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*Percutaneous Coronary Intervention*

# Crusade Microcatheter-Facilitated Reverse Wire Technique for Revascularization of Bifurcation Lesions of Coronary Arteries

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***Background:*** This study aims to analyze the lesion characteristics of bifurcations that required reverse wire technique and the efficacy and safety of this technique in approaching branches with a highly angulated take-off.

***Methods:*** We enrolled patients in whom reverse wire technique was used after failed conventional antegrade wiring with the support of a Crusade catheter. The study endpoints were the technical success defined as succeeding in sending the reversely bent wire to the targeted branches without complications and the procedural success defined as succeeding in revascularization of the bifurcation lesions without complications.

***Results:*** Among 158 patients with bifurcation lesions undergoing percutaneous coronary intervention using a Crusade catheter to facilitate wiring, 23 (14.6%) requiring the reverse wire technique in an attempt to access branches of the bifurcation lesions with an acutely angulated take-off were enrolled for analysis. The obtainable angle of take-off was 162.9 ± 4.7 degrees. For the parent vessel, the ostium of the targeted branch, and nontargeted branch, the minimal luminal diameters were 0.3 ± 0.5 mm, 0.4 ± 0.2 mm, and 1.8 ± 0.5 mm, respectively; the diameter stenosis were 88.8 ± 18.5%, 83.0 ± 7.3%, and 32.0 ± 14.5%, respectively. Technical and procedural success was achieved in 22 cases (96% for both).

***Conclusions:*** We showed in the present study that the reverse wire technique is effective and safe for approaching highly angulated branches of bifurcation lesions and consequently for complete revascularization of difficult bifurcation lesions.

**Key Words:** Bifurcation lesion • Percutaneous coronary intervention • Reverse wire technique

## INTRODUCTION

Successful wiring to approach branches is essential for a successful percutaneous coronary intervention (PCI) for bifurcation lesions.[1,2] However, wiring for side branches with an extremely angulated take-off can be challenging, as the wire is prone to prolapse into non-targeted branches if a conventional wiring technique is used. For such lesions, the double-lumen Crusade catheter (Kaneka, Osaka, Japan) is commonly used. Held by a wire placed at the non-targeted branch, the Crusade catheter provides a firm support and enhances the advancing force of the guidewire to approach the angulated targeted branch.[3] However, conventional wiring is almost impossible for some extremely angulated lesions, even with the support of a Crusade catheter. According to in vitro bench tests, when the bifurcation angle is larger than 150°, the wire cannot approach the branch using a conventional antegrade wiring technique even under the support of a Crusade catheter.[4] The reverse wire technique was specifically developed to overcome these challenging bifurcation lesions. It was first

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reported in 2008 by Kawasaki and colleagues,[5] and it is being increasingly used in PCIs. Although the feasibility and potential indications of this technique have been tested in in vitro bench tests,[4] its performance in clinical practice has yet to be validated. Therefore, the aim of this single center cohort study was to analyze: 1) the characteristics of bifurcation lesions that require this technique during PCI; 2) the step-by-step procedural details; and 3) the rates of technical and procedural success using this technique.

## METHODS

### Patient population

We enrolled patients in whom a reverse wire technique was used in an attempt to approach branches of bifurcation lesions with an acute angle of take-off larger than 150°,[4] and in whom conventional antegrade wiring with the support of a Crusade catheter had failed. This study was conducted at Chang Gung Memorial Hospital, Linkou, Taiwan from September 2012 (first case) to May 2016.

### Definitions

We defined a branch with an angulated take-off requiring the reverse wire technique to facilitate wiring as the targeted branch, and the other as the non-targeted branch regardless of whether it was a main or side branch. The angle of take-off was defined as 180° minus the angle between the parent vessel and the targeted branch (Figure 1A). The obtainable viewing angle of take-off was characterized by an orthogonal view of the bifurcation, such that the overlap and foreshortening of the bifurcation lesions were minimized. Technical success was defined as successfully sending the reversely bent wire to the distal part of the targeted branch. Procedural success was defined as success in revascularizing the bifurcation lesions with less than 30% residual stenosis with TIMI flow grade 3 and less than 50% residual stenosis with TIMI flow grade 3 for main and side branches, respectively.[6]

### Preparation of the system and details of the procedure

A Crusade catheter and Fielder Fc (Asahi Intec) guidewire were used exclusively for the reverse wire technique. The guidewire was introduced into the over-the-wire lumen of the Crusade catheter and shaped by making a minimal primary tip curve (≒ 1-2 mm) followed by a secondary curve that fit the angle of take-off of the targeted branch in aretrograde approach. A bend was then intentionally made in the opposite direction of the tip curve at about 3 cm away from the wire tip, with the distal 3 cm of wire being left bent outside the catheter.

The steps involved in the reverse wire technique were as follows:

1. A guidewire was placed in the non-targeted branch to support delivery of the Crusade catheter alone with the bent wire down to the non-targeted branch with the tip of the reversely bent wire remaining distal to the take-off of the targeted branch (Figure 1B).
2. After pulling the Crusade microcatheter back to the parent vessel, the reversely bent wire was pulled back slowly and manipulated gently so that the wire tip was engaged into the ostium of the target branches (Figure 1C). The wire was then further pulled back slowly, and the reversely bent segment was spontaneously advanced by tracking the targeted branch (Figure 1D). Intentional torque control was needed sometimes to deliver the wire down to the distal segment.
3. The secondary curve was reshaped to better fit the angle of take-off of the targeted branch if the wire failed to engage the ostium, or advanced with its original tip curve.

### Statistical analysis

Descriptive analysis was performed. Results are pre-

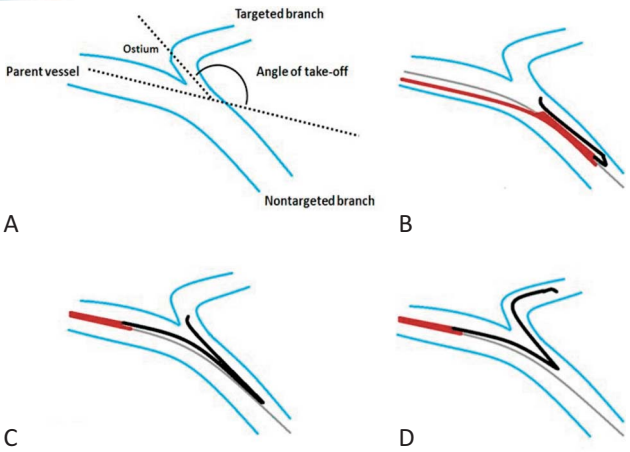


***Figure 1.*** *Schematic diagram.*

sented as frequency or percentage for categorical data, and mean ± standard deviation for continuous variables.

## RESULTS

### Baseline demographics

From September 2012 to May 2016, a total of 158 patients with bifurcation lesions underwent PCI using the Crusade catheter to facilitate wiring. Among them, 23 (14.6%) required the reverse wire technique to access either branch of the bifurcation lesion due to an acutely angulated take-off. The baseline characteristics of the study cohort are listed in Table 1. Most of the patients were male, the mean age was 65.4 ± 6.0 years, and all of the patients presented with stable angina except for 4 patients who presented with acute coronary syndrome.

### Angiographic and procedural characteristics

Table 2 presents the angiographic characteristics of the bifurcation lesions. Most of the bifurcation lesions were located in left anterior descending and diagonal coronary arteries (74%), followed by the left circumflex and obtuse marginal coronary arteries (17%), and posterior descending and posterior lateral coronary branches of the right coronary arteries (9%). The types of bifurcation according to the Medina classification[7] were 1,1,1 (17%), 1,0,1 (48%), 1,1,0 (30%), and 0,1,1 (5%). The obtainable viewing angle of take-off was 162.9 ± 4.7°. The targeted branch was the main branch in 10 (44%) patients, and the side branchin 13 (56%) patients. For the parent vessel, the ostium of the targeted branch, and the non-targeted branch, the minimal luminal diameters

**Table 1.** Baseline characteristics of patients (n = 23)

| | |
|---|---|
| Age, years | 65.4 ± 6.0 |
| Male, n (%) | 17 (74) |
| Ejection fraction, % | 62.5 ± 10.0 |
| Smoking, n (%) | 4 (17) |
| Hypertension, n (%) | 17 (74) |
| Diabetes mellitus, n (%) | 11 (48) |
| Dyslipidemia, n (%) | 16 (70) |
| Chronic kidney disease, n (%) | 4 (17) |
| Previous stroke, n (%) | 1 (4) |
| Previous bypass surgery, n (%) | 2 (9) |
| Acute coronary syndrome, n (%) | 4 (17) |

Values are expressed as mean ± standard deviation or number (percentage).

**Table 2.** Angiographic characteristics of bifurcation lesions (n = 23)

| | | | |
|---|---|---|---|
| Location of bifurcation | | | |
| LAD/D, n (%) | 17 (74) | | |
| LCX/OM, n (%) | 4 (17) | | |
| PD/PL, n (%) | 2 (9) | | |
| Type of bifurcation according to the medina classification | | | |
| 1,1,1, n (%) | 4 (17) | | |
| 1,0,1, n (%) | 11 (48) | | |
| 1,1,0, n (%) | 7 (30) | | |
| 0,1,1, n (%) | 1 (5) | | |
| Obtainable viewing angle of take-off, degree | 162.9 ± 4.7 | | |
| Targeted branch for reverse wire technique | | | |
| Main branch, n (%) | 10 (44) | | |
| Side branch, n (%) | 13 (56) | | |
| | Parent vessel | Ostium of targeted branch | Nontargeted branch |
| Minimal luminal diameter, mm* | 0.3 ± 0.5 (0-2.5) | 0.4 ± 0.2 (0.2-0.7) | 1.8 ± 0.5 (1.1-2.8) |
| Reference vessel diameter, mm* | 2.7 ± 0.2 (2.4-3.3) | 2.2 ± 0.2 (1.7-2.7) | 2.6 ± 0.2 (2.4-3.0) |
| Diameter stenosis, % | 88.8 ± 18.5 | 83.0 ± 7.3 | 32.0 ± 14.5 |
| Chronic total occlusion, n (%) | 8 (35) | 0 | 0 |

D, diagonal artery; LAD, left anterior descending artery; LCX, left circumflex artery; LM, left main; OM, obtuse marginal artery; PD, posterior descending artery; PL, posterior lateral artery; RCA, right coronary artery.

* Mean and interquartile range.

(MLD) were 0.3 ± 0.5 mm, 0.4 ± 0.2 mm, and 1.8 ± 0.5 mm, and the stenosis diameters were 88.8 ± 18.5%, 83.0 ± 7.3%, and 32.0 ± 14.5%, respectively. Eight lesions were chronic total occlusion (CTO) lesions involving the parent vessels. For these patients with CTO lesions, which vessel was the targeted or non-targeted branch was determined after opening the CTO lesion with balloon angioplasty. For the non-targeted branches that were used to accommodate the bulky reverse wire system, the diameters were small (mean 1.8 mm).

The procedural characteristics are described in Table 3. Fifteen cases (65%) were approached via the radial artery, and 8 cases (35%) via the femoral artery. A 6 Fr guiding catheter was used in 11 cases (48%), and a 7 Fr guiding catheter was used in 12 cases (52%). Guiding catheters with strong backup support, EBU4 for the left coronary artery and Amplaz Left 1 short tip, were used in 86% and 100% of the cases, respectively. Twenty-two patients (96%) with severe stenosis or CTO of the parent vessel required balloon pre-dilatation to allow passage of the Crusade catheter alone with the reversely bent wire. When pre-dilation was needed, the balloon used was small (median diameter: 2.0 mm; interquartile range: 1.2 to 2.5 mm). In all cases, the reverse wire system was successfully delivered to the non-targeted branch without dissection or perforation in spite of the small diameter. After successful delivery of the system, the reversely bent wires successfully engaged and tracked down to the targeted branches in all but 1 case, with a median of 1 attempt (interquartile range 1 to 3). No dissections were caused by the wire. In the single case of wiring failure, the targeted branch was the left anterior descending with an acute take-off right distal to a totally occluded segment. When the reversely bent wire had tracked down to the targeted branch for less than 2 mm, the wire encountered another nearly occluded lesion and could not be advanced further.

In 2 cases, after crossing the ostium of the targeted branch, the reversely bent wire inevitably tracked down to a nearby unexpected small side branch instead of the major targeted branch itself due to the preferential angulation. The coronary angiography of 1 of these two cases is illustrated in Figure 2. In an attempt to approach the expected major branch, fine torque control of the wire with adequate support at the ostium of the targeted branch was required. The wiring procedure can be challenging using this intentionally bent wire, and the wire may be prone to go back to the parent vessel during manipulation. In such cases, we applied a balloon anchoring technique as shown in Figures 2B-D. First, the wire that went into the unexpected small branch was advanced as distally as possible (Figure 2B). Then a small monorail balloon catheter (1.2 or 1.5 mm) was advanced to the targeted branch by tracking the wire and then inflated with the balloon across the bifurcation and the tip slightly proximal to the take-off of the expected branch (Figure 2C). In addition to providing a stable support for the wiring, the monorail channel of the balloon catheter located across the bifurcation provided a route for easy access of the wire to the angulated targeted branch if it unintentionally returned proximally to the parent vessel during manipulation. Using this technique, the wire was successfully delivered to the targeted branch (Figure 2D). Good angiographic results were achieved after sequential balloon angioplasty and stent deployment (Figures 2E-F).

**Table 3.** Procedural characteristics of bifurcation lesions (n = 23)

| | | |
|---|---|---|
| Vascular access | | |
| Transradial approach, n (%) | 15 (65) | |
| Transfemoral approach, n (%) | 8 (35) | |
| Guiding catheter, n (%) | | |
| 6 Fr/7 Fr | 11 (48)/12 (52) | |
| LCA: EBU 3.5/4.0 | 3 (14)/18 (86) | |
| RCA: SAL1/others | 2 (100)/0 | |
| Pre-dilatation, n (%) | 22 (96) | |
| Balloon size for predilatation, mm* | 2.0 (1.2-2.5) | |
| Intravascular imaging guidance, n (%) | 4 (17) | |
| | Main branch | Side branch |
| Stent diameter, mm (n) | 2.8 ± 0.3 (21) | 2.4 ± 0.1 (6) |
| Stent length, mm (n) | 30.1 ± 7.8 (21) | 23.8 ± 5.2 (6) |
| Single stent technique, n (%) | 15 (65) | |
| 2 stent technique, n (%) | 6 (26) | |
| Culotte technique, n | 4 | |
| Crush technique, n | 2 | |
| Drug eluting balloon, n (%) | 1 (5) | |
| Number of attempts to achieve reverse wiring* | 1 (1-3) | |
| Balloon anchor technique, n (%) | 2 (9) | |
| Technical success, n (%) | 22 (96) | |
| Procedural success, n (%) | 22 (96) | |

LCA, left coronary artery; RCA, right coronary artery.
* Median and interquartile range.

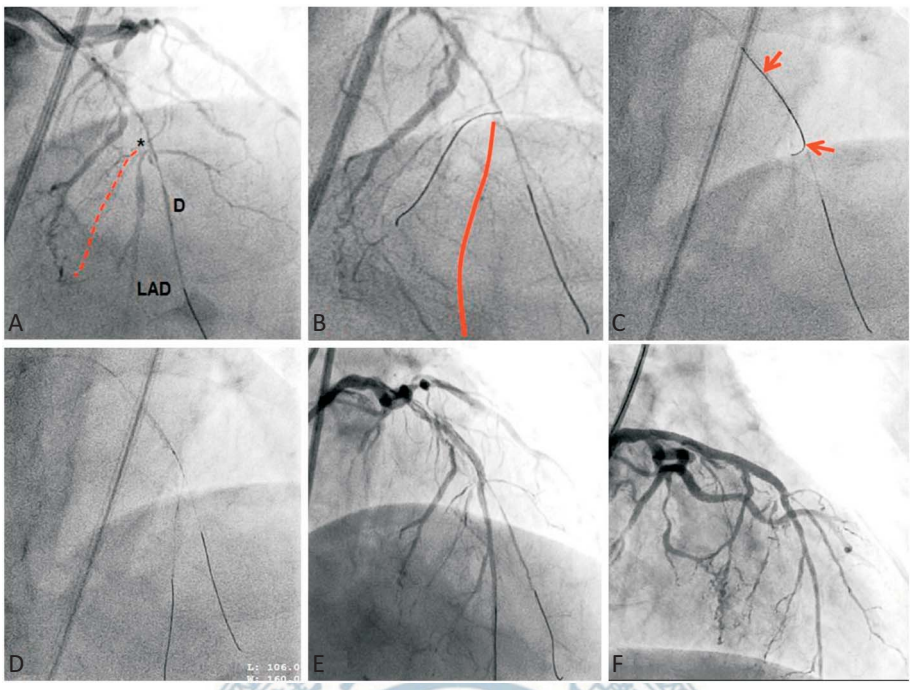


***Figure 2.*** *Balloon anchoring used as an adjunct along with the reverse wire technique (A) Coronary angiogram (anterior-posterior view) with cranial angulation showing extremely angulated take-off (asterisk) of the left anterior descending artery (LAD), and a septal branch (red dotted line) at the bifurcation of the LAD and diagonal branch (DB) presenting near the take-off of the LAD; (B) Using the reverse wire technique, the guidewire inevitably went into the septal branch instead of the LAD (red line) due to the preferential angulation; (C) A 1.2-mm balloon (indicated by red arrows) was inflated across the bifurcation to support the wiring procedure and to ensure easy access to the angulated LAD; (D) With the support of the anchored balloon, the guidewire was successfully delivered to the targeted branch; (E) Coronary angiogram showing successful delivery of the guidewires into the LAD and DB, and stent deployment for the middle part of the LAD; (F) Final angiogram of the LAD after the intervention in right anterior view with cranial angulation.*

### Procedural and technical success rates

Technical success of the reverse wire technique was achieved in 22 of the 23 cases (96%). For the cases with successful wiring, successful revascularization was achieved in all 15 patients using the single stent technique (65%), 6 patients using the two stent technique (26%), and 1 patient using a drug-eluting balloon (5%), resulting in a procedural success rate of 96%. No cases of vascular perforation or dissection, thromboembolism, or other remarkable events were noted during the interventions. Furthermore, none of the patients required emergency coronary artery bypass graft surgery or pericardiocentesis.

## DISCUSSION

Coronary bifurcation lesions are found in approximately 15% to 20% of PCIs, and they have been shown to be associated with lower procedural success rates compared with non-bifurcation lesions.[8] Bifurcation lesions with branches with an acutely angulated take-off may make wiring extremely challenging. Two wiring techniques, the reverse wire and pull-back technique, have been developed specifically to overcome such challenging wiring. A deflectable microcatheter, the Venture microcatheter, has also been designed to facilitate difficult wiring.[9] The reverse wire technique was first reported in 2008 by Kawasaki and colleagues.[5] Recently, Watanabe et al. evaluated the performance of this technique in an in vitro bifurcation model, and showed its feasibility in approaching branches with acute take-off. However, its performance in clinical practice has not previously been systemically analyzed.

In the present single center cohort study, we analyzed both the lesion characteristics of bifurcation that required the reverse wire technique and the step-by-step procedural details. We found that in cases with bi-

furcation lesions requiring the Crusade catheter to facilitate challenging wiring, 14.6% of all cases required the reverse wire technique to accomplish the wiring procedure. In these cases, the average bifurcation angle was about 163°. Although the incidence of patients requiring this technique is not that high, successful revascularization would barely be possible in these cases without this technique. In the present study, we showed that with adequate support of the guiding catheter and predilatation of the parent vessel, the reverse wire system including a Crusade catheter and a reversely bent wire could be successfully delivered to all of the non-targeted branches, even those with a small diameter, without causing any vascular injury or other remarkable complications. After successful delivery of the system, successful wiring to the targeted branches was achieved in all but 1 case, with a median of 1 attempt (interquartile range 1 to 3). There were no remarkable complications in any of the cases. These findings indicate that this technique is effective and safe in overcoming challenging wiring for branches of bifurcation lesions with a highly angulated take-off. In two cases, the reversely bent wire preferentially tracked down to nearby small branches instead of the targeted major branches due to specific anatomy. In these cases, we developed a balloon anchoring technique to facilitate the approach for the targeted major branch, which finally resulted in successful wiring in both cases. In the 22 cases with successful wiring, successful revascularization for the bifurcation lesions was achieved in all cases with either a single or two stent technique.

There are several limitations to the present study. First, the number of cases was small, and the majority of procedures were performed by an experienced operator. Thus, the results may not be applicable for less experienced operators. Second, there are inherent limitations in the retrospective observational design at a single center.

## CONCLUSIONS

In this single center cohort study, we showed that with proper preparation of the system, the reverse wire technique is effective and safe to approach highly angulated braches of bifurcation lesions and consequently for complete revascularization of difficult bifurcation lesions.

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## CONFLICT OF INTEREST STATEMENT

All authors have no conflicts of interest to declare.

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