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Microcatheter collateral channel tracking failure in retrograde percutaneous coronary intervention for chronic total occlusion: incidence, predictors, and management

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KEYWORDS

- chronic coronary total occlusion
- clinical research
- risk stratification

Abstract

Aims: This study sought to demonstrate the incidence, predictors, and management of microcatheter collateral channel (CC) tracking failure in retrograde percutaneous coronary intervention (PCI) for chronic total occlusion (CTO) lesions.

Methods and results: Prospectively collected data from 371 consecutive retrograde CTO-PCI procedures between March 2015 and January 2018 were retrospectively analysed. The incidence of initial microcatheter CC tracking failure was 22.5% in 280 procedures with wire CC tracking success. For septal collaterals, CC grade 0-1 collaterals (odds ratio [OR]: 8.3; p<0.001), channel entry angle <90° (OR: 13.0; p=0.001), channel exit angle <90° (OR: 44.3; p=0.004), and Finecross MG as initial microcatheter (OR: 2.7; p=0.032) were independently related to initial microcatheter CC tracking failure. Meanwhile, the only predictor for epicardial collaterals was CC 1 collaterals (OR: 26.9; p<0.001). Frequently applied solutions included microcatheter switching (61.9%), and microcatheter switching combined with GUIDEZILLA (14.3%) or anchoring balloon technique (6.3%).

Conclusions: Initial microcatheter CC tracking failure was found in nearly one quarter of procedures after wire CC tracking success. Independent angiographic predictors of initial microcatheter CC tracking failure included CC 0-1 collaterals, channel entry angle <90°, and channel exit angle <90° for septal collaterals, and CC 1 collaterals for epicardial collaterals.

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Abbreviations

CART	controlled antegrade or retrograde subintimal tracking
CC	collateral channel
CTO	chronic total occlusion
MACCE	major adverse cardiac and cerebrovascular events
MI	myocardial infarction
PCI	percutaneous coronary intervention
TIMI	Thrombolysis In Myocardial Infarction

Introduction

Chronic total occlusion (CTO) lesions have been observed in as many as 16~18% of patients with coronary artery disease (CAD) referred for a coronary angiogram[1,2]. Previous studies have demonstrated that successful percutaneous coronary intervention (PCI) for CTO yields beneficial effects including symptom relief, improving quality of life, and improving left ventricular function[3-6]. However, even with emerging new techniques and novel devices, percutaneous treatment of CTO lesions remains a major challenge[7].

Over the last decade, the retrograde approach has improved the success rate of CTO-PCI remarkably[8-11]. Selection of a suitable collateral channel (CC) for both wire and microcatheter tracking is vital for retrograde intervention. Nevertheless, even after wire CC tracking success, retrograde microcatheter CC tracking remains a challenge in some cases. To the best of our knowledge, data on microcatheter CC tracking in retrograde CTO-PCI are very limited. Moreover, the management and procedural outcome of microcatheter CC tracking failure have not been well elucidated.

In the present study, we evaluated the incidence, predictors, and management of microcatheter CC tracking failure in retrograde CTO-PCI.

Methods

STUDY POPULATION

Prospectively collected data for patients who underwent retrograde CTO-PCI performed at the Shanghai Institute of Cardiovascular Diseases, Zhongshan Hospital, Shanghai, were retrospectively analysed. Between March 2015 and January 2018, 371 consecutive retrograde CTO-PCI cases were screened from the database of the Chronic Total Occlusion Club, China (CTOCC). No attempted retrograde case was excluded. According to current clinical practice, only when patients displayed symptoms of ischaemia or when ischaemia was confirmed by non-invasive assessments related to occlusive coronary arteries was recanalisation therapy performed[12,13]. A total of four high-volume operators (>100 total CTO-PCI cases per year) and seven non-high-volume operators participated in the present study. Baseline characteristics, angiographic characteristics, procedural parameters, and in-hospital events were collected via electronic case report forms. The study complied with the Declaration of Helsinki. All patients provided informed consent for both the procedure and subsequent data collection and analysis for research purposes. The research protocol was approved by the ethics committee of Zhongshan Hospital.

DEFINITIONS

CTO was defined as Thrombolysis In Myocardial Infarction (TIMI) grade 0 flow and the duration of coronary occlusion ≥3 months[7,14,15]. The J-CTO score was calculated according to the study reported by Morino et al[16]. CC grade was defined according to the report by Werner et al[17]. Tortuosity, as defined by McEntegart et al[18] and CC score, as defined by Huang et al[19] were adopted in the present study. Adverse channel entry and exit angles were defined using a cut-off angle <90°[18]. Morphological assessments of first attempted collaterals were recorded for retrograde wire tracking failure procedures. All of the angiograms were reviewed by at least two qualified interventional cardiologists. If there were any ambiguities in the evaluation of angiograms, the angiograms were then subjected to independent review by a third qualified interventional cardiologist.

Retrograde wire CC tracking success was defined as the retrograde wire crossing the collateral to reach the distal cap of the CTO segment[19]. Procedural success was defined as a restoration of TIMI flow grade 3 in the target vessel and a residual stenosis <30% by visual estimation. Clinical success was defined as achievement of procedural success without in-hospital major adverse cardiac and cerebrovascular events (MACCE), which included death from all causes, Q-wave myocardial infarction (MI), stent thrombosis[20], ischaemia-driven revascularisation, and stroke. Procedural complications were defined as donor vessel dissection, vessel perforation[21], cardiac tamponade, cardiac tamponade requiring pericardiocentesis, emergent PCI, and emergent coronary artery bypass grafting (CABG).

INTERVENTIONAL PROCEDURES

All patients without a contraindication received dual antiplatelet therapy (aspirin and clopidogrel/ticagrelor). Heparin was introduced intravenously to achieve an activated clotting time of 300 to 350 seconds during the procedure. Selection of vascular access site was at the operator's discretion, and bilateral coronary injections were performed to evaluate CTO lesion morphology. The retrograde approach was used as the primary approach or after failure of the antegrade approach. The retrograde approach was initiated by manipulating a floppy wire into a CC supported by a 150 cm microcatheter[22], such as the Corsair™ (Asahi Intecc, Aichi, Japan), Finecross® MG (Terumo Corp., Tokyo, Japan) or other microcatheters. The wires used for CC tracking included SION® (Asahi Intecc), SION® black (Asahi Intecc), SION® blue (Asahi Intecc), SUOH 03 (Asahi Intecc), Fielder™ XT-R (Asahi Intecc), Fielder™ FC (Asahi Intecc), and Runthrough® NS (Terumo Corp.). After wire CC tracking success, microcatheter advancement through the CC was attempted. Utilisation of the retrograde wire technique depended on the patient's coronary anatomy and general condition during the procedure. Generally, retrograde wire crossing and the kissing wire technique were preferred for short lesions, and the reverse controlled antegrade or retrograde subintimal tracking (CART) technique[9,23] for longer lesions. After recanalisation, drug-eluting stents were implanted to achieve procedural success.

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STATISTICAL ANALYSIS

The data are expressed as the mean±SD for the continuous variables and as frequencies for the categorical variables. The comparison of continuous variables was performed by the independent Student's t-test or the Mann-Whitney U test, as appropriate. Statistical analysis of the categorical variables was performed using Pearson's chi-square or Fisher's exact test (when at least 25% of values showed expected cell frequencies <5), as appropriate. Stepwise logistic regression analysis was conducted to identify the angiographic and procedural predictors. Univariate analysis was initially performed and univariate variables with p-values <0.05 were thereafter included in the multivariate model. P-values were two-tailed, and p<0.05 was considered statistically significant. The data were analysed using statistical software SPSS, Version 20.0 (IBM Corp., Armonk, NY, USA).

Results

BASELINE CHARACTERISTICS AND CLINICAL OUTCOMES

The baseline clinical characteristics are summarised in **Table 1**. In the present study, a procedural success rate of 76.5% (284/371) and a clinical success rate of 76.0% (282/371) were achieved. No deaths were observed. Three occurrences of Q-wave MI were adjudicated, two of which were related to the occlusion of diagonal branches proximal to left anterior descending artery CTOs; the third was due to stent implantation in the false lumen followed by subacute stent thrombosis. One patient was recommended for bypass surgery four days after the index procedure of a failed right coronary artery CTO-PCI. In terms of complications, the occurrence of donor vessel dissection and target vessel perforation was 0.8% (3/371) and 2.4% (9/371), respectively. Collateral perforations, consisting of 11 septal and 16 epicardial collateral perforations, occurred in 7.3% of all cases. A total of nine (2.4%) cases exhibited pericardial tamponade, and pericardiocentesis was performed in eight (2.2%) cases. One patient, in whom delayed pericardial tamponade was found, was only given conservative treatment due to gradually decreased pericardial effusion.

Table 1. Baseline patient characteristics and clinical results.

		Overall (n=371)
Gender, male		329 (88.7)
Age, years		60.4±11.3
Clinical presentation	Asymptomatic	9 (2.4)
	Stable angina	334 (90.0)
	Unstable angina	17 (4.6)
	NSTEMI	11 (3.0)
Hypertension		245 (66.0)
Diabetes		111 (29.9)
Insulin-treated		21 (5.7)
Dyslipidaemia on admission		191 (51.5)
Prior MI		106 (28.6)
Prior CABG		21 (5.7)
Smoking		185 (49.9)
LVEF		59.9±8.6
Wire collateral tracking success		280 (75.5)
Procedural success		284 (76.5)
Clinical success		282 (76.0)
In-hospital major adverse cardiac and cerebrovascular events	All-cause death	0 (0)
	Q-wave MI	3 (0.8)
	Stent thrombosis	1 (0.3)
	Ischaemia-driven revascularisation	1 (0.3)
	Stroke	0 (0)
Procedural complications	Donor vessel dissection	3 (0.8)
	Target vessel perforation	9 (2.4)
	Collateral perforation	27 (7.3)
	Cardiac tamponade	9 (2.4)
	Cardiac tamponade requiring pericardiocentesis	8 (2.2)
	Emergent PCI	0 (0)
	Emergent CABG	0 (0)

Values are mean±SD or n (%). CABG: coronary artery bypass grafting; LVEF: left ventricular ejection fraction; MI: myocardial infarction; NSTEMI: non-ST-segment elevation myocardial infarction; PCI: percutaneous coronary intervention

EVALUATION OF RETROGRADE WIRE CC TRACKING

The overall success rate of wire CC tracking was 75.5% (280/371). A detailed analysis of the retrograde wire CC tracking is shown in **Supplementary Appendix 1** and **Supplementary Table 1**.

EVALUATION OF RETROGRADE MICROCATHETER CC TRACKING

Among 280 procedures with wire CC tracking success, initial microcatheter collateral tracking failure occurred in 63 (22.5%) procedures. Stepwise logistic regression analysis was performed to identify angiographic factors for predicting initial microcatheter CC tracking failure **(Table 2)**. A detailed incidence of serial variables is shown in **Supplementary Table 2**. For septal collaterals (n=199), CC 0-1 collaterals (odds ratio [OR]: 8.3, 95% confidence interval [CI]: 2.7-26.1, p<0.001), channel entry angle <90° (OR: 13.0, 95% CI: 3.0-57.1, p=0.001), channel exit angle <90° (OR: 44.3, 95% CI: 3.4-577.6, p=0.004), and Finecross MG as initial microcatheter (OR: 2.7, 95% CI: 1.1-6.5, p=0.032) were independently related to initial microcatheter CC tracking failure. Meanwhile, the only independent predictor for epicardial collaterals was CC 1 collaterals (OR: 26.9, 95% CI: 5.4-134.2, p<0.001) (n=76). After wire CC tracking success, several retrograde wire techniques were deployed - retrograde wire crossing (35.4%), kissing wire (15.4%), and reverse CART technique (41.1%).

In 63 initial microcatheter CC tracking failures, 51 procedures achieved final microcatheter CC tracking success after subsequent attempts; five procedures switched to kissing wire technique, and seven procedures failed to advance the microcatheter through collaterals after various attempts. Overall, the final

Table 2. Univariable and multivariable analyses for angiographic predictors of initial microcatheter CC tracking failure in septal and epicardial collaterals.

	Septal collateral				Epicardial collateral			
	Univariable		Multivariable		Univariable		Multivariable	
	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
RCA to LAD septal	1.4 (0.7–2.7)	0.382	–	–	–	–	–	–
Ipsilateral collateral	–	–	–	–	3.5 (1.1–10.5)	0.028	2.1 (0.4–10.2)	0.380
High-volume operator	0.9 (0.4–2.1)	0.838	–	–	6.5 (0.8–52.7)	0.081	–	–
CC 0-1 collaterals*	7.0 (2.6–18.8)	<0.001	8.3 (2.7–26.1)	<0.001	36.7 (8.0–167.7)	<0.001	26.9 (5.4–134.2)	<0.001
Severe collateral tortuosity	1.3 (0.6–2.5)	0.511			2.0 (0.6–6.3)	0.250	–	–
Channel entry angle <90°	13.5 (3.5–52.5)	<0.001	13.0 (3.0–57.1)	0.001	28.5 (3.1–258.9)	0.003	9.6 (0.7–139.0)	0.099
Channel exit angle <90°	15.9 (1.7–146.3)	0.015	44.3 (3.4–577.6)	0.004	2.3 (0.4–14.9)	0.386	–	–
Retrograde from radial	0.8 (0.4–1.5)	0.424	–	–	0.8 (0.3–2.7)	0.756	–	–
Retrograde guide catheter with strong support	1.0 (0.4–2.1)	0.938	–	–	2.3 (0.6–8.8)	0.242	–	–
Retrograde guide catheter size	1.1 (0.6–2.0)	0.764	–	–	0.9 (0.3–2.8)	0.883	–	–
Finecross MG as initial microcatheter	2.7 (1.2–5.7)	0.013	2.7 (1.1–6.5)	0.032	2.1 (0.7–6.5)	0.177	–	–

* CC grade 1 for epicardial collateral. CC: collateral channel; CI: confidence interval; LAD: left anterior descending artery; OR: odds ratio; RCA: right coronary artery

success rate of microcatheter CC tracking achieved was 95.7% (268/280) after management. The detailed management of final microcatheter CC tracking success is illustrated in **Figure 1** and **Supplementary Table 3**. Frequently applied solutions included simple microcatheter switching (61.9%, 39/63), and microcatheter switching combined with GUIDEZILLA™ (Boston Scientific, Marlborough, MA, USA) (14.3%, 9/63), anchoring balloon technique (6.3%, 4/63), or septal collateral dilation (3.2%, 2/63). Other measures included independent application of GUIDEZILLA support (4.8%, 3/63) or anchoring balloon technique (1.6%, 1/63). A detailed distribution of initial microcatheter selection in different collaterals is shown in **Figure 2**. In all 54 microcatheter switching attempts, 28 switched from Corsair to other microcatheters and 26 switched from Finecross MG to other microcatheters **(Figure 1, Supplementary Table 3)**. No complications were related to microcatheter switching and the other measures mentioned above.

LOGISTIC REGRESSION ANALYSIS TO IDENTIFY POSSIBLE PREDICTORS OF RETROGRADE PROCEDURE FAILURE

Table 3 presents the stepwise logistic regression analysis performed to identify angiographic factors for predicting retrograde procedure failure after wire CC tracking success (n=280). In univariate analysis, CC 0-1 collaterals, channel exit angle <90°, retrograde guide catheter with strong support, and retrograde guide catheter size were related to the retrograde procedure outcome. A multivariate model showed that CC 0-1 collaterals (OR: 1.8, 95% CI: 1.1-3.2, p=0.031) and channel exit angle <90° (OR: 5.1, 95% CI: 1.3-19.4, p=0.017) were associated with retrograde procedure failure. Meanwhile, a retrograde guide catheter with strong support (OR: 0.5, 95% CI: 0.3-1.0, p=0.046) was revealed to be a negative predictor of retrograde procedure failure.

Table 3. Univariable and multivariable analyses for retrograde procedure failure after wire CC tracking success.

	Univariable		Multivariable	
	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Reattempted lesion	1.0 (0.6–1.8)	0.950	–	–
ISR CTO	0.4 (0.1–1.9)	0.269	–	–
Blunt stump	1.2 (0.6–2.4)	0.670	–	–
Calcification	1.7 (0.9–3.2)	0.125	–	–
Vessel tortuosity	1.5 (0.8–2.6)	0.176	–	–
Occlusion length >20 mm	0.8 (0.4–1.6)	0.593	–	–
High-volume operator	0.6 (0.3–1.0)	0.057	–	–
Septal collateral used	1.0 (0.6–1.8)	0.935	–	–
Epicardial collateral used	1.0 (0.6–1.8)	0.976	–	–
Ipsilateral collateral	1.4 (0.6–3.2)	0.476	–	–
CC 0-1 collaterals	1.7 (1.0–2.9)	0.043	1.8 (1.1–3.2)	0.031
Severe collateral tortuosity	1.2 (0.7–2.0)	0.504	–	–
Channel entry angle <90°	2.3 (0.9–5.8)	0.076	–	–
Channel exit angle <90°	4.2 (1.2–15.3)	0.030	5.1 (1.3–19.4)	0.017
Retrograde from radial	1.4 (0.8–2.6)	0.232	–	–
Retrograde guide catheter with strong support	0.5 (0.3–1.0)	0.036	0.5 (0.3–1.0)	0.046
Retrograde guide catheter size	0.6 (0.3–1.0)	0.044	0.6 (0.3–1.1)	0.115
Finecross MG as initial microcatheter	1.6 (0.9–2.8)	0.093	–	–

CC: collateral channel; CI: confidence interval; CTO: chronic total occlusion; ISR: in-stent restenosis; OR: odds ratio

Discussion

The main findings of the present study can be summarised as follows: 1) initial microcatheter CC tracking failure was found in 22.5% of cases after wire CC tracking success; 2) for septal

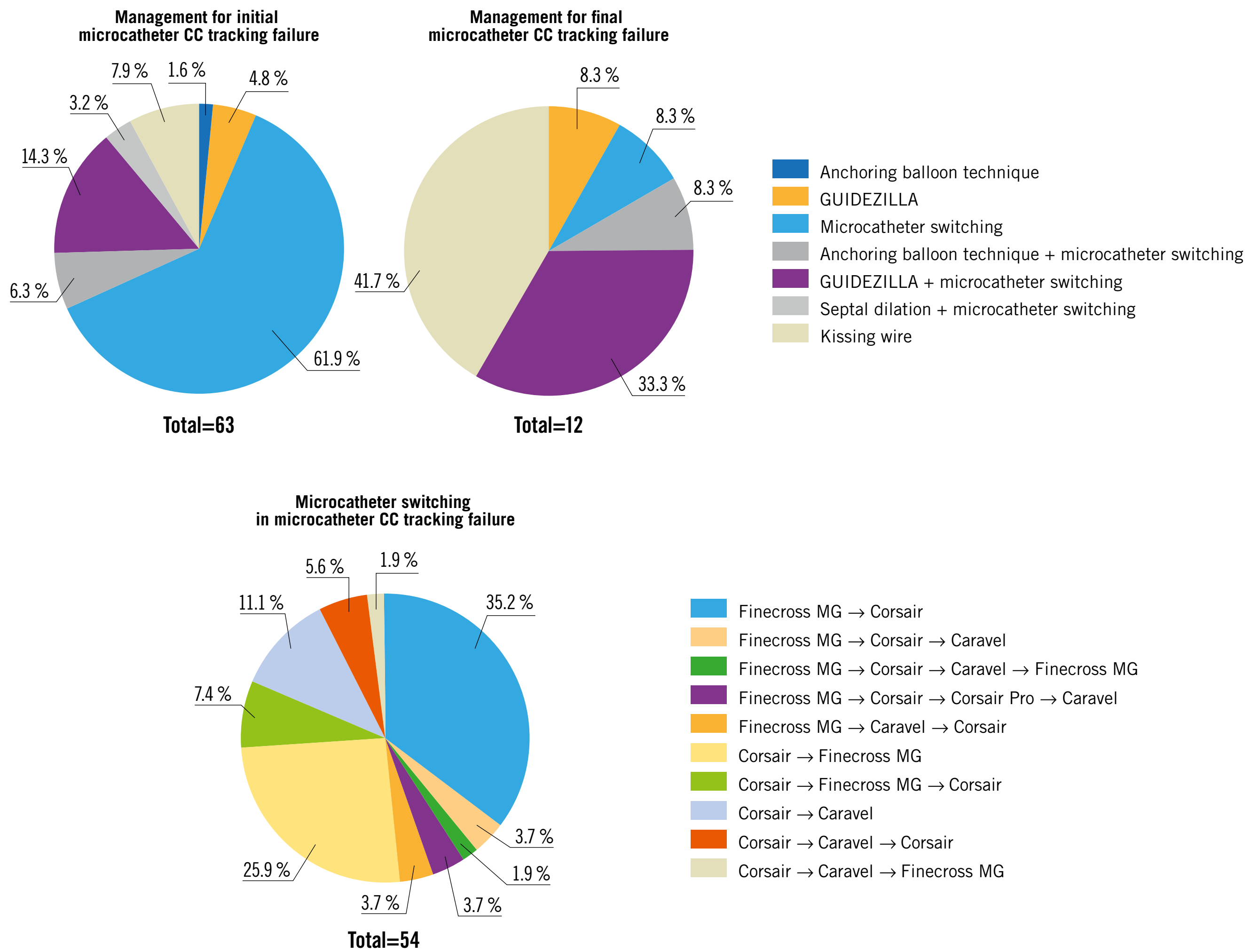

Figure 1. *Detailed management of microcatheter CC tracking failure. CC: collateral channel*

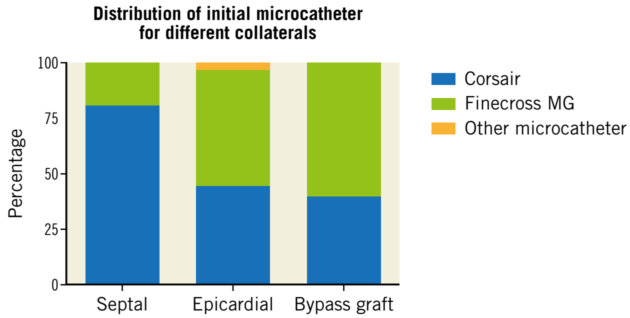

Figure 2. *Distribution of the initial microcatheter for different collaterals in 280 procedures with wire CC tracking success. CC: collateral channel*

collaterals, initial microcatheter CC tracking failure was independently related to CC 0-1 collaterals, channel entry angle <90°, channel exit angle <90°, and Finecross MG as the initial microcatheter; 3) the only independent predictor of epicardial collaterals was CC 1 collaterals; and 4) microcatheter switching combined with support enhancement was an effective measure in managing the microcatheter CC tracking failure.

PREDICTORS OF INITIAL MICROCATHETER CC TRACKING FAILURE

Initial microcatheter CC tracking failure after wire CC tracking success may be related to: 1) the anatomical characteristics of the CC, especially entry and exit angle, CC grade, tortuosity, etc.; 2) weak back-up support supplied by the guide catheter; and 3) different microcatheter features. In the present study, we identified different predictors of microcatheter tracking for septal and epicardial collaterals. A previous study showed that CC grade 0-1 and severe tortuosity were related to wire CC tracking failure[19]. However, due to the different anatomical features of septal and epicardial collaterals, we usually adopted the following principles for CC selection in our daily practice: for septal collaterals, the straighter the better; for epicardial collaterals, the bigger the better. As a result, we often chose a less tortuous septal channel irrespective of its CC grade and a larger size epicardial channel irrespective of its tortuosity. This may, at least partially, explain why different predictors were identified between septal and epicardial collaterals. An intriguing finding in the present study was the irrelevance of collateral tortuosity to initial microcatheter CC tracking failure **(Table 2)**. A reasonable explanation may be that successful wire CC tracking arguably provided support to straighten the CC and decrease tortuosity. The channel entry and exit angles of epicardial collaterals were not related to microcatheter CC tracking failure in the present study. Due to the limited sample size in the epicardial group (n=76), a future study with a large sample size is needed. It should be pointed out that an evaluation of channel entry and exit angle[18] should also be undertaken before microcatheter CC tracking. Advancing a microcatheter through an adverse channel entry or exit angle would be a challenge and should be avoided during collateral selection.

In the present study, the Finecross MG microcatheter was shown to be associated with initial microcatheter septal tracking failure. This finding was potentially related to different designs among microcatheters. **Figure 2** shows the detailed distribution of initial microcatheter selection in different collaterals. The major reasons for choosing the Finecross MG as the initial microcatheter in our centre included: 1) the 150 cm Corsair microcatheter was sometimes not available; and 2) the lower cost of the Finecross MG compared to the Corsair. At the same time, it is important to point out that microcatheter selection was influenced by operator consideration of the anatomical complexity of collaterals.

MANAGEMENT OF MICROCATHETER CC TRACKING FAILURE

To solve microcatheter CC tracking failure, the measure most frequently applied in the present study was microcatheter switching. It is very important to point out that microcatheter switching from Corsair to Finecross MG, and vice versa, should be considered. Interestingly, microcatheter switching back to the original failed microcatheter may achieve final CC tracking success in select cases. One probable explanation could be the additive dilating effects of all microcatheter switching attempts prior to the final CC tracking success.

Regarding the back-up support of guide catheters, several items including retrograde access, retrograde guide catheter type and catheter size were analysed. The results did not show significant differences among these characteristics. However, we should exercise great caution in coming to this conclusion. In our daily practice, we found microcatheter CC tracking failure paired with weaker back-up guide catheters in some cases. Since guide catheter switching was always the second choice just after wire CC tracking success, selecting a retrograde guide catheter with extra back-up support played a pivotal role in the whole procedure. Simple and effective measures to increase guide catheter support present in the current study included the deployment of guide catheter extensions, such as GUIDEZILLA, and anchoring balloon technique. Another alternative was septal channel dilation using a small balloon at a low atm pressure. In the present study, septal channel dilation was performed in two procedures. One case used a small balloon and the other the THREADER™ micro-dilatation catheter (Boston Scientific). As a result, after management, the final success rate of microcatheter CC tracking achieved was 95.7%. The suggested management for microcatheter CC tracking failure is illustrated in **Figure 3**. It is very important to point out that, when the combination of the above measures fails, the kissing wire technique may be a reasonable option in some cases. Modified microcatheter rendezvous was also an option if the retrograde wire could cross the occluded segment.

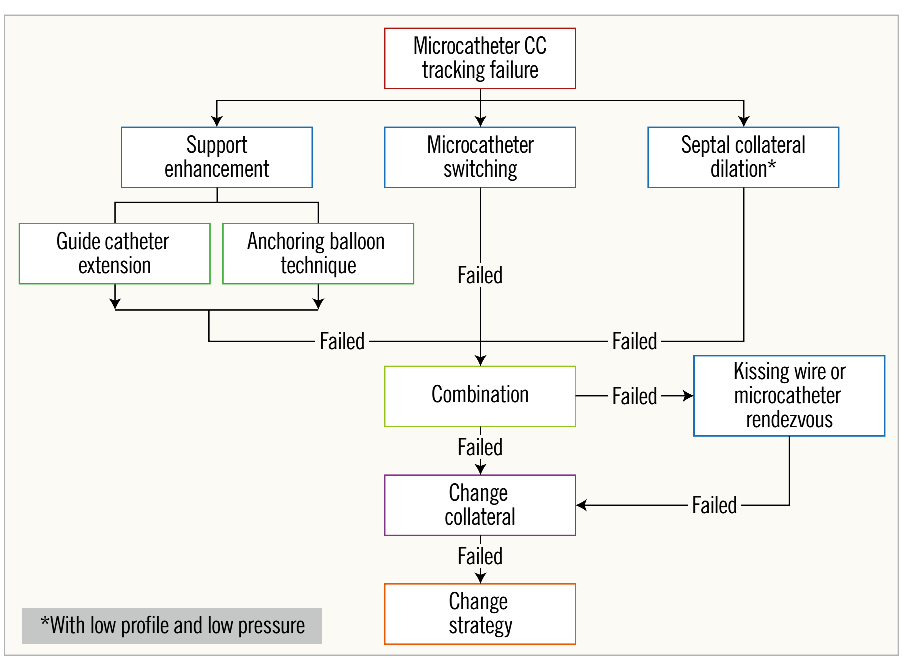

Figure 3. *Flow chart of management strategies for microcatheter CC tracking failure.*

Limitations

Several limitations of the present study should be mentioned. First, the retrospective, single-centre study design may have resulted in potential for bias in patient selection and interventional strategy. Second, both high-volume and non-high-volume operators were involved in this study. While there were no significant differences in procedural characteristics between the two groups, a higher J-CTO score (3.0±1.0 vs. 2.8±0.9, p=0.042) was noted in the high-volume operator group. The high-volume operator group also demonstrated a higher wire CC tracking success rate (79.3% vs. 64.6%, p=0.004) and overall procedural success rate (82.2% vs. 60.4%, p<0.001) (n=371). However, after wire CC tracking success (n=280), there were no significant differences in initial microcatheter CC tracking failure between high- and non-high-volume operators **(Table 2)**. Third, the J-CTO score (3.0±1.0) in the present study was relatively higher than in some registries. This may be partly related to the specificity of the retrograde subgroup and heterogeneous evaluation among operators. Fourth, this study included a relatively small sample size and it may need a future large prospective study to validate its findings. Fifth, the average contrast consumption was 382.9±142.7 ml, which may be related to the high proportion of rescue retrograde approach use after a failed antegrade attempt (73.3%). Additionally, even with widely used perioperative hydration, more attention needs to be paid to control contrast consumption.

Conclusions

Initial microcatheter CC tracking failure was observed in 22.5% of successful wire CC tracking procedures. For septal collaterals, CC 0-1 collaterals, channel entry angle <90°, and channel exit angle <90° were independent angiographic predictors of initial microcatheter CC tracking failure after wire CC tracking success. CC 1 collaterals were identified as the only independent predictor in epicardial collaterals.

Impact on daily practice

Currently, data on microcatheter collateral tracking in retrograde percutaneous coronary intervention for chronic total occlusion lesions are very limited. Clarification of the angiographic predictors and management experience of microcatheter collateral tracking failure will be of significant benefit in procedure planning and will allow appropriate treatment.

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Conflict of interest statement

The authors have no conflicts of interest to declare.

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Supplementary data

Supplementary Appendix 1. Evaluation of retrograde wire CC tracking.

Supplementary Table 1. Assessment of variables associated with wire CC tracking.

Supplementary Table 2. Assessment of variables associated with microcatheter CC tracking.

Supplementary Table 3. Management for microcatheter CC tracking failure.

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Supplementary data

Supplementary Appendix 1. Evaluation of retrograde wire CC tracking

The overall success rate of wire CC tracking was 75.5% (280/371). In general, SION accounted for 90.6% of all initial wires attempted for CC tracking. In cases of initial wire CC tracking failure, Fielder XT-R, SION blue, and SUOH 03 were used for further attempts in 35.0%, 19.6%, 10.5% of these cases, respectively. In other cases, further attempts for CC tracking were performed with SION (4.9%), SION black (4.2%), Runthrough NS (2.8%), and Fielder FC (1.4%). In general, tip injection was performed in 66.1% of cases in the successful wire CC tracking group and in 85.7% in the unsuccessful wire CC tracking group ($p<0.001$). Actually, some tip injection was initiated and performed after a failed surfing technique in the septal collateral. Therefore, the higher prevalence of tip injection in the unsuccessful wire CC tracking group was in reality a manifestation of difficulties encountered in wire CC tracking. An average of 1.2±0.5 and 1.5±0.7 different types of wire were used for CC tracking in the two groups ($p<0.001$), respectively. All cases with final wire CC tracking failure switched to the antegrade approach. The procedural success rate in the successful and unsuccessful wire CC tracking groups was 86.4% (242/280) and 46.2% (42/91), respectively. Details of the angiographic and procedural characteristics were compared between the successful and unsuccessful wire CC tracking groups and are shown in **Supplementary Table 1**. There were significant differences between the two groups in terms of CC grade, CC tortuosity, and Kao CC score. This study also identified wire CC tracking success as being associated with a higher prevalence of primary retrograde approach and retrograde guide catheters with strong support.

Supplementary Table 1. Assessment of variables associated with wire CC tracking.

	Overall (n=371)	Wire CC tracking success (n=280)	Wire CC tracking failure (n=91)	*p*-value
Reattempted lesion	129 (34.8)	101 (36.1)	28 (30.8)	0.356
ISR CTO	20 (5.4)	14 (5.0)	6 (6.6)	0.594
CTO vessel				
LM	2 (0.5)	2 (0.7)	0 (0)	0.530
LAD	170 (45.8)	123 (43.9)	47 (51.6)	
LCX	15 (4.0)	12 (4.3)	3 (3.3)	
RCA	184 (49.6)	143 (51.1)	41 (45.1)	
Blunt stump	303 (81.7)	232 (82.9)	71 (78.0)	0.300
Calcification	274 (73.9)	211 (75.4)	63 (69.2)	0.248
Vessel tortuosity	102 (27.5)	78 (27.9)	24 (26.4)	0.783
Occlusion length >20 mm	287 (77.4)	224 (80.0)	63 (69.2)	0.033
J-CTO score	3.0±1.0	3.0±1.0	2.7±0.8	0.013
High-volume operator	275 (74.1)	218 (77.9)	57 (62.6)	0.004
Collateral attempted				

Septal	260 (70.1)	199 (71.1)	61 (67.0)	
Epicardial	106 (28.6)	76 (27.1)	30 (33.0)	0.273
Bypass graft	5 (1.3)	5 (1.8)	0 (0)	
Ipsilateral collateral	39 (10.5)	27 (9.6)	12 (13.2)	0.338
Tip injection	263 (70.9)	185 (66.1)	78 (85.7)	<0.001
CC grade				
0	32 (8.6)	16 (5.7)	16 (17.6)	
1	179 (48.2)	120 (42.9)	59 (64.8)	<0.001
2	160 (43.1)	144 (51.4)	16 (17.6)	
Severe collateral tortuosity	209 (56.3)	140 (50.0)	69 (75.8)	<0.001
Kao CC score	1.3±1.1	1.5±1.1	0.6±0.9	<0.001
Primary retrograde approach	99 (26.7)	87 (31.1)	12 (13.2)	0.001
Types of wire used for collateral tracking	1.3±0.6	1.2±0.5	1.5±0.7	<0.001
Back-up support variables				
Retrograde from radial	268 (72.2)	196 (70.0)	72 (79.1)	0.091
Retrograde guide catheter with strong support	263 (70.9)	207 (73.9)	56 (61.5)	0.024
Retrograde guide catheter size				

6 Fr	278 (74.9)	206 (73.6)	72 (79.1)	
7 Fr	82 (22.1)	64 (22.9)	18 (19.8)	0.369
8 Fr	11 (3.0)	10 (3.6)	1 (1.1)	
Finecross MG as initial microcatheter	96 (25.9)	81 (28.9)	15 (16.5)	0.019
Contrast volume, ml	382.9±142.7	374.9±135.0	407.7±162.4	0.056
Procedural success	284 (76.5)	242 (86.4)	42 (46.2)	<0.001
Clinical success	282 (76.0)	240 (85.7)	42 (46.2)	<0.001

Values are mean±SD or n (%).

CC: collateral channel; CTO: chronic total occlusion; ISR: in-stent restenosis; LAD: left anterior descending artery; LCX: left circumflex artery; LM: left main; RCA: right coronary artery

Supplementary Table 2. Assessment of variables associated with microcatheter CC tracking.

	Overall (n=280)	Initial microcatheter CC tracking success (n=217)	Initial microcatheter CC tracking failure (n=63)	*p*-value
High-volume operator	218 (77.9)	166 (76.5)	52 (82.5)	0.309
Collateral used				
Septal	199 (71.1)	156 (71.9)	43 (68.3)	
Epicardial	76 (27.1)	58 (26.7)	18 (28.6)	0.597
Graft	5 (1.8)	3 (1.4)	2 (3.2)	
Ipsilateral collateral	27 (9.6)	18 (8.3)	9 (14.3)	0.156
CC grade				
0	16 (5.7)	7 (3.2)	9 (14.3)	
1	120 (42.9)	78 (35.9)	42 (66.7)	<0.001
2	144 (51.4)	132 (60.8)	12 (19.0)	
Severe collateral tortuosity	140 (50.0)	105 (48.4)	35 (55.6)	0.316
Kao CC score	1.5±1.1	1.7±1.0	0.8±1.0	<0.001
Channel entry angle <90º	20 (7.1)	4 (1.8)	16 (25.4)	<0.001

Channel exit angle <90º	10 (3.6)	4 (1.8)	6 (9.5)	0.010
Retrograde back-up support variables				
Retrograde from radial	196 (70.0)	154 (71.0)	42 (66.7)	0.512
Retrograde guide catheter with strong support	207 (73.9)	160 (73.7)	47 (74.6)	0.890
Retrograde guide catheter size				
6 Fr	206 (73.6)	160 (73.7)	46 (73.0)	
7 Fr	64 (22.9)	49 (22.6)	15 (23.8)	0.965
8 Fr	10 (3.6)	8 (3.7)	2 (3.2)	
Finecross MG as initial microcatheter	81 (28.9)	54 (24.9)	27 (42.9)	0.006
Retrograde wire technique				
Retrograde wire crossing	99 (35.4)	87 (40.1)	12 (19.0)	
Reverse CART	115 (41.1)	89 (41.0)	26 (41.3)	<0.001
Kissing wire technique	43 (15.4)	21 (9.7)	22 (34.9)	
None	23 (8.2)	20 (9.2)	3 (4.8)	
Retrograde procedure failure	77 (27.5)	50 (23.0)	27 (42.9)	0.002

Values are mean±SD or n (%).

CART: controlled antegrade and retrograde tracking; CC: collateral channel

Supplementary Table 3. Management of microcatheter CC tracking failure.

	Success (n=51)	Failure (n=12)
Anchoring balloon technique	**1**	/
GUIDEZILLA	**2**	**1**
Microcatheter switching	**38**	**1**
Finecross MG→Corsair	19	/
Finecross MG→Corsair→Caravel→Finecross MG	1	/
Finecross MG→Corsair→Corsair Pro→Caravel	/	1
Finecross MG→Caravel→Corsair	1	/
Corsair→Finecross MG	11	/
Corsair→Caravel	3	/
Corsair→Caravel→Corsair	2	/
Corsair→Caravel→Finecross MG	1	/
Anchoring balloon technique + microcatheter switching	**3**	**1**
Corsair→Caravel	2	/
Corsair→Finecross MG	1	1
GUIDEZILLA + microcatheter switching	**5**	**4**
Finecross MG→Corsair→Caravel	/	2
Finecross MG→Corsair→Corsair Pro→Caravel	/	1
Corsair→Caravel	/	1
Corsair→Caravel→Corsair	1	/
Corsair→Finecross MG	1	/
Corsair→Finecross MG→Corsair	3	/
Septal collateral dilation + microcatheter switching	**2**	/
Corsair→Finecross MG→Corsair	1	/
Finecross MG→Caravel→Corsair	1	/
Kissing wire technique	/	**5**

Data are presented as numbers. CC: collateral channel