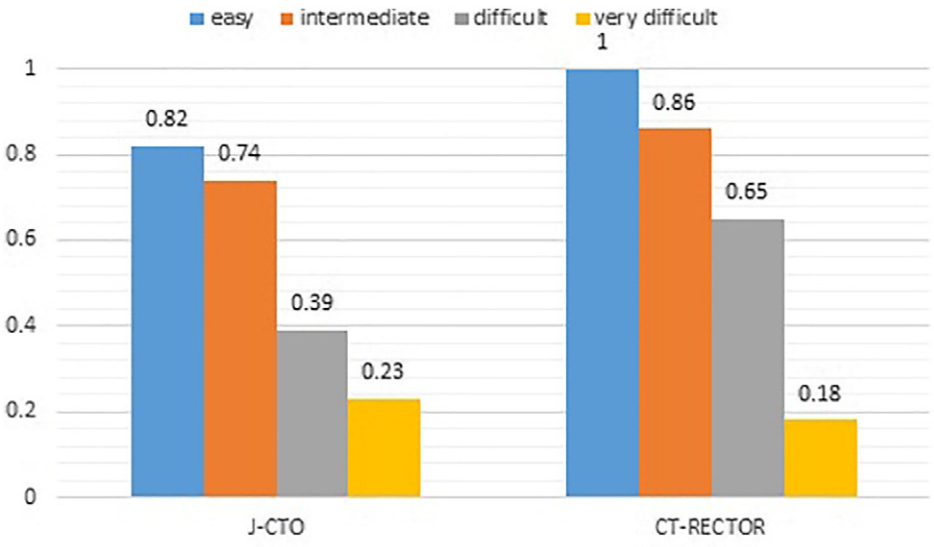

Fig. 2. Comparison of successful guidewire crossing < 30 min by CT-RECTOR and J-CTO. The probability of successful GW crossing within 30 min for each difficulty group (from easy to very difficult) was 100%, 86%, 65% and 18% using CT-RECTOR, and 82%, 74%, 39%, 23% using J-CTO ($p = 0.0027$*). Easy = 0; intermediate = 1; Difficult = 2; Very difficult > 2.

replaced with multiple occlusions in the CT-RECTOR system. The presence of multiple occluded segments with double entry and exit sites hinders successful GW crossing [17]. This important characteristic influencing GW crossing is usually seen clearly on CCTA but missed on ICA [16].

Beyond the different imaging variables concerning the CTO, clinical factors regarding the duration of occlusion may also be important. A new clinical variable (occlusion duration ≥12 months or unknown) was added to this scoring system based on CCTA. Previous studies demonstrated that different stages of CTO influence the procedural outcome of PCI [18]. An early-stage CTO has a favorable outcome after PCI compared with a late-stage lesion. The importance of occlusion duration was emphasized in a consensus document from the EuroCTO club [19]. We observed that more patients received an additional point using the CT-RECTOR score due to the duration of CTO.

In the original CT-RECTOR study, the authors pointed out that this scoring system may be used indirectly to estimate the final PCI success. In our study, we validated their assumptions. We demonstrated a significantly higher diagnostic accuracy and improved classification of the CT-RECTOR score compared with the J-CTO score for the prediction of final PCI success. To our knowledge, this is the first study to use NRI and ROC analysis to demonstrate the ability of CT-RECTOR to predict the final PCI success of CTO lesions, which has important clinical significance, because final recanalization of occluded lesions is associated with improved patient symptoms, quality of life, left ventricular function, and survival [2,20].

The fear of complications after CTO PCI remains a major challenge for many interventional cardiologists [21]. Because careful attention was given to patients receiving CTO PCI during the pre- and postoperative periods at our center, the incidence of in-hospital complications was

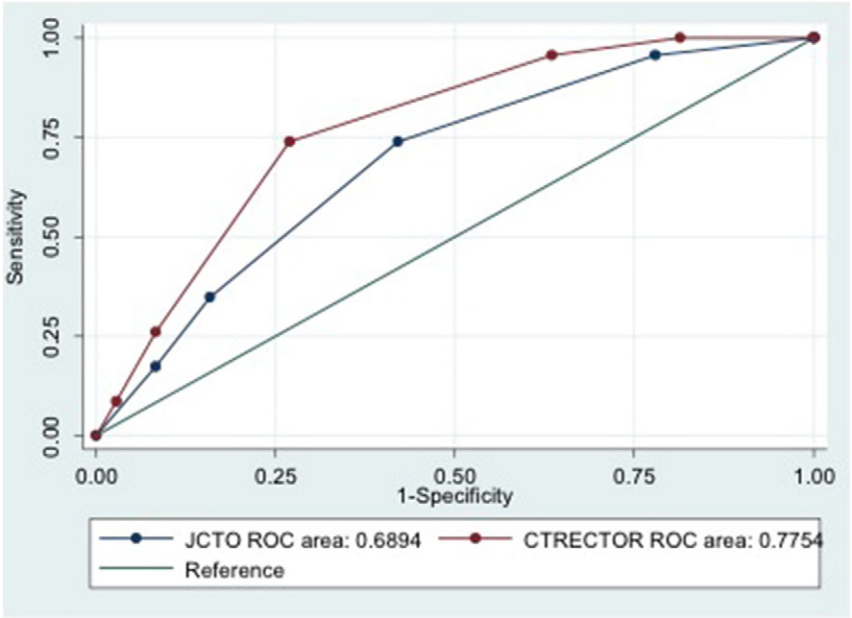

Fig. 3. ROC curves for prediction of final procedure success. Receiver-operating characteristic (ROC) curves for the probability of final procedure success. The area under the curve was 0.6894 for the J-CTO score and 0.7754 for CT-RECTOR. *$p = 0.0025$. J-CTO: Multicenter CTO Registry of Japan score. CT-RECTOR: Computed Tomography Registry of Chronic Total Occlusion Revascularization.

Table 5
Reclassification table using CT-RECTOR for prediction of final procedure success.

J-CTO	CT-RECTOR					Reclassification		NRI	*p* Value for NRI
	Easy	Intermediate	Difficult	Very difficult	Total	Up	Down		
FS						35.17%	7.59%	28.94%	0.0190*
Easy	20	2	6	4	32				
Intermediate	5	22	25	0	52				
Difficult	2	2	20	14	38				
Very difficult	0	0	2	21	23				
Total	27	26	53	39	145				
FFS						56.52%	0		
Easy	0	0	2	0	2				
Intermediate	0	2	6	2	10				
Difficult	0	0	2	16	18				
Very difficult	0	0	0	16	16				
Total	0	2	10	34	46				

NRI = net reclassification improvement; other abbreviations as in Table 4.
FS: Final success.
FFS: Final failure success.
Patients were reclassified by CT-RECTOR and were compared to J-CTO.
NRI = †NRI = [P(Up|Positive) − P(Down|Positive)] − [P(Up|Negative) − P(Down|Negative)].

minimized. With appropriate hydration administration, the rate of CIN was only 2.6%. The incidence of cardiac tamponade was very low (0.5%) as a result of retrograde approaches and adequate hemostatic procedures. However, two emergent PCI cases were observed in our study, which is consistent with a <4% MACE rate after CTO-PCI [19].

5. Study limitations

This study has several limitations. Firstly, it was a retrospective, single-center study; however, we collected CTO PCI data from a high-volume center. There was selection bias resulting from the different reasons for CCTA referral. Additionally, the validation was performed at a single center; therefore, the application of the CT-RECTOR score to other populations should be confirmed in future studies to determine generalizability. Secondly, the rate of a retrograde approach was relatively low (15.7%), which limits subgroup analysis of the two scores in each approach to CTO PCI. Thirdly, the ability of the two scores to predict in-hospital complications was not assessed due to the low rate of complications. Finally, the long-term follow-up of these patients was not included in this study because such data were lacking.

6. Conclusion

As a simple and accurate prediction tool for assessing CTO difficulty based on CCTA, the CT-RECTOR score showed good performance and improved classification in predicting GW crossing within 30 min and final procedure success in an independent cohort. Compared with the J-CTO score, which is based on ICA, the CT-RECTOR score represents a more accurate noninvasive tool for predicting time-efficient GW crossing. CTA-based scores that combine verified anatomical features with recently described signs including the reverse attenuation gradient sign and linear intrathrombus enhancement will be a trend for a comprehensive assessment before performing CTO PCI and may allow interventional cardiologists to rely upon these scores for treatment decisions.

Conflict of interest

The authors report no relationships that could be construed as a conflict of interest.

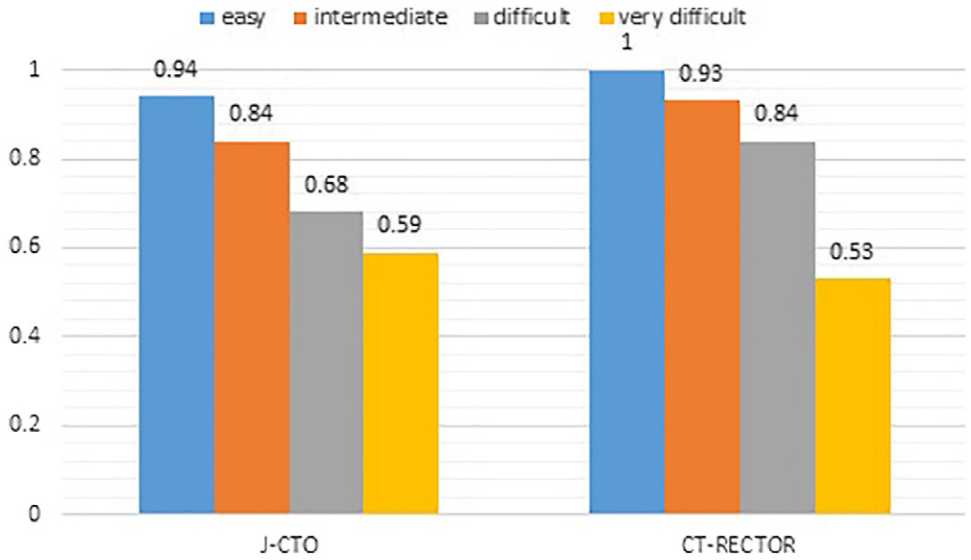

Fig. 4. Comparison of final procedure success by CT-RECTOR and J-CTO. The probability of for final procedure success for each group (from easy to very difficult) was 100%, 93%, 84% and 53% using CT-RECTOR, and 94%, 84%, 68%, and 59% using J-CTO ($p = 0.0190^*$). Easy = 0; intermediate = 1; Difficult = 2; Very difficult > 2. J-CTO: Multicenter CTO Registry of Japan score. CT-RECTOR: Computed Tomography Registry of Chronic Total Occlusion Revascularization.

Table 6
Complications and in-hospital outcomes.

Complications	
Cardiac tamponade	1 (0.5)
Emergent PCI	2 (1)
Emergent CABG	0 (0)
Blood transfusion	1 (0.5)
Contrast-induced nephropathy	5 (2.6)
Radiation dermatitis	1 (0.5)
In-hospital adverse outcomes	
All-cause death	1 (0.5)
Cardiac death	1 (0.5)
Q-wave myocardial infarction	1 (0.5)
Non-Q-wave myocardial infarction	3 (1.6)
Stroke	0 (0)
Stent thrombosis	1 (0.5)

Values are *n* (%).

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