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Collateral grading systems in retrograde percutaneous coronary intervention of chronic total occlusions

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Abstract

Background: The Japanese Channel (J-Channel) score was introduced to aid in retrograde percutaneous coronary intervention (PCI) of chronic total coronary occlusions (CTOs). The predictive value of the J-Channel score has not been compared with established collateral grading systems such as the Rentrop classification and Werner grade.

Aims: To investigate the predictive value of the J-Channel score, Rentrop classification and Werner grade for successful collateral channel (CC) guidewire crossing and technical CTO PCI success.

Methods: A total of 600 prospectively recruited patients underwent CTO PCI. All grading systems were assessed under dual catheter injection. CC guidewire crossing was considered successful if the guidewire reached the distal segment of the CTO vessel through a retrograde approach. Technical CTO PCI success was defined as thrombolysis in myocardial infarction flow grade 3 and residual stenosis <30%.

Results: Of 600 patients, 257 (43%) underwent CTO PCI through a retrograde approach. Successful CC guidewire crossing was achieved in 208 (81%) patients. The predictive value of the J-Channel score for CC guidewire crossing (area under curve 0.743) was comparable with the Rentrop classification (0.699, $p = 0.094$) and superior to the Werner grade (0.663, $p = 0.002$). Technical CTO PCI success was reported in 232 (90%) patients. The Rentrop classification exhibited a numerically higher discriminatory ability (0.676) compared to the J-Channel score (0.664) and Werner grade (0.589).

Abbreviations: AUC, area under the curve; CABG, coronary artery bypass grafting; CC, collateral channel; CTO, chronic total coronary occlusion; MACE, major adverse cardiovascular events; MI, myocardial infarction; PCI, percutaneous coronary intervention; TIMI, thrombolysis in myocardial infarction.

Conclusions: The J-channel score might aid in strategic collateral channel selection during retrograde CTO PCI. However, the J-Channel score, Rentrop classification, and Werner grade have limited value in predicting technical CTO PCI success.

KEYWORDS
chronic total coronary occlusion, percutaneous coronary intervention, retrograde

1 | INTRODUCTION

The retrograde approach represents a vital complement to the antegrade approach in percutaneous coronary intervention (PCI) of a chronic total coronary occlusion (CTO). Its implementation has led to higher technical success rates in experienced centers.[1–5] As such, expertise in retrograde PCI has become an essential adjunct to the toolkit of a CTO interventionalist. A multitude of angiographic grading systems coexist to facilitate preprocedural planning and to optimize case selection, including the Japanese CTO (J-CTO), PROGRESS, EURO-CTO, and CL- score.[6–10] Notably, these scoring systems are tailored to predict successful antegrade guidewire crossing through the CTO lesion or technical CTO PCI success, but do not pertain to the retrograde approach. Instead, the use of descriptive tools such as the Rentrop classification and Werner grade is encouraged. The Rentrop classification grades the collateral filling of the recipient artery, whereas the Werner grade assesses the size of the collateral channels (CCs).[11–13] Studies have shown the predictive value of the Rentrop classification for technical failure, as well as the added value of the Werner grade in predicting CC guidewire crossing and technical CTO PCI success.[14–16] A recent study on angiographic predictors preceding difficult CC crossing led to the Japanese Channel (J-Channel) score; a prediction tool to evaluate the suitability of septal and epicardial CCs for guidewire tracking by grading CC characteristics such as size and tortuosity.[17] Importantly, the J-Channel score has yet to be validated in an external cohort. Moreover, data on the added value of the J-Channel score in comparison to the Rentrop classification and Werner grade is lacking. This study sought to validate and compare the predictive value of the J-Channel score, Rentrop classification, and Werner grade for CC guidewire crossing success and technical CTO PCI success. Additionally, we aimed to investigate differences between septal and epicardial CCs pertaining to the previously mentioned outcomes.

2 | METHODS

2.1 | Study population

Patients presenting with a CTO at the Amsterdam University Medical Center, Vrije Universiteit, were prospectively recruited in a single-center CTO PCI registry between 2013 and 2018. Patients were eligible for inclusion if they underwent CTO PCI. Treatment was performed by two expert CTO interventionalists (PK and AN). All cases in whom either a septal or epicardial CC could be angiographically graded according to the J-Channel criteria by Nagamatsu et al.[17] were included. For the final analysis, patients were divided into two groups: cases with an antegrade-only approach, and cases with a retrograde approach. Exclusion criteria entailed attempted CC guidewire crossing via saphenous vein graft (SVG). All patients provided written informed consent.

2.2 | Angiographic and procedural characteristics

All angiographic and procedural characteristics were evaluated by an expert CTO observer (RG) using a monoplane cardiovascular X-ray system (Allura Xper FD 10/10; Philips Healthcare, Best, the Netherlands). A CTO was defined as a luminal occlusion of a coronary artery with an estimated or documented duration of ≥3 months with no or minimal contrast penetration through the lesion (thrombolysis in myocardial infarction [TIMI] flow grade 0 or 1).[18] Using dual catheter injection invasive coronary angiography images, the following grading systems were retrospectively determined: the J-CTO score as depicted by Morino et al.,[6] the J-Channel score defined by Nagamatsu et al.,[17] the Rentrop classification formulated by Rentrop et al.,[11] and the Werner grade according to Werner et al.[12] In all cases with a documented retrograde approach, only the final CC selected by the operator for guidewire tracking was included in the analysis. All PCIs were performed in accordance with the hybrid algorithm, which guided the operator's decision to execute a retrograde approach.[19] Guidewire crossing through the CC from a retrograde approach to the distal segment was defined as CC guidewire crossing success.[17] Technical CTO PCI success was defined as TIMI flow grade 3 and residual stenosis <30%.[3] In-hospital major adverse cardiovascular events (MACE) were documented and included: all-cause death, non-fatal MI, emergency revascularization of the target vessel with PCI or coronary artery bypass grafting (CABG) surgery, tamponade requiring pericardiocentesis or thoracotomy, and stroke. Side-branch loss (≥2 mm) was documented and cardiac biomarkers were obtained if periprocedural MI was suspected. Periprocedural MI was defined according to the Fourth Universal Definition of Myocardial Infarction.[20] Finally, retrograde complications were defined as a composite endpoint, including: collateral channel injury, native vessel perforation, tamponade requiring treatment (pericardiocentesis or thoracotomy), and donor vessel complications (dissection requiring stenting, acute thrombus formation).

2.3 | Statistical analysis

Continuous variables with a normal distribution are presented as mean ± standard deviation (SD), whereas continuous variables with a non-normal distribution are summarized as median values with interquartile ranges (IQR). Categorical variables are presented as numbers and percentages. Statistical comparison between septal and epicardial CCs was conducted using the unpaired two-samples T-test or Fisher's Exact test, accordingly. Chi-square testing was performed to determine the association between the retrograde grading systems and CC guidewire crossing success, technical CTO PCI success, and device crossing failure. A receiver operating characteristic (ROC) analysis was conducted to investigate the predictive value of the grading systems for successful CC guidewire crossing and technical CTO PCI success. A comparison of area under the curve (AUC) was performed using the DeLong method. A Spearman's rank order correlation was run to determine the relationship between the J-CTO score and CC grading systems. A binomial logistic regression model was used to assess the predictive value of CC complexity (as indicated by each CC grading system) for the occurrence of retrograde complications. Subsequently, a multivariable regression analysis was conducted to adjust for clinically relevant variables as potential confounders. The following variables were entered into the model: age, gender, prior MI, prior CABG, renal insufficiency, lesion calcification, lesion tortuosity, lesion length ≥20 mm, procedure time, technical success, Rentrop classification score 0–1, and Rentrop classification score 2. A level of $p < 0.05$ was considered significant. Statistical analyses were carried out using SPSS software (IBM SPSS Statistics 28.0) and MedCalc (MedCalc Software 11.6.0.0).

3 | RESULTS

3.1 | Study population

A total of 600 patients were identified for analysis. Conservatively treated patients ($n = 102$) were excluded, as shown in Figure 1. Baseline characteristics are demonstrated in Table 1, which depicts patients with an antegrade-only approach ($n = 343$) and a documented retrograde approach ($n = 257$). The mean age was 65 ± 11 years and did not differ between the antegrade and retrograde cohort. The majority of patients were male (83%). Patients with a retrograde approach had higher rates of prior MI and CABG. Cardiovascular risk factors, cardiac medication, and clinical presentation were distributed equally among the cohorts, with the exception of higher rates of renal insufficiency and statin use in the retrograde group.

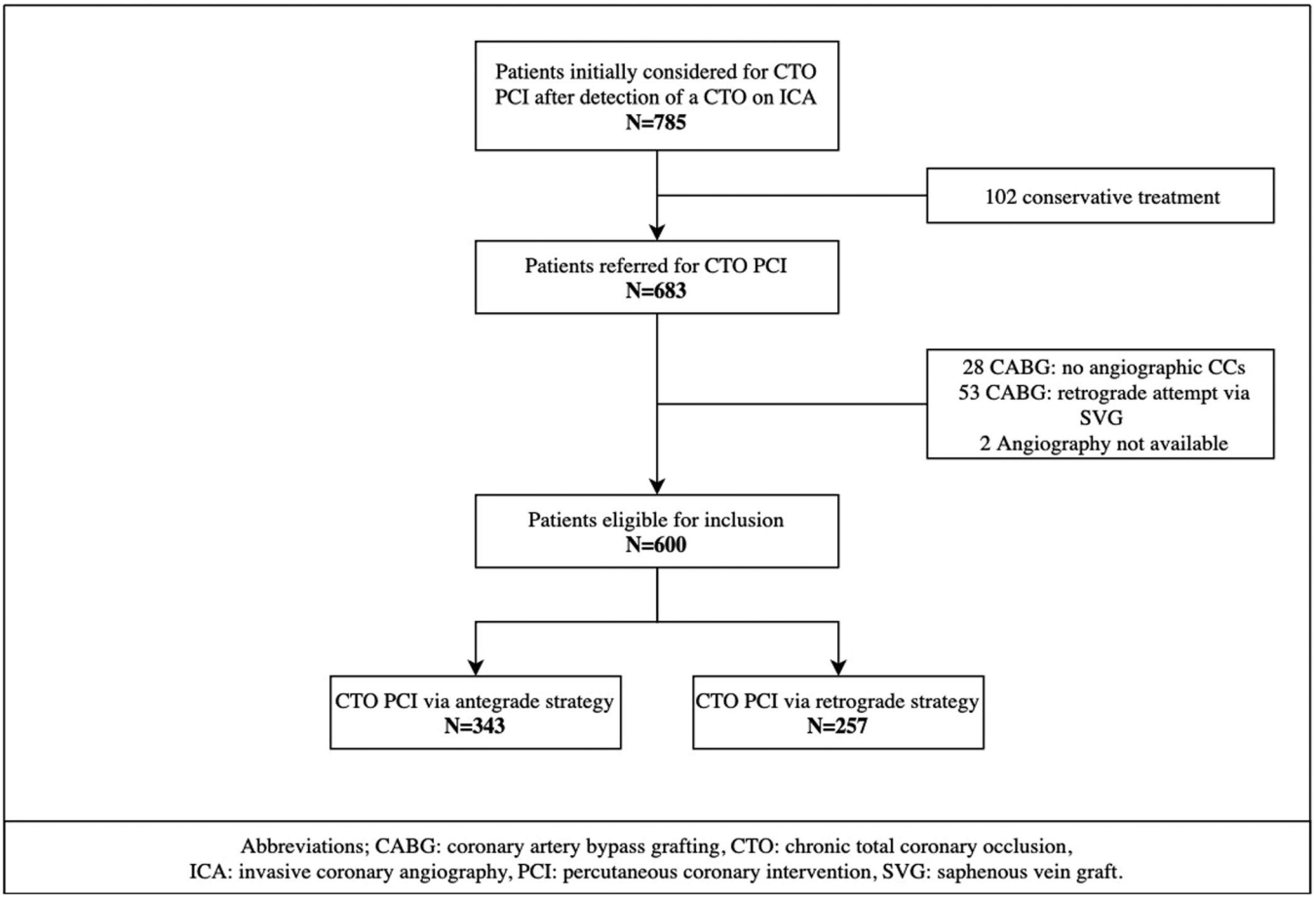


FIGURE 1 Flowchart of the study population.

TABLE 1 Baseline characteristics of total, antegrade, and retrograde cohort.

	Total cohort (n = 600)	Antegrade cohort (n = 343)	Retrograde cohort (n = 257)	p-Value*
Demographics				
Age, years	65 ± 11	65 ± 11	65 ± 11	0.828
Male gender	498 (83)	278 (81)	220 (86)	0.142
BMI, kg · m^{-2}	28 ± 5	28 ± 5	28 ± 5	0.298
Prior MI	314 (52)	160 (47)	154 (60)	0.001
Prior PCI	360 (60)	198 (58)	162 (63)	0.189
Prior CABG	85 (14)	39 (11)	46 (18)	0.023
LVEF, %				0.046
>55	214 (36)	134 (40)	80 (32)	-
45–55	202 (34)	115 (34)	87 (34)	-
30–45	120 (20)	56 (17)	64 (25)	-
<30	52 (9)	30 (9)	22 (9)	-
Cardiac risk factors				
Hypertension	313 (53)	173 (51)	140 (55)	0.405
Hypercholesterolemia	247 (42)	135 (40)	112 (44)	0.372
Diabetes mellitus	159 (27)	85 (25)	74 (29)	0.299
History of smoking	340 (57)	189 (55)	151 (59)	0.576
Renal insufficiency	115 (19)	55 (16)	60 (23)	0.025
Family history of CAD	199 (34)	120 (35)	79 (31)	0.273
Medication				
Antiplatelet therapy	519 (87)	300 (88)	219 (85)	0.425
ACE inhibitor/ARB	365 (61)	201 (59)	164 (64)	0.196
β-blocker	466 (78)	264 (77)	202 (79)	0.635
Calcium channel blocker	163 (27)	88 (26)	75 (29)	0.337
Long-acting nitrate	160 (27)	89 (26)	71 (28)	0.645
Statin	517 (86)	287 (84)	230 (90)	0.041
Clinical presentation				0.424
Typical angina or dyspnea on exertion	368 (61)	222 (67)	146 (59)	-
Atypical angina	45 (8)	25 (8)	20 (8)	-
Asymptomatic	64 (11)	35 (11)	29 (12)	-

Note: Values are presented as mean ± SD or n (%).

Abbreviations: ACE, angiotensin-converting enzyme; ARB, angiotensin receptor blocker; BMI, body mass index; CABG, coronary artery bypass grafting; CAD, coronary artery disease; LVEF, left ventricular ejection fraction; MI, myocardial infarction; PCI, percutaneous coronary intervention.

*Statistical testing is performed between antegrade and retrograde cohort.

3.2 | Angiographic and procedural characteristics

Angiographic characteristics are listed in Table 2. Anatomical parameters befitting high CTO lesion complexity were more common in patients with a retrograde approach, such as the presence of calcification, bending >45°, and occlusion length ≥20 mm. Consequently, a J-CTO score of ≥3 was less common in the antegrade cohort versus the retrograde cohort. A Rentrop classification of ≥3 and a Werner grade of 2 were more often reported in patients with a retrograde approach. Figure 2 shows the prevalence of guidewire types in the retrograde cohort. The SUOH® 03 wire was more often used in tracking of nonseptal CCs compared with septal CCs.

TABLE 2 Angiographic characteristics of total, antegrade, and retrograde cohort.

	Total cohort (*n* = 600)	Antegrade cohort (*n* = 343)	Retrograde cohort (*n* = 257)	*p*-Value*
CTO target vessel				<0.001
RCA	390 (65)	175 (51)	215 (84)	-
LAD	136 (23)	108 (32)	28 (11)	-
LCX	73 (12)	59 (17)	14 (5)	-
LM	1 (<11)	1 (<1)	0	-
Number of diseased vessels				0.534
1	385 (64)	214 (62)	171 (67)	-
2	167 (28)	99 (29)	68 (27)	-
3	48 (8)	30 (9)	18 (7)	-
CTO lesion characteristics				
Blunt cap	160 (29)	90 (30)	70 (27)	0.572
Calcification	346 (58)	180 (53)	166 (65)	0.003
Bending >45°	246 (41)	106 (31)	140 (55)	<0.001
Occlusion length ≥20 mm	274 (46)	115 (34)	159 (62)	<0.001
Retry lesion	68 (11)	43 (13)	25 (10)	0.283
Rentrop classification				<0.001
0–1	92 (15)	71 (21)	21 (8)	-
2	191 (32)	114 (33)	77 (30)	-
3	314 (53)	156 (46)	158 (62)	-
Werner grade				0.003
0	2 (<1)	2 (<1)	0	-
1	371 (62)	230 (67)	141 (55)	-
2	227 (38)	111 (32)	116 (45)	-
J-CTO score				<0.001
0–1	232 (39)	167 (49)	65 (25)	-
2	180 (30)	104 (30)	76 (30)	-
≥3	188 (31)	72 (21)	116 (45)	-
J-Channel score				<0.001
0	106 (18)	40 (12)	66 (26)	-
1–2	292 (49)	162 (47)	130 (51)	-
≥3	202 (34)	141 (41)	61 (24)	-

Note: Values are presented as mean ± SD or *n* (%).

Abbreviations; J-CTO, Japanese chronic total coronary occlusion; J-Channel, Japanese Channel; LAD, left anterior descending artery; LCX, left circumflex artery; LM, left main; RCA, right coronary artery.

*Statistical testing is performed between antegrade and retrograde cohort.

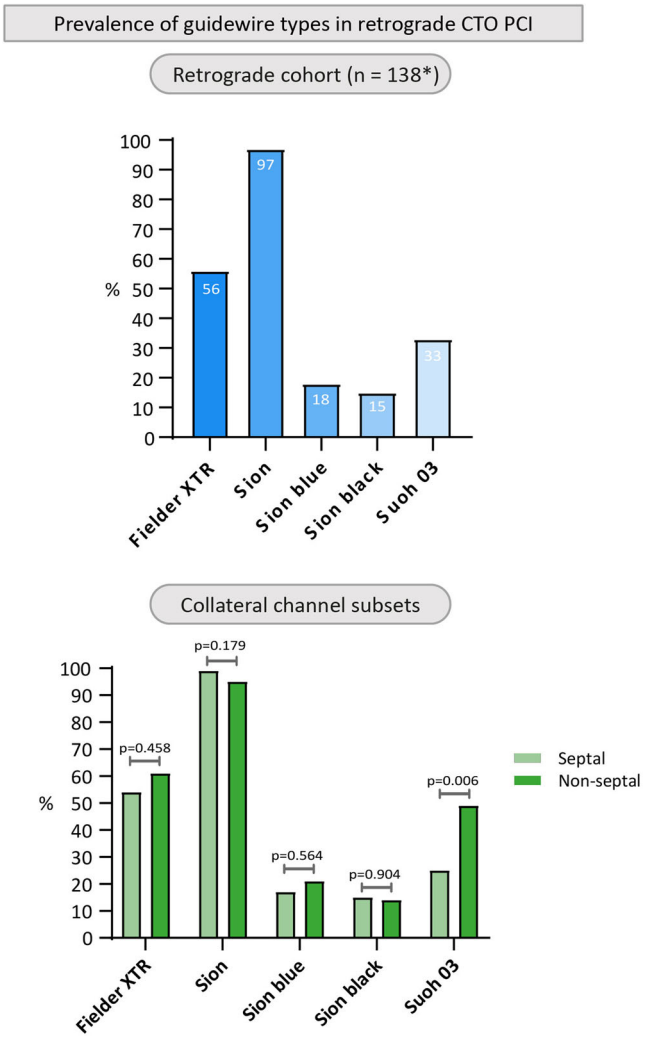


FIGURE 2 Prevalence of guidewire types in retrograde CTO PCI. This figure depicts the prevalence of guidewire types in the retrograde cohort. The distribution of preferred guidewires for CC tracking was comparable between CC subsets, with the exception of the SUOH® 03 wire. *Guidewire-type data was available in 138 (54%) cases. CC, collateral channel; CTO, chronic total coronary occlusion; PCI, percutaneous coronary intervention. [Color figure can be viewed at wileyonlinelibrary.com]

3.3 | Predictive value of the J-Channel score, Rentrop classification, and Werner grade

Figure 3 demonstrates the observed rates of CC guidewire crossing success and technical CTO PCI success across all grading systems in the retrograde cohort. A high J-Channel score (≥3) was inversely associated with CC guidewire crossing success and technical CTO PCI success ($p < 0.001$ and $p = 0.002$). Conversely, higher rates of CC guidewire crossing success and technical CTO PCI success were observed in cases with a high Rentrop classification score (3). A high Werner grade (2) was associated with increased rates of CC guidewire crossing success ($p < 0.001$), but not with technical CTO PCI success. In Figure 4, the predictive value as illustrated by the

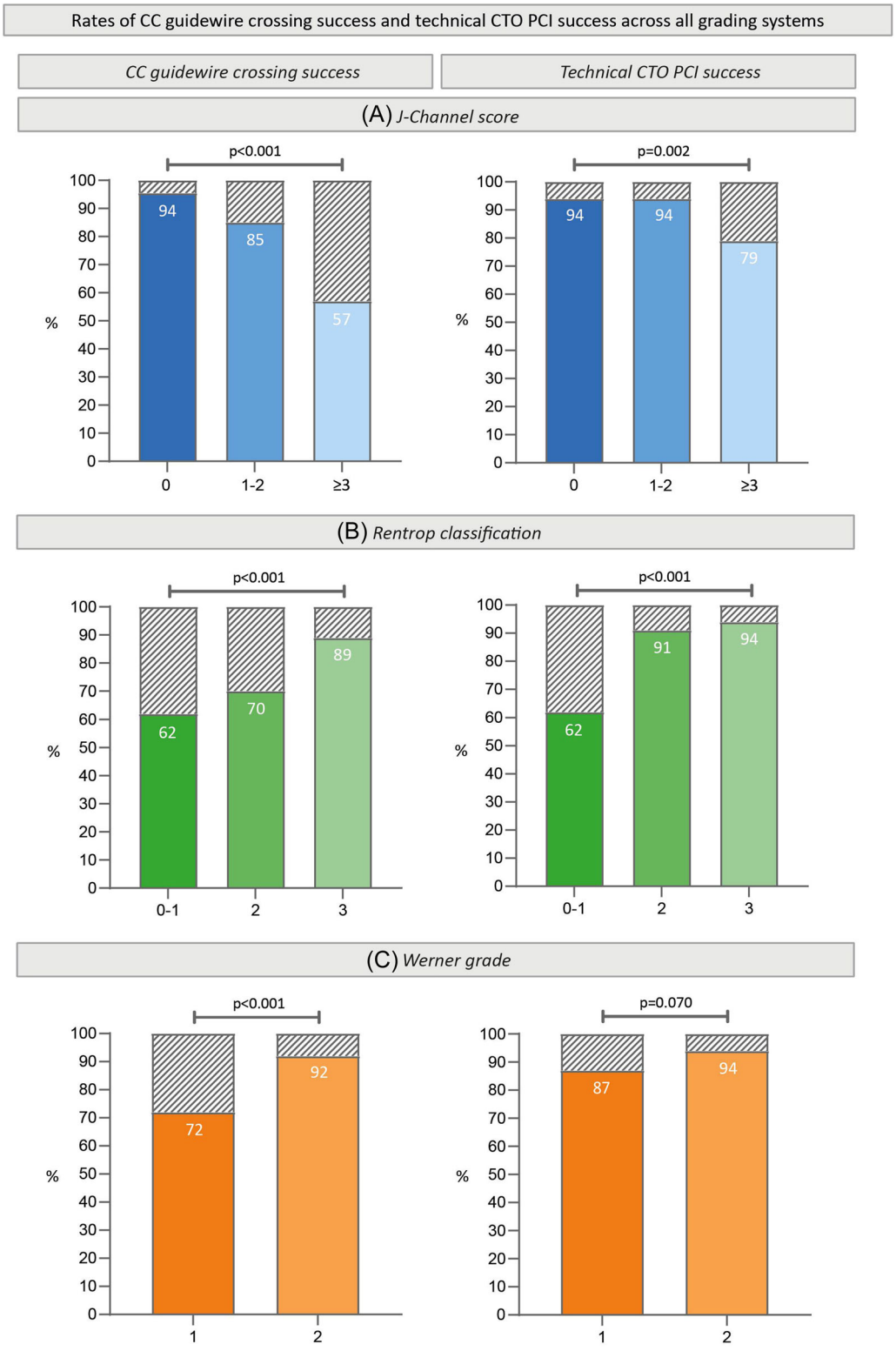


FIGURE 3 Rates of CC guidewire crossing success and technical CTO PCI success across all grading systems. This figure illustrates the association of each grading system with CC guidewire crossing success and technical CTO PCI success in the retrograde cohort. (A) A high J-Channel score, as defined by Nagamatsu et al.,[17] is associated with lower rates of CC guidewire crossing and technical CTO PCI success. (B) Higher rates of CC guidewire crossing and technical CTO PCI success are found in cases with extensive filling of the CCs and/or target vessel, as defined by Rentrop et al.[11] (C) A larger size of the CC, according to Werner et al.,[12] was associated with increased rates of CC guidewire crossing success, but not with technical CTO PCI success. CC, collateral channel; CTO, chronic total coronary occlusion; J-Channel, Japanese Channel; PCI, percutaneous coronary intervention. [Color figure can be viewed at wileyonlinelibrary.com]

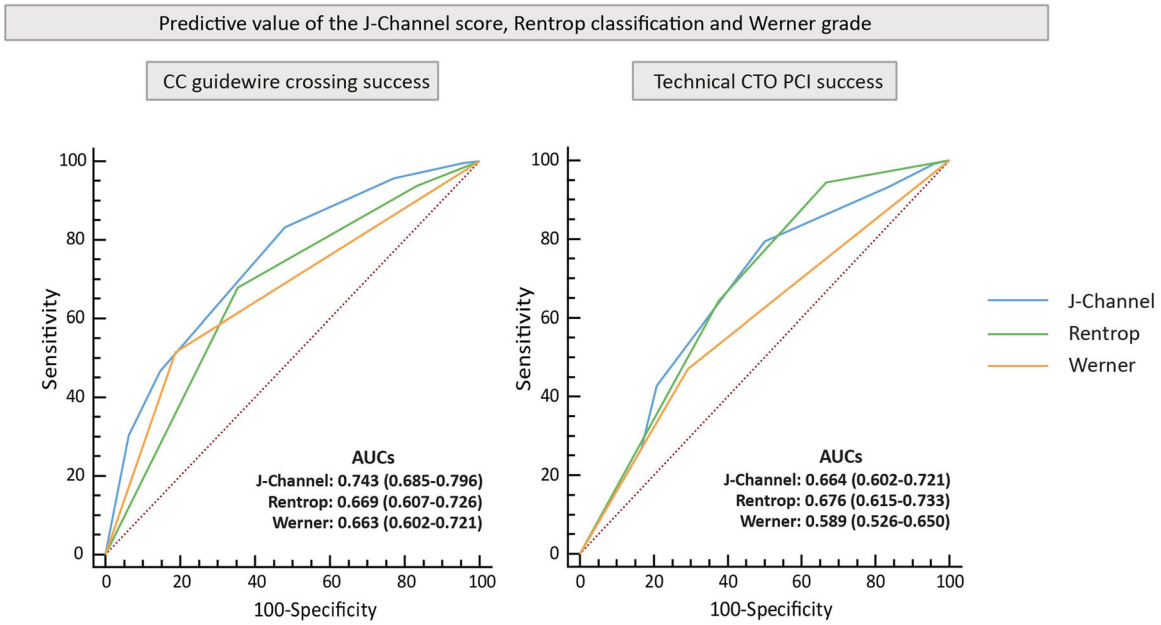


FIGURE 4 Predictive value of the J-Channel score, Rentrop classification, and Werner grade. AUCs of the J-Channel score, Rentrop classification, and Werner grade for CC guidewire crossing success and technical CTO PCI success in the retrograde cohort. The predictive value for CC guidewire crossing success was highest for the J-Channel score. For technical CTO PCI success, the predictive value of the Rentrop classification was numerically highest. Additional data on the pairwise comparison between each grading system is provided in Supporting Information: Table 1. CC, collateral channel; CTO, chronic total coronary occlusion; J-Channel, Japanese Channel; PCI, percutaneous coronary intervention. [Color figure can be viewed at wileyonlinelibrary.com]

ROC curves across all grading systems strata is shown. The predictive value for CC guidewire crossing success was highest for the J-Channel score (AUC 0.743, 95% confidence interval [CI]: 0.685–0.796), and demonstrated a superior discriminative capacity compared with the Werner grade ($p = 0.002$). For technical CTO PCI success, the predictive value of the Rentrop classification was numerically highest (AUC 0.676, 95% CI: 0.615–0.733). All data on the pairwise comparison between each grading system is provided in Supporting Information: Table 1. Additional analysis to determine a possible relationship between the J-CTO and the CC grading systems did not show a significant correlation (Supporting Information: Table 2). Furthermore, the collateral channel grading systems were not associated with the rate of device crossing failure, as listed in Supporting Information: Table 3. Finally, logistic regression analysis demonstrated a lower Rentrop classification score to be associated with an increased likelihood of retrograde complications (Supporting Information: Table 4), which was no longer significant in a multivariable regression model (Supporting Information: Table 5).

3.4 | Comparison between septal and epicardial CCs

Table 3 shows the angiographic characteristics of the retrograde cohort and CC subsets. Reverse bend, continuous bends, and corkscrew morphology characterized the non-septal CC subset. The majority of septal CCs were appointed a J-Channel score of intermediate difficulty (1–2), whereas a difficult score (≥3) was more commonly reported in the epicardial CC subset ($p < 0.01$). Procedural outcomes of the retrograde cohort and CC subsets are listed in Table 4. The number of repeat attempts at the CTO lesion was lower in the septal group compared with

TABLE 3 Angiographic characteristics of retrograde cohort and collateral channel type subsets.

	Retrograde cohort ($n = 257$)			
	All CCs ($n = 257$)	Septal CC ($n = 186$)	Non-septal CC ($n = 71$)	p-Value*
CC characteristics				
Small vessel size	141 (55)	109 (59)	32 (45)	0.051
Reverse bend	53 (21)	25 (13)	28 (39)	<0.001
Continuous bends	33 (13)	18 (10)	15 (21)	0.014
Corkscrew	34 (13)	4 (2)	30 (42)	<0.001
J-Channel score				<0.001
0	66 (26)	57 (31)	9 (13)	-
1–2	130 (51)	101 (54)	29 (41)	-
≥3	61 (24)	28 (15)	33 (47)	-

Note: Values are presented as *n* (%).
Abbreviations: CC, collateral channel; J-Channel, Japanese Channel.
*Statistical testing is performed between CC subsets.

TABLE 4 Procedural outcomes of retrograde cohort and collateral channel type subsets.

	Retrograde cohort (*n* = 257)			
	All CCs (*n* = 257)	Septal CC (*n* = 186)	Nonseptal CC (*n* = 71)	*p*-Value*
Repeat attempt at CTO lesion	19 (7)	8 (4)	11 (16)	0.002
CC guidewire crossing success	208 (81)	158 (85)	50 (70)	0.008
Technical CTO PCI success				
After successful CC crossing[a]	202 (97)	154 (98)	48 (96)	0.589
Overall	232 (90)	177 (93)	59 (83)	0.016
Tip injection	71 (28)	44 (24)	27 (38)	0.024
Septal surfing	156 (62)	156 (85)	-	-
Procedure time, min.	132 ± 48	131 ± 45	133 ± 55	0.833
Total fluoroscopy time, min.	58 ± 26	58 ± 24	57 ± 30	0.922
Total contrast volume, mL	359 ± 136	361 ± 132	355 ± 145	0.834
Number of wires used	12 ± 6	11 ± 6	13 ± 7	0.147
Number of stents	2.7 ± 1.3	2.8 ± 1.3	2.5 ± 1.5	0.111
CTO vessel stent length, mm	91 ± 42	94 ± 39	82 ± 48	0.039
Complete revascularization	207 (81)	152 (82)	55 (78)	0.441

Note: Values are presented as mean ± SD or *n* (%).

Abbreviations: CC, collateral channel; CTO, chronic total coronary occlusion; PCI, percutaneous coronary intervention.

[a]Percentage is calculated over a number of cases with successful CC guidewire crossing.

*Statistical testing is performed between CC subsets.

the epicardial group. In addition, the CTO vessel stent length (mm) was longer in septal CCs than in epicardial CCs. CC guidewire crossing success was achieved in 158 (85%) septal CCs versus 50 (70%) epicardial CCs ($p = 0.008$). Importantly, overall technical success rates were higher in the septal group as compared with the epicardial group (177 (93%) vs. 59 (83%), $p = 0.016$). Analysis of the CC crossing rate divided by time period (2013–2015 versus 2016–2019) showed comparable CC guidewire crossing success rates (Supporting Information: Table 6). Lastly, Table 5 lists complications in the retrograde cohort and CC subsets. The complication rate between septal and non-septal CCs was comparable, with the exception of higher bleeding rates in the septal CC subset.

4 | DISCUSSION

The present study aimed to investigate the predictive value of the J-Channel score, Rentrop classification, and Werner grade for CC guidewire crossing success and technical CTO PCI success in retrograde CTO PCI (Central Illustration 1). To our knowledge, this is the first study to externally validate the J-Channel score and compare it to the Rentrop classification and Werner grade. First, our results demonstrate a modest discriminative capacity for all scores in predicting CC guidewire crossing success, wherein the J-Channel score showed the highest predictive value. Second, we report a weak performance across all grading systems in predicting technical CTO PCI success.

4.1 | Applicability of grading systems in retrograde CTO PCI

Independent angiographic predictors of CC tracking and technical success in retrograde CTO PCI have been investigated at length. Among these predictors are CC size (as defined by Werner's grade), tortuosity, diameter of the distal CTO segment, the utilization of epicardial CCs for guidewire crossing, nonvisible CC connection, and an angle <90° with the recipient vessel.[14,15,21–23] Several studies have translated components of these predictors to a model in an effort to accurately forecast retrograde CTO PCI success. Chai et al. reported an excellent predictive value of the Retrograde CTO score (AUC 0.83 in the derivation set), which includes CC size (according to the Werner grade), diameter of the distal CTO segment, and tortuosity of the CC.[21] However, external validation of the Retrograde CTO score in a study by Huang et al.[15] showed a modest predictive value (AUC 0.76). In this same study, the Epicardial CTO (Epi-CTO) score, which contains a small CC size besides other parameters, demonstrated a high predictive value for technical success (AUC 0.94) in 103 cases with retrograde CTO PCI via epicardial CCs. Notably, neither of these studies included the Rentrop classification, despite its earlier introduction to Werner's grade and its ability to provide insight into the connection between CCs and the distal landing zone during dual catheter injection. The additional value of the Rentrop classification is highlighted by Galassi et al.,[16] who reported a Rentrop grade <2 as an independent predictor of technical failure. Finally, the recently introduced J-Channel score bears similarity to the existing retrograde grading systems, adding

TABLE 5 Complications in retrograde cohort and collateral channel type subsets.

	Retrograde cohort (*n* = 257)			
	All CCs (*n* = 257)	Septal CC (*n* = 186)	Nonseptal CC (*n* = 71)	*p*-Value*
Collateral channel				
CC injury	23 (9)	18 (10)	5 (7)	0.494
Septal hematoma	19 (8)	15 (8)	-	-
Treatment by fat embolization	2 (<1)	0	2 (3)	0.022
Donor vessel				
Dissection requiring stenting	6 (2)	5 (3)	1 (1)	0.537
Acute thrombus formation	2 (<1)	1 (<1)	1 (1)	0.483
Native vessel				
Vessel perforation	32 (13)	22 (12)	10 (14)	0.646
Ellis grade[a]				0.408
I	3 (10)	3 (15)	0	-
II	14 (47)	10 (50)	4 (40)	-
III	10 (33)	5 (25)	5 (50)	-
III cavity spilling	3 (10)	2 (10)	1 (10)	-
Side branch loss, >2 mm	31 (12)	24 (13)	7 (10)	0.503
RV branch	29 (11)	22 (12)	7 (10)	0.403
In-hospital MACE				
Death	3 (1)	2 (1)	1 (1)	0.824
Periprocedural MI	31 (12)	22 (12)	9 (13)	0.852
Tamponade req. pericardiocentesis	7 (3)	6 (3)	1 (1)	0.143
Tamponade req. thoracotomy	3 (1)	2 (1)	1 (1)	1.000
Emergency PCI	1 (<1)	1 (<1)	0	0.536
Emergency CABG	0	0	0	-
Contrast-induced nephropathy	4 (2)	3 (2)	1 (1)	0.906
Stroke	1 (<1)	1 (<1)	0	0.536
Bleeding	18 (7)	17 (9)	1 (1)	0.030
Vascular access site complications	5 (2)	5 (3)	0	0.163

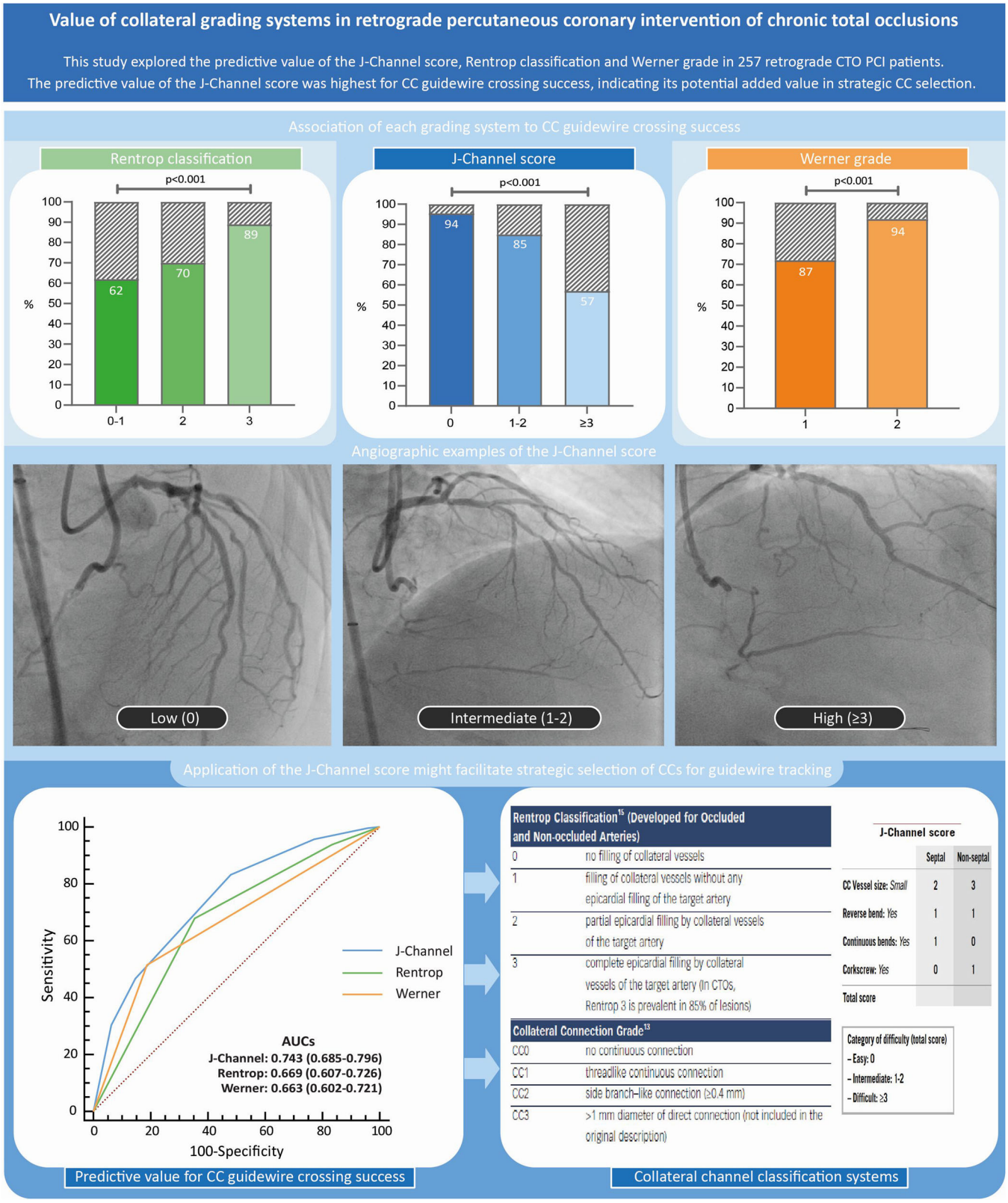
Note: Values are presented as *n* (%).

Abbreviations: CABG, coronary artery bypass grafting; CC, collateral channel; MACE, major adverse cardiovascular events; MI, myocardial infarction; PCI, percutaneous coronary intervention; RV, right ventricular.

*Statistical testing is performed between CC subsets.

[a]Percentage is calculated over a number of cases with documented perforation. In two cases, the Ellis Grade was not available.

CC bending (continuous and reverse) and corkscrew morphology to its arsenal. In this first report, the J-Channel score depicted the difficulty of CC guidewire crossing with an AUC > 0.7 in septal and epicardial CCs. The authors did not report the predictive capacity for technical CTO PCI.[17] The aforementioned grading systems have crystallized the loosely defined term 'interventional collaterals' or "feasible retrograde option" (as proposed by Wu et al.[24]), providing tangible characteristics for the CTO operator to assess.[24] Moreover, evaluating the suitability of the collateral circulation for retrograde CTO PCI is strongly advised, as it maximizes the likelihood of procedural success by allowing the operator to alternate between strategies.[19] Interestingly, the previously described collateral grading systems have failed to make their entrance into clinical practice, with the exception of the Rentrop classification and Werner grade. We speculate this is a result of the wide range in performance of the available grading systems when they are translated to a predictive model. The choice of grading system is, therefore, at the discretion of the operator,



CENTRAL ILLUSTRATION 1 (See caption on next page).

paradoxically complicating the intended simplification of the retrograde approach. Our study counteracts the ambivalence of selection of the most suitable grading system, as it shows that the J-Channel score is superior to the Rentrop classification and Werner grade in predicting CC guidewire crossing success. From a historical point of view, this result can be expected as the Rentrop classification and Werner grade were initially introduced to predict myocardial viability of the CTO territory, whereas the J-Channel was specifically developed to aid in proper CC selection for a retrograde approach. Of note, neither grading system showed superiority in predicting technical CTO PCI success. A possible explanation might be that the interventionalist may utilize the hybrid algorithm, which allows for rapid alternation between different strategies and is known to enhance the technical success rate.[3,19] In case of failed CC tracking, technical CTO PCI success may still be achieved (either upfront or staged) by reverting to antegrade dissection and re-entry strategies such as limited antegrade subintimal tracking (LaST) or subintimal tracking and re-entry (STAR).[25] Another explanation for the low predictive value of the CC grading systems for technical CTO PCI success may lie in the lack of correlation between the J-CTO score (a strong predictor for technical success) and collateral channel grading systems (Supporting Information: Table 2). It should be emphasized that while the J-Channel score may facilitate a framework for CC selection, other factors set the stage for switching to a retrograde approach, such as proximal cap ambiguity or a poor distal target.[19] Furthermore, to maximize the likelihood of technical success in retrograde CTO PCI, proctorship has been proven to increase the number of performed retrograde procedures and subsequently raise success rates.[26,27] Together with routine assessment of the CTO lesion through grading systems before undertaking a retrograde approach, proctorship facilitates safe and efficient CTO PCI.

4.2 | Comparison of outcomes in CC type

In this study, we found a higher rate of CC guidewire crossing success in septal versus epicardial CCs. Moreover, technical CTO PCI success rate was higher in septal CCs. Current evidence on CC guidewire tracking success and technical CTO PCI success rates in different CC types is scarce. Generally, septal CCs are preferred over epicardial CCs due to a lower risk of perforation and subsequent tamponade.[28] In practice, the majority of CC guidewire tracking is performed through septal CCs (60%–65%), with epicardial CCs (20%–25%) representing a minority.[3,29] We report a modest difference in the percentile distribution of septal and epicardial CCs compared with the previously mentioned cohorts. Nagamatsu et al.[17] presented a similar distribution in their study of 630 retrograde CTO PCI cases, wherein CC guidewire crossing was attempted via septal CCs in 610 (69%) cases, and epicardial CCs in 204 (23%) cases. In this study, equal rates of CC guidewire tracking success between septal and epicardial CCs was reported. These results align with a previous study by Huang et al.,[14] showing no statistical difference among CC type. Equally, Huang et al.[14] reported comparable technical CTO PCI success rates for septal and epicardial CCs, which was not explored by Nagamatsu et al. In a third study by Benincasa et al.,[30] non-epicardial CCs are compared to epicardial CCs in 81 patients undergoing retrograde CTO PCI. The authors reported higher rates of successful CC guidewire crossing in non-epicardial CCs versus epicardial CCs (84% vs. 51%, $p = 0.002$), as well as higher technical success rates (76% vs. 35%, $p < 0.001$). Finally, Tsuchikane et al.[10] and Sianos et al.[31] displayed that septal CCs are favored for guidewire crossing, yet neither study explored the stratification to CC type for the detection of differences in outcome. Notwithstanding the inclination to choose septal CCs over epicardial CCs, the latter has emerged as a feasible and widely accepted option for guidewire tracking in retrograde CTO PCI. In a recent study, Simsek et al. described high technical CTO PCI success rates (81%) with similar and acceptable MACE rates when conducted by experienced operators (defined as >20 epicardial crossing attempts). In the absence of septal CCs amenable to guidewire tracking, epicardial CCs should thus not be branded as non-interventional and thereupon discarded in retrograde CTO PCI. However, it should be noted that coronary perforation rates are higher when epicardial CCs are selected, ranging from 7% to 17%.[15,32] Therefore, as the threshold for epicardial CC tracking may decrease, the operator's familiarity with complication management becomes increasingly essential).

4.3 | Study limitations

First, the choice of CCs for guidewire tracking was performed at the operator's discretion, possibly resulting in case selection bias. Second, CCs not selected for intervention were not assessed, therefore, data on the utilization of retrograde grading systems in the presence of

CENTRAL ILLUSTRATION 1 This study comprised 600 prospectively recruited patients who underwent single-vessel CTO PCI. In 257 patients, a retrograde approach was performed. The aim of this study was to investigate the predictive value of the J-Channel score, Rentrop classification, and Werner grade for CC guidewire crossing success and technical CTO PCI success. A high J-Channel score (≥3) was inversely associated with CC guidewire crossing success, whereas higher rates of CC guidewire crossing success were observed in cases with a high Rentrop classification score (3) and Werner grade (2). In comparative AUC analysis, the J-Channel score showed the highest discriminative capacity in predicting CC guidewire crossing success. Images of the Rentrop classification score, Werner grade, and J-Channel score are drawn from previously published reports by Galassi et al. and Nagamatsu et al.[17,34] AUC, area under the receiver operating characteristic curve; CC, collateral channel; CTO, chronic total coronary occlusion; J-Channel, Japanese Channel; PCI, percutaneous coronary intervention. [Color figure can be viewed at wileyonlinelibrary.com]

coexisting CCs is lacking. Third, the present study does not provide details on the chosen sequence of dedicated retrograde guidewires. Fourth, insight in the strategies applied by the interventionalists to overcome device crossing failure is lacking. Furthermore, CC grading was performed irrespective of the application of a tip injection, which could have hampered correct assessment of the CC anatomy. Finally, it should be noted that the process of external validation of a grading system in an independent cohort is subject to a decrease in performance, as the grading system is tailored to its derivation cohort.[33]

5 | CONCLUSION

In retrograde CTO PCI, failure to cross the collateral channels reduces the likelihood of achieving technical CTO PCI success. The J-Channel score might aid in strategic collateral channel selection before attempted guidewire crossing. However, the J-Channel score, Rentrop classification, and Werner grade have limited value in predicting technical CTO PCI success.

CONFLICT OF INTEREST STATEMENT

All the authors declare that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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