

Predictors of failure in the reverse wire technique for complex coronary bifurcation lesions



Yoshinobu Murasato*, MD, PhD; Kyohei Meno, MD; Soichiro Omura, MD; Yujiro Ura, MD; Takahiro Mori, MD, PhD

*Corresponding author: Department of Cardiology, National Hospital Organization, Kyushu Medical Center, 1-8-1, Jigyohama, Chuo, Fukuoka, 810-8563, Japan. E-mail: y.murasato@gmail.com

This paper also includes supplementary data published online at: <https://AsiaIntervention.pcronline.com/doi/10.4244/AIJ-D-24-00069>

ABSTRACT

BACKGROUND: The reverse wire technique (RWT), with a guidewire shaped in a swan-neck configuration, is used to address challenging side branch (SB) wiring in complex coronary bifurcation lesions (CBLs). However, its success is not guaranteed.

AIMS: This study aimed to identify factors associated with RWT failure and to assess the feasibility of the balloon blocking technique (BBT) in the distal main vessel (MV) as an alternative.

METHODS: Thirty-two consecutive complex CBLs with difficult SB wiring were retrospectively analysed. Patients were divided into two groups: those with successful RWT (RWT-S, n=17) and those who underwent BBT, either after RWT failure or as a primary approach (RWT-F/BBT, n=15). Risk factors for RWT failure were examined.

RESULTS: The success rate of SB wiring with BBT was 80%. RTW-F/BBT was associated with less involvement of the left anterior descending artery (40% vs 71%), smaller-diameter MV stent implantation (2.8 ± 0.5 mm vs 3.2 ± 0.5 mm), wider bifurcation angle (BA) between the distal MV and middle SB ($BA-\beta$: $51.6 \pm 29.8^\circ$ vs $36.4 \pm 18.6^\circ$), and smaller minimum lumen diameter (MLD) in the distal MV (1.72 ± 0.68 mm vs 2.14 ± 0.58 mm). SB calcification (33% vs 0%; $p=0.01$), severe bending in the distal MV (53% vs 12%; $p=0.02$) and severe bending in the SB (73% vs 24%; $p=0.01$) were more common in the RTW-F/BBT group. A receiver operating characteristic curve analysis showed that a combination of preprocedural $BA-\beta > 34.1^\circ$, distal MV MLD < 1.77 mm, and SB calcification had good discrimination ability for predicting RWT failure (area under the curve 0.85, 95% confidence interval: 0.71-0.98).

CONCLUSIONS: RWT is challenging in complex CBLs with calcification, significant tortuosity, and small vessels. BBT offers a viable alternative in these cases.

KEYWORDS: balloon blocking technique; coronary bifurcation intervention; guidewire; reverse wire technique; side branch

Advancing a guidewire in the side branch (SB) before main vessel (MV) stenting in coronary bifurcation lesions (CBLs) can effectively prevent SB occlusion, which is associated with procedural myocardial infarction and adverse cardiac events^{1,2}. However, antegrade wiring of the SB is challenging in some complex CBLs with extremely angulated SB branching. The reverse wire technique (RWT), in which the distal guidewire is bent into a swan-neck shape, is employed in these complex CBLs²⁻⁵. Although the efficacy of the RWT for SB patency has been reported in series of case reports³⁻⁵, it is not universally effective for all complex CBLs, and the factors that determine RWT failure have not been elucidated. We investigated the risk factors for RWT failure.

In the balloon blocking technique (BBT), an optimal-sized balloon is inflated in the distal MV to block guidewire advancement to the MV and promote entry into the SB; this approach is also adopted in cases of challenging antegrade wiring due to complex bifurcation anatomy. This technique was initially used in endovascular interventions⁶ and has recently been used in percutaneous coronary interventions (PCIs)^{7,8}. We also investigated the feasibility and efficacy of the BBT as an alternative method in cases of RWT failure or challenging RWT.

Methods

STUDY POPULATION AND DESIGN

We analysed 32 consecutive cases of drug-eluting stent implantation in complex CBLs with difficult SB wiring performed at the National Hospital Organization Kyushu Medical Center (Fukuoka, Japan) from January 2015 to May 2024. Successful SB wiring with the RWT was observed in 17 of 25 cases (**Figure 1A, Moving image 1**). The BBT was attempted in 8 cases of RWT failure, resulting in successful SB wiring in 5 cases (**Figure 1B, Moving image 2, Figure 1C, Moving image 3**). The BBT was selected upfront in 7 cases as the delivery of the bent guidewire in the RWT was strongly predicted to be difficult because of severe tortuosity, calcification or dissection in the distal MV; all 7 cases ultimately resulted in successful SB wiring. The included cases were divided into two groups: one in which RWT was successful (RWT-S, n=17) and another in which RWT failed or primary BBT was used (RWT-F/BBT, n=15). Patient characteristics, PCI procedural details, and lesion characteristics were compared between the two groups.

PERCUTANEOUS CORONARY INTERVENTION

All patients were treated with sufficient periprocedural heparin and dual antiplatelet therapy with aspirin and either clopidogrel or prasugrel, which was continued for at least 1 month according to the Japanese Circulation Society guidelines⁹. All PCIs were guided by intracoronary imaging (intravascular ultrasound [IVUS] or optical coherence tomography [OCT]). In

Impact on daily practice

The findings highlight key predictors of failure in the reverse wire technique (RWT) for complex coronary bifurcation lesions (CBLs), including large bifurcation angles, small main vessel lumen diameters, calcification, and vessel tortuosity. Understanding these risk factors can help operators anticipate potential challenges and select appropriate strategies early in the procedure. The balloon blocking technique is an effective alternative when the RWT is likely to fail, achieving high success rates in difficult side branch wiring. Incorporating this knowledge into daily practice should allow interventional cardiologists to make informed decisions, potentially improving procedural outcomes and reducing complications in patients with complex CBLs. Tailoring the approach based on lesion characteristics can optimise success rates in challenging cases.

the RWT, the bent shape, curve, and length of the compatible guidewires (SION black and FIELDER FC [both Asahi Intecc] and Amati [Japan Lifeline]) were determined according to the anatomy of the target CBL. Predilation of the MV was allowed in cases of an uncrossed bent wire, and a double-lumen catheter (Crusade [Kaneka] or SASUKE [Asahi Intecc]) was used concomitantly to advance the bent guidewire to the distal end without significant friction^{4,5}. In the BBT, a blocking balloon with a size determined according to intracoronary imaging was inflated at the orifice of the distal MV so that the guidewire would not slip on the surface of the balloon towards the distal MV. SB predilation and kissing balloon inflation before MV stenting, as well as the jailed balloon technique for more active protection of SB patency after MV stenting, were operator dependent. The proximal optimisation technique, using a short balloon according to the proximal MV size, was recommended; however, its use relied on the discretion of the operator after an intracoronary imaging assessment for MV stent expansion. After MV crossover stenting, SB ostial dilation and the choice of method (kissing balloon inflation or SB dilation alone) were also operator dependent.

LESION ASSESSMENT

Quantitative coronary angiography (QCA; CAAS Workstation 7.0 [Pie Medical Imaging]) was performed just prior to the RWT or BBT procedure, after MV predilation if necessary, and at the end of the procedure to investigate the minimum lumen diameter (MLD) in the proximal and distal MV and SB. The proximal (BA- α : between the proximal site of the SB and distal MV) and distal bifurcation angles (BA- β : between the middle site of the SB and distal MV) were measured on the baseline angiogram without guidewire insertion. The vessel condition just prior to the RWT or BBT was assessed visually

Abbreviations

AUC	area under the curve	IVUS	intravascular ultrasound	PCI	percutaneous coronary intervention
BA	bifurcation angle	MLD	minimum lumen diameter	ROC	receiver operating characteristic
BBT	balloon blocking technique	MV	main vessel	RWT	reverse wire technique
CBL	coronary bifurcation lesion	OCT	optical coherence tomography	SB	side branch

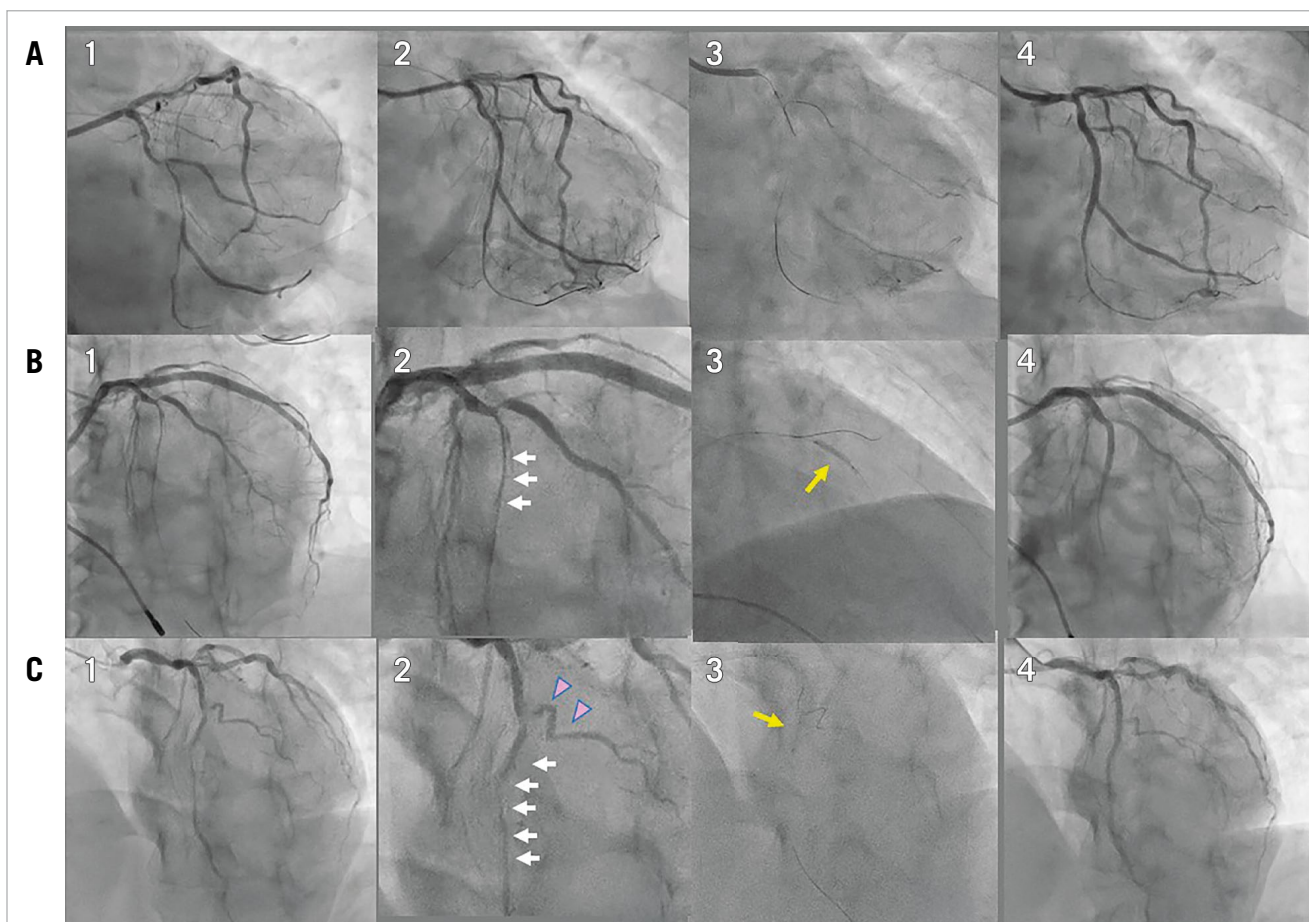


Figure 1. Representative cases of side branch wiring with the RWT and BBT after RWT failure. A) Case 1: RWT success; A1) pre-PCI; A2) immediately after orbital atherectomy in the MV in the left circumflex artery; A3) SB wiring with RWT; A4) final angiography after drug-eluting stent deployment in the MV and drug-coated balloon inflation in the SB (*Moving image 1*). B) Case 2: RWT failure and subsequent SB wiring with the BBT; B1) angiography prior to the SB wiring showed diffuse vessel dissection after predilation in the distal MV; B2) magnified view. Vessel dissection, indicated by white arrows, inhibited the advancement of the bent portion of the reverse wire; B3) SB wiring with the BBT. An appropriately sized balloon for the distal MV was inflated, indicated by the yellow arrow, to prevent guidewire advancement to the distal MV and to promote SB wiring; B4) final angiography after drug-eluting stent deployment in the MV and plain balloon dilation in the SB (*Moving image 2*). C) Case 3: RWT failure and subsequent SB wiring with BBT; C1) angiography prior to SB wiring showed diffuse in-stent restenosis in the distal MV; C2) magnified view. A diffuse in-stent restenotic lesion (white arrows) inhibited the advancement of the bent portion of the wire. Additionally, a severe bend in the SB (pink triangles) made SB wiring more challenging; C3) SB wiring with BBT. An appropriately sized balloon for the distal MV was inflated, indicated by the yellow arrow, to promote SB wiring without guidewire prolapse into the distal MV; C4) final angiography after drug-coated balloon inflation in the MV and plain balloon dilation in the SB (*Moving image 3*). BBT: balloon blocking technique; MV: main vessel; PCI: percutaneous coronary intervention; RWT: reverse wire technique; SB: side branch

using angiography. Coronary dissections classified as type B or higher, according to National Heart, Lung, and Blood Institute classification¹⁰, were included. Severe calcification was identified as dense opacification visible along both sides of the vessel contour without contrast injection on fluoroscopy¹¹. Severe bending was defined as a lesion with either two bends $>90^\circ$ or three bends $>75^\circ$ ¹². Coronary calcium, identified as a bright, high-echoic deposit with a sharp acoustic shadow on IVUS and as distinct, low-signal areas with sharp borders on OCT, was assessed based on its location – either on the SB ipsilateral or contralateral side in the proximal or distal MV.

This assessment was performed prior to any PCI treatment in cases where imaging catheter delivery was successful and after predilation or plaque modification in cases where catheter delivery initially failed.

CLINICAL OUTCOME AT FOLLOW-UP

Coronary angiography was performed in cases of recurrent angina or myocardial ischaemia during the follow-up period. Death, target lesion revascularisation, target vessel revascularisation, and myocardial infarction up to August 2024 were investigated at an outpatient clinic.

STATISTICAL ANALYSIS

Continuous variables are expressed as mean±standard deviation. Categorical variables are presented as percentages. Between-group comparisons of continuous variables were performed using the Student's t-test. A predictive model for RWT failure was developed, and its discriminatory ability was evaluated using receiver operating characteristic (ROC) curves and the area under the curve (AUC). All reported p-values were determined by two-sided analyses, and p-values<0.05 were considered statistically significant. Analyses were performed using R version 4.2.2 (R Foundation for Statistical Computing).

Results

PATIENT BACKGROUND

High prevalences of hypertension (88% and 100%), dyslipidaemia (76% and 87%), and diabetes mellitus (41% and 60%) were observed in the RWT-S and RWT-F/BBT groups, respectively; however, there were no significant differences between the two groups (**Table 1**).

PCI PROCEDURE

The target lesion was located numerically less frequently in the left anterior descending artery (40% vs 71%) and more frequently in the right or left circumflex coronary artery in the RWT-F/BBT group than in the RWT-S group (56% vs 30%; p=0.07). The final success rate of SB guidewire crossing in the RWT-F/BBT group reached 80% and did not differ significantly from the RWT-S group (p=0.09); however, SB occlusion occurred in 1 case of RWT failure. The success rate of SB guidewire crossing per technique did not differ (RWT 17/25 [68%] vs BBT 12/15 [80%]; p=0.49). The MV stent size tended to be smaller in the RWT-F/BBT group than in the RWT-S group (2.8±0.4 mm vs 3.2±0.5 mm; p=0.07). Although predilation before MV stenting was performed similarly, the jailed balloon technique for the prevention of SB occlusion was performed less frequently in the RWT-F/BBT group than in the RWT-S group (13% vs 35%; p=0.23). In the BBT, the total balloon occlusion time was 67.5±45.0 seconds per 1.6±0.7 attempts, which did not result in significant myocardial ischaemia (**Table 1**).

LESION CHARACTERISTICS

Distal MV MLD before the procedure tended to be smaller in the RWT-F/BBT group than in the RWT-S group (1.72±0.68 mm vs 2.14±0.58 mm; p=0.07). After the procedure, there were no significant differences in the MLD of each bifurcation segment (**Table 2**). Regarding the vessel condition before the procedure, more calcification in the SB (33% vs 0%; p=0.01) and more bending in the distal MV (53% vs 12%; p=0.02) and SB (73% vs 24%; p=0.01) were observed in the RWT-F/BBT group (**Figure 2**). In a bifurcation angle analysis, both groups had a wide BA-α, with a mean value of >85°, and a narrow BA-β, which tended to be wider in the RWT-F/BBT group than in the RWT-S group (51.6±29.8° vs 36.4±18.6°; p=0.09). Although both BA-α (64.7±25.1°; p=0.0003 vs pre-PCI) and BA-β (31.6±14.7°; p=0.19) decreased after the completion of bifurcation PCI in the RTW-S group, neither BA-α (82.3±21.6°; p=0.20) nor BA-β (56.2±28.6°; p=0.33)

Table 1. Patient characteristics and PCI procedure details.

	RWT success n=17	RWT failure/ primary BBT n=15	p-value
Patient background			
Age, years	65.2±11.5	71.5±13.3	0.17
Male	15 (88)	9 (60)	0.11
Hypertension	15 (88)	15 (100)	0.49
Dyslipidaemia	13 (76)	13 (87)	0.66
LDL cholesterol, mg/dL	104±43	92±38	0.40
Diabetes mellitus	7 (41)	9 (60)	0.48
HbA1C, %	6.4±1.2	6.3±0.7	0.68
Current smoker	6 (35)	4 (27)	0.70
Haemodialysis	1 (6)	0 (0)	1.00
Acute coronary syndrome	5 (29)	2 (13)	0.40
Prior myocardial infarction	4 (24)	8 (53)	0.14
Left ventricular ejection fraction, %	56±16	60±15	0.48
PCI procedure			
Lesion location			0.07
Left anterior descending artery	12 (71)	6 (40)	
Left circumflex artery	4 (24)	5 (33)	
Right coronary artery	1 (6)	2 (13)	
Left main coronary artery	0	2 (13)	
SB guidewire cross	17 (100)	12 (80)	0.09
SB occlusion	0 (0)	1 (7)	1.00
MV drug-eluting stent			
Size, mm	3.2±0.5	2.8±0.4	0.07
Length, mm	24.4±7.3	29.5±11.5	0.16
SB drug-eluting stent	1 (6)	0 (0)	1.00
Drug-coated balloon	4 (24)	2 (13)	
Plain balloon angioplasty	9 (53)	7 (47)	
Jailed balloon technique	6 (35)	2 (13)	0.23
Kissing balloon/SB dilation	3 (18)	2 (13)	1.00
Imaging			
IVUS	9 (53)	11 (73)	0.29
OCT	8 (47)	4 (27)	
Pre-PCI observation			
MV	10 (59)	2 (13)	0.03
SB	0 (0)	0 (0)	1.00
Balloon blocking technique	-		
Total occlusion time, sec	-	67.5±45.0	
Number of attempts	-	1.6±0.7	

Data are presented as mean±standard deviation or n (%). BBT: balloon blocking technique; IVUS: intravascular ultrasound; LDL: low-density lipoprotein; MV: main vessel; OCT: optical coherence tomography; PCI: percutaneous coronary intervention; RWT: reverse wire technique; SB: side branch

changed significantly in the RTW-F/BBT group, with greater values than those in the RTW-S group (BA-α; p=0.06; BA-β; p=0.006) (**Figure 3**). Regarding the location of coronary calcification observed on intracoronary imaging, a similar distribution was noted in the proximal MV in

Table 2. Quantitative coronary angiography analysis of side branch wiring pre- and post-procedure.

	RWT success	RWT failure/primary BBT	p-value
Preprocedure			
Minimum lumen diameter, mm			
Proximal MV	2.08±0.68	2.15±0.92	0.83
Distal MV	2.14±0.58	1.72±0.68	0.07
SB	1.47±0.46	1.16±0.65	0.15
Bifurcation angle α, °	91.4±20.5	82.0±22.3	0.22
Bifurcation angle β, °	36.4±18.6	51.6±29.8	0.09
Post-procedure			
Minimum lumen diameter, mm			
Proximal MV	3.15±0.40	3.09±0.62	0.75
Distal MV	2.96±0.48	2.68±0.57	0.17
SB	1.68±0.46	1.62±0.76	0.79
Bifurcation angle α, °	64.7±25.1	82.3±21.6	0.06
Bifurcation angle β, °	31.6±14.7	56.2±28.6	0.01

Values are mean±standard deviation. BBT: balloon blocking technique; MV: main vessel; RWT: reverse wire technique; SB: side branch

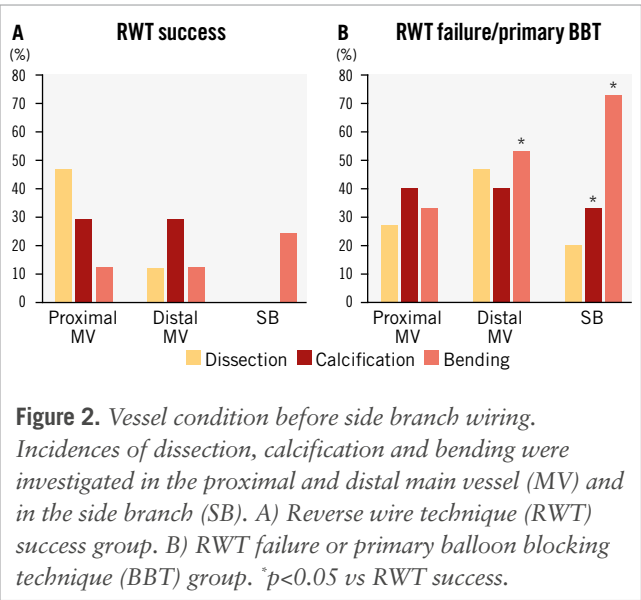


Figure 2. Vessel condition before side branch wiring. Incidences of dissection, calcification and bending were investigated in the proximal and distal main vessel (MV) and in the side branch (SB). A) Reverse wire technique (RWT) success group. B) RWT failure or primary balloon blocking technique (BBT) group. *p<0.05 vs RWT success.

both groups. However, significantly more calcification was detected on the SB ipsilateral side in the RWT-F/BBT group compared to the RWT-S group (62% vs 18%; p=0.02) (Table 3).

DISCRIMINATORY CAPACITY OF RWT FAILURE

A predictive model for RWT failure was developed using ROC analysis with the AUC. Based on the observed trend (p<0.1) of reduced BA-β and greater distal MV MLD before the procedure in the RWT-S group compared to the RWT-F/BBT group, cutoff values for predicting RWT failure were identified as >34.1° (AUC 0.67, 95% confidence interval [CI]: 0.47-0.86) for BA-β and <1.77 mm (AUC 0.70, 95% CI: 0.50-0.89) for distal MV MLD. The combination of BA-β >34.1°, distal MV MLD <1.77 mm, and SB calcification

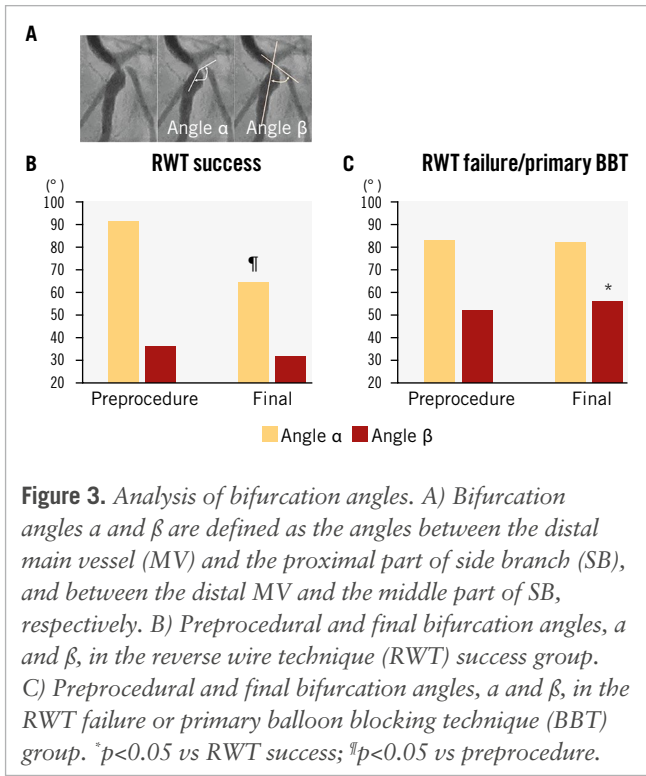


Figure 3. Analysis of bifurcation angles. A) Bifurcation angles α and β are defined as the angles between the distal main vessel (MV) and the proximal part of side branch (SB), and between the distal MV and the middle part of SB, respectively. B) Preprocedural and final bifurcation angles, α and β, in the reverse wire technique (RWT) success group. C) Preprocedural and final bifurcation angles, α and β, in the RWT failure or primary balloon blocking technique (BBT) group. *p<0.05 vs RWT success; #p<0.05 vs preprocedure.

showed high predictive accuracy for RWT failure (AUC 0.85, 95% CI: 0.71-0.98) (Figure 4).

CLINICAL OUTCOMES DURING THE FOLLOW-UP PERIOD

The mean follow-up periods for the RWT-S and RWT-F/BBT groups were 991±807 days and 1,489±856 days, respectively. The incidences of coronary angiography were 53% and 47%, respectively. Target lesion revascularisation, target vessel revascularisation, and myocardial infarction occurred in 0%, 12%, and 0% in the RWT-S group and 7%, 13%, and 7%

Table 3. Calcium location in intracoronary imaging observation.

	RWT success	RWT failure/ primary BBT	p-value
Proximal MV			
SB ipsilateral side	10 (59)	6 (46)	0.71
SB contralateral side	7 (41)	7 (54)	0.71
Distal MV			
SB ipsilateral side	3 (18)	8 (62)	0.02
SB contralateral side	5 (29)	6 (46)	0.45

Values are n (%). BBT: balloon blocking technique; MV: main vessel; RWT: reverse wire technique; SB: side branch

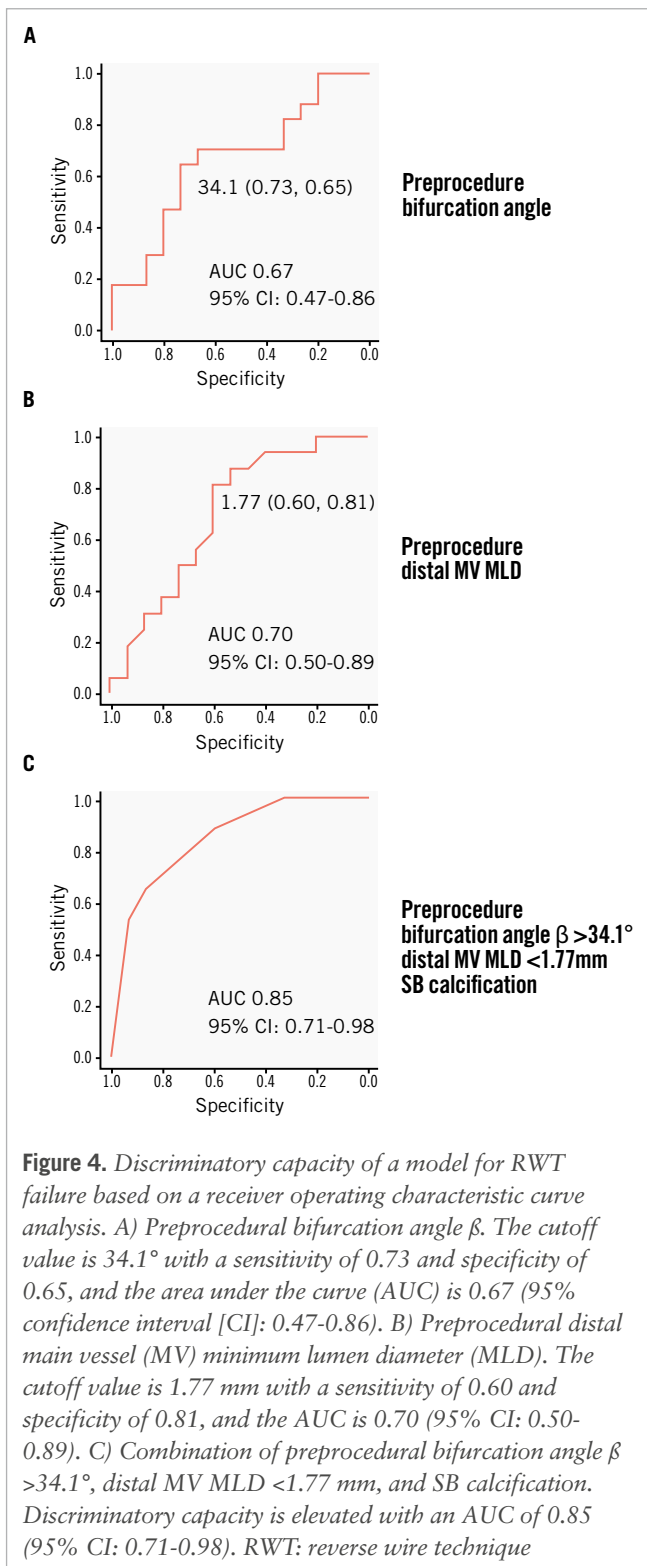
in the RWT-F/BBT group, respectively; these differences were not significant. No deaths occurred in either group.

ANALYSIS OF RWT SUCCESS AND FAILURE

We analysed data from 25 patients undergoing a primary attempt at RWT. Similar trends were observed as in the original analysis, including smaller distal MV MLD, greater BA- β , and more SB calcification, SB bending, and distal MV bending in the RWT failure group ($p < 0.1$) (**Supplementary Table 1**). ROC analysis identified the same cutoff values for distal MV MLD (1.77 mm) and BA- β (34.1°) (**Supplementary Figure 1A, Supplementary Figure 1B**). The combination of SB calcification, distal MV MLD < 1.77 mm, and BA- $\beta > 34.1^\circ$ demonstrated fair discrimination for predicting RWT failure (AUC 0.70) (**Supplementary Figure 1C**), although this performance was inferior to the original analysis (AUC 0.85) (**Figure 4C**).

Discussion

It has been reported that SB occlusion after MV stenting occurs in 7.4-8.4% of cases^{1,2,13}, leading to procedural myocardial infarction and elevated rates of adverse cardiac events at long-term follow-up. The RESOLVE score is a scoring system using angiographical features to predict SB occlusion; it weighs the risks of SB occlusion in plaque distributed on the same side of SB, worse preprocedural Thrombolysis in Myocardial Infarction flow grade in the MV, greater diameter stenosis of the bifurcation core, wider bifurcation angle, greater MV/SB diameter ratio, and greater SB diameter stenosis before MV stenting¹³. A risk analysis based on IVUS observation listed preprocedural SB diameter stenosis $> 50\%$, proximal MV diameter stenosis $> 50\%$, SB lesion length, and acute coronary syndrome as risk factors¹. Analyses based on OCT revealed calcium plaque, bifurcation angle $< 70^\circ$, preprocedural SB diameter stenosis¹⁴, carina tip angle $< 50^\circ$, and length from branching point to carina tip < 1.70 mm as predictive factors¹⁵. SB occlusion occurs via two mechanisms¹⁶: (1) carina shift due to MV stenting (where a narrow bifurcation angle, a smoky carina with a long tip and a rich or hard plaque burden in the MV are considerable risks)^{17,18}; and (2) plaque shift from the same side of the SB (where a wide bifurcation angle with a rich plaque burden close to the SB is associated with an elevated risk)¹³. Greater stenosis in the proximal



MV, bifurcation core, and SB are common risks in both mechanisms.

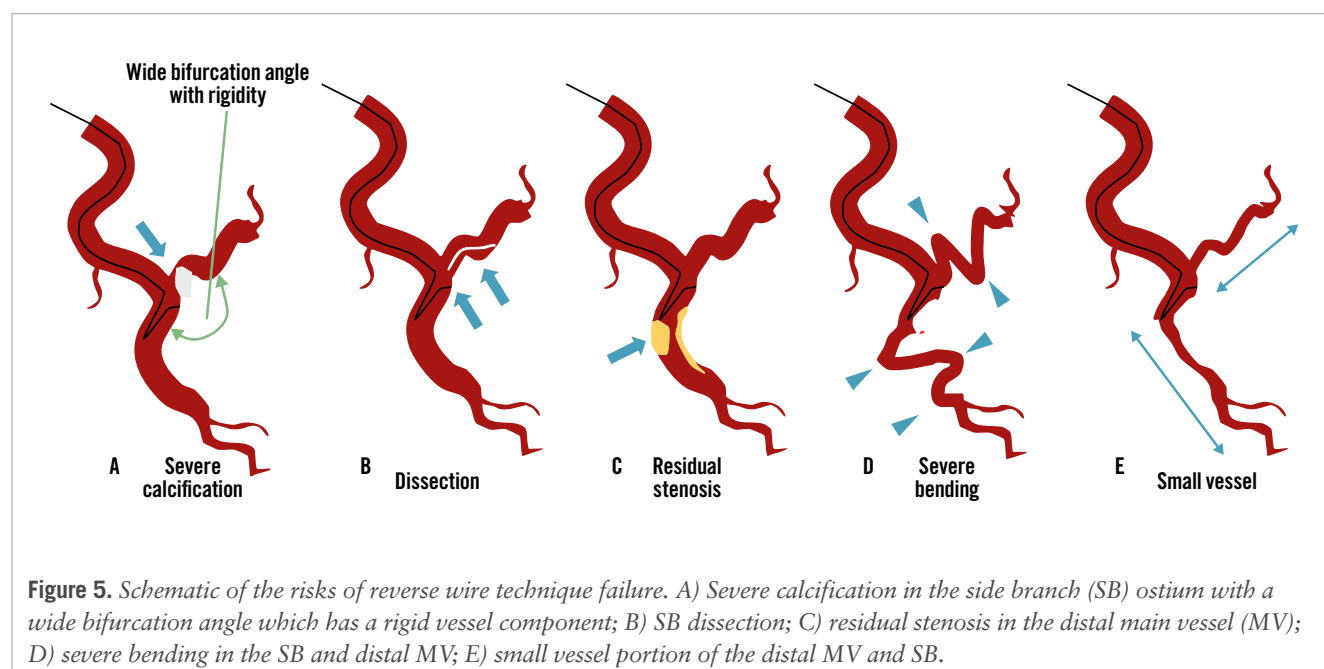
RWT is useful for wiring to extremely bent SBs with a kick-back shape, which leads to the failure of usual antegrade wiring due to the lack of control in advancing the main part of the guidewire into the SB without its collapse in the distal MV²⁻⁵. The kick-back shape bifurcation consists of a wider

BA- α between the distal MV and proximal part of the SB and a narrower BA- β between the distal MV and the middle part of the SB. In the present study, RWT was successful in CBLs with a relatively wide BA- α ($91.4 \pm 20.5^\circ$) and a narrow BA- β ($36.4 \pm 18.6^\circ$) (**Figure 3**). CBLs with a kick-back shape have risks of both carina and plaque shifts, which elevate the risk of SB occlusion. Once SB occlusion has occurred after MV stenting, rewiring into the SB becomes difficult because of the peculiar anatomical features. Therefore, SB wiring before MV stenting is crucial to prevent SB occlusion. Additional plaque modification by balloon dilation in the SB ostium to change BA- α , or the jailed balloon technique, can effectively preserve SB patency¹⁹. In the RWT-F/BBT group, the pre-PCI BA- β was wide ($51.6 \pm 29.8^\circ$) despite the wide BA- α ($82.0 \pm 22.3^\circ$), and these angles did not change significantly post-PCI, as was seen in the RWT-S group (**Figure 3**). More frequent calcified lesions were detected on the SB ipsilateral side in the distal MV in the RWT-F/BBT group compared to the RWT-S group (**Table 3**). These findings indicate the presence of solid SB ostial lesions limiting advancement of an acutely bent wire and a change in the bifurcation angle after wiring or balloon dilation (**Figure 5A**).

Technical difficulties in the RWT are as follows: (1) setting the optimal tip angle and bending length of the guidewire for the individual kick-back shape of each CBL, (2) advancement of the hairpin-like bent portion to the distal MV without intimal injury, (3) directional control of the tip of the guidewire towards the SB, and (4) advancing the tail of the bent portion into the SB entirely. In the current RWT, a double-lumen catheter was used for safer advancement of the bent portion towards the distal MV, without intimal injury or tangling with the MV guidewire, with some improvement in directional control of the guidewire tip towards the SB and more backup support for advancing the bent portion into the SB entirely^{4,5}. Although double-lumen catheters were used in all cases in which the RWT was attempted in the present

study, the success rate was limited to 68% (17/25 cases). Optimal setting of the guidewire – with an acute bend at the tip, an appropriate curve in the proximal part and a bending length of 2-5 cm – is dependent on the individual anatomical features of CBLs and the expertise of the operator. In the RWT-F/BBT group, dissection or remaining stenosis after predilation, with a smaller MLD, was more frequent in the distal MV, which inhibited advancement of the double-lumen catheter and the bent portion of the guidewire. In the RWT-F/BBT group, the MV stent diameter was smaller, and tortuosity in the distal MV was greater, compared with the RWT-S group, suggesting that a smaller vessel lumen and severe tortuosity in the distal MV are also obstacles for advancing the bent portion of the guidewire (**Figure 5B-Figure 5E**). SB calcification and tortuosity were greater issues in the RWT-F/BBT group, indicating that these are obstacles to complete advancement of the bent portion of the guidewire into the SB. More SB calcification might be associated with rigidity of the bifurcated vessels, with unchanged bifurcation angles post-PCI (**Figure 5A, Figure 5B, Figure 5E**). In the predictive model for RWT failure, a combination of BA- $\beta > 34.1^\circ$, distal MV MLD < 1.77 mm, and SB calcification before the procedure had reasonable accuracy (AUC 0.85) (**Figure 4**). These results were also confirmed in the analysis of cases with successful and failed primary RWT attempts (**Supplementary Figure 1**).

In the present study, BBT was successful in 5 of the 8 cases with RWT failure (success rate 62.5%) and in all 7 cases of primary BBT (100%) in which it would be difficult to deliver the bent portion to the distal MV using the RWT. In the BBT, optimal-sized balloon inflation at the bifurcated orifice in the distal MV, visualised on the imaging screen, is necessary to promote guidewire advancement to the SB^{7,8}. A shorter balloon shoulder is advantageous for preventing the guidewire tip from entering the outer rim of the balloon. Once the guidewire tip has entered the SB ostium, usual manipulation of the guidewire can be applied, and support with a microcatheter is feasible



in the ≥ 7 Fr guiding catheter system. Possible risks of this technique include injury to the distal MV by balloon dilation and temporary myocardial ischaemia in the broad MV-perfused area during the procedure, which limits procedural time to 30-120 seconds. However, the BBT has an advantage in cases where it is difficult to advance the bent guidewire to the distal MV or where it is expected to be difficult to manage the guidewire inside the SB with the RWT. There was no significant difference between the RWT and BBT with respect to clinical events during the follow-up period. In cases with a high risk of RWT failure, primary BBT is feasible, and BBT can be an alternative technique in cases of RWT failure.

Limitations

This study has several limitations. 1) This was a retrospective, single-centre, observational study that included only a small number of cases. Large-scale, multicentre studies are needed to confirm the efficacy and feasibility of the RWT and BBT. 2) A combined control group of RWT failure and primary BBT was used because 7 cases were deemed unsuitable for RWT and required primary BBT. While the combined control group showed similar trends to those observed in RWT failure cases (**Supplementary Table 1, Supplementary Figure 1**), it may not accurately reflect the predictors of pure RWT failure. 3) Quantitative assessment of coronary angiography before the procedure may have been inaccurate due to intimal dissection with hazy imaging induced by predilation in the MV. 4) In this series of complex coronary bifurcation PCI involving challenging SB wiring and imaging device delivery, pre-PCI imaging was obtained in 12 cases for the MV but none for the SB, which proved insufficient for predicting RWT failure. 5) Since angiographical SB patency was not confirmed in all cases during the follow-up period, asymptomatic SB-related events were likely undercounted.

Conclusions

The findings identify key predictors of RWT failure in complex CBLs, including large bifurcation angles, small distal MV lumen diameters, calcification, and vessel tortuosity. In such cases, the BBT presents a viable alternative when RWT failure is highly suspected.

Authors' affiliation

Department of Cardiology & Clinical Research Center, National Hospital Organization Kyushu Medical Center, Fukuoka, Japan

Conflict of interest statement

Y. Murasato received a research grant from OrbusNeich; and lecturer fees from Abbott, Medtronic, Boston Scientific, Terumo, and Kaneka. The other authors have no conflicts of interest to declare.

References

- Hahn JY, Chun WJ, Kim JH, Song YB, Oh JH, Koo BK, Rha SW, Yu CW, Park JS, Jeong JO, Choi SH, Choi JH, Jeong MH, Yoon JH, Jang Y, Tahk SJ, Kim HS, Gwon HC. Predictors and outcomes of side branch occlusion after main vessel stenting in coronary bifurcation lesions: results from the COBIS II Registry (COronary BIfurcation Stenting). *J Am Coll Cardiol*. 2013;62:1654-9.
- Pan M, Lassen JF, Burzotta F, Ojeda S, Albiero R, Lefevre T, Hildick-Smith D, Johnson TW, Chieffo A, Banning AP, Ferenc M, Darremont O,

- Chatzizisis YS, Louvard Y, Stankovic G. The 17th expert consensus document of the European Bifurcation Club - techniques to preserve access to the side branch during stepwise provisional stenting. *EuroIntervention*. 2023;19:26-36.
- Kawasaki T, Koga H, Serikawa T. New bifurcation guidewire technique: a reversed guidewire technique for extremely angulated bifurcation—a case report. *Catheter Cardiovasc Interv*. 2008;71:73-6.
- Watanabe S, Saito N, Bao B, Tokushige A, Watanabe H, Yamamoto E, Kawase Y, Kimura T. Microcatheter-facilitated reverse wire technique for side branch wiring in bifurcated vessels: an in vitro evaluation. *EuroIntervention*. 2013;9:870-7.
- Hasegawa K, Yamamoto W, Nakabayashi S, Otsuji S. Streamlined reverse wire technique for the treatment of complex bifurcated lesions. *Catheter Cardiovasc Interv*. 2020;96:E287-91.
- Morishita H, Takeuchi Y, Ito T, Hayashi N, Sato O. Balloon Blocking Technique (BBT) for Superselective Catheterization of Inaccessible Arteries with Conventional and Modified Techniques. *Cardiovasc Interv Radiol*. 2016;39:920-6.
- Li L, Liu J, Jin Q, Chen S. Case report of a novel maneuver to facilitate wire access to the side branch in bifurcation intervention-balloon block and support technique. *Medicine (Baltimore)*. 2018;97:e9673.
- Vijayvergiya R, Batta A, Kasinadhuni G, Gupta A, Gawalkar AA. A side branch balloon block and support technique for difficult distal main branch access during percutaneous coronary intervention. *AsiaIntervention*. 2023;9:52-5.
- Nakamura M, Kimura K, Kimura T, Ishihara M, Otsuka F, Kozuma K, Kosuge M, Shinke T, Nakagawa Y, Natsuaki M, Yasuda S, Akasaka T, Kohsaka S, Haze K, Hirayama A. JCS 2020 Guideline Focused Update on Antithrombotic Therapy in Patients With Coronary Artery Disease. *Circ J*. 2020;84:831-65.
- Albertal M, Van Langenhove G, Regar E, Kay IP, Foley D, Sianos G, Kozuma K, Bejsterveldt T, Carlier SG, Belardi JA, Boersma E, Sousa JE, de Bruyne B, Serruys PW; DEBATE II Study Group. Uncomplicated moderate coronary artery dissections after balloon angioplasty: good outcome without stenting. *Heart*. 2001;86:193-8.
- Hemetsberger R, Abdelghani M, Toelg R, Mankierious N, Allali A, Garcia-Garcia HM, Windecker S, Lefevre T, Saito S, Slagboom T, Kandzari D, Koolen J, Waksman R, Richardt G. Impact of Coronary Calcification on Clinical Outcomes After Implantation of Newer-Generation Drug-Eluting Stents. *J Am Heart Assoc*. 2021;10:e019815.
- Konigstein M, Ben-Yehuda O, Redfors B, Mintz GS, Madhavan MV, Golomb M, McAndrew T, Zhang Z, Kandzari DE, Hermiller JB, Leon MB, Stone GW. Impact of Coronary Artery Tortuosity on Outcomes Following Stenting: A Pooled Analysis From 6 Trials. *JACC Cardiovasc Interv*. 2021;14:1009-18.
- Dou K, Zhang D, Xu B, Yang Y, Yin D, Qiao S, Wu Y, Yan H, You S, Wang Y, Wu Z, Gao R, Kirtane AJ. An angiographic tool for risk prediction of side branch occlusion in coronary bifurcation intervention: the RESOLVE score system (Risk prEdiction of Side branch OccLusion in coronary bifurcation interVENTion). *JACC Cardiovasc Interv*. 2015;8:39-46.
- Fujino Y, Attizzani GF, Tahara S, Takagi K, Naganuma T, Wang W, Bezerra HG, Costa MA, Nakamura S. Impact of main-branch calcified plaque on side-branch stenosis in bifurcation stenting: an optical coherence tomography study. *Int J Cardiol*. 2014;176:1056-60.
- Watanabe M, Uemura S, Sugawara Y, Ueda T, Soeda T, Takeda Y, Kawata H, Kawakami R, Saito Y. Side branch complication after a single-stent crossover technique: prediction with frequency domain optical coherence tomography. *Coron Artery Dis*. 2014;25:321-9.
- Murasato Y, Meno K, Mori T, Tanenaka K. Impact of coronary bifurcation angle on the pathogenesis of atherosclerosis and clinical outcome of coronary bifurcation intervention-A scoping review. *PLoS One*. 2022;17:e0273157.
- Vassilev D, Gil R. Clinical verification of a theory for predicting side branch stenosis after main vessel stenting in coronary bifurcation lesions. *J Interv Cardiol*. 2008;21:493-503.
- Kang SJ, Mintz GS, Kim WJ, Lee JY, Oh JH, Park DW, Lee SW, Kim YH, Lee CW, Park SW, Park SJ. Changes in left main bifurcation geometry after

a single-stent crossover technique: an intravascular ultrasound study using direct imaging of both the left anterior descending and the left circumflex coronary arteries before and after intervention. *Circ Cardiovasc Interv.* 2011;4:355-61.

19. Dou K, Zhang D, Pan H, Guo N, Li L, Li Y, Zhang Q, Liu B, Shen Z, Zhang B, Liu J, Han W, Wang Y, Zhao Y, Yang Y, Chen S, Xie L, Guan C, Kirtane AJ, Xu B; CIT-RESOLVE Investigators. Active SB-P Versus Conventional Approach to the Protection of High-Risk Side Branches: The CIT-RESOLVE Trial. *JACC Cardiovasc Interv.* 2020;13:1112-22.

Supplementary data

Supplementary Table 1. Comparison between cases with success and failure of primary attempt of RWT.

Supplementary Figure 1. Discriminatory capacity of a model for RWT failure in the primary attempt based on ROC curve analysis.

Moving image 1. Case 1: RWT success.

Moving image 2. Case 2: RWT failure due to diffuse vessel dissection after predilation in the distal main vessel and subsequent BBT success.

Moving image 3. Case 3: RWT failure due to diffuse in-stent restenosis in the distal main vessel and subsequent BBT success.

The supplementary data are published online at:

<https://AsiaIntervention.pcronline.com/>

doi/10.4244/AIJ-D-24-00069



Supplementary data

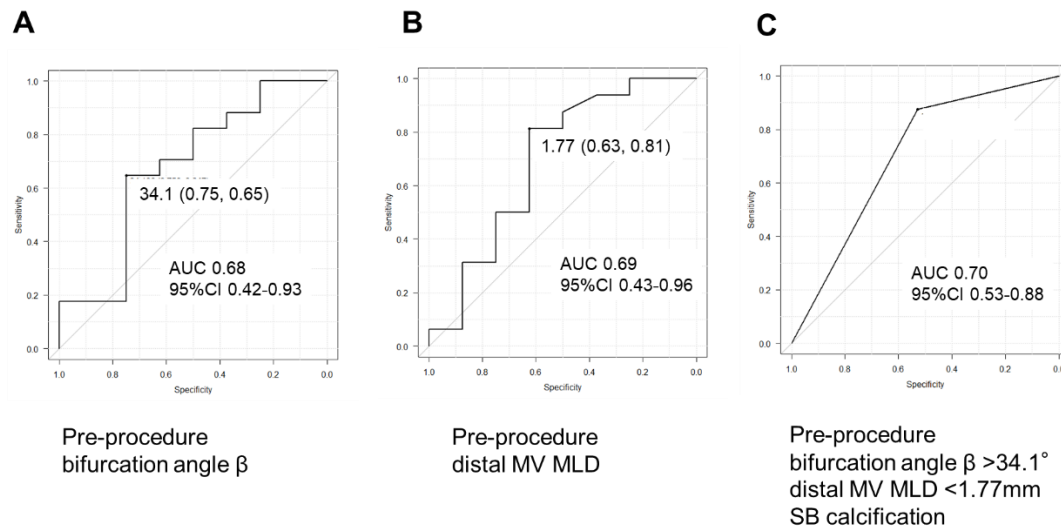
Supplementary Table 1. Comparison between cases with success and failure of primary attempt of RWT.

	RWT success	RWT failure
Patients, n	17	8
Patient background		
Age, years-old	65.2±11.5	73.4±13.4
Male, n (%)	15 (88)	4 (50)
Hypertension, n (%)	15 (88)	8 (100)
Dyslipidemia, n (%)	13 (76)	6 (75)
LDL cholesterol (mg/dL)	104±43	109±45
Diabetes mellitus, n (%)	7 (41)	4 (50)
HbA1C (%)	6.4±1.2	6.1±0.6
Current smoking, n (%)	6 (35)	2 (25)
Hemodialysis, n (%)	1 (6)	0 (0)
Acute coronary syndrome, n (%)	5 (29)	1 (13)
Prior myocardial infarction, n (%)	4 (24)	2 (25)
Left ventricular ejection fraction, %	56±16	60±15
PCI procedure		
Lesion location, n (%)		
Left anterior descending artery	12 (71)	4 (50)
Left circumflex artery	4 (24)	1 (13)
Right coronary artery	1 (6)	1 (13)
Left main coronary artery	0	2 (25)
SB guidewire crosss, n (%)	17 (100)	5 (63)
SB occlusion, n (%)	0 (0)	1 (13)
MV drug-eluting stent		
Size, mm	3.2±0.5	2.8±0.5
Length, mm	24.4±7.3	32.5±12.3†
SB drug-eluting stent, n (%)	1 (6)	0 (0)
drug-coated balloon, n (%)	4 (24)	0 (0)
Plain balloon angioplasty, n (%)	9 (53)	5 (63)
Jailed balloon technique, n (%)	6 (35)	2 (13)
FKB /SB dilation, n (%)	3 (18)	1 (13)

	Imaging		
	IVUS	9 (53)	5 (63)
	OCT / OFDI	8 (47)	3 (38)
	Pre-PCI observation: MV	10 (59)	4 (50)
	SB	0 (0)	0 (0)
Pre-procedure			
	Proximal MV		
	Minimum lumen diameter, mm	2.08±0.68	2.43±0.93
	Dissection, n (%)	8 (47)	3 (38)
	Calcification, n (%)	5 (29)	4 (50)
	Bending, n (%)	2 (12)	3 (38)
	Distal MV		
	Minimum lumen diameter, mm	2.14±0.58	1.78±0.77†
	Dissection, n (%)	4 (12)	3 (38)
	Calcification, n (%)	5 (29)	4 (50)
	Bending, n (%)	2 (12)	5 (63)*
	SB		
	Minimum lumen diameter, mm	1.47±0.46	1.24±0.77
	Dissection, n (%)	0 (0)	2 (25)†
	Calcification, n (%)	0 (0)	3 (38)*
	Bending, n (%)	4 (24)	5 (63)*
	Bifurcation angle α , °	91.4±20.5	83.1±23.9
	Bifurcation angle β , °	36.4±18.6	53.3±30.8†
Final			
	Proximal MV		
	Minimum lumen diameter, mm	3.15±0.40	3.30±0.65
	Dissection, n (%)	0 (0)	0 (0)
	Distal MV		
	Minimum lumen diameter, mm	2.96±0.48	2.77±0.57
	Dissection, n (%)	0 (0)	1 (13)
	SB		
	Minimum lumen diameter, mm	1.68±0.46	1.66±0.97
	Dissection, n (%)	9 (53)	2 (25)
	Bifurcation angle α , °	64.7±25.1	79.4±26.7
	Bifurcation angle β , °	31.6±14.7	56.6±32.3*

RWT: reverse wire technique, LDL: low-density lipoprotein, PCI: percutaneous coronary intervention, SB: side branch, MV: main vessel, FKB: final kissing balloon inflation, IVUS: intravascular ultrasound, OCT: optical coherence tomography, OFDI: optical frequency domain imaging.

† $p < 0.1$, * $p < 0.05$ vs. RWT success



Supplementary Figure 1. Discriminatory capacity of a model for RWT failure in the primary attempt based on ROC curve analysis.

A. Pre-procedure bifurcation angle β . The cut-off value is 34.1° with a sensitivity of 0.75 and specificity of 0.65, and the area under the curve (AUC) is 0.68 (95% confidence interval [CI] 0.42–0.93). B. Pre-procedure distal main vessel (MV) minimal lumen diameter (MLD). The cut-off value is 1.77 mm with a sensitivity of 0.63 and specificity of 0.81, and AUC is 0.69 (95% CI 0.43–0.96). C. Combination of pre-procedure bifurcation angle $\beta > 34.1^\circ$, distal MV MLD < 1.77 mm, and SB calcification. Discriminatory capacity is elevated with AUC 0.70 (95% CI 0.53–0.88).

Supplementary moving images: representative cases of side branch wiring with reverse wire technique (RWT) and with the balloon blocking technique (BBT) after RWT failure shown in **Figure 1**.

Moving image 1. Case 1: RWT success.

Moving image 2. Case 2: RWT failure due to diffuse vessel dissection after predilation in the distal main vessel and subsequent BBT success.

Moving image 3. Case 3: RWT failure due to diffuse in-stent restenosis in the distal main vessel and subsequent BBT success.