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ORIGINAL PAPER

Culotte versus the novel nano-crush technique for unprotected complex bifurcation left main stenting: difference in procedural time, contrast volume and X-ray exposure and 3-years outcomes

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Abstract

To assess the procedural performance and 3-years outcomes of unprotected complex bifurcation Left Main (LM) stenting using either Culotte or the novel nano-crush techniques, consisting in the use of two ultra-thin strut stents with a 1-ring stent crushed into the LM. We analysed the records of patients with complex distal/bifurcation LM disease and contraindications and/or refusal of bypass surgery, who from 1 January 2014 to 1 November 2017, received at operators' discretion LM double stenting by means of nano-crush technique using Orsiro (Biotronik Inc, Bulack, Switzerland) or Onyx (Medtronic Inc, Galway, Ireland) stents or Culotte stenting using same stent platforms. Among 65 patients (28 females, mean age 77.2 ± 6.2 years), 32 received nano-crush while 33 patients received Culotte technique. Mean angles between left anterior descending coronary artery and left circumflex was 63.6 ± 21.3°. Post-operative success was achieved in 100% of cases. Nano-crush patients showed lower contrast medium volume and X-ray exposure, shorter fluoroscopy and procedural times compared to Culotte patients group. At a mean follow-up of 27.4 ± 10.8 months, clinical-driven target lesion revascularization, myocardial infarction and cardiovascular death were 0 versus 4/33 (12.1%, p = 0.04), 1/32 (3.1%) versus 6/33 (18.1%, p = 0.03) and 2/32 (6.2%) versus 8/33 (24.2%, p = 0.04) in nano-crush versus Culotte patients, respectively. In this single center study, the nano-crush technique was associated with less use of contrast, less procedural time and less X-ray exposure compared to the culotte technique for the treatment of unprotected left main bifurcation lesions.

Keywords Left main · PCI · Stent · Crush · Interventional

Introduction

Although several studies have shown that stenting in LM is a safe and effective treatment strategy [1–4], stenting of unprotected complex distal/bifurcation LM remains challenging, providing less optimal outcomes than usually achieved after non-distal LM stenting. The amount of double metal layer at the bifurcation site and the used technique appeared important factors for long-term results.

Last generation of DES, and in particular the ultrathin cobalt-chromium biodegradable polymer Orsiro stent (Biotronic Inc, Bulack, Switzerland) and the Onyx stent (Medtronic Inc, Galway, Ireland) [5], thanks to the very thin struts (60–80 µm for the Orsiro, 81–91 µm for the Onyx), might have the potential to improve the overall results. Techniques aimed to decrease as much as possible the amount of metal inside the bifurcation and possibly applicable to both any diameter ratio between main vessel/

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side branch and to any bifurcation angle, seem another critical issue impacting in cardiovascular adverse events and stent thrombosis rate [6]. The nano-crush technique [7] minimizing the amount of metal at the carina, has the potential to have a beneficial impact on the long-term outcomes compared to well-established technique such as the Culotte.

Our study was aimed to assess the immediate success and outcomes of nano-crush technique compared to Culotte technique in a single-center observational registry of patients with complex LM bifurcation disease. Our hypothesis was that the nano-crush technique [7] minimizing the amount of metal at the carina, would have the potential to have a beneficial impact on the long-term outcomes compared to well-established technique such as the Culotte.

Methods

We analysed the procedural and medical records of patients admitted to our center from 1 January 2014 to 1 November 2017 who had complex LM bifurcation disease and contraindications and/ or refusal to surgery and received double stenting using a very minimal crush technique (nano-crush) or Culotte stenting at the operators' discretion, using Orsiro or Onyx stents. Clinical (cardiovascular risk factors, Canadian Cardiovascular Score class, EUROSCORE [8]) and angiographic characteristics (lesion/s location and severity according to the SYNTAX score [9] and MEDINA classification [10]) were calculated and analysed by a Heart Team composed of the referral cardiac surgeon, the referral clinical cardiologist and the interventional cardiologist: refusal to aorto-coronary bypass surgery and/or contraindications to surgery have been discussed among the patient and Heart Team members as mandatory inclusion criteria. Written informed consent to the indexed procedure was obtained from all patients.

Definition of unprotected complex LM bifurcation disease include: (1) a stenosis with a diameter of $>50\%$ involving the mid-shaft/distal main vessel with significant involvement ($\geq 50\%$ luminal narrowing and ≥ 10 mm length by visual estimation) of the Left anterior descending coronary artery (LAD) and left circumflex artery ostia (diameter ≥ 2.5 mm by visual estimation) and, (2) without any patent graft to the left anterior descending artery or left circumflex artery.

Patients with acute ST-elevation Myocardial Infarction (STEMI) of the LAD or LCx at the time of LM procedure, and/or contraindications for dual antiplatelet therapy, and/ or life expectance <24 months were excluded from the analysis.

Hospital Department Board approved the observational study.

Interventional Protocol

A 6F right radial approach has been selected whenever possible. During PCI, patients were anticoagulated with unfractionated heparin (a bolus of 40 U/kg and additional heparin to achieve an activated clotting time of 250–300 s). Additional significant lesions in other vessels were treated with staged procedures and a routine last generation DES of the operator's choice (Promus Premier, Boston Scientific, Galway, Ireland; Orsiro, Biotronik, Bulack, Switzerland, Resolute Integrity or Onyx, Galway, Ireland). Twelve-month Ticagrelor or Prasugrel treatment and life-long aspirin were recommended to all patients according to our regional guidelines.

Nano-crush technique

The very minimal or "so-called" nano-crush as already described [7] was based upon the use of ultra-thin struts stents, the crush of just one single stent ring protruding into the main vessel in order to minimize as much as possible the amount of metal crushed preserving coverage of the side branch ostium, and the use of the sequence Proximal optimization technique (POT)–snuggle kissing–POT. The technique was used for any angles and is resumed in Fig. 1a. The Orsiro stent has been chosen on the basis of IVUS when diameter of the proximal LM was <5 mm, whereas Onyx stent has been selected when proximal LM diameter was ≥ 5 mm.

A short time (2–3 s) angiographic scene with the highest magnification field and maximization of the diaphragms has been used to precisely positioning the SB stent with protrusion of 1 stent ring or at maximum of 0.5 mm before crushing with non-compliant balloon.

Culotte technique

The Culotte technique was performed following the step in Fig. 1b in particular when angle between LAD and LCx was $<60°$ and the LCx diameter equalized the LAD diameter on IVUS with a maximal difference of 0.5 mm.

IVUS protocol

Intravascular Ultrasound examination was performed routinely following current guidelines [11] using the 3F Opticross coronary IVUS catheter (Boston Scientific, Fremont, CA, USA) and automatic pull-back system (0.5 mm/s). On-line ultrasound assessment was performed in diastole. IVUS images were recorded after administration of 100–200 mg of nitroglycerin. The ultrasound catheter was

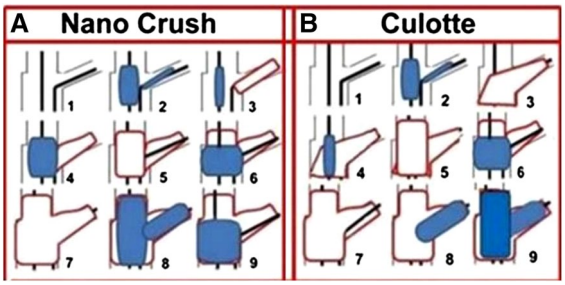

Fig. 1 Schematic representation of the key steps of nano-crush and Culotte of nano-crush stenting technique (**a**): (1) wiring both branches; (2) predilating sequentially or simultaneously both branches with non compliant balloons; (3) stent deployment on side branch (SB) with 1—ring only protrusion (by image magnification or stent magnification) maintaining a non-compliant balloon of the same diameter of Main Branch (MB) into the MB; (4) withdrawing the stent balloon of the deployed stent and inflating the main branch at high pressure (around 20 atm); (5) deploying the MB stent of the diameter of the distal reference diameter; (6) POT with non-compliant balloon of the same diameter of the main branch; (7) rewiring SB; (8) snuggle kissing overexpansion; (9) final re-POT. **b** Schematic representation of the key steps of Culotte stenting technique: (1) wiring both branches; (2) predilate sequentially or simultaneously both branches with non-compliant balloons; (3) stent deployment to side branch (SB); (4) rewiring distal MB and opening the struct with a small semicompliant balloon; (5) deploying the MB stent of the diameter of the distal reference diameter; (6) POT with a non-compliant balloon of the same diameter of the proximal MB; (7) rewiring SB and opening the struts with a small semi-compliant balloon; (8) kissing balloon; (9) final re-POT

advanced 0.5 mm beyond the lesion/stent and was pulled back to a point 0.5 mm proximal to the lesion/stent using motorized transducer pullback at 0.5 mm/s IVUS was performed and interpreted by the treating physician and at least one experienced IVUS technician. The lumen cross-sectional area (CSA) at the stent level was assessed by planimetry at the interface of the blood and the stent, at multiple levels (at least three), and the smallest area was chosen. The proximal and distal reference lumen areas and diameters were also measured by manual planimetry. The reference segments were selected as the most normal-looking cross section within 10 mm proximal and distal to the stent [12]. AVIO criteria have been used for area and stenosis evaluation [13]. To reduce the variability, all IVUS measurements were repeated, and the average of the two values was used in the analysis. Routine measurements were recorded pre- and post-stent implantation.

Definitions

Quantitative coronary angiographic (QCA) analysis at baseline, post-stenting and at follow-up was performed using edge detection techniques (CAAS II 5.0 version; Pie Medical, Maastricht, Netherlands). Angiographic success was defined as residual stenosis 30% by visual analysis in the presence of Thrombolysis in Myocardial Infarction (TIMI) 3 flow grade. Binary restenosis was defined as stenosis $\geq 50\%$ of the luminal diameter in target lesions. Angiographic measurements included the stented segment as well as the margins 5-mm proximal and distal to the stent.

Major adverse cardiac events were defined as (1) cardiovascular death, (2) non-fatal myocardial infarction (MI), or (3) target lesion revascularization (TLR). All deaths were considered to be of cardiac origin unless a noncardiac origin was established clinically or at autopsy. AMI was diagnosed by a rise following Thygesen et al. [14]. TVR was defined as a repeated intervention (surgical or percutaneous) to treat a luminal stenosis within the stent or in the 5-mm distal or proximal segments adjacent to the stent, including the ostium of the left anterior descending artery (LAD) and/or circumflex artery. Stent thrombosis was classified according to the Academic Research Consortium (ARC) definitions as definite, probable or possible, as early (0–30 days), late (31–360 days) or very late (> 360 days).

In-stent restenosis (ISR) was classified as focal (< 10 mm long), diffuse (> 10 mm long), proliferative (> 10 mm long and extending outside the stent edges), or totally occluded [15]. Information about in-hospital outcomes was obtained from an electronic clinical database for patients maintained at our institution and by review of hospital records for those discharged to referring hospitals. Post-discharge survival status was obtained from the Municipal Civil Registries. Information on occurrence of AMI or repeated interventions at follow-up was collected by consulting our institutional electronic database and by contacting referring physicians and institutions and all living patients.

Procedural measurements

Radiological equipment was the GE Medical System Innova 3100 30″–30″ Flat Panel in all cases. An estimation of the effective dose has been obtained from the measurements of the dose-area product (DAP). DAP was recorded automatically by the radiological equipment during the procedures. Fluoroscopy and procedural time and contrast volume were analysed as well.

Clinical follow-up

Per our institutional protocol, follow-up was conducted by physical examination at 1, 6, and 12 months and then yearly. Induced ischemia tests including ergometric test, nuclear stress test or stress echocardiography was scheduled at 6/8 months. Similarly, transthoracic echocardiography (TTE) was scheduled at 6 months. Angiographic with intravascular ultrasound control was scheduled at the time of additional vessel treatment or driven by clinical symptoms or instrumental evidence of myocardial ischemia.

Information about the in-hospital outcome was obtained from an electronic clinical database for patients maintained at our institution and by review of hospital records for those discharged to referring hospitals.

Statistical analysis

Continuous variables are described as mean ± standard deviation, and categorical variables are described as proportions. ROC curve analysis was adopted to find the SYNTAX score cut-off associated with cardiovascular death. Mantel–Cox analysis was used to analyse difference in cardiovascular mortality between nano-crush and Culotte groups. Cox regression analysis was used to identify the independent predictors of cardiovascular death in both groups. Occurrence of MI, death and TLR over the follow-up period were represented using the Kaplan Meirer curves and compared using the Log-rank (Mantel–Cox) analysis among the two groups. Statistical analysis was performed using a statistical software package (SAS for Windows, version 8.2; SAS Institute; Cary, NC). A probability value of <0.05 was considered to be statistically significant.

Results

Sixty-five patients out of 224 patients (29%, 28 females, mean age 77.2 ± 6.2 years, Table 1) submitted to LM stenting received LM double stenting fulfilling the inclusion criteria: 32 patients received nano-crush while 33 patients received Culotte technique.

Nano-crush group overcame Culotte group of patients in terms of cardiogenic shock presentation, 3-vessel disease prevalence, and mean SINTAX score. ROC curve analysis demonstrated that a SYNTAX Score ≥ 20 was associated with cardiovascular death both in the nano-crush (AUC 0.85, p = 0.03) and culotte (AUC 0.88, p = 0.02) groups.

Post-operative success was achieved in 100% of cases. Mean angles between left main (LM) and left circumflex (LCx) was 63.6 ± 21.3°; the mean diameter and length of implanted stents was 4.4 ± 0.8 mm and 27.1 ± 8.7 mm in LM and 3.1 ± 0.9 mm and 22.1 ± 0.7.1 mm in LCx in the nano-crush of patients and 4.3 ± 0.8 mm and 28.2 ± 7.1 mm in LM to LAD and 3.5 ± 0.8 mm and 22.6 ± 0.8.6 mm in LM to LCx in the Culotte group of patients. Nano-crush patients group showed lower contrast medium volume and X-ray exposure, and shorter fluoroscopy and procedural times compared to Culotte patients' group (Table 2).

Additional staged PCI in other vessels has been accomplished in 18/65 patients (27.6%, 6 patients in Culotte group and 12 patients in nano-crush group): right coronary artery PCI in 12 patients and obtuse marginal branch PCI in 6 patients, performed at a mean time after the indexed procedure of 3.3 ± 1.1 months (1 RCA CTO in each group).

Clinical follow-up was available in 65/65 patients (100%), whereas instrumental (stress-tests) follow-up was available in 56/65 patients (86.1%). Clinically driven angiographic follow-up was available in 28/65 (43.0%) after a mean of 5.6 ± 1.2 months (Table 3): IVUS examination revealed a bigger LCx ostium CSA in Nano crush patients compared to Culotte one, despite the smaller stent used in the first group to treat LCx.

At a mean follow-up of 27.4 ± 10.8 months, clinical-driven target lesion revascularization, myocardial infarction and cardiovascular death were 0 versus 4/33 (12.1%, p = 0.04), 1/32 (3.1%) versus 6/33 (18.1%, p = 0.03) and 2/32

Table 1 Demographical and clinical data of the entire population

	N° (%) or mean (± SD)		p
	Nano-crush	Culotte	
Female gender	15/32 (42.8)	13/33 (39.3)	0.77
Age (years)	77.1 ± 5.8	78.1 ± 6.8	0.52
Hypertension	22/32 (68.5)	20/33 (60.6)	0.60
Hypercholesterolemia	24/32 (75.0)	21/33 (63.6)	0.32
Diabetes	8/32 (25.0)	9/33 (27.2)	0.84
Smoking	12/32 (37.5)	9/33 (27.2)	0.37
Valvular heart disease	6/32 (18.7)	8/33 (24.4)	0.57
EF (%)	47.2 ± 8.6	50.1 ± 3.3	0.07
EF < 30%	5/33 (15.1)	6/33 (18.1)	0.90
CCS class	2.4 ± 0.7	2.5 ± 0.4	0.48
Stroke	8/32 (25.0)	9/33 (27.3)	0.83
Heart failure	9/32 (28.1)	11/33 (33.3)	0.65
Severe COPD	13/32 (40.6)	14/33 (42.4)	0.88
Renal failure stage > II	3/32 (9.3)	4/33 (18.2)	0.86
Peripheral arterial disease	11/32 (34.3)	9/33 (27.2)	0.53
Carotid artery disease	3/32 (9.3)	5/33 (15.1)	0.47
Rest angina	13/32 (40.6)	17/33 (51.5)	0.38
Non-ST elevation ACS	19 /32 (59.3)	16/33 (48.4)	0.09
Cardiogenic shock	8/32 (25.0)	2/33 (9.1)	0.09
1-Vessel disease	0 (0)	0 (0)	0(0)
2-Vessel disease	14/32 (43.7)	19/33 (57.6)	0.26
3-Vessel disease	18/32 (56.2)	14/33 (42.2)	0.26
CTO RCA	1/32 (3.1)	1/33 (3.0)	0.90
Bifurcation angle	61.1 ± 19.8°	64.4 ± 20.1°	0.28
Medina classification			
0,1,1	8/32 (25.0)	16/33 (48.4)	0.05
1,1,1	24/32 (75.0)	17/33 (51.5)	0.05
SINTAX score	26.3 ± 7.2	21.4 ± 4.8	0.002
EUROSCORE I	23.0 ± 11.7	18.0 ± 9.1	0.05

ACS acute coronary syndrome, *CCS* Canadian Cardiovascular Score, *EF* ejection fraction calculated from left ventricle angiography, *RCA* right coronary artery, *SD* standard deviation

Table 2 Procedural data of the nano-crush and Culotte groups of patients

	N° (%) or mean (±SD)		p
	Nano-crush	Culotte	
6F radial access	21/32 (65.6)	14/33 (42.4)	0.06
7-in-6F radial access	9/32 (28.1)	3/33 (9.1)	0.04
7 Femoral access	2/32 (6.2)	16/33 (48.4)	< 0.01
Orsiro	24/32 (75.0)	20/33 (60.6)	0.21
Onyx	8/32 (25.0)	13/33 (39.4)	0.21
Procedural time (min)	70.3 ± 20.1	110.5 ± 12.8	0.001
Fluoroscopy time (min)	16.4 ± 5.3	21.4 ± 6.4	0.03
Contrast medium volume (ml)	154.2 ± 56.2	182 ± 48.7	< 0.001
Dose area product (cGy/cm^2)	11,904 ± 5112	16,177 ± 4331	< 0.01
IABP back-up	3/32 (9.3)	8/33 (24.2)	0.04
Intraprocedural complications	4/32 (12.5)	12/33 (36.3)	0.02
Stent embolization*	1/32 (3.1)	3/33 (9.1)	0.31
Abrupt vessel occlusion°	1/32 (3.1)	4/33 (12.1)	0.17
Access hematomas/bleeding/occlusion	2/32 (6.2)	5/33 (15.1)	0.24

*Stent embolization while crossing calcified LCx artery ostium in three cases and crossing distal calcified LM in two cases: all were snared successfully

°One cases of abrupt closure of distal LM-Ostial LCx after LM stenting but resolved by POT in nano-crush and four cases of abriupt closure in Culotte, three resolved kissing balloon, one after kissing balloon resolved by additional POT

Table 3 Angiographic and IVUS finding in the whole cohort

	Baseline		Post-stent	
	MLD (mm)	% Stenosis	MLD (mm)	CSA (mm^2)
Distal LM				
Nano-crush	1.9 ± 1.2	85.2 ± 6.6	4.6 ± 0.5	14.1 ± 1.1
Culotte	1.8 ± 1.1	86.1 ± 5.2	4.4 ± 0.3	12.1 ± 0.8
p	ns	ns	ns	0.03
LAD ostium				
Nano-crush	1.3 ± 0.9	88.7 ± 2.1	3.7 ± 0.8	9.4 ± 0.4
Culotte	1.4 ± 0.8	89.1 ± 2.3	3.4 ± 0.7	9.3 ± 0.3
p	ns	ns	ns	ns
LCx ostium				
Nano-crush	1.2 ± 1.4	84.1 ± 3.2	3.5 ± 0.6	9.1 ± 0.2
Culotte	1.2 ± 1.3	85.3 ± 2.9	3.4 ± 0.8	8.2 ± 0.3
p	ns	ns	ns	0.02

(6.2%) versus 8/33 (24.2%, p = 0.04) in Nano crush versus Culotte patients, respectively (Fig. 2).

Stent thrombosis was observed in 2 patients (6.0%) with Culotte compared to none with nano-crush (p = 0.17). Cardiovascular mortality was independently predicted by the same angiographical and clinical variable in both patients treated with nano-crush or culotte technique. Specifically, Cox regression analysis demonstrated that cardiovascular mortality was independently predicted in nano-crush group by a SYNTAX score ≥ 20 (HR 1.89, 95% CI 1.12–2.31, p = 0.03), need of IABP back-up (HR 1.76, 95% CI 1.02–1.96, p = 0.02) and the occurrence of intra-procedural complications (HR 1.88, 95% CI 1.26–2.02, p = 0.03). Adding gender or stent type did not modify the model. Similarly, the same clinical outcome in Culotte group was independently predicted by a SYNTAX score ≥ 20 (HR 1.99, 95% CI 1.22–2.53, p = 0.03), need of IABP back-up (HR 1.16, 95% CI 1.02–1.24, p = 0.03) and the occurrence of intra-procedural complications (HR 1.98, 95% CI 1.87–2.13, p = 0.02); also in this case, the addition of gender or stent type did not modify the model.

Discussion

Our brief study suggests that despite more challenging clinical characteristics, the nano-crush appears operatively less time, less contrast and less X-ray consuming than Culotte technique in our small population of unprotected complex LM bifurcation disease. The 3-years outcomes of nano-crush technique appeared slightly superior to Culotte stenting even if the small number of patients enabled any statistical significance. Although surgery has been considered the "gold standard" for unprotected LM disease revascularization, PCI is becoming an attractive therapeutic choice [4].

Stenting of the LM ostium or trunk is straighter-more forward than treating distal bifurcation which generally requires larger operator experience and skill. Currently available evidence suggests that outcomes are less favourable when distal LM lesions are treated with a 2-stent

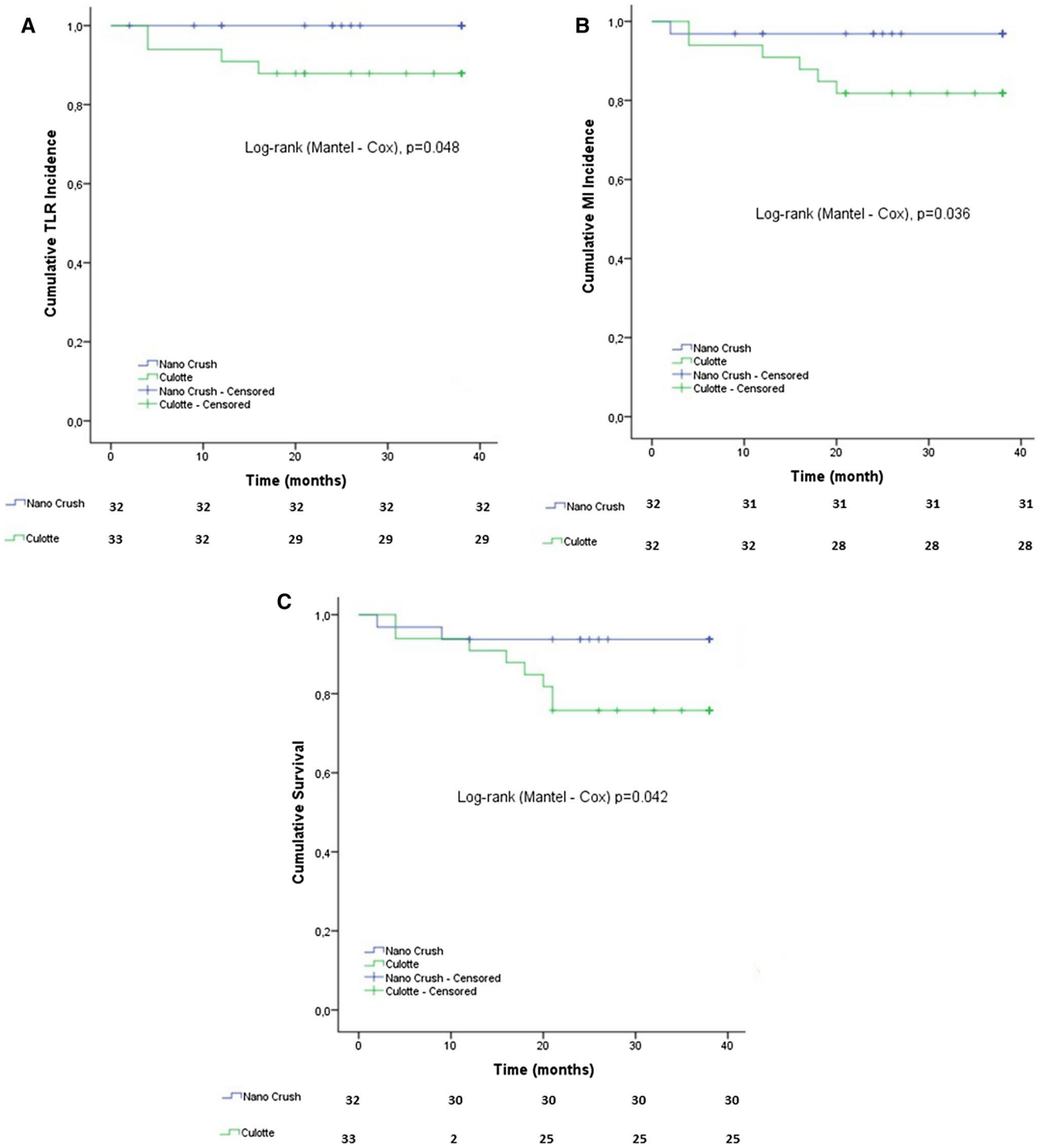

Fig. 2 Kaplan–Meier representation of clinically-driven target lesion revascularization (**a**), myocardial infarction (**b**) and death (**c**) occurrence during the follow-up period

compared with a single stent approach [16]. Nevertheless, it is clear that complex anatomies cannot be treated always with provisional cross-over stenting. When a double stenting technique is required, culotte stenting and crush technique have been considered the techniques with the highest profile of safety and efficacy in treating distal/bifurcation LM disease [17, 18]. Nevertheless a net superiority of one over the other has never been demonstrated,

and Culotte remains the preferred technique in many countries and especially in northern European countries.

Recently a modified Crush technique, the DK-crush [4, 19, 20], has shown excellent outcomes, even better of Culotte although remain doubts about the propensity of this technique towards stent malposition which is common to observe in bench tests when crush-techniques involve long segment of crushed stent [21].

The Orsiro and the Onyx stents are considered a last generation DES and actually are among the stents with the thinnest struts on the market. Assessed in randomized trials in Europe [22, 23], it demonstrated a very good safety and efficacy profile with low rate of stent thrombosis reaching the non inferiority compared to Xience Prime stent and Nobori. Some structural limitations intrinsic to the its constructive philosophy have been suggested to results in a certain amount of longitudinal shortening [24] and possible stent embolization in highly calcified and tortuose segments. Onyx having 81–91 μm strut thickness, and the capability to expand in the 4.5 mm diameter version up to 5.75 mm, is actually considered one of the most suitable stent for LM treatment.

In our patients stent embolization occurred crossing calcified and tortuosus segments and although uneventful, claim for a careful lesion preparation being the ultrathin stents constructively less robust than old generation stent. Moreover, the rate of stent thrombosis was not trivial in our registry but in line with current reported trials about double stenting treatment of complex bifurcations [19, 20].

From an operative point of view, complex LM bifurcation treatment by nano-crush technique using the Orsiro or Onyx stents has the potential to decrease operative time, X-ray exposure, and contrast usage. Our study suggests that the reduced number of both steps and multiple inflations as well as 6F handling in most cases contributed to decrease the ischemic time and minimize complications probably helping to improve immediate outcomes. Moreover, as recently suggested also by fluid dynamic study [25], it potentially would provide a smaller amount of metal left into the vessel and carina compared to Culotte technique. The sequence POT–snuggle kissing–POT seems a mandatory step to both preserving LM circularity and ensuring a large SB area maintaining a proper strut apposition to the carina as appeared from follow-up IVUS measurements which observed a bigger LCx ostium CSA in nano-crush compared to Culotte.

Study limitations

Our brief study suffers of a number of limitations which include the retrospective non-randomized fashion nature, which enables hard recommendations, the small patients sample which came from both the single center nature and the particular patients setting (really complex LM bifurcation disease requiring double stenting). The use of different stent platforms might induce differences in the outcomes independently from the stenting technique used. Finally, the lack of a dedicated Bifurcation QCA might confuse the angiographic data interpretation which however we believe mitigated by the routine IVUS use.

Conclusion

Further larger and possibly randomized studies are needed to establish the long-term efficacy of the nano-crush technique in LM revascularization compared to the other well-established technique such as the Culotte and the DK-crush. In this small non-randomized comparison performed at single center study, the nano-crush technique was associated with less use of contrast, less procedural time and less X-ray exposure compared to the culotte technique for the treatment of unprotected left main bifurcation lesions.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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