

Supplementary Appendix

Collateral Channel Crossing Failure During Retrograde CTO PCI: Predictors and Associated Procedural Outcomes From a Multicenter Registry

This supplementary appendix provides descriptive and sensitivity analyses that support the main manuscript.

Supplementary Methods. Procedural complication definitions and operational rules

Procedural complications were site-reported and based on registry fields. Events were counted when the corresponding in-hospital or procedural registry field was explicitly coded positive. Myocardial infarction and stroke were used as recorded in the registry, without central adjudication or post hoc reclassification to standardized definitions.

Collateral perforation and coronary perforation were counted when the corresponding registry field documented the event. Donor-vessel dissection or thrombus, emergency repeat PCI, emergency CABG, and vascular complications were counted when the corresponding registry field was explicitly coded positive. Composite endpoints were counted once per procedure, whereas individual component events were non-mutually exclusive.

The extended procedural-complication composite used in the present analysis comprised procedure-related death, myocardial infarction, stroke, emergency repeat PCI, emergency CABG, donor-vessel dissection or thrombus, collateral perforation, coronary perforation, and vascular complications.

Supplementary Table S1. Distribution of retrograde procedural results

Retrograde procedural result	n/N (%)
Retrograde successful	375/577 (65.0)
Collateral not crossed	135/577 (23.4)
Lesion not crossed by wire	48/577 (8.3)
Lesion not crossed by device	19/577 (3.3)

Supplementary Table S2. Outcomes according to detailed number of recorded collateral attempts

Collateral attempts	n	Retrograde success	Collateral crossing failure	Overall technical success
0 recorded attempts	76	33/76 (43.4)	37/76 (48.7)	46/76 (60.5)
Missing recorded attempt count	61	22/61 (36.1)	22/61 (36.1)	47/61 (77.0)
1	280	239/280 (85.4)	16/280 (5.7)	250/280 (89.3)
2	55	38/55 (69.1)	12/55 (21.8)	48/55 (87.3)
3	71	37/71 (52.1)	25/71 (35.2)	53/71 (74.6)
4	14	4/14 (28.6)	10/14 (71.4)	8/14 (57.1)
5	14	1/14 (7.1)	8/14 (57.1)	6/14 (42.9)
6	5	1/5 (20.0)	4/5 (80.0)	4/5 (80.0)
10	1	0/1 (0.0)	1/1 (100.0)	0/1 (0.0)

Supplementary Note on collateral-attempt recording

The number of collateral attempts was treated as an intraprocedural difficulty marker rather than a baseline predictor because it is partly determined by the operator's response during the procedure. Procedures with zero recorded attempts or missing recorded attempt counts were not included in the main collateral-attempt gradient figure but are shown descriptively in Supplementary Table S2. Zero recorded attempts may reflect the absence or incomplete recording of attempted channels rather than the absence of any collateral manipulation.

Supplementary Table S3. Retrograde success versus retrograde failure

Outcome	Retrograde unsuccessful (n=202)	Retrograde successful (n=375)	p value
Overall technical success	99/202 (49.0)	363/375 (96.8)	<0.001
Collateral perforation	24/202 (11.9)	15/375 (4.0)	<0.001
Coronary perforation	26/202 (12.9)	20/375 (5.3)	0.001
Donor-vessel dissection/thrombus	8/202 (4.0)	14/375 (3.7)	0.892
Extended complication composite	54/202 (26.7)	45/375 (12.0)	<0.001
Procedural time, min	142 (112-173)	140 (113-178)	0.996
Fluoroscopy time, min	71 (55-88)	71 (55-94)	0.514
Contrast volume, mL	310 (200-450)	300 (180-400)	0.030

Supplementary Table S4. Pathway distribution according to collateral crossing failure

Pathway	No CCF (n=442)	CCF (n=135)
Apical	15/442 (3.4)	4/135 (3.0)
Atrial (LCX $\diamond$ RCA)	9/442 (2.0)	1/135 (0.7)
Epicardial	4/442 (0.9)	6/135 (4.4)
Epicardial (LCX $\diamond$ LAD)	25/442 (5.7)	3/135 (2.2)
Epicardial (LCX $\diamond$ RCA)	48/442 (10.9)	12/135 (8.9)
Ipsilateral	18/442 (4.1)	3/135 (2.2)
Septal	256/442 (57.9)	54/135 (40.0)
Septo-septal	18/442 (4.1)	4/135 (3.0)
Via bypass -> collateral	7/442 (1.6)	1/135 (0.7)
Via bypass direct	23/442 (5.2)	1/135 (0.7)
Unknown	19/442 (4.3)	46/135 (34.1)

Supplementary Table S5. Full-cohort sensitivity model retaining unknown/missing collateral connection grade as a separate category

Variable	Adjusted OR	95% CI	p value
Corkscrew collateral morphology	7.05	3.80-13.09	<0.001
CC0 collateral connection grade	4.34	1.83-10.28	<0.001
CC2/CC3 collateral connection grade	0.47	0.23-0.94	0.034
Unknown/missing collateral connection grade	4.10	2.30-7.30	<0.001
Good distal opacification	0.50	0.26-0.98	0.043
Reverse bend >90 degrees	1.64	0.97-2.77	0.063
LAD target vessel	1.53	0.93-2.52	0.092
Model AUC	0.76 (95% CI 0.71-0.81)		

This full-cohort sensitivity model retained unknown/missing collateral connection grade as a separate category (n=577; collateral crossing failure events=135). Unknown/missing collateral connection grade should be interpreted as a marker of incomplete angiographic characterization, not as an anatomic predictor.

Supplementary Table S6. Sensitivity analysis additionally adjusted for age, sex, eGFR, and center

Variable	Adjusted OR	95% CI	p value
Corkscrew collateral morphology	7.20	3.75-13.80	<0.001
CC0 collateral connection grade	4.48	1.75-11.43	0.002
CC2/CC3 collateral connection grade	0.40	0.19-0.86	0.019
Unknown/missing collateral connection grade	4.25	2.34-7.72	<0.001
Good distal opacification	0.53	0.27-1.02	0.058
Reverse bend >90 degrees	1.54	0.90-2.64	0.112
LAD target vessel	1.47	0.88-2.46	0.142
Age, per year	1.06	1.03-1.08	<0.001
Male sex	0.51	0.25-1.03	0.062
eGFR, per mL/min/1.73 m ²	1.00	0.99-1.01	0.598
Center fixed effects	Included		
Model AUC	0.79		

The primary collateral crossing failure model was repeated with additional adjustment for baseline clinical differences and center fixed effects (n=577; collateral crossing failure events=135).

Supplementary Table S7. Exploratory collateral-attempt model restricted to procedures with at least one recorded collateral attempt

Variable	Adjusted OR	95% CI	p value
≥3 collateral attempts	9.85	5.12-18.93	<0.001
Corkscrew collateral morphology	7.03	3.30-15.00	<0.001
CC0 collateral connection grade	3.35	1.15-9.73	0.026
CC2/CC3 collateral connection grade	0.54	0.22-1.32	0.179
Unknown/missing collateral connection grade	2.04	0.77-5.45	0.153
Good distal opacification	0.36	0.15-0.87	0.023
Reverse bend >90 degrees	1.44	0.72-2.84	0.300
LAD target vessel	1.26	0.61-2.63	0.532
Model AUC	0.86		

Procedures with zero or missing recorded collateral attempts were excluded from this sensitivity analysis (n=440; collateral crossing failure events=76). The number of collateral attempts remains an intraprocedural difficulty marker and should not be interpreted as a baseline predictor.

Supplementary Table S8. Sensitivity analysis for the extended procedural-complication composite

Model	Exposure	Adjusted OR	95% CI	p value
Standard logistic regression	Collateral crossing failure	2.04	1.27-3.28	0.003
Penalized logistic regression	Collateral crossing failure	2.02	1.26-3.24	0.003

Outcome models adjusted for collateral crossing failure, prior CABG, stump morphology, severe calcification, distal opacification, and target vessel. Penalized logistic regression was used as a sensitivity analysis for the extended-complication model.

Supplementary Table S9. Components of the extended procedural-complication composite according to collateral crossing failure

Component	No CCF (n=442)	CCF (n=135)	p value
Procedure-related death	8/442 (1.8)	1/135 (0.7)	0.693
Periprocedural MI	3/442 (0.7)	2/135 (1.5)	0.333
Stroke	0/442 (0.0)	0/135 (0.0)	1.000
Emergency repeat PCI	1/442 (0.2)	2/135 (1.5)	0.138
Emergency CABG	2/442 (0.5)	2/135 (1.5)	0.235
Donor-vessel dissection/thrombus	19/442 (4.3)	3/135 (2.2)	0.440
Collateral perforation	22/442 (5.0)	17/135 (12.6)	0.002
Coronary perforation	26/442 (5.9)	20/135 (14.8)	<0.001
Major vascular complication	3/442 (0.7)	6/135 (4.4)	0.007
Extended complication composite	64/442 (14.5)	35/135 (25.9)	0.002

The higher extended-complication rate in the collateral crossing failure group was mainly driven by more frequent collateral perforation, coronary perforation, and vascular complications. CCF indicates collateral channel crossing failure; MI, myocardial infarction; PCI, percutaneous coronary intervention; CABG, coronary artery bypass grafting.

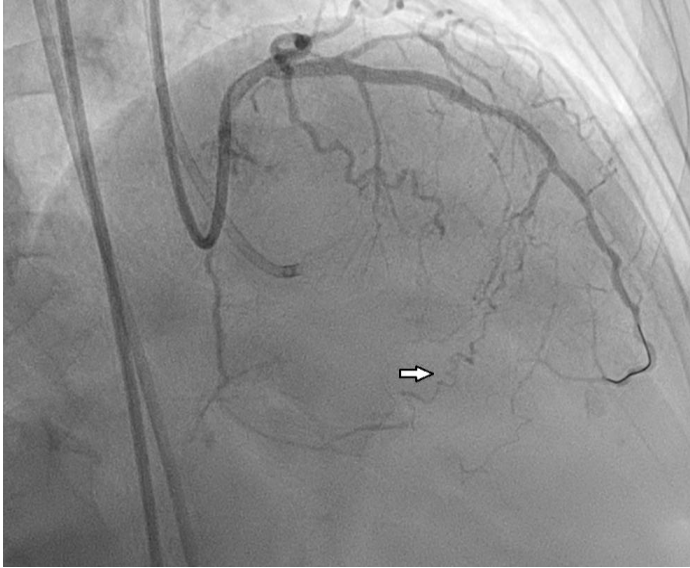
Supplementary Table S10. Calendar-year-adjusted sensitivity model for collateral crossing failure

Variable	Adjusted OR	95% CI	p value
Corkscrew collateral morphology	6.78	3.60-12.77	<0.001
CC0 collateral connection grade	4.58	1.92-10.95	<0.001
CC2/CC3 collateral connection grade	0.42	0.20-0.88	0.021
Good distal opacification	0.73	0.35-1.50	0.389
Reverse bend >90 degrees	2.27	1.22-4.24	0.010
LAD target vessel	1.10	0.60-2.01	0.764
Calendar year, per year	0.90	0.71-1.14	0.392
Model AUC	0.76		

The primary collateral crossing failure model was repeated after additional adjustment for calendar year modeled as a continuous variable (n=453; collateral crossing failure events=89). The model was restricted

to procedures with known collateral connection grade, consistent with the primary model. Calendar year was used as an indirect sensitivity analysis for possible temporal learning or changes in case selection because operator-level lifetime CTO PCI and retrograde CTO PCI volumes before registry entry were not systematically captured. The collateral-specific associations were not materially changed after calendar-year adjustment.

Supplemental Figure 1. Representative angiographic example of corkscrew collateral morphology.



Representative deidentified angiographic still image showing corkscrew collateral morphology. The arrow indicates a corkscrew collateral segment. Corkscrew morphology refers to the angiographic pattern described in the J-Channel score: 3 or more continuous bends with a vessel amplitude-to-vessel diameter ratio ≤ 2 . The image is provided for illustrative purposes only and was not used for quantitative analysis.