ORIGINAL ARTICLE

Percutaneous Treatment of Bifurcation Lesions by Crush T Stenting: Immediate and Medium-Term Outcomes

Luis S. Díaz de la Llera, Sara M. Ballesteros, Agustín Guisado, Almudena Aguilera, Ana Campos, Ángel Sánchez, Manuel Villa, and Gabriel Retegui

Unidad de Hemodinámica y Cardiología Intervensionista, Hospital General Universitario Virgen del Rocío, Sevilla, Spain

Introduction and objectives. Percutaneous coronary intervention for coronary bifurcations is usually associated with a low success rate, a high rate of complications, and a more frequent need for target lesion revascularization. The aim of this prospective study was to evaluate immediate and medium-term clinical and angiographic outcomes after the application of crush T stenting.

Methods. This approach to bifurcation stenting follows the same steps as modified T stenting. The only difference is that the side branch stent protrudes 3-4 mm into the main vessel from the carina. The aim is to ensure that the circumference of the side branch ostium is covered by the stent strut.

Results. Between December 2003 and February 2005, 82 patients were included in the study. The lesion involved the left main coronary artery in 53% of patients, the left anterior descending or diagonal coronary artery in 29%, the circumflex or marginal branch in 11%, and the right coronary artery or the posterior or posterolateral descending branch in 7%. Angiographic and clinical success was obtained in 100% and 96.4% of cases, respectively. Final dilatation was performed using a kissing balloon in 87%. Overall, 100% of patients were followed up clinically for 12 months and 77% were followed up angiographically for a mean of 8.7 (3.3) months. Target lesion revascularization was performed in 9 patients (10.8%).

Conclusions. Treatment of coronary bifurcation lesions using the crush T stenting technique is safe and effective. It reduces both the restenosis rate and the major adverse cardiac event rate at one year.

Key words: *Bifurcation. Drug-eluting stents. Revascularization.*

Tratamiento de las lesiones bifurcadas mediante técnica de *crush T stenting:* resultados inmediatos y a medio plazo

Introducción y objetivos. El tratamiento percutáneo de las lesiones bifurcadas se asocia con una menor tasa de éxito y una mayor frecuencia de complicaciones y de nueva revascularización de la lesión tratada. El objetivo de este estudio prospectivo fue evaluar los resultados clínicos y angiográficos iniciales y a medio plazo de la técnica de *crush T stenting*.

Métodos. Este método de tratamiento percútaneo de las lesiones bifurcadas con implante de *stents* coronarios reproduce la técnica *T stenting* modificada con la diferencia de que el *stent* de la rama lateral protruye dentro de la rama principal a 3-4 mm de la carina. El propósito es asegurar que el *ostium* de la rama lateral es cubierto circunferencialmente con la malla de los *stents.*

Resultados. Entre diciembre de 2003 y febrero de 2005 se incluyó a 82 pacientes en este estudio. La lesión afectaba al tronco coronario izquierdo en bifurcación en el 53%, a la arteria descendente anterior/diagonal en el 29%, a la arteria circunfleja/marginal en el 11% y a la coronaria derecha/descendente posterior-posterolateral en el 7%. Hubo éxito angiográfico y clínico en el 100 y el 96,4%, respectivamente. Se realizó posdilatación con doble balón en el 87%. Se obtuvo seguimiento clínico a los 12 meses en el 100% y angiográfico en el 77%. El tiempo medio de seguimiento angiográfico fue 8,7 ± 3,3 meses. Se realizó una nueva revascularización de la lesión tratada en el 10,8%.

Conclusiones. El tratamiento de las lesiones bifurcadas con técnica de *crush T stenting* es segura y efectiva, y presenta una baja tasa de eventos cardiacos mayores y de necesidad de nueva revascularización.

Palabras clave: *Bifurcación.* Stents *liberadores de fármacos. Revascularización.*

Correspondence: Dr. L.S. Díaz de la Llera.
Pinsapo, 10.
Urb. Pinares de Oromana. Alcalá de Guadaira.
41500 Sevilla. España.
E-mail: luissalvadordiaz@hotmail.com

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ABBREVIATIONS

CK-MB: creatine kinase MB isoenzyme.
DES: drug-eluting stents.
ECG: electrocardiogram.
MACE: major adverse cardic avents.
MB: main branch.
PCI: percutaneous coronary intervention.
SB: side branch.

INTRODUCTION

True bifurcation lesions involve the main branch (MB) and the side branch (SB), and their treatment by percutaneous coronary intervention (PCI) continues to evolve. This technique now comprises approximately 10% to 12% of all coronary interventional procedures.[1] The use of a coronary stent for bifurcation lesions of more than 2.5 mm involving the SB is now universally widespread and has been proposed as a common treatment. The presence of a large atheromatous plaque at the site of bifurcation is frequently associated with deterioration, or even occlusion, of the SB after implantation of a stent in the MB.[2] Other important questions concerning the use of coronary stents in bifurcation lesions following stent implantation in the MB include difficulties in redirecting the guide wire toward the SB, the impossibility of covering the SB ostium with the stent and stent distortion, resulting in a high restenosis rate (around 20%), especially in the SB, despite the use of drug-eluting stents (DES).[1,3] A number of studies have pointed out that a MB stent with provisional implantation of a stent in the SB is associated with a lower incidence of major adverse cardiac events (MACE) and of revascularization of the treated vessel, when compared with the techniques involving stent placement in both the MB and SB,[4-6] and is considered by a substantial number of interventional cardiologists as the standard treatment for bifurcation lesions. However, in cases in which the SB arises at an angle, the stent can not cover the SB ostium completely, regardless of the technique employed (T, Y, V, inverted T).[7-11] In an attempt to improve the results of stent implantation, the simultaneous balloon postdilatation of both branches and the use of stents that partially cover the SB ostium has been suggested.[1,12-14]

We propose the utilization of the crush T stenting technique[15] for its safety in true bifurcation lesions measuring more than 2.5 mm in diameter, ensuring that the SB ostium is covered by the stent. We also systematically perform simultaneous kissing balloon postdilatation in the two branches to optimize the outcome in the carina.

METHODS

We analyzed 82 consecutive patients who underwent stent implantation with the crush T stenting technique in 83 true bifurcation lesions[1] (stenosis >50% involving the MB and SB in the form of an inverted Y) using DES (Cypher, Cordis, and Taxus; Boston Scientific) between December 2003 and February 2005. During this period, 176 bifurcations were treated by means of PCI according to different techniques, depending on the type of lesion, the development and the diameters of the MB and SB, as well as the clinical condition of the patient: 83 lesions were treated with crush T stenting (the population studied in this report); 41 with DES alone; 9 with 2 stents (DES), 1 of them provisional; 6 with 2 simultaneous DES, and 36 with 1 or more metallic stents. The patients were followed during the hospital stay to assess the possibility of chest pain, heart failure, bleeding or some other ischemic event. The creatine kinase MB isoenzyme (CK-MB) and troponin were quantified 12 and 24 hours after the procedure. Lifelong aspirin (300 mg/day) and clopidogrel (75 mg/day) for at least 6 to 12 months were recommended. If the patient had not been taking clopidogrel and PCI was performed immediately after diagnosis, a loading dose of 300 or 600 mg (from October 2004 on) of clopidogrel was administered, together with intravenous abciximab, prior to the commencement of the procedure. When PCI was performed in an elective setting, the administration of aspirin and clopidogrel was required during at least the preceding 72 hours. All the patients who were to undergo coronary angiography were taking aspirin.

Definitions

Angiographic success was defined as the presence of residual stenosis of less than 30% following the procedure. Clinical success was defined as the presence of angiographic success without death, emergency myocardial revascularization surgery, repeat PCI in the treated vessel, Q-wave myocardial infarction and non-Q-wave myocardial infarction (CK-MB more than three-fold higher than normal) prior to hospital discharge. Major adverse cardiac events (MACE) 30 days after the procedure were defined as death, emergency repeat PCI and myocardial infarction with CK-MB more than or equal to 3 times the normal value. MACE during follow-up were defined as death, Q-wave and non-Q-wave myocardial infarction or repeat revascularization during the first 12 months following PCI. Subacute stent thrombosis was defined as angiographically documented total or partial occlusion of the stent within 30 days of implantation or occurrence of sudden cardiac death or sudden death of unknown cause, or chest pain with

TABLE 1. **Clinical Characteristics***

Crush T stenting (n=82)	
Age, mean (SD), y	63.4 (10.9)
Men, %	74.3
Diabetes mellitus, %	33.3
Hypertension, %	53.8
Hyperlipidemia, %	46.2
Clinical presentation, %	
Stable angina/asymptomatic	20.9
Unstable angina	61.2
Myocardial infarction	17.9
LVEF, mean (SD), %	57.1 (10.4)
Multivessel disease, %	75.7
Use of glycoprotein IIb/IIIa inhibitors, %	27.5
Bifurcation site, %	
Left main coronary artery/ADA/Cx	52.9
ADA/diagonal artery	28.6
Cx/marginal artery	11.4
Right coronary artery/PLB/PDA	7.1

*ADA indicates anterior descending artery; Cx, circumflex artery; LVEF, left ventricular ejection fraction; PDA, posterior descending artery; PLB, posterolateral branch; SD, standard deviation.

electrocardiographic (ECG) changes suggestive of myocardial infarction, and late stent thrombosis was defined as the development of one of these events after the initial 30-day period.

Techniques

Crush T Stenting Technique

This technique was described by Colombo et al[15]: the MB and SB should be crossed with guide wires measuring 0.014 inches and be dilated prior to stent implantation. In our series, we performed direct stenting when the clinical indications, characteristics of the lesions and coronary anatomy made it possible and if a better outcome could be expected. The guiding catheter should have a diameter of at least 7 Fr. The first stent is advanced along the SB, but is not expanded, and the second stent is advanced within the MB to completely cover the bifurcation. The SB stent is drawn into the MB, 3 to 4 mm from the carina of the bifurcation, and the circumference of the ostium of the SB must be completely covered by the stent strut. At this point, it is important to ensure that the MB stent completely covers the lesion, with its marker in a more proximal position than that of the SB stent since, when the SB stent is expanded, it may by very difficult to mobilize and reposition the MB stent in the desired direction.

When the SB stent is in the proper position, the balloon is inflated and the stent is thus expanded. After the implantation of the stent, the proximal portion protrudes into the MB. The balloon is removed and angiography should be performed to confirm the absence of distal dissection in the SB and, thus, that no additional stents are needed; at this point, the guide wire is removed from the SB. Then, the MB stent is expanded and, during the inflation of the balloon and the implantation of the stent in the MB, the portion of the stent that protrudes is crushed against the vessel wall and, at this point, no portion of the stent remains floating; there are, however, three layers of metal superimposed in the area proximal to the MB and near the ostium of the SB (Figure).

In our center, we included lesions with a reference diameter less than or equal to 2.5 mm in the branch of lesser lumen and, since we first undertook said technique, we systematically pass the guide wire once again into the SB and perform postdilatation, with simultaneous inflation of kissing balloons in the MB and SB. If the angiographic results are satisfactory, we consider the procedure to be completed and, should there be any doubt in this respect, intracoronary ultrasound is carried out to enable us to optimize the outcome.

Modified Crush T Stenting Technique

This approach was described by Lim and Dzavik.[16] It was designed to permit the use of the technique in 6 Fr catheters. It was employed in our series when transradial PCI was performed. The difference consists in the presence of the simultaneous placement of a stent in the SB and a balloon in the MB. The SB stent is expanded and, when the absence of distal dissection of the SB has been confirmed angiographically, the stent strut is crushed against the walls of the MB, proximal to the carina, when the balloon in the MB is inflated. The balloon is then withdrawn and the MB stent is introduced and inflated. This leaves the three layers of metal superimposed, and the procedure is continued in accordance with the technique described above.

Quantitative Angiographic Analysis

The coronary angiograms were analyzed by 2 independent observers, using an automatic border detection system (CMS, version 5.2), at baseline, immediately after PCI and during angiographic follow-up. Angiographic restenosis was defined as a diameter stenosis greater than or equal to 50% in the implanted stents (inside the stent and within the 5 mm proximal and/or distal to the edges) during angiographic follow-up.

Follow-up

All the patients returned for follow-up visits 30 days and 3, 6, 9, and 12 months post-PCI. The

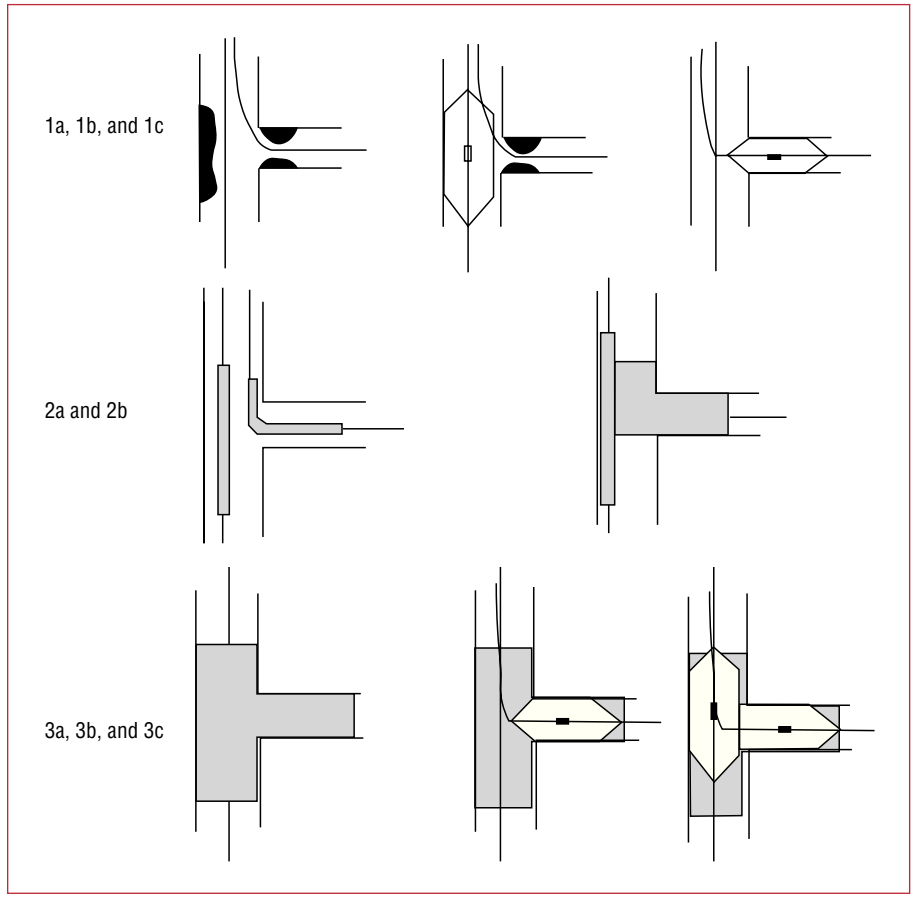

Figure. Sequential diagram of the crush T stenting procedure. 1 a-c: passage of the guide wires through the bifurcation lesion into the main and side branches. Predilatation with balloon catheter in both branches, sequentially or simultaneously. 2 a and b: placement of 2 stents in the bifurcation, with the side branch stent protruding into the main branch, and implantation of the side branch stent. 3 a-c: implantation of the main branch stent, which crushes the portion of the side branch stent proximal to the carina. The guide wire is again made to cross into the side branch, with predilatation and simultaneous inflation in the 2 branches.

clinical symptoms were studied and tests were performed to detect ischemia on the basis of the individual characteristics of the patients; these included incremental ergometry, myocardial perfusion studies by means of nuclear medicine and stress echocardiography from the first month post-PCI on. The clinical events associated with death, myocardial infarction, myocardial revascularization surgery and repeat PCI were recorded. All the patients underwent at least 12 months of follow-up. Coronary angiography was systematically repeated 6 months after PCI in those patients who had bifurcation lesions in the left main coronary artery, and in the rest, when symptoms recurred or when noninvasive tests were positive for myocardial ischemia.

Statistical Analysis

The quantitative variables are expressed as the mean plus or minus standard deviation and the categorical variables as percentages. We employed descriptive statistics to study all the variables, univariate analysis with Student's *t* test for independent samples and the χ^2 test. The calculations were carried out using version 12.0 of the SPSS statistical package in Spanish.

RESULTS

Eighty-two consecutive patients with 83 bifurcation lesions were treated with crush T stenting during the study period. The clinical and angiographic features are presented in Table 1.

The most common site of these lesions was the left main coronary artery (53%). The use of glycoprotein IIb/IIIa inhibitors was left to the discretion of the interventionalist, and abciximab was administered in 27.5% of the cases. The characteristics of the procedure are shown in Table 2. Angiographic success (residual stenosis of less than 30% in both branches) was achieved in 100% of the target lesions. Rotational atherectomy was utilized in calcified lesions. A cutting balloon was employed for the ostia of the branches in 65% of the cases. Distal dissection occurred in 7.2% of the cases, in which an additional stent was required, and subacute stent thrombosis in 2.4%. Simultaneous kissing balloon postdilatation was performed in 87% of the lesions, but could not be carried out in the remaining 13% because it was impossible to clear the SB with low-profile balloons. There was 1 hospital death, occurring 10 days after PCI as a consequence of renal failure, with development of sepsis and multiple organ failure, in a patient treated for left main

TABLE 2. **Angiographic and Technical Features***

	Baseline	Post-PCI	Crush T Stenting (82 patients; 83 lesions)
Main branch			
Reference diameter, mean (SD), mm	3.46 (0.97)	3.88 (0.99)	
Minimal luminal diameter, mean (SD), mm	1.22 (0.53)	3.85 (0.85)	
Acute gain, mean (SD), mm			2.60 (0.82)
Rotablator, %			1.4
Cutting balloon, %			29.4
Direct stenting, %			14.5
Stent diameter, mean (SD), mm			3.2 (0.5)
Stent length, mean (SD), mm			19.9 (5.3)
Maximal inflation pressure, mean (SD), atm			14.2 (2.4)
Side branch			
Reference diameter, mean (SD), mm	3.31 (0.88)	3.43 (1.01)	
Minimal luminal diameter, mean (SD), mm	1.47 (0.61)	3.38 (0.72)	
Acute gain, mean (SD), mm			2.08 (0.76)
Rotablator, %			0
Cutting balloon, %			39.6
Direct stenting, %			11.1
Stent diameter, mean (SD), mm			2.93 (0.3)
Stent length, mean (SD), mm			15.3 (5.1)
Maximal inflation pressure, mean (SD), atm			13.8 (3.6)
Postdilatation with kissing balloon, %			87.1

PCI indicates percutaneous coronary intervention; SD, standard deviation.

coronary artery. No patient underwent myocardial revascularization surgery during the hospital stay or within 30 days of PCI. The incidences of MACE occurring in the hospital and during the first 30 days were 3.6% and 2.4%, respectively, and most were attributed to non-Q-wave myocardial infarction, and may have been related to PCI performed in coronary arteries other than those treated with crush T stenting.

TABLE 3. **Results of the Procedure During the Hospital Stay and 30 Days Later***

	Crush T Stenting (82 Patients; 83 Lesions)
Angiographic success, %	100
Additional stent due to dissection, %	7.2
Post-PCI residual stenosis, %	
Main branch	10.3
Side branch	2.1
Periprocedure MI, %	
Q-wave MI	0
Non-Q-wave MI	2.4
Clinical success, %	96.4
In-hospital MACE, %	
Death	1.2
Periprocedure MI	2.4
MACE at 30 days, %	
Death	1.2
Q-wave MI	1.2
Stent thrombosis at 30 days, %	2.4

*MACE indicates major adverse cardiac events; MI, myocardial infarction; PCI, percutaneous coronary intervention.

There was 1 case of subacute stent thrombosis 9 days post-PCI that led to myocardial infarction, and was treated by means of intravenous fibrinolysis in a referral hospital (Table 3). All the patients underwent clinical follow-up of at least 12 months, during which the incidence of myocardial infarction was 2.4% (1 Q-wave myocardial infarction involving a lesion other than the lesion treated by crush T stenting and 1 non-Q-wave infarction) and that of sudden death was 1.2% (in a patient treated for left main coronary artery disease with a severely depressed ejection fraction and significant comorbidity, and a score of 10 in the EuroSCORE) (Table 4). Angiographic follow-up was carried out in 63 patients (77%) within a mean period of 8.7±3.3 months after the procedure. Revascularization of the target lesion was necessary in

TABLE 4. **Outcome 1 Year After the Procedure***

Death, n (%)	1 (1.2)
Myocardial infarction, n (%)	2 (2.4)
Q-wave, n (%)	1 (1.2)
Non-Q-wave, n (%)	1 (1.2)
Late stent thrombosis, n (%)	1 (1.2)
Revascularization of the treated lesion, n (%)	9 (10.8)
Main branch, n (%)	2 (2.4)
Side branch, n (%)	4 (4.8)
Both, n (%)	3 (3.6)
Coronary revascularization surgery, n (%)	0 (0)
MACE-free, n (%)	85.6

*MACE indicates major adverse cardiac events.

9 patients (10.8%): 4 (4.8%) in the SB, 2 (2.4%) in the MB and 3 (3.6%) in both. Isolated restenosis of the SB and MB was focal and diffuse when it involved both branches. MACE-free survival was 85.5%. Other factors that could influence restenosis, such as the cutting balloon, the rotablator, lesion length or stent length showed no statistically significant differences in terms of the need for repeat revascularization in the lesions treated with crush T stenting.

DISCUSSION

True bifurcation lesions are complex lesions, and their treatment with PCI is associated with a lower success rate, a higher frequency of restenosis and greater possibilities of SB closure when compared with nonbifurcation lesions.[3,5,11,17] The increasingly widespread use of DES to prevent intimal proliferation and restenosis[18] is resulting in the introduction of alternative techniques in the treatment of bifurcation lesions. The classical strategy involving a stent in the MB and a provisional stent in the SB has been the systematic approach to these lesions.[4-6] When the technique for the treatment of bifurcation lesions with DES involving stents in both branches was compared with that involving a stent in the MB and balloon alone in the SB, the rate of angiographic restenosis in SB was 21%,[3] probably due to incomplete coverage of the SB ostium with the T-stenting technique. The latter assertion is supported by the theory that when the SB forms a sharp angle with the MB, the circumference of the ostium of the SB containing a stent will never be totally covered, unless it protrudes toward the MB. For this reason, we undertook the treatment of these lesions with the crush T stenting technique, ensuring that the stent strut covered the entire circumference of the ostium of the SB. This guarantees the immediate patency of both branches and delivers a higher drug dose per square millimeter near the bifurcation, due to the presence of several (3) layers of metal in the proximal portion of the MB, joined to the carina. The major advantages of this technique are that it is safe and relatively easy to perform since both stents are placed simultaneously, a circumstance that eliminates the difficulty or impossibility of introducing a second stent in the SB after a stent has been implanted in the MB (T stenting technique), and guarantees the immediate patency of both branches, with excellent results. However, it must be completed by newly passing the guide wire into the SB, a step that can be complicated, and by postdilatation involving simultaneous inflation with balloons in the MB and the SB, a measure that improves the immediate and medium-term results. Colombo et al[15] and Airoldi et al[19] confirmed excellent immediate results with the crush T tenting technique, but with an incidence of stent thrombosis of 2.9%, of MACE at 30 days of 7.6% and a relatively high rate of restenosis (15% to 18%) at 6 to 9 months. In the group of patients in which simultaneous final dilatation was performed with kissing balloons, the rate of restenosis was reduced to 8% and MACE at 30 days to 5.5%. Intrastent stenosis was most frequently focal and localized in the ostium of the SB, perhaps due to the excessive separation of the stent strut or incomplete expansion of the stent in highly angulated lesions. In our experience, glycoprotein IIb/IIIa inhibitors were employed infrequently and at the discretion of the interventionalist. Their use was related more to the clinical condition of the patient than to the technique performed, and was associated with good immediate results and the absence of acute stent thrombosis, despite the large amount of metal situated near the carina, a circumstance that could predispose to thrombosis; however, the incidence of subacute stent thrombosis increased to 2.4%, a finding that contrasts with the data reported in studies involving DES in selected lesions, in which an incidence of 0.4% was observed with rapamycin and of 0.6% with paclitaxel,[20,21] while in unselected lesions, the rate of subacute thrombosis increased to 1.1%.[22] These data indicate that there is a higher risk of stent thrombosis when 2 DES are implanted into a bifurcation, and that to reduce the incidence of this complication, it is necessary to use glycoprotein IIb/IIIa inhibitors more liberally, employ a high loading dose of clopidogrel and maintain the dual antiplatelet therapy over a minimum of 9 to 12 months. In our study, we insisted on a good initial angiographic result and the utilization of intracoronary ultrasound when, after final simultaneous postdilatation with balloons in both the MB and SB, the angiogram was not optimal.

Limitations of the Study

Compared with other techniques, the treatment of bifurcation lesions using the crush T stenting technique involving the implantation of two DES is associated with a high rate of success and a low rate of restenosis. The absence of systematic angiographic follow-up in those patients in which the left main coronary artery was not involved may have led to the underestimation of the incidence of restenosis in the SB when it was not symptomatic. However, all the patients underwent clinical follow-up in the outpatient cardiology units and, regardless of the symptomatology, tests were performed to detect myocardial ischemia and the need for repeat coronary angiography when ischemia was suspected (77% underwent angiographic follow-up). Another important limitation to this study is the absence of randomization and comparison with the conventional T stenting technique, which, at the present time, is the reference standard for the treatment of bifurcation lesions.

CONCLUSIONS

The treatment of bifurcation lesions with drug-eluting stents using the crush T stenting technique, followed by dilatation of the main branch and the side branch by means of simultaneous inflation is safe, and is associated with a low incidence of major adverse cardiac events and of the need for repeat revascularization.

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