# Treatment of coronary bifurcation lesions with two-stent techniques: short- and long-term outcomes

# Traitement des lésions de bifurcations coronaires par techniques à deux stents : résultats immédiats et à long terme

Selim Boudiche[1], Amal Ben Salem[2], Faten El Ayech[3], Zeynab Jebbari[1], Khaled Ezzaouia[1], Foued Daly[1], Boutheina Besbes[1], Rim Ben Rejeb[1], Dhekra Sebki[4], Ines Bounaoues[4], Mehrez Gouader[4], Fathia Mghaieth[1], Sana Ouali[1], Noureddine Larbi[1], Manel Ben Halima[1], Mohamed Sami Mourali[1]

1. *University Tunis El Manar, Faculty of Medicine of Tunis, La Rabta Hospital, Cardiology Department, Tunis, Tunisia.*
2. *University Tunis El Manar, Faculty of Medicine of Tunis, La Rabta Hospital, CardioVascular Surgery Department, Tunis, Tunisia.*
3. *University Tunis El Manar, Faculty of Medicine of Tunis, Charles Nicolle Hospital, Cardiology Department, Tunis, Tunisia.*
4. *University Tunis El Manar, Faculty of Medicine of Tunis, La Rabta Hospital, Anesthesiology Department, Tunis, Tunisia.*

## Summary

**Introduction:** Angioplasty of coronary bifurcation lesions (CBL) using 2-stent techniques represents 5% of percutaneous coronary interventions (PCI) being real challenge. This study aimed to evaluate immediate and long-term prognosis of these patients.

**Methods: Monocentric retrospective study led between January 2014 and June 2020 including all patients who underwent CBL-PCI using** a two-stent strategy. A minimum 12-month follow-up was required. Primary endpoint was target lesion failure (TLF), a composite of cardiac death, target vessel myocardial infarction (TVMI) and clinically driven target lesion revascularization (TVR).

**Results: 80 patients were included with a mean age 61.4±11 years old and a gender ratio=3. Diabetes was noted in 66.3%. PCI was elective in** 85% of cases. Strategies were: T and protrusion (61.3%), DK-Crush (13.8%), T stenting (8.8%), Culotte (6.3%), Mini-Crush (6.3%), V stenting (1.3%), SKS (1.3%) and a 3-stent technique (1.3%). Proximal optimization and final kissing balloon techniques were underused being performed in 82.5% and 86.3% respectively. Procedural success was achieved in all cases. At 13.5-month follow-up, TLF rate was 18.8% (cardiac death 1.3%, TVMI 13.8% and TLR 17.5%). Definite or probable stent thrombosis rate was 3.8%. TLF predictive factors were bifurcation angle >90° (p=0.001, OR=21.42 [3.3–60]), side branch reference diameter ≤2.5mm (p=0.005, OR=1.23 [2.07–50.7]), a length of the main branch lesion ≥25mm (p=0.002, OR=6.50 [1.9–21.19]), and calcifications of the main branch (p=0.019, OR=3.98 [1.28–12.63]).

**Conclusion:** Two-stent techniques for CBL-PCI were associated with a high adverse events rate at long-term follow-up despite initial

## Keywords

Coronary bifurcation lesion; Percutaneous coronary intervention; Target lesion failure; Stent thrombosis; In-stent restenosis.

## Résumé

**Introduction:** L'angioplastie des lésions de bifurcation coronaire (LBC) par une technique à 2 stents représente 5 % des interventions coronaires percutanées (ICP) représentant un véritable défi. Cette étude visait à évaluer le pronostic immédiat et à long terme de ces patients.

**Méthodes :** Étude rétrospective monocentrique menée entre janvier 2014 et juin 2020, incluant tous les patients ayant bénéficié d'une LBC-ICP par 2 stents. Un suivi minimum de 12 mois était requis. Le critère d'évaluation principal était l'échec de la lésion cible (TLF), composite de décès cardiaque, infarctus du myocarde du vaisseau cible (TVMI) et revascularisation de la lésion cible (TLR).

**Résultats :** 80 patients ont été inclus avec un âge moyen 61,4±11 ans. et un genre-ratio à 3. L'ICP était élective dans 85 % des cas. Les stratégies étaient : T and protrusion (61,3 %), DK-Crush (13,8 %), stenting en T (8,8 %), Culotte (6,3 %), Mini-Crush (6,3 %), stenting en V (1,3 %), SKS (1,3 %) et une technique à 3 stents (1,3 %). Les techniques d'optimisation proximale et de kissing-balloon final étaient sous-utilisées, réalisées dans 82,5 % et 86,3 % respectivement. Un succès procédural a été obtenu dans tous les cas. Au suivi à 13,5 mois, le taux de TLF était de 18,8% (décès cardiaque 1,3%, TVMI 13,8% et TLR 17,5%). Le taux de thrombose de stent était de 3,8 %. Les facteurs prédictifs de TLF étaient un angle de bifurcation >90° (p=0,00, OR=21,42 [3,3–60]), un diamètre de référence de la branche latérale ≤2,5mm (p=0,005, OR=1,23 [2,07–50,7]), une longueur de la lésion de la branche principale ≥25 mm (p=0,002, OR=6,50 [1,9–21,19]) et des calcifications de la branche principale (p=0,019, OR=3,98 [1,28–12,63]).

**Conclusion :** Les techniques à deux stents pour l'ICP de CBL étaient associées à un taux élevé d'événements indésirables à long terme, malgré un succès initial de la procédure chez tous les patients. Une meilleure sélection des patients et des techniques rigoureuses pourrait optimiser ces résultats.

## Mots-clés

Lésion de bifurcation coronaire ; Angioplastie coronaire ; Défaillance de lésion cible ; thrombose de stent ; resténose intra-stent,

*Correspondance*

Selim Boudiche

University of Tunis El Manar, Faculty of Medicine of Tunis, La Rabta Hospital, Cardiology Department, 1007, Tunis, Tunisia.

Email: selim.boudiche@fmt.utm.tn

## INTRODUCTION

Angioplasty of coronary bifurcation lesions (CBL) represents approximately 15 to 20% of percutaneous coronary interventions (PCI) and poses a significant challenge in interventional cardiology. The anatomical complexity of these lesions contributes to higher rates of immediate procedural failure and subsequent failures during follow-up (1).

Until the 1980s, CBL were typically addressed surgically, but starting from the 1990s, various percutaneous treatment techniques rapidly developed, including balloon angioplasty, debulking, and stenting with the placement of one or multiple stents using different techniques as well as imaging guidance (2).

Feasibility, effectiveness, and safety of these interventional techniques have been extensively evaluated in international publications within the field of interventional cardiology. Several randomized trials comparing different techniques of angioplasty for CBL have been published during last years with the one-stent technique, known as "Provisional" stenting being the gold standard approach according to various consensus statements (3–6).

Majority of these studies have shown that a two-stent strategy does not outperform a provisional one-stent strategy in terms of clinical events (7).

Elective or bailout use of a two-stent technique remains necessary in 5% of cases, dictated by complex anatomy with diffuse atherosclerotic involvement of both the main branch and the side branch. Experienced operators and meticulous technique are necessary when considering a two-stent strategy for the treatment of CBL to avoid short- and long-term pitfalls, mainly driven by the demonstrated increased risk of stent thrombosis (ST) (3,8–10).

To the best of our knowledge, no study about two-stent CBL PCI has been published in Tunisia to date. Scarcity of data could be explained, among other factors, by the lack of reimbursement for such procedures by the national health insurance fund.

This study aimed to evaluate immediate and long-term outcomes of patients treated with two-stent techniques for CBL in a Tunisian University Hospital.

## METHODS

### Study Design and population

This was a monocentric retrospective observational study led between January 2014 and June 2020.

All patients who underwent PCI for de novo CBL using a two-stent technique, regardless of clinical presentation and whether the indication was elective or bailout. A minimum follow-up of 12 months was required.

Patients who underwent CBL-PCI using bare-metal stents, patients treated for in-stent restenosis involving the index bifurcation and patients with incomplete data (lost medical records, etc.) were excluded.

### Study definitions

Bifurcation lesion is "a coronary artery narrowing occurring adjacent to, and/or involving, the origin of a significant side branch (SB)." A significant SB is a branch that you do not want to lose in the global context of a particular patient (symptoms, location of ischemia, branch responsible for symptoms or ischemia, viability, collateralizing vessel, left ventricular function) (11)

Medina Classification : This classification attributes a score of 0 or 1 to the 3 segments of a bifurcation lesion—proximal main vessel, distal main vessel, and side branch—as a binary function dependent on an angiographic stenosis of >50% (score 1) or <50% (score 0) in each location (12)

### Study endpoints

Primary endpoint was the target lesion failure (TLF) at 12 months, defined as the composite of cardiac death, target vessel myocardial infarction (TVMI), or clinically driven target lesion revascularization (TLR) (13). Death from cardiac causes was defined as any death without a clear non-cardiac cause (14). TLR was defined as any repeat percutaneous intervention of the target lesion or bypass surgery of the target vessel performed for restenosis or other complication of the target lesion (13).

Secondary endpoint was the occurrence of major adverse cardiovascular events (MACE) at 12 months, defined as the composite of all-cause death, myocardial infarction and any repeat revascularization (14). A focus on stent thrombosis (ST) and in-stent restenosis (ISR) incidence was considered according to the Academic-Research-Consortium (ARC) criteria (15).

## Statistical analysis

For all statistical analyses, SPSS version 23 was used. Simple and relative frequencies for qualitative variables, means with standard deviations or medians with inter-quartile intervals for quantitative variables were calculated. Search for survival prognostic factors was performed in univariate analysis, after transformation of continuous variables into categorical variables according to the median or risk levels in the literature, by comparing the survival curves by the Log rank test. Variables whose degree of significance p was <0.10 were included in the multivariate analysis of TLF using the Cox model as well as age, sex that were forced into the model. Degree of significance p was set at ≤ 0.05.

# RESULTS

80 patients were included. This represented 1.6% of total PCI volume (5,042 PCI) performed during the 6.5 years investigated period.

## Baseline characteristics

Mean age was 61.4±11 years, ranging from 37 to 82 years. Male predominance was evident with a sex ratio of 3.

Diabetes was the most represented cardiovascular risk factor (66.3%).

Acute coronary syndrom (ACS) was the most frequently reported clinical presentation (73.8%) followed by chronic coronary syndrom (CCS) (26.3%).

Mean LVEF was 49.9±9.7% with extremes ranging from 25% to 68%.

Baseline characteristics are summarized in table 1.

Table 1. Baseline characteristics.

| Variable | N=80 |
|---|---|
| Age (years) | 61.4±11 |
| Male sex | 60 (75%) |
| Diabetes\ | 53 (66.3%) |
| Smoking | 46 (57.5%) |
| Hypertension | 44 (55%) |
| Prior PCI | 24 (30%) |
| Previous myocardial infarction | 18 (22.5%) |
| Prior coronary artery bypass graft | 3 (3.8%) |
| eGFR <60 mL/min/1.73 m2 | 16 (20%) |
| Peripheral artery stenosis | 6 (7.5%) |
| Clinical presentation | |
| • CCS | 21 (26.3%) |
| • NSTEMI | 40 (50%) |
| • STEMI | 19 (23.8%) |
| Mean LVEF | 49.9 ±9.7% |

CCS: Chronic coronary syndrom; eGFR: estimated glomerular filtration rate; LVEF: left ventricular ejection fraction; NSTEMI: non-ST Elevation Myocardial Infarction; STEMI: ST Elevation Myocardial Infarction; PCI: percutaneous coronary intervention.

## Lesion characteristics

Multivessel disease present in 47.5% of the patients. Bifurcation lesions were located as follows: left anterior descending (LAD) / diagonal (Dg) artery (n=40, 50%); distal left main coronary artery (LMCA) (n=32, 40%); left circumflex (LCX) / obtuse marginal (Mg) artery (n=8, 10%). According to the Medina classification, a true bifurcation lesion (type 1.1.1, type 1.0.1, and type 0.1.1) was observed in 75 (93.8%) patients.

Angiographic characteristics are detailed in table 2.

Table 2. Lesion characteristics.

| Variable | N=80 |
|---|---|
| Coronary status | |
| • 3 vessels | 38 (47.5%) |
| • 2 vessels | 19 (23.8%) |
| • 1 vessel | 23 (28.7%) |
| Lesion location | |
| • LAD-Dg | 40 (50%) |
| • Distal LMCA | 32 (40%) |
| • LCX-Mg | 8 (10%) |
| Medina Classification | |
| • 1-1-1 | 52 (65%) |
| • 0-1-1 | 19 (23.8%) |
| • 1-0-1 | 4 (5%) |
| • 1-1-0 | 2 (25%) |
| • 0-1-0 | 2 (2.5%) |
| • 0-0-1 | 1 (1.3%) |
| True bifurcation | 75 (93.8%) |
| Bifurcation angle | |
| • ≤70° | 41 (51.2%) |
| • >90° | 10 (12.5%) |
| SYNTAX score I | |
| • ≤ 22 | 51 (63.7%) |
| • 23 to 32 | 27 (33.8%) |
| • ≥33 | 2 (2.5%) |
| Lesion length | |
| • Main branch | 22.8±8.8mm |
| • Side branch | 15.28±7.61mm |
| Main branch (MB) | |
| • Chronic total occlusion | 3 (3.8%) |
| • Moderate-to-severe calcification | 14 (17.5%) |
| • Thrombus | 7 (8.8%) |
| Side branch (SB) | |
| • Moderate-to-severe calcification | 10 (12.5%) |
| Proximal MB diameter | 3.50 ±0.53mm |
| Distal MB diameter | 2.89 ± 0.48mm |
| SB diameter | 2.62 ± 0,47mm |

CTO: Chronic total occlusion; Dg: Diagonal; MB: Main branch; LAD: Left anterior descending; LCX: Left circumflex; LMCA: Left main coronary artery; Mg: Marginal; SB: side branch.

## Procedural data

Transradial approach was predominantly used 71.3% and a 7 French guiding catheter was needed in 8.7% of cases.

An elective two-stent technique was considered after medical discussion in 68 patients (85%).

In the rest of patients (15%), this strategy was used in a bail-out setting motivated by a procedural complication such as dissection, occlusion or severe residual stenosis after balloon optimization of the side branch.

Most used technique was the T and protrusion (TAP) technique in 61.2% of cases followed by the crush techniques (Dkcrush and minicrush) in 20% of cases.

Rotational atherectomy was used in 10% of cases. Proximal optimization technique and final kissing balloon were performed in 82.5% and 86.3% of procedures respectively.

Procedural success was achieved in all cases.

Other lesions were treated during the same procedure in 23 patients (28.7%), Implantation of three stents or more was necessary in 28 patients (35%). Revascularization was complete in 67 patients (83.8%).

Procedural characteristics are summarized in the table 3.

Table 3. Procedural data.

| Variable | N=80 |
|---|---|
| Vascular status | |
| • Radial | 57 (71.3%) |
| • Femoral | 23 (28.7%) |
| Guiding catheter | |
| • 6F | 73 (91.3%) |
| • 7F | 7 (8.7%) |
| GPIIbIIIa inhibitors use | 2 (2.5%) |
| Rotational atherectomy | 8 (10%) |
| MB predilation | 38 (47.5%) |
| SB predilation | 47 (58.8%) |
| MB stent diameter | 3.21 ± 0.42mm |
| MB stent length | 30.8 ± 9.36mm |
| SB stent diameter | 2.77 ± 0.40mm |
| SB stent length | 22.71 ± 8.7mm |
| Total stent lenght | 54.88 ± 15mm |
| Techniques | |
| • TAP | 49 (61.2%) |
| • DK-Crush | 11 (13.8%) |
| • Culotte | 5 (6.2%) |
| • T stenting | 7 (8.7%) |
| • Mini-Crush | 5 (6.2%) |
| • V stenting (2 stents) | 1 (1.3%) |
| • SKS | 1 (1.3%) |
| • Extended V (3 stents) | 1 (1.3%) |
| Optimisation techniques | |
| • First POT | 58 (72.5%) |
| • Final POT | 34 (42.5%) |
| • FKB | 69 (86.3%) |
| Number of used balloons | 5 ± 2 |

DK-Crush: Double kissing double crush; FKB: Final kissing balloon; MB: Main branch; POT: Proximal optimisation technique; SB: Side branch; SKS: Simultaneous kissing stents; TAP: T and Protrusion

## Clinical outcomes

Clinical follow-up was available in 100% of patients and angiographic follow-up was available in 32.5% of patients. Median follow-up was 13.5 months.

During the follow-up period, 15 (18.8%) TLF occurred: 1 (1.3%) cardiac death, 11 (13.8%) TVMI, 14 (17.5%) TLR.

The ST and ISR rates were 3.8% and 15% respectively.

Kaplan-Meier curves for TLF and its components at one, two and five-year follow-up are shown in figure 1.

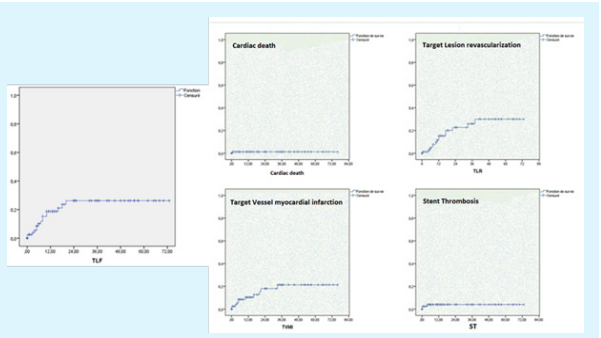


Figure 1. Time-to-Event Curves for the Primary Composite endpoint (TLF: Target Lesion Failure) and its Components.

Details of ST are shown in the table 4.

Table 3. Characteristics of patients with stent thrombosis

| Pt | Bifurcation location technique | Stent length (mm) | Procedural cause | DAPT Observance | Time | ARC | Clinical presentation | Evolution |
|---|---|---|---|---|---|---|---|---|
| H, 60 y | LAD/Dg TAP FKB- | 49 | Under-expansion, Geographic miss of the Dg ostium | Yes | Subacute (9 days) | Certain | Lateral STEMI, stent thrombosis at the level of the Dg ostium, treated with a balloon | Favorable |
| H, 54 y | LAD/Dg DK-Crush FKB | 76 | Longitudinal stent elongation | Yes | Late (4 months) | | Anterior STEMI, fibrinolysis Residual ISR at angiographic control, treated by CABG | Favorable |
| F, 77 y | Distal LMCA DK-Crush FKB+ | 102 | Excessive stented length (inoperable patient due to high surgical risk) | Yes | | | Sudden cardiac death at home | Fatal |

DK-Crush: Double kissing double crush; FKB: Final kissing balloon; MB: Main branch; POT: Proximal optimisation technique; SB: Side branch; SKS: Simultaneous kissing stents; TAP: T and Protrusion

Among the 12 cases of ISR, were noted 8 cases of TAP technique (66.7%), 3 cases of crush technique (25%) and one case of culotte stenting (8.3%). Seven ISR cases (58.3%) involved the bifurcation of the distal LMCA, 3 (25%) the bifurcation of the LAD-Dg and 2 (16.7%) the bifurcation of the LCX-Mg. In almost all cases, ISR was focal (type I of Mehran's classification) (11 cases, 91.6%). In 6 cases (50%), ISR involved the two branches of the bifurcation and in 4 cases (33.3%) the side branch. Ostia were the most frequently affected site (Figure 2).

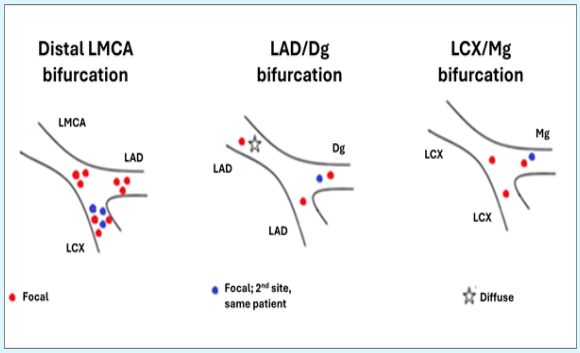


Figure 2. In-stent restenosis location (towards the coronary bifurcation) and type according to Mehran's classification.

Dg: Diagonal branch; LAD: Left anterior descending artery; LCX: Left circumflex artery; LMCA: Left main coronary artery; Mg: Marginal branch.

During the follow-up period, 24 (30%) MACE occurred. Mortality rate was 3.8%.

Details of clinical events are shown in table 5.

Table 5. Major Adverse Cardiac Events at 13.5-month median follow-up.

| | |
|---|---|
| MACE | 24 (30%) |
| TLF | 15 (18.8%) |
| All-cause death | 3 (3.8%) |
| Cardiac death | 1(1.3%) |
| MI | 15 (18.8%) |
| Target vessel MI | 11 (13.8%) |
| Target lesion revascularization | 14 (17.5%) |
| • PCI | |
| • CABG | |

CABG: Coronary Artery Bypass Graft surgery; MACE: Major Adverse cardiovascular events; MI: myocardial infarction; TLF: target lesion failure; PCI: Percutaneous Coronary Intervention.

Predictive factors for TLF were a bifurcation angle >90° (OR=21.42 [3.3–60]; p=0.001),a side branch diameter ≤2.5mm (OR=11.23 [2.07–50.7]; p=0.005), a main branch lesion length ≥25mm (OR=6.50 [1.9–21.19]; p=0.002), and severe main branch calcifications (OR=3.98 [1.28–12.63]; p=0.019) (Figure 3).

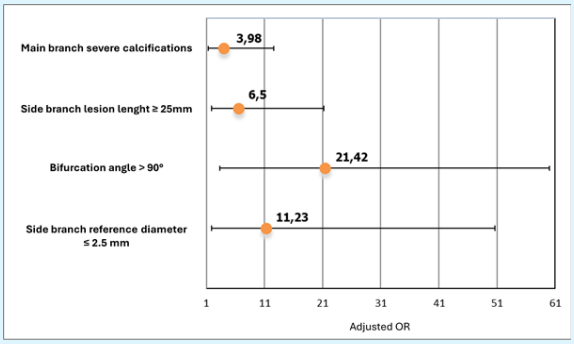


Figure 5. Predictive factors according to multivariate analysis for target vessel failure at a 13.5 month median follow-up.

## DISCUSSION

In this study, outcomes of 80 patients treated with a two-stent strategy for CBL were investigated. Median follow-up period was 13.5 months. Techniques deployed were TAP (61.2%), DK-Crush (13.8%), T stenting (8.7%), Culotte (6.2%), Mini-Crush (6.2%), V stenting (1.3%), SKS (1.3%), and a 3-stent technique (1.3%). Initial and/or final proximal optimization was performed in only 82.5% of cases, and a final kissing balloon was performed in 86.3% of procedures. Procedural success was achieved in all cases. During the follow-up period, 15 patients (18.8%) had TLF, and 24 patients (30%) had MACE. Rates of cardiac death, myocardial infarction, and target lesion revascularization were 1.3%, 13.8%, and 17.5%, respectively. Rate of definite and probable ST was 3.8%. In this study, significant predictors of increased TLF were angle bifurcation >90°, side branch diameter ≤2.5mm, main vessel lesion length ≥25mm and severe calcifications of MV.

To compare our results with literature, six randomized trials were selected: Nordic Baltic Bifurcation Study IV (16), British Bifurcation Coronary Study (BBC one) (17), European Bifurcation Coronary TWO (EBC II) (18) , Double Kissing Crush II study (DK-Crush II) (19), DEFINITION II trial (13), Bifurcations Bad Krozingen I (BBK I) (20).

Baseline characteristics: In line with selected studies where the mean age ranged generally between 60 and 70 years, the mean age in this series was 61.4±11 years. Male predominance is consistent across all selected studies with a sex ratio of approximately 3, mirroring our series. Diabetes (66.3%) followed by tobacco use (57.5%) were the two most prevalent

cardiovascular risk factors in our series, as was reported also in several studies conducted on Tunisian coronary patients (FAST-MI Tunisia registry (21)) contrasting with international studies where hypertension and dyslipidaemia are primary (16-20).

Prevalence of prior myocardial infarction, PCI, and coronary bypass history in this study sample were similar to that observed in international studies.

Clinical presentation in this series aligns with that in the DEFINITION II study (13) and the DK-Crush II study (19) where acute coronary syndrome was the most frequent presentation.

Mean left ventricular ejection fraction (LVEF) was 49.9 ± 9.7% in this study, with 10% of patients having an LVEF <40%, contrasting with literature where it was mostly preserved (16-20).

Angiographic characteristics: Coronary status of patients in this study closely resembles that reported in the BBK I study (20) with 47.5% of patients with three-vessel disease. In this cohort, distal LMCA involvement, accounting for 40%, was excluded in certain studies such as BBC I (17) EBC II (18), and BBK I (20). Additionally, the most frequently treated bifurcation by a two-stent technique in the literature, as well as in this series, was the LAD-Dg bifurcation. A Medina 1-1-1 type bifurcation was the most encountered in the literature, mirroring our findings.

Procedural data: TAP (61.2%), followed by Crush technique (DK-Crush and Mini-Crush) (20%) were the most deployed two-stent techniques.

According to the 15th consensus document of the European Bifurcation Club (EBC) (3) provisional stenting of the main branch with the use of a proximal optimization technique (POT) is the preferred technique for the treatment of CBL as a first-line approach. However, in certain cases, stenting of the side branch may be considered: - As a bailout after provisional stenting of the main branch (10% of cases) in the presence of a significant decrease in flow in the side branch (TIMI flow <3 and/or myocardial infarction in the territory supplied by this branch), and/or the presence of significant dissection or occlusion of the side branch (10) - Planned in cases of complex CBL and significant involvement of the side branch. The 12th EBC consensus recommends a two-stent strategy in cases of a large side branch with a long ostial lesion ≥5mm from the carina and difficulty in accessing it (8).

In elective two-stent angioplasty, the most frequently used techniques are TAP, culotte, and DK-Crush (5,22). Choice depends on the bifurcation angle, size of the two branches, and operator experience. Typically, T-stenting is preferred for T-shaped angulation >70° close to 90° (23,24), while TAP or culotte are preferred for Y-shaped angulation (<70°) (23–25) . Culotte and Crush techniques are indicated for narrow angle and significant diameter of the side branch (23,26,27).

Proximal optimization technique was performed in 82.5%. This rate was 100% in the DEFINITION II study (13). Non-compliant balloons are usually used for POT [41], but recent data suggest that semi-compliant balloons can also be used (5,10,28). Proximal optimization technique is always recommended regardless of the strategy (10). This technique ensures proper stent deployment at the appropriate diameter in its proximal portion, thus avoiding stent malapposition at this level.

In two-stent techniques, final kissing balloon is mandatory to achieve full stent expansion at both ostia, may correct stent deformation and ensure optimal stent scaffolding (10,24,29). This was performed only in 86.3% of cases in this series.

Optimization of bifurcation angioplasty by intracoronary imaging (IVUS or OCT) was not used in this series due to lack of resources. Intracoronary imaging techniques not only allow more precise evaluation than angiography but can also influence angioplasty technique and outcomes. Before stent implantation, these techniques allow evaluation of longitudinal distribution of atheroma plaque, reference diameters of the main and side branches, and the ostium of the side branch. After stent implantation, they enable analysis of expansion (search for under expansion), apposition (search for malapposition), evaluation of the side branch ostium (search for stenosis), final vessel sizes (over- or under dilation of the stent), and detection of dissection or peri-adventitial hematoma (30–32).

Cardiac Events: In the DEFINITION II study (13) which is the closest to this study in terms of inclusion and exclusion criteria and follow-up duration, results were comparable with an all-cause mortality rate of 3.8% vs 2.7%, cardiac death rate of 1.3% vs 2.1%, and ST rate of 3.8% vs 1.2%. However, our incidence of TLF was higher at 18.8% in this series (13.8% at 12 months) vs 6.1%.

In the literature, incidence of ST ranges from 1% to 3% for CBL, which is comparable to our rate of 3.8% (33,34). ST is multifactorial, involving patient- and lesion-related factors, procedural factors (underexpansion, incomplete apposition, tissue protrusion, dissection), and stent thrombogenicity (defective endothelialization by the antiproliferative agent, late malapposition) (35,36). Incidence of ISR in this series was 16.3% and was even higher in the literature reaching 26.4% (37). CBL are more prone to stent failure, which can be explained by incomplete stent apposition and/or expansion at the bifurcation, resulting in delayed endothelialization, persistent turbulence, and insufficient scaffolding, leading to a higher risk of thrombosis and restenosis (38). It is of note that restenosis is more frequently located at the ostium of the side branch and the confluence polygon (39,40), data that has been corroborated in this series: six cases (50% of ISR) at the confluence polygon and four cases at the side branch ostium (33.3% of ISR).

Predictive Factors of Target Lesion Failure (TLF): In multivariate analysis, predictive factors for TLF were a bifurcation angle >90°, lesion length of the main branch (BM) ≥25 mm, side branch (BF) diameter ≤2.5 mm, and significant calcifications of the main branch (BM) and the « Crush » technique.

The DEFINITION study (41) defined the complexity criteria of a CBL: two major criteria are a stenosis ≥70% and a side branch lesion length ≥10 mm for distal LMCA bifurcation or a stenosis ≥90% and a side branch lesion length ≥10 mm for other bifurcations; and six minor criteria including moderate to severe calcifications, multiple lesions, angle <45°, main branch diameter <2.5 mm, thrombus, and main branch lesion length ≥25 mm. Complex lesions are associated with higher rates of MACE, ST, and TLR (41).

Coronary artery calcification hinders stent delivery, associates with stent under-expansion, and may impair drug delivery with DES increasing the likelihood of ISR and ST (42).

Flow patterns in bifurcations are inherently complex, including vortex formation and creation of zones of low and oscillating wall shear stress that coincide with early intimal thickening. Bifurcation geometry (in particular, the angle between the side branches), is of paramount importance in creating these proatherogenic conditions. A larger value of the angle would increase the disparity in wall shear stress between the medial and lateral walls. In other words, a larger bifurcation angle, with no change in the amount of branch flow, increases the likelihood of low and oscillating wall shear stress at the lateral walls. Indeed, larger values of this angle have been associated with higher degrees of early intimal thickening (43). Ormiston et al. reported that a bifurcation angle >70° causes stent distortion which is due to underexpansion at the side-branch ostium and incomplete apposition of the struts wich are not always corrected by kissing balloon inflation (44). Adriaenssens et al. showed that a large angle is an independent predictive factor of angiographic restenosis (45). Several studies reported that with an angle > 80° complete apposition of the stent struts cannot be obtained with the Crush or culotte technique despite a Kissing Balloon (44,46,47).

## CONCLUSION

This study demonstrated that a two-stent strategy for CBL PCI was feasible with 100% of procedural success. However, this was counterbalanced by a high TLF and MACE rates reaching 18.8% and 30% respectively at 13.5-month median follow-up. These were supported by ST and ISR high incidence that mandates a rigorous patients' selection and optimal techniques that should be performed under imaging guidance to tackle these issues and improve long-term results.

## REFERENCES

1. Sharma SK, Kini AS. Coronary Bifurcation Lesions. Cardiol Clin. 1 mai 2006;24(2):233-46.
2. Louvard Y, Lefèvre T, Morice MC. Percutaneous coronary intervention for bifurcation coronary disease. Heart. juin 2004;90(6):713-22.
3. Burzotta F, Lassen JF, Lefèvre T, Banning AP, Chatzizisis YS, Johnson TW, et al. Percutaneous coronary intervention for bifurcation coronary lesions: the 15th consensus document from the European Bifurcation Club. EuroIntervention J Eur Collab Work Group Interv Cardiol Eur Soc Cardiol. 19 mars 2021;16(16):1307-17.
4. Neumann FJ, Sousa-Uva M, Ahlsson A, Alfonso F, Banning AP, Benedetto U, et al. 2018 ESC/EACTS Guidelines on myocardial revascularization. Eur Heart J. 7 janv 2019;40(2):87-165.
5. Burzotta F, Lassen JF, Louvard Y, Lefèvre T, Banning AP,

Daremont O, et al. European Bifurcation Club white paper on stenting techniques for patients with bifurcated coronary artery lesions. Catheter Cardiovasc Interv Off J Soc Card Angiogr Interv. nov 2020;96(5):1067-79.

6. Banning AP, Lassen JF, Burzotta F, Lefèvre T, Darremont O, Hildick-Smith D, et al. Percutaneous coronary intervention for obstructive bifurcation lesions: the 14th consensus document from the European Bifurcation Club. EuroIntervention J Eur Collab Work Group Interv Cardiol Eur Soc Cardiol. 20 mai 2019;15(1):90-8.
7. Di Gioia G, Sonck J, Ferenc M, Chen SL, Colaiori I, Gallinoro E, et al. Clinical Outcomes Following Coronary Bifurcation PCI Techniques: A Systematic Review and Network Meta-Analysis Comprising 5,711 Patients. JACC Cardiovasc Interv. 22 juin 2020;13(12):1432-44.
8. Lassen JF, Burzotta F, Banning AP, Lefèvre T, Darremont O, Hildick-Smith D, et al. Percutaneous coronary intervention for the left main stem and other bifurcation lesions: 12th consensus document from the European Bifurcation Club. EuroIntervention J Eur Collab Work Group Interv Cardiol Eur Soc Cardiol. 20 janv 2018;13(13):1540-53.
9. Ferenc M, Gick M, Comberg T, Rothe J, Valina C, Toma A, et al. Culotte stenting vs. TAP stenting for treatment of de-novo coronary bifurcation lesions with the need for side-branch stenting: the Bifurcations Bad Krozingen (BBK) II angiographic trial. Eur Heart J. 1 déc 2016;37(45):3399-405.
10. Lassen JF, Holm NR, Banning A, Burzotta F, Lefèvre T, Chieffo A, et al. Percutaneous coronary intervention for coronary bifurcation disease: 11th consensus document from the European Bifurcation Club. EuroIntervention J Eur Collab Work Group Interv Cardiol Eur Soc Cardiol. 17 mai 2016;12(1):38-46.
11. Louvard Y, Thomas M, Dzavik V, Hildick-Smith D, Galassi AR, Pan M, et al. Classification of coronary artery bifurcation lesions and treatments: Time for a consensus! Catheter Cardiovasc Interv. 2008;71(2):175-83.
12. Pan M, Ojeda S. Medina classification since its description Zhang JJ, Ye F, Xu K, Kan J, Tao L, Santoso T, et al. Multicentre, randomized comparison of two-stent and provisional stenting techniques in patients with complex coronary bifurcation lesions: the DEFINITION II trial. Eur Heart J. 14 juill 2020;41(27):2523-36.
13. Kip KE, Hollabaugh K, Marroquin OC, Williams DO. The problem with composite end points in cardiovascular studies: the story of major adverse cardiac events and percutaneous coronary intervention. J Am Coll Cardiol. 19 févr 2008;51(7):701-7.
14. Garcia-Garcia HM, McFadden EP, Farb A, Mehran R, Stone GW, Spertus J, et al. Standardized End Point Definitions for Coronary Intervention Trials: The Academic Research Consortium-2 Consensus Document. Circulation. 12 juin 2018;137(24):2635-50.
15. Kumsars I, Holm NR, Niemelä M, Erglis A, Kervinen K, Christiansen EH, et al. Randomised comparison of provisional side branch stenting versus a two-stent strategy for treatment of true coronary bifurcation lesions involving a large side branch: the Nordic-Baltic Bifurcation Study IV. Open Heart. 19 janv 2020;7(1):e000947.
16. Hildick-Smith D, de Belder AJ, Cooter N, Curzen NP, Clayton TC, Oldroyd KG, et al. Randomized trial of simple versus complex drug-eluting stenting for bifurcation lesions: the British Bifurcation Coronary Study: old, new, and evolving strategies. Circulation. 16 mars 2010;121(10):1235-43.
17. Hildick-Smith D, Behan MW, Lassen JF, Chieffo A, Lefèvre T, Stankovic G, et al. The EBC TWO Study (European Bifurcation Coronary TWO): A Randomized Comparison of Provisional T-Stenting Versus a Systematic 2 Stent Culotte Strategy in Large Caliber True Bifurcations. Circ Cardiovasc Interv. sept 2016;9(9):e003643.
18. Chen SL, Santoso T, Zhang JJ, Ye F, Xu YW, Fu Q, et al. Clinical Outcome of Double Kissing Crush Versus Provisional Stenting of Coronary Artery Bifurcation Lesions: The 5-Year Follow-Up Results From a Randomized and Multicenter DKCRUSH-II Study (Randomized Study on Double Kissing Crush Technique Versus Provisional Stenting Technique for Coronary Artery Bifurcation Lesions). Circ Cardiovasc Interv. févr 2017;10(2):e004497.
19. Ferenc M, Gick M, Kienzle RP, Bestehorn HP, Werner KD, Comberg T, et al. Randomized trial on routine vs. provisional T-stenting in the treatment of de novo coronary bifurcation lesions. Eur Heart J. déc 2008;29(23):2859.
20. Prise en charge de l'infarctus du myocarde en Tunisie : résultats préliminaires du registre FAST-MI Tunisie de la Société tunisienne de cardiologie et de chirurgie cardiovasculaire - EM consulte [Internet]. [cité 12 avr 2024]. Disponible sur: https://www.em-consulte.com/article/1017361/prise-en-charge-de-l-infarctus-du-myocarde-en-tuni
21. Bifurcation intervention with a two-stent strategy: can one size fit all? | European Heart Journal | Oxford Academic [Internet]. [cité 12 avr 2024]. Disponible sur: https://academic.oup.com/eurheartj/article/37/45/3406/2661783
22. Foin N, Alegria-Barrero E, Torii R, Chan PH, Viceconte N, Davies JE, et al. Crush, culotte, T and protrusion: which 2-stent technique for treatment of true bifurcation lesions? - insights from in vitro experiments and micro-computed tomography. Circ J Off J Jpn Circ Soc. 2013;77(1):73-80.
23. Lassen JF, Holm NR, Stankovic G, Lefèvre T, Chieffo A, Hildick-Smith D, et al. Percutaneous coronary intervention for coronary bifurcation disease: consensus from the first 10 years of the European Bifurcation Club meetings. EuroIntervention J Eur Collab Work Group Interv Cardiol Eur Soc Cardiol. sept 2014;10(5):545-60.
24. Chevalier B, Glatt B, Royer T, Guyon P. Placement of coronary stents in bifurcation lesions by the « culotte » technique. Am J Cardiol. 15 oct 1998;82(8):943-9.
25. Zhang JJ, Chen SL. Classic crush and DK crush stenting techniques. EuroIntervention J Eur Collab Work Group Interv Cardiol Eur Soc Cardiol. 2015;11 Suppl V:V102-105.
26. Ki YJ, Jung JH, Han JK, Hong S, Cho JH, Gwon HC, et al.

Clinical Implications of Bifurcation Angles in Left Main Bifurcation Intervention Using a Two-Stent Technique. J Intervent Cardiol. 2020;2020:2475930.

27. Hoye A. The Proximal Optimisation Technique for Intervention of Coronary Bifurcations. Interv Cardiol Rev. sept 2017;12(2):110-5.
28. Ge L, Airoldi F, Iakovou I, Cosgrave J, Michev I, Sangiorgi GM, et al. Clinical and Angiographic Outcome After Implantation of Drug-Eluting Stents in Bifurcation Lesions With the Crush Stent Technique: Importance of Final Kissing Balloon Post-Dilation. J Am Coll Cardiol. 16 août 2005;46(4):613-20.
29. Maehara A, Matsumura M, Ali ZA, Mintz GS, Stone GW. IVUS-Guided Versus OCT-Guided Coronary Stent Implantation: A Critical Appraisal. JACC Cardiovasc Imaging. déc 2017;10(12):1487-503.
30. Huo Y, Finet G, Lefèvre T, Louvard Y, Moussa I, Kassab GS. Optimal diameter of diseased bifurcation segment: a practical rule for percutaneous coronary intervention. EuroIntervention J Eur Collab Work Group Interv Cardiol Eur Soc Cardiol. mars 2012;7(11):1310-6.
31. Kubo T, Imanishi T, Takarada S, Kuroi A, Ueno S, Yamano T, et al. Assessment of culprit lesion morphology in acute myocardial infarction: ability of optical coherence tomography compared with intravascular ultrasound and coronary angioscopy. J Am Coll Cardiol. 4 sept 2007;50(10):933-9.
32. Armstrong EJ, Yeo KK, Javed U, Mahmud E, Patel M, Shunk KA, et al. Angiographic stent thrombosis at coronary bifurcations: short- and long-term prognosis. JACC Cardiovasc Interv. janv 2012;5(1):57-63.
33. Kim JH, Franchin L, Hong SJ, Cha JJ, Lim S, Joo HJ, et al. Two-Year clinical outcomes after coronary bifurcation stenting in older patients from Korea and Italy. Front Cardiovasc Med. 23 mars 2023;10:1106594.
34. 2011 ACCF/AHA/SCAI Guideline for Percutaneous Coronary Intervention | Circulation [Internet]. [cité 12 avr 2024]. Disponible sur: https://www.ahajournals.org/doi/10.1161/CIR.0b013e31823ba622?url_ver=Z39.88-2003&rfr_id=ori:rid:crossref.org&rfr_dat=cr_pub%20%200pubmed
35. Stent Thrombosis | Journal of the American College of Cardiology [Internet]. [cité 12 avr 2024]. Disponible sur: https://www.jacc.org/doi/10.1016/j.jacc.2010.07.016
36. Cassese S, Byrne RA, Tada T, Pinieck S, Joner M, Ibrahim T, et al. Incidence and predictors of restenosis after coronary stenting in 10 004 patients with surveillance angiography. Heart Br Card Soc. janv 2014;100(2):153-9.
37. Di Mario C, Morici N, Godino C, Goktekin O, Tamburino C, Barbagallo R, et al. Predictors of restenosis after treatment of bifurcational lesions with paclitaxel eluting stents: a multicenter prospective registry of 150 consecutive patients. Catheter Cardiovasc Interv Off J Soc Card Angiogr Interv. 15 févr 2007;69(3):416-24.
38. Chen SL, Santoso T, Zhang JJ, Ye F, Xu YW, Fu Q, et al. A Randomized Clinical Study Comparing Double Kissing Crush With Provisional Stenting for Treatment of Coronary Bifurcation Lesions: Results From the DKCRUSH-II (Double Kissing Crush versus Provisional Stenting Technique for Treatment of Coronary Bifurcation Lesions) Trial. J Am Coll Cardiol. 22 févr 2011;57(8):914-20.
39. Sheiban I, Albiero R, Marsico F, Dharmadhikari A, Tzifos V, Pagnotta P, et al. Immediate and long-term results of « T » stenting for bifurcation coronary lesions. Am J Cardiol. 1 mai 2000;85(9):1141-4, A9.
40. Chen SL, Sheiban I, Xu B, Jepson N, Paiboon C, Zhang JJ, et al. Impact of the complexity of bifurcation lesions treated with drug-eluting stents: the DEFINITION study (Definitions and impact of complEx biFurcation lesIons on clinical outcomes after percutaNeous coronary IntervenTIOn using drug-eluting steNts). JACC Cardiovasc Interv. nov 2014;7(11):1266-76.
41. Murphy JL, Patel N, Vengrenyuk Y, Okamoto N, Barman N, Sweeny J, et al. Cardiovascular outcomes after percutaneous coronary intervention on bifurcation lesions with moderate to severe coronary calcium: A single-center registry study. Catheter Cardiovasc Interv Off J Soc Card Angiogr Interv. 1 juill 2021;98(1):35-42.
42. Moore JE, Timmins LH, Ladisa JF. Coronary artery bifurcation biomechanics and implications for interventional strategies. Catheter Cardiovasc Interv Off J Soc Card Angiogr Interv. 15 nov 2010;76(6):836-43.
43. Ormiston JA, Currie E, Webster MWI, Kay P, Ruygrok PN, Stewart JT, et al. Drug-eluting stents for coronary bifurcations: insights into the crush technique. Catheter Cardiovasc Interv Off J Soc Card Angiogr Interv. nov 2004;63(3):332-6.
44. Adriaenssens T, Byrne RA, Dibra A, Iijima R, Mehilli J, Bruskina O, et al. Culotte stenting technique in coronary bifurcation disease: angiographic follow-up using dedicated quantitative coronary angiographic analysis and 12-month clinical outcomes. Eur Heart J. déc 2008;29(23):2868-76.
45. Miyazawa A, Ako J, Hassan A, Hasegawa T, Abizaid A, Verheye S, et al. Analysis of bifurcation lesions treated with novel drug-eluting dedicated bifurcation stent system: intravascular ultrasound results of the AXXESS PLUS trial. Catheter Cardiovasc Interv Off J Soc Card Angiogr Interv. 1 déc 2007;70(7):952-7.
46. Chen SL, Santoso T, Zhang JJ, Ye F, Xu YW, Fu Q, et al. Coronary bifurcation angle from 3-D predicts clinical outcomes after stenting bifurcation lesions. Chin Med J (Engl). juin 2012;125(12):2083-8.