Collateral Channel Size and Tortuosity Predict Retrograde Percutaneous Coronary Intervention Success for Chronic Total Occlusion

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Background—There is little evidence on how to select an interventional collateral channel (CC) in retrograde chronic total occlusion (CTO) percutaneous coronary intervention. We aimed to identify independent angiographic predictors of CC tracking and technical success in retrograde CTO percutaneous coronary intervention.

Methods and Results—From January 2012 to December 2015, a total of 216 consecutive retrograde CTO percutaneous coronary intervention attempts by a high-volume operator in a tertiary university-affiliated hospital were enrolled. The clinical, angiographic, and procedural details were collected. The characteristics analyzed included channel type, size, tortuosity, angle of attack, length to emerging point, and the Multicenter CTO Registry of Japan score. The Multicenter CTO Registry of Japan score was 4.2±0.8. A total of 242 CCs were attempted for intervention. CC tracking success rate was 83.5%, and the technical success rate (per CC) was 81.4%. The per-patient technical success rate was 91.2%, and the major procedural complication rate was 4.6%. The atrioventricular groove, epicardial, and septal CCs were used in 36 (14.9%), 84 (34.7%), and 122 (50.4%) tracking attempts, respectively. In multivariable analysis, only large channel size and lack of tortuosity were significant independent predictors of CC tracking and technical success. A new scoring system was developed, while large size was given 1 point and lack of tortuosity was given 2 points. The receiver-operating characteristic area by the new model to predict CC tracking and technical success were 0.800 and 0.752, respectively.

Conclusions—In retrograde CTO percutaneous coronary intervention, only size and tortuosity of a CC are independent angiographic predictors of CC tracking and technical success. **(*Circ Cardiovasc Interv*. 2018;11:e005124. DOI: 10.1161/CIRCINTERVENTIONS.117.005124.)**

Key Words: collateral circulation ■ coronary angiography ■ percutaneous coronary intervention

Chronic total occlusion (CTO) comprises as high as 20% of all patients referred for diagnostic coronary angiography in daily practice.[1,2] Percutaneous coronary intervention (PCI) for CTO is technically challenging, associated with lower success and higher complication rates compared with non-CTO PCI.[3] Previous studies have demonstrated that successful CTO PCI might improve prognosis.[2,4–6] With recent advances in devices, techniques, and operator experience, the technical success rate of modern CTO PCI is consistently high with low complication rate.[7,8] Recently, a few scoring systems have been developed to predict procedural success in CTO PCI.[9–12] Retrograde approach has been developed and used worldwide recently, especially in challenging CTO lesions.[13] Some experts suggest antegrade approach as the default initial strategy and reserve retrograde only for reattempts.[14,15] When suitable, however, primary retrograde approach may still result in high success and low complication rates.[13,16–21] To select an adequate interventional collateral channel (CC) for tracking attempt is the crucial first step, but there is scarce literature for guidance. The aim of this study was to identify independent angiographic predictors of CC tracking and technical success in retrograde CTO PCI.

Methods

The data, analytic methods, and study materials will not be made available to other researchers for purposes of reproducing the results or replicating the procedure.

Patient Population

From January 2012 to December 2015, consecutive primary retrograde CTO PCI attempts by a high-volume operator (H.-L.K) in a tertiary university-affiliated hospital were enrolled. High-volume operator was defined as having >75 total CTO PCI cases and >20 retrograde attempts during the study period that was proposed by Thompson et al[15] in their

Received March 12, 2017; accepted November 27, 2017.

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WHAT IS KNOWN

- Percutaneous coronary intervention for chronic total occlusion (CTO) is technically challenging.
- Retrograde approach has been developed and used worldwide recently, especially in challenging CTO lesions.
- To select an adequate interventional collateral channel for tracking attempt is the crucial first step of retrograde CTO percutaneous coronary intervention, but the literature provides scarce guidance.

WHAT THE STUDY ADDS

- In retrograde CTO percutaneous coronary intervention, only size and tortuosity of a collateral channel are independent angiographic predictors of procedural outcomes.
- A new retrograde collateral channel scoring system may be helpful to guide the initial selection of collateral channel for tracking attempt in retrograde CTO percutaneous coronary intervention.

previous study. Coronary CTO was defined as a totally occluded segment with Thrombolysis in Myocardial Infarction flow grade 0 and an estimated duration of at least 3 months.[18] The clinical, angiographic, and procedural details were collected. The study was approved by the Institutional Review Board of National Taiwan University Hospital, Taipei, Taiwan. No informed consent was required for this study.

Study End Points

The major efficacy end points included CC tracking success rate and technical success rate (both were per CC). CC tracking success was defined as retrograde guidewire crossing the CC to reach the distal cap of CTO segment. Technical success was defined as successful CTO recanalization with <20% residual stenosis within the treated segment and restoration of Thrombolysis in Myocardial Infarction grade 3 antegrade flow. The safety end points were calculated per patient, including major procedural complications that developed before hospital discharge, such as death from any cause, myocardial infarction, recurrent angina requiring target vessel revascularization with PCI or coronary artery bypass grafting, cardiac tamponade requiring pericardiocentesis or surgery, or puncture site bleeding requiring transfusion or surgical management.

Angiographic Assessments

The angiographic characteristics included in the analysis were CC type (atrioventricular groove [AVG], epicardial, or septal; Figure 1), size, tortuosity, angle of attack (AoA), length to emerging point (LEP), and the Multicenter CTO Registry of Japan (J-CTO) score of the target CTO.[10] The size of CC was assessed by a 3-grade system (CC0, CC1, and CC2) proposed by Werner et al,[21] and CC2 was defined as large. The definition of tortuosity by McEntegart et al[22] was adopted in the present study. Channel tortuosity was defined as the presence of ≥2 high-frequency, successive curves (within 2 mm) in the context of epicardial collaterals and ≥1 high-frequency curve that failed to uncoil in diastole for septal channels (thus a measure of channel distensibility). A high-frequency curve is defined as a curve that is >180° occurring within a segment length <3× the diameter of the collateral. The AoA was defined as the angle at the convergence point between CC and the distal true vessel. A larger AoA was supposed to be less favorable for retrograde CTO segment crossing. The LEP was defined as the distance between the convergence point and the distal cap (Figure 2). A shorter LEP was presumed to be less favorable than a longer one for retrograde CTO crossing. For each CC

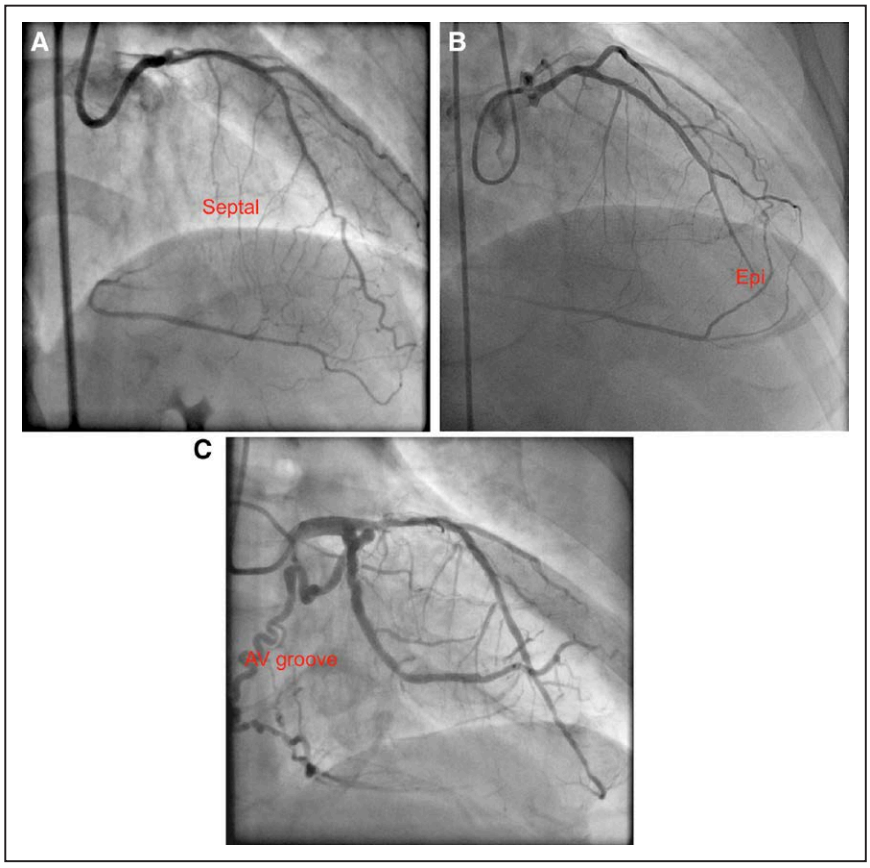

Figure 1. Collateral channel types. **A**, Septal type. **B**, Epicardial type. **C**, Atrioventricular groove (AVG) type.

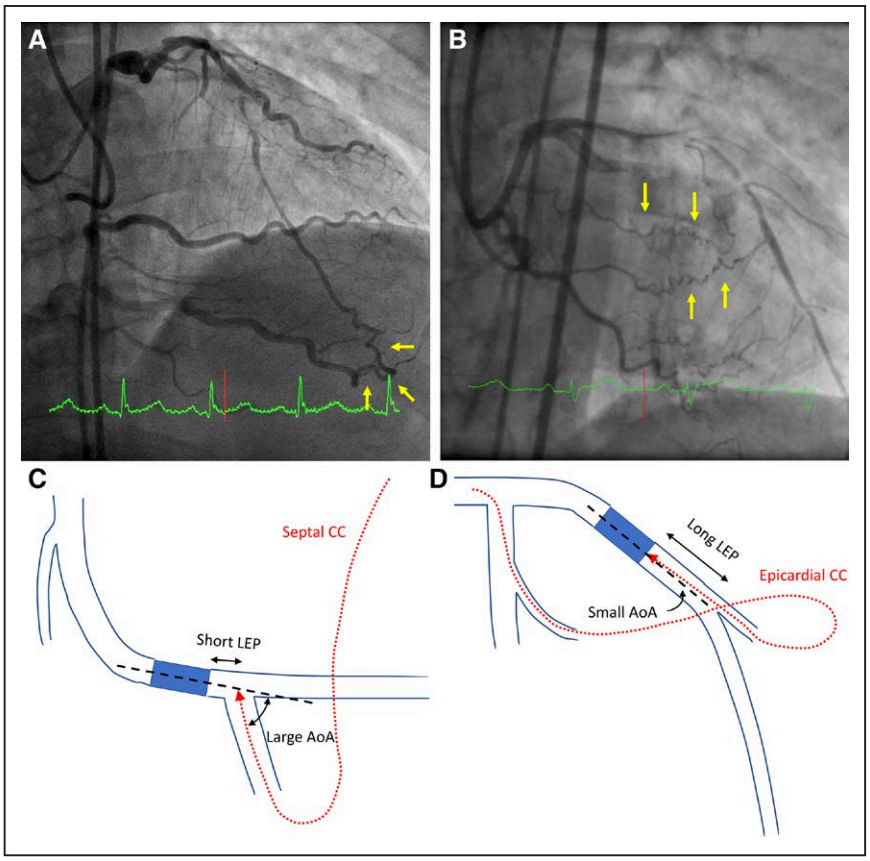

Figure 2. Angiographic characteristics of collateral channels. **A**, A large epicardial collateral channel without significant tortuosity from left anterior descending artery (LAD) to posterior descending artery (arrow). A few tiny septal collateral channels (CCs) from LAD to posterior descending arteries are also present. **B**, Tortuous epicardial collateral channels from right coronary artery (RCA) to LAD (arrows). **C**, A septal collateral channel from LAD to posterior descending artery with large angle of attack (AoA) and short length to emerging point (LEP). **D**, An epicardial CC from an obtuse marginal branch to a diagonal branch with small AoA and long LEP.

that was attempted, the channel type, size (large or small), tortuosity (lack or presence), AoA (< or ≥45°), and LEP (> or ≤5 mm) were all read by an independent interventionist and collected.

Interventional Strategies

All procedures were primary retrograde PCI, via femoral route. Retrograde would be chosen as primary approach in our institution if CTO anatomy was unfavorable for antegrade (proximal cap ambiguity, poor distal target vessel, long occlusion length, etc), of high (>3) J-CTO score, or was a reattempt case. If there were multiple CCs, the first to be attempted was selected based on factors including size, tortuosity, AoA, and LEP. The decision algorithm was shown in Figure 3. The CC tracking process was always started with a floppy wire, such as Sion or Sion Blue (both Asahi Intecc Co, Aichi, Japan) supported by a 150-cm microcatheter, either Finecross MG (Terumo Co, Tokyo, Japan) or Corsair (Asahi Intecc Co). Once the retrograde CC was tracked successfully with guidewire, the occlusion segment was then crossed with retrograde wire crossing, kissing wiring, or reverse controlled antegrade–retrograde subintimal tracking techniques.

Statistical Analysis

Categorical variables were presented as frequencies and percentages. Continuous variables were expressed as mean±SD. Differences in categorical variables were analyzed by χ^2 or Fisher exact test as appropriate. Logistic regression analysis was performed to identify angiographic factors that were associated with successful CC tracking and technical success. Variables with a P value <0.10 on univariable analysis were included in a multivariable model. A scoring system predicting CC tracking and technical success would be generated based on the result of the multivariable analysis. The discriminatory performance of the model was evaluated by the receiver-operating characteristics curve analysis. The area under curve was calculated. A P value <0.05 was considered statistically significant in all statistical analyses. All analyses were performed using STATA software (version 13; StataCorp, College Station, TX).

Results

Patient Population and Procedural Outcomes

A total of 216 primary retrograde CTO PCI attempts (50.2% out of a total of 430 CTO PCI attempts during the study

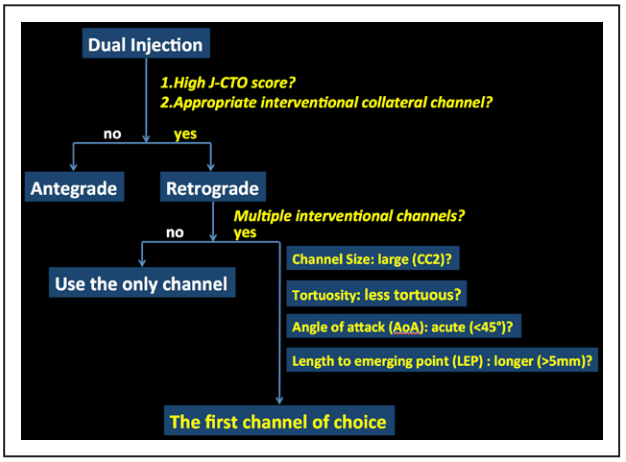

Figure 3. Interventional strategy algorithm in the present cohort. In lesions with high Multicenter CTO Registry of Japan (J-CTO) score with presence of interventional collateral channel (CC), a primary retrograde approach was selected. If there were multiple interventional CCs, a few CC-specific angiographic factors were taken into consideration. Then the first channel of choice was decided.

period) by a high-volume CTO PCI operator (H.-L.K) were enrolled in this study. The demographic and angiographic data were summarized in Table 1. Patients' mean age was 61.6±11.3 years, and 92.1% were male. Prior myocardial infarction was documented in 12.5% and prior coronary artery bypass grafting in 1.9%. More than half (54.7%) was reattempts with prior failures. The target CTO was located in right coronary artery in 61.1%, left anterior descending artery in 31.5%, and left circumflex artery in 7.4%. The documented duration of occlusion was 26.2±29.9 months, and the J-CTO score was 4.2±0.8. In 193 procedures (89.4%), only one CC was attempted, whereas in the other procedures, multiple CC tracking was attempted (2 CCs attempted in 20 procedures and 3 CCs attempts in 3 procedures). A total of 242 CCs were attempted for intervention. The AVG, epicardial, and septal CCs were used in 36 (14.9%), 84 (34.7%), and 122 (50.4%) tracking attempts, respectively. The procedural outcomes were shown in Table 2. By per CC analysis, the CC tracking success rate was 83.5% and the technical success rate was 81.4%.

Table 1. Demographic and Angiographic Characteristics

Per patient	
Variables	n=216
Age, y, (mean±SD)	61.6±11.3
Male sex (%)	199 (92.1%)
Diabetes mellitus (%)	68 (31.5%)
Hypertension (%)	175 (81.0%)
Hyperlipidemia (%)	119 (55.1%)
Smoking (%)	73 (33.8%)
Prior CABG (%)	4 (1.9%)
Prior MI (%)	27 (12.5%)
Prior failed attempt (%)	124 (54.7%)
CTO target vessel	
LAD (%)	68 (31.5%)
LCx (%)	16 (7.4%)
RCA (%)	132 (61.1%)
CTO duration, mo	26.2±29.9
J-CTO score	4.2±0.8
No. of channel attempted in the index procedure	
1	193 (89.4%)
2	20 (9.3%)
3	3 (1.5%)
Per collateral channel	
Channel type	n=242
Septal (%)	122 (50.4%)
Epicardial (%)	84 (34.7%)
AVG (%)	36 (14.9%)

AVG indicates atrioventricular groove; CABG, coronary artery bypass grafting; CTO, chronic total occlusion; J-CTO, Multicenter CTO Registry of Japan; LAD, left anterior descending artery; LCx, left circumflex artery; MI, myocardial infarction; and RCA, right coronary artery.

Table 2. Procedural Outcomes

Variables		*P* Value
Per CC (n=242)		
CC tracking success rate (%) (per CC)	202/242 (83.5%)	
Septal	100/122 (82.0%)	0.80
Epicardial	71/84 (84.5%)	
AVG	31/36 (86.1%)	
First CC attempted in a procedure	183/216 (84.7%)	0.30
Second CC attempted in a procedure	17/23 (73.9%)	
Third CC attempted in a procedure	2/3 (66.7%)	
Technical success rate (%) (per CC)	197/242 (81.4%)	
Septal	99/122 (81.1%)	0.77
Epicardial	70/84 (83.3%)	
AVG	28/36 (77.8%)	
First CC attempted in a procedure	178/216 (82.4%)	0.49
Second CC attempted in a procedure	17/23 (73.9%)	
Third CC attempted in a procedure	2/3 (66.7%)	
CC perforation-related cardiac tamponade	5/242 (2.07%)	
Septal	1/122 (0.81%)	0.31
Epicardial	3/84 (3.57%)	
AVG	1/36 (2.78%)	
Per patient (n=216)		
Technical success rate (%)	197/216 (91.2%)	
Major complication rate (%)	10/216 (4.6%)	
Procedure time, min	123.8±39.1	
Fluoroscopy time, min	52.8±19.9	
Fluoroscopy dose, Gy	6.4±2.9	
Contrast medium consumption, mL	303.9±94.8	

AVG indicates atrioventricular groove; and CC, collateral channel.

There was no significant statistical difference among the 3 CC types (AVG, epicardial, and septal) in terms of tracking and technical success rates. When CC tracking was successful, technical success was almost guaranteed (97.5%, 197/202). By per-patient analysis, technical success rate was 91.2%, and major procedural complication rate was 4.6% (5 patients with cardiac tamponade, 4 with non–ST-segment–elevation myocardial infarction, and 1 with puncture site bleeding requiring transfusion). The procedure and fluoroscopy times were 123.8±39.1 and 52.8±19.9 minutes, respectively. The total radiation exposure and contrast medium consumption were 6.4±2.9 Gy and 303.9±94.8 mL, respectively.

Logistic Regression Analysis to Identify Possible Predictors and to Develop a Scoring System

All the important angiographic variables including CC type, size, tortuosity, AoA, LEP, the J-CTO score, and whether a CC was the first channel to be used in a procedure were included in the univariable logistic regression analysis. Only large size, lack of tortuosity, and AoA <45° were associated with CC

Table 3. Univariable and Multivariable Analyses for Predictors of Successful CC Tracking

	Univariable		Multivariable	
	OR (95% CI)	*P* Value	OR (95% CI)	*P* Value
Large size	4.14 (2.05–8.38)	<0.001	2.94 (1.35–6.43)	0.007
Lack of tortuosity	9.93 (4.32–22.83)	<0.001	9.02 (3.77–21.5)	<0.001
AoA <45°	1.82 (0.9–3.69)	0.096	1.12 (0.5–2.53)	0.78
LEP >5 mm	0.66 (0.2–2.12)	0.48		
AVG	1.27 (0.46–3.49)	0.65		
Epicardial	1.13 (0.55–2.32)	0.75		
Septal	0.80 (0.41–1.59)	0.53	0.68 (0.31–1.51)	0.35
J-CTO score	0.75 (0.47–1.2)	0.23		
First CC attempted	2.03 (0.79–5.21)	0.14		

AoA indicates angle of attack; AVG, atrioventricular groove; CC, collateral channel; CI, confidence interval; J-CTO, Multicenter CTO Registry of Japan; LEP, length to emerging point; and OR, odd ratio.

tracking and technical success with a *P* value <0.10. The 3 variables were then included in the multivariable model along with channel type (septal). Only large size and lack of tortuosity were proven to be independent significant predictors of CC tracking and technical success, but not AoA <45°, channel type, or whether a CC was the first channel to be used (Tables 3 and 4). The results were similar when considering the first attempt only. We then constructed a new scoring system, by assigning 2 points to lack of tortuosity and 1 point to large size for each CC, weighed to their relative odds ratios. The relationship between this new CC score and the 2 major efficacy end points was shown in Figure 4. The ROC curves by the new model to predict procedural outcomes were shown in Figure 5. The area under the curve to predict CC tracking success and to predict technical success was 0.800 and 0.752, respectively.

Table 4. Univariable and Multivariable Analyses for Predictors of Technical Success

	Univariable		Multivariable	
	OR (95% CI)	*P* Value	OR (95% CI)	*P* Value
Large size	3.14 (1.6–6.14)	0.001	2.27 (1.08–4.75)	0.029
Lack of tortuosity	6.75 (3.26–14)	<0.001	5.87 (2.76–12.5)	<0.001
AoA<45°	1.79 (0.92–3.51)	0.088	1.18 (0.55–2.49)	0.661
LEP >5 mm	0.79 (0.27–2.28)	0.663		
AVG	0.77 (0.32–1.82)	0.545		
Epicardial	1.22 (0.61–2.45)	0.574		
Septal	0.97 (0.51–1.85)	0.917	0.88 (0.42–1.83)	0.737
J-CTO score	0.71 (0.45–1.11)	0.135		
First CC attempted	1.71 (0.67–4.37)	0.257		

AoA indicates angle of attack; AVG, atrioventricular groove; CC, collateral channel; CI, confidence interval; CTO, chronic total occlusion; J-CTO, Multicenter CTO Registry of Japan; LEP, length to emerging point; and OR, odd ratio.

Discussion

CTO PCI is technically challenging with lower success and higher complication rates compared with non-CTO PCI in the past.[3] Recent progress in devices, techniques, and experiences has resulted in improved success and complication rates.[7,8] Retrograde approach was developed as an alternative in challenging CTO cases, especially when failed antegradely. Some experts recommended antegrade approach as the default initial strategy and reserve retrograde approach only for reattempts.[14,15] This was mainly because of previous observations that retrograde CTO PCI was associated with lower success and higher complication rates, in comparison to antegrade-only procedures.[13] However, in certain situations, primary retrograde approach may actually achieve success more efficiently.[13,16–21] Brilakis et al,[16] in their proposed treatment algorithm for CTO PCI, have indicated scenarios (ambiguous proximal cap, poor distal target, and existence of interventional collateral) where primary retrograde approach would be reasonable. But in actual procedures, the choice of approach may still be variable and lacking specific guidance.

Scoring systems have been constructed to predict success and guide patient/lesion selection in CTO PCI. This is especially crucial for inexperienced operators. The J-CTO score is the first ever published to evaluate lesion complexity and predict procedural outcome,[9] and there are at least 3 other systems reported.[10–12] All of these scoring systems were derived and validated by data set comprising antegrade only or mainly antegrade procedures. For example, the percentage of retrograde procedure in J-CTO registry was only 26.9%[9]; hence, the predictive performance of these systems in retrograde CTO PCI might be questionable. A scoring system with specific indications for primary retrograde approach would be helpful for interventionists to predict procedure outcome and to plan intervention strategy more efficiently. Although the recent PROGRESS CTO (Prospective Global Registry for the Study of Chronic Total Occlusion Intervention) included absence of interventional collaterals to predict overall success rate, but it is not used to decide initial approach.[11] Moreover, there was no clear definition of the so-called interventional channel. In addition, tracking of an adequate CC is the first and most crucial step of retrograde procedure. This is shown clearly in the present study, as the final technical success could be achieved in 97.5% (197/202) of the cases with successful CC tracking. However, consensus on the choice of CC is lacking in any of the previous literature.

To our best knowledge, the present study was one of the first to investigate the relationship between CC-specific angiographic factors and procedural outcomes, based on a pure retrograde data set. Among the factors evaluated in our study, only large size (CC2) and lack of tortuosity could predict CC tracking and technical success. The size and tortuosity of a CC can be semiquantified using standard definition.[21,22] Previously, Chai et al[23] also reported that only collateral size, tortuosity, and diameter of distal segment were independent predictors of procedural success in their retrograde study cohort. However, some presumably important angiographic factors specific for CCs, such as AoA and LEP, were not evaluated in their regression model. The present study included most (if not all) of the important CC-specific angiographic factors and confirmed that CC size and tortuosity were true

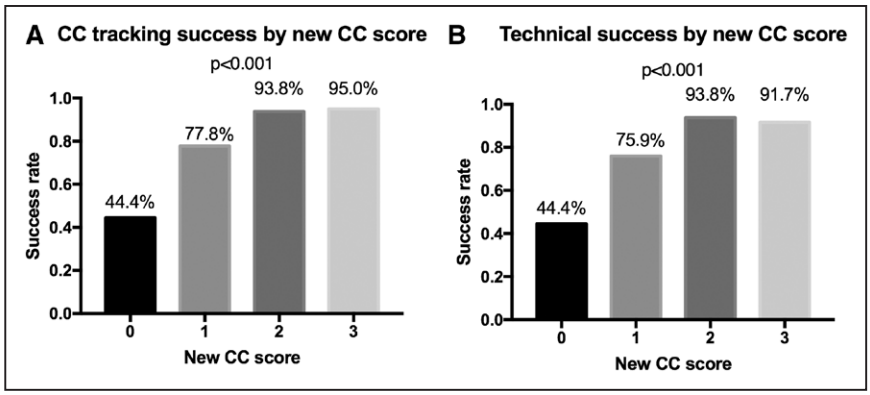

Figure 4. Relationship between new retrograde collateral channel (CC) scores and procedural outcomes. In groups with high retrograde score (2 and 3), both the CC tracking and technical success rates were >90%.

independent predictors of retrograde procedural outcomes. A larger CC will accommodate devices better with less tracking friction, and a less tortuous CC will obviously reduce the difficulty in traversing. Of note is that the impact of CC tortuosity outweighs CC size by a factor of 2 in our current study. The profiles of modern guidewires and microcatheters have been reduced significantly. But finesse in wiring techniques is still required for operators to negotiate channel tortuosity. According to our findings, a CC with less tortuosity should be attempted first, despite a smaller channel size.

Another interesting finding is that CC type was found to be insignificant in the selection. We classify CCs into 3 types, because of the specific consequences once they are damaged. Although septal CC has been recommended as the CC of choice for its safety,[24] catastrophic hematoma after septal CC rupture has been reported.[25,26] Unlike the pericardial tamponade after epicardial CC rupture that can be easily diagnosed and managed with drainage, enlarging septal hematoma may be very difficult to control. We propose to separate AVG CC from other epicardial CCs, as unique left atrial wall hematoma causing acute mitral regurgitation may occur after its rupture.[27] The latter is different from tamponade after epicardial CC rupture and is even more difficult to manage. In the current study, CC tracking and technical success rates were not different among all 3 CC types, and channel type did not predict procedural outcomes. Only 5 CC ruptures resulted in tamponade in the current series: 1 (0.81%, 1/122), 3 (3.57%, 3/84), and 1 (2.78%, 1/36) in the septal, epicardial, and AVG channels, respectively. Even we lumped the AVG and epicardial as nonseptal, there was still no significant difference between septal and nonseptal groups (1/122 versus 4/120; P=0.171). Chai et al[23] also showed that channel type (septal, epicardial, or saphenous vein graft) was not an independent predictor of successful retrograde procedure in their study cohort. We think that as long as being selected properly by size and tortuosity, all types of CCs are effective for retrograde approach.

The J-CTO score, although a well-adopted tool to evaluate lesion complexity and to predict antegrade wire crossing, could not predict procedural outcomes in our retrograde-only series. In the present cohort of primary retrograde approach with extremely high J-CTO scores (4.2±0.8) and reattempts, it is therefore not surprising that J-CTO score predicts the success rate poorly. Our scoring system, on the other hand, predicted the likelihood of procedural success very well. If a retrograde score is ≥2, a >90% technical success rate for retrograde procedure can be expected regardless of a high J-CTO score. Our algorithm, based on CC-specific angiographic factors, is also very helpful for CC selection. This will offer a clear and structured guidance on the choice of initial approach, and CC channel selection

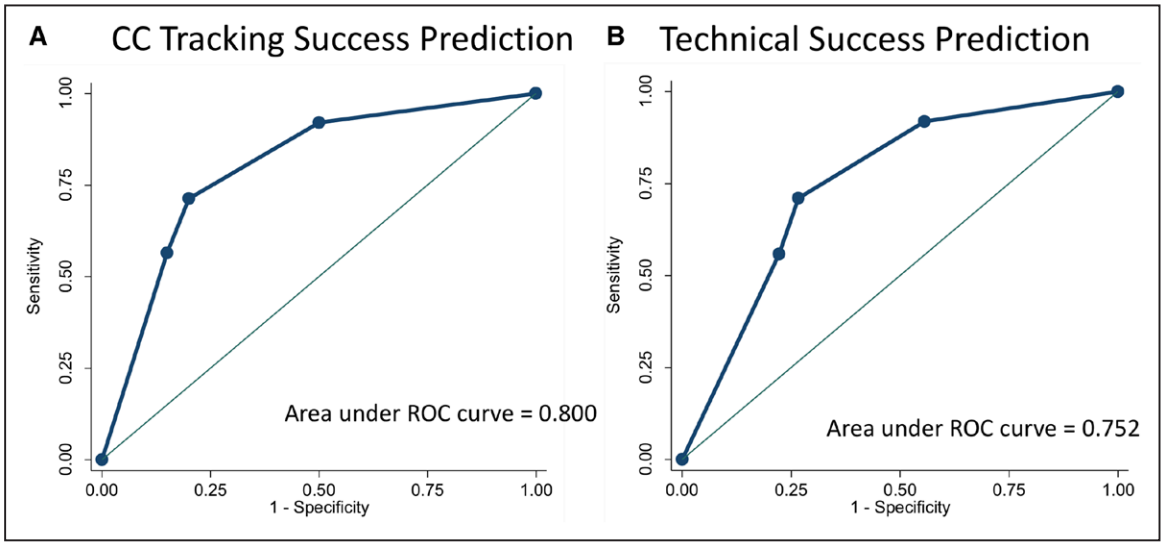

Figure 5. Predictive performance of the new collateral channel scoring system in retrograde CTO PCI. The new retrograde collateral channel (CC) score to predict CC tracking success (**A**) and technical success (**B**), expressed as receiver-operating characteristic (ROC) curves.

should retrograde approach is considered. We think our scoring system is useful in future scientific communications and comparisons of different patient populations, especially in retrograde CTO PCI.

Study Limitations

This was a retrospective registry with relatively small sample size. All procedures were done by a high-volume CTO PCI operator, and the majority of cases were referred with prior failures. Selection bias in patients, interventional strategy, and priority CC could potentially exist. Like other reported scoring series, therefore, extrapolation of results should be cautious. Future large prospective registry is needed to validate our findings and to compare with existing algorithm/scoring systems, such as the Hybrid algorithm, or PROGRESS score[11] on their predictive performance. Septal surfing technique[28] was not adopted in this study. Because CCs of less tortuosity and larger size had priority in our prespecified selection algorithm, only visible channels were evaluated and attempted. Therefore, evaluation of effectiveness and safety of this technique was not feasible in the current study. As only CCs attempted were analyzed, comparison between attempted and nonattempted CCs on efficacy and safety was not possible. But we emphasize that a prespecified algorithm for CC choice was adopted in the present study.

Conclusions

In retrograde CTO PCI, CC size and tortuosity were the only independent angiographic predictors for successful CC tracking and technical success. A retrograde score of ≥2 points predicts a >90% technical success rate.

Acknowledgments

We thank Kuo-Liong Chien (Institute of Preventive Medicine, School of Public Health, National Taiwan University, and Department of Internal Medicine, National Taiwan University Medical College and National Taiwan University Hospital, Taipei, Taiwan) for his statistical support. We thank the staff of the Eighth Core Laboratory, Department of Medical Research, National Taiwan University Hospital for technical support during the study.

Sources of Funding

This work received unrestricted financial support for research from Taiwan Health Foundation.

Disclosures

None.

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Collateral Channel Size and Tortuosity Predict Retrograde Percutaneous Coronary Intervention Success for Chronic Total Occlusion

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Circ Cardiovasc Interv. 2018;11:
doi: 10.1161/CIRCINTERVENTIONS.117.005124
Circulation: Cardiovascular Interventions is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231

Print ISSN: 1941-7640. Online ISSN: 1941-7632