IMR Press

Original Research

Comparison of standard versus modified stenting technique for treatment of tapered coronary artery lesions

Dan Ke[1,2,†], Xi He[1,2,†], Chaogui Lin[1,2], Lianglong Chen[1,2,*]

[1] *Department of Cardiology, Fujian Medical University Union Hospital, 350001 Fuzhou, Fujian, China*

[2] *Fujian Institute of Coronary Artery Disease, 350001 Fuzhou, Fujian, China*

*Correspondence: lianglongchen@126.com (Lianglong Chen)

† These authors contributed equally.

DOI:10.31083/j.rcm2203101

Submitted: 27 February 2021 Revised: 3 May 2021 Accepted: 27 May 2021 Published: 24 September 2021

Tapered coronary artery lesions (TCALs) are often seen clinically, optimal stenting of TCALs remains challengeable. This study sought to compare clinical outcomes between the modified single stenting (MSS) and conventional overlapped stenting (COS) in treatment of TCALs. 150 patients were treated with MSS (MSS group), another 150 patients were matched with propensity score matching from 5055 patients treated with COS (COS group). Quantitative coronary angiography was performed to measure minimal lumen diameter (MLD), late lumen loss (LLL). The primary endpoint was immediate angiographic success, one-year cumulative major cardiac adverse events (MACEs) composing cardiac death, target vessel myocardial infarction (TVMI), target lesion/vessel revascularization (TLR/TVR) or stent thrombosis (ST). Post-procedural in-stent MLD (2.96 $\pm$ 0.34 versus 3.08 $\pm$ 0.33, P = 0.004) was smaller and diameter stenosis (11.7 $\pm$ 4.0% versus 9.0 $\pm$ 4.8%, P = 0.003) was higher in MSS group than COS group. At 1-year follow-up, in-stent MLD (2.76 $\pm$ 0.38 mm versus 2.65 $\pm$ 0.60 mm, P = 0.003) was reduced, LLL (0.20 $\pm$ 0.26 mm versus 0.42 $\pm$ 0.48 mm, P = 0.001), diameter stenosis (24.02 $\pm$ 20.94% versus 19.68 $\pm$ 11.75%, P = 0.028) and binary restenosis (18.7% versus 10.0%, P = 0.047) were increased in COS group. Angiographic success (96.7% versus 98.0%, P = 0.723) was similar between MSS group and COS group. At 1-year, the cumulative MACEs (12.0% versus 22.7%, P = 0.022) and TLR/TVR (10.0% versus 18.7%, P = 0.047) were reduced in MSS group as compared to COS group, there was no difference in cardiac death, TVMI and ST between the groups. Compared to conventional overlapped stenting, modified single stenting for TCALs is associated with similar angiographic success, fewer one-year cumulative MACEs and less treatment cost.

Keywords

Percutaneous coronary intervention; Tapered coronary artery lesion; Stenting

1. Introduction

The tapered coronary artery lesions (TCALs) are frequently seen in many clinical scenarios (e.g., long lesions with or without branches, bifurcation lesions, and unusual lesions with positive remodeling, ectasia or aneurism). Tapering is defined as the ratio of the area change to the vessel length [1]. Earlier, Zhang LR *et al.*, have determined the coronary anatomy of 526 adult subjects from Asia. They identified that the average diameter of LAD was 3.92 mm at origin and 2.10 mm at distal end, with a decremented ratio of 7.7%; the average diameter of LCX was 3.57 mm at origin and 2.10 mm at distal end, with a decremented ratio of 9.7%; and average diameter of RCA was 3.97 mm at origin and 2.15 mm at the distal end, with a decremented ratio of 5.1% [2]. In another study, Banka VS *et al.* [3], determined the degree of taper between 1 cm proximal and distal to the stenosis. They found that 23% arteries showed $\geq$1 cm taper, 19% arteries showed 0.5–0.99 mm taper, and 8% arteries showed reverse taper [3]. These findings indicate that the dimensions naturally taper along the length of coronary arteries [2, 3]. In cases involving stenosis or occlusions in major parts of a long vessel, natural tapering may create dilemma for optimal balloon sizing and optimal stent sizing during PCI [4].

Some clinicians may prefer to deploy multiple overlapping stents against one long stent. However, the available literature suggests that stent overlapping is associated with delayed healing and increased inflammation at the site of deployment. Further, it has been demonstrated that overlapping stents is associated with impaired angiographic and long-term clinical outcome, including death or myocardial infarction. The stenting of TCALs remains technically challenging. Generally, stent sizing is based on the distal reference-vessel diameter (RVD), and proximal stent mal-apposition can be corrected by post-dilation by using a short sizable balloon [5]. Obviously, this standard for stent sizing is no longer appropriate for TCALs because post-dilation with oversized balloons may cause deformation or structural damage of implanted stents, possibly leading to unfavorable clinical outcomes [6–10]. To overcome this dilemma, conventional overlapped stenting (COS) offers an option but may increase risks of in-stent restenosis or thrombosis, as well as the therapeutic cost [11–17]. Recently, a long tapered stent customized for TCALs has been developed but is not yet extensively used [18–23]. Accordingly, we proposed a modified single stenting (MSS) by using a conventional long stent for TCAL treatment. The initial application was promising but required further investigation.

In the present study, we aimed to compare clinical outcomes between MSS and COS for the treatment of TCALs.

2. Methods

2.1 Patient selection and study design

This study is a propensity score-matching case-control type. Patients with the following criteria were included: (1) de novo TCALs defined as ≥25% diameter difference between the proximal and distal segments, (2) stable angina and non-ST-elevation acute coronary syndrome, and (3) available 12-month angiography. Conversely, patients with the following criteria was excluded: (1) lesions unsuitable for PCI, such as multiple-vessel disease with >32 syntax score, (2) ST-elevation myocardial infarction (MI) within one month, (3) patients without clinical and angiographic follow-up dada, (4) severe renal insufficiency (eGFR <30 mL/min), (5) hematopoietic disorders (platelet count $<100 \times 10^{\hat{}}9$/L or $>700 \times 10^{\hat{}}9$/L, leukocyte count $<3 \times 10^{\hat{}}9$/L), (6) Intolerance to long-term antiplatelet therapy; and (7) life expectancy <1 year.

From January 2015 to May 2019, among 5055 patients who had underwent PCI, the patients who met the above criteria were matched based on propensity score matching, resulting in 150 pairs of patients treated either by MSS or COS.

2.2 Stenting techniques

2.2.1 Modified single stenting (MSS)

If one stent (the longest was 38 mm in our center) could cover the entire lesion, only one stent could be used with stent sizing through the mean distal and proximal RVD, otherwise, overlapped stenting was allowable (TCAL ≥38 mm). The stent was deployed by initially inflating with 6 atm (much lower than the nominated pressure), The stent balloon was then pulled back by 1–2 mm before reinflating with the nominated pressure or a higher one.

2.2.2 Conventional overlapped stenting (COS)

Overlapped stenting with two stents or more was adopted to adapt to TCAL anatomy. The distal and proximal stents were sized by 1.0- to 1.1-fold of the distal and proximal RVDs, respectively. The distal stent was deployed routinely with the nominated pressure. One stent for a very short TCAL was allowed at the operator's discretion.

For both of the stenting techniques, compliant or noncompliant balloon was allowed for post-dilation to achieve full stent expansion and apposition. Bailout stenting was also allowable as indicated.

2.3 Medications and stents

All patients received pretreatments of aspirin and clopidogrel or ticagrelor with loading doses as indicated. Aspirin was maintained indefinitely, whereas clopidogrel or ticagrelor was maintained for 12 months unless contraindicated. Intraprocedural heparin of 70–100 U/kg was administered intravenously with an additional bolus of 1000 U given per hour to maintain an activated clotting time of 250–300 s. The use of platelet glycoprotein receptor antagonists was left to the discretion of the operators.

Second-generation drug-eluting stents (DESs) including Resolute (Medtronic, Minneapolis, Minnesota), Xience (Abbott Vascular, Santa Clara, CA, USA), Firebird-2 (Microport, Shanghai, China) and Excel (JW, Shandong, China) were used.

2.4 Follow-up

Clinical follow-up was performed through clinic visits or telephone contact at 1, 6, and 12 months after discharge and annually thereafter. Coronary angiography was planned at 12 months or performed earlier as clinically indicated. Quantitative coronary analysis was conducted in the stented segment (in-stent) and 5 mm proximal or distal to the stent end (in-edge). Restenosis was defined as >50% stenosis-diameter percentage at follow-up.

2.5 Definition of events and end points

The primary endpoint was as follows: (1) immediate angiographic success, defined as no residual diameter stenosis ≥20%, abnormal TIMI flow, edge dissection ≥type-C, or bailout stenting; (2) major cardiac adverse events (MACEs) at one year, including cardiac death, target-vessel MI (TVMI), target lesion revascularization (TLR)/target vessel revascularization (TVR), or stent thrombosis (ST). The secondary endpoint was the MACE component.

MI was diagnosed according to the Forth Universal Definition of MI [24]. All MIs were considered as TVMI unless clear evidence indicated that they were caused by non-target vessels. TLR/TVR was repeat target vessel/lesion treatment either by PCI or CABG. ST was diagnosed according to the ARC definition [25].

2.6 Statistical analysis

Data were expressed as the mean ± SD for continuous or frequency (%) for discrete variables. To compare differences, Student's t test was used for continuous variables, and Chi square or Fisher's exact test was used for the discrete variables. Statistically significance was considered at $P < 0.05$. Data were analyzed with IBM SPSS statistics (version 20.0, IBM Corp., Chicago, IL, USA).

Propensity score matching was used to reduce treatment bias and potential impact of confounding factors from baseline characteristics. All baseline clinical and lesion characteristics that may affect outcomes upon univariate analysis were deemed as candidate variables. All variables with $P <$ 0.20 were retained. Model reliability was evaluated using the Hosmer-Lemeshow test. Based on the nearest match algorithm, we created case-matched pairs without replacement at 1:1 ratio.

3. Results

A total of 150 patients were enrolled and treated with MSS (denoted as MSS group); another 150 patients were matched as controls based on the propensity score matching of baseline clinical and lesion characteristics from 5055 pa-

Table 1. Comparison of baseline clinical characteristics in both groups.

	Modified (n = 150)	Standard (n = 150)	*P* values
Male, n (%)	120 (80.0%)	116 (77.3%)	0.673
Age (years)	66.5 ± 10.2	64.1 ± 10.8	0.246
Hypertension (%)	100 (66.7%)	94 (62.7%)	0.546
Hypercholesterolemia, n (%)	108 (72.0%)	119 (79.3%)	0.178
Diabetes, n (%)	48 (32.0%)	50 (33.3%)	0.902
Smoking, n (%)	75 (50.0%)	71 (47.3%)	0.729
Prior PCI, n (%)	30 (20.0%)	24 (16.0%)	0.453
Prior MI, n (%)	9 (6.0%)	10 (6.8%)	1.000
LVEF (%)	61.3 ± 9.0	60.9 ± 7.6	0.812
Coronary artery disease, n (%)			
Stable angina pectoris	81 (54.0%)	74 (49.3%)	0.488
Unstable angina pectoris	51 (34.0%)	47 (31.3%)	0712
NSTEMI	18 (12.0%)	25 (16.7%)	0.323
Antiplatelet therapy, n (%)			
Aspirin	150 (100%)	150 (100%)	1.000
Clopidogrel/Ticargrelor	150 (100%)	150 (100%)	1.000
GP IIb/IIIa inhibitors	5 (3.3%)	5 (3.3%)	1.000

Note: PCI, Percutaneous Coronary Intervention; MI, myocardial infarction; NSTEMI, non–ST-segment elevation myocardial infarction.

tients treated with COS (denoted as COS group) in the PCI Database.

3.1 Clinical and procedural data

The baseline clinical and lesion's characteristics (Tables 1,2) were comparable between the groups. As shown in Table 2, fewer stents were implanted (1.03 ± 0.16 mm or MSS versus 2.01 ± 0.11 mm for COS, $P = 0.000$) with shorter stent length per TCAL (32.08 ± 4.41 mm for MSS versus 34.42 ± 4.78 mm for COS, $P = 0.012$). Fewer non-compliant balloons (1.22 ± 0.47 mm for MSS versus 1.78 ± 0.55 mm for COS, $P = 0.000$) were used for post-dilation in the MSS group. Immediate angiographic success was comparable between the groups (96.7% for MSS versus 98.0% for COS, $P = 0.723$) with similarly low rates of edge dissection (2.7% for MSS versus 1.3% for COS, $P = 0.684$) and edge bailout stenting (2.7% for MSS versus 1.3% for COS, $P = 0.684$). Additionally, procedural time, radiation dosage, contrast volume and treatment cost per lesion were reduced in the MSS group.

3.2 Angiographic results

Table 3 shows that the baseline lesion characteristics were similar between the groups. Immediately after the procedure, we observed smaller in-stent MLD (2.96 ± 0.34 mm for MSS versus 3.08 ± 0.33 mm for COS, $P = 0.004$) and higher diameter stenosis (11.7 ± 4.0% for MSS versus 9.0 ± 4.8% for COS, $P = 0.003$) in the MSS group, as well as similar in-edge MLD and diameter stenosis between the groups. At 1-year follow-up, we observed larger in-stent MLD (2.76 ± 0.38 mm for MSS versus 2.65 ± 0.60 mm for COS, $P = 0.003$), less LLL (0.20 ± 0.26 mm for MSS versus 0.42 ± 0.48 mm for COS, $P = 0.001$), less diameter stenosis (19.68 ± 11.75% for MSS versus 24.02 ± 20.94% for COS, $P = 0.028$), and fewer binary restenosis (10.0% for MSS versus 18.7% COS, $P = 0.047$) in the MSS group. The in-edge MLD, LLL, diameter stenosis, and binary restenosis were similar between the groups.

3.3 Clinical outcomes

Angiographic success (96.7% versus 98.0%, $P = 0.723$) was comparable between the MSS group and COS groups. The one-year cumulative MACE (12.0% versus 22.7%, $P = 0.022$) and TLR/TVR (10.0% versus 18.7%, $P = 0.047$) were significantly reduced in the MSS group compared with the COS group. No difference in cardiac death, TVMI, and ST was observed between the groups (Table 4).

4. Discussion

This study addressed the interventional strategies for a special subset of long tapered lesions (TCALs) in contrast to the usual long lesions. All enrolled patients had >25% mean proximal and distal diameter difference and >30 mm lesion length. Accordingly, all lesions were absolutely tapped and relatively long, representing the typical anatomical characteristics of TCALs. Our study demonstrated that compared with the use of COS to treat TCALs, MSS was associated with similar rates of immediate angiographic success with less use of stents, lower cost of treatment, and lower rate of MACE at one-year follow-up.

4.1 Controversial outcomes of current stenting strategies for TCALs

Current strategies to treat TCALs include overlapped stenting with multiple short stents [26–28], single stenting with a conventional long tubular stent [29, 30], or single stenting with a tapered long stent [18–23].

Overlapped stenting, applied as early as the era of bare-metal stents (BMS), remains the most common treatment for TCALs. The benefit of stent overlapping is that it can

Table 2. Lesions and procedural characteristics.

	Modified (n = 150)	Standard (n = 150)	*P* values
Lesion locations, n (%)			
LM-LAD	12 (8.0%)	12 (8.0%)	1.000
LAD	66 (44.0%)	71 (47.3%)	0.643
LCX	48 (32.0%)	43 (28.7%)	0.616
RCA	24 (16.0%)	24 (16.0%)	1.000
Lesion length, mm	30.60 ± 4.48	31.08 ± 4.81	0.607
Reference vessel diameter, mm			
Proximal	3.17 ± 0.37	3.24 ± 0.47	0.401
Distal	2.33 ± 0.26	2.38 ± 0.34	0.459
ΔD	0.83 ± 0.12	0.86 ± 0.14	0.333
Diameter stenosis percentage, %	80.56 ± 8.45	79.82 ± 8.55	0.664
Calcified lesion, n (%)	6 (4.0%)	6 (4.0%)	1.000
Chronic total occlusion, n (%)	4 (2.7%)	3 (2.0%)	1.000
Lesion pre-treatment			
Cutting balloon	18 (12.0%)	9 (6.0%)	0.501
Rotational atherectomy	6 (4.0%)	6 (4.0%)	1.000
Stent implantation per TOCAL			
Stent number, n	1.03 ± 0.16	2.01 ± 0.11	0.000
Stent length, mm	32.08 ± 4.41	34.42 ± 4.78	0.012
Post-dilation			
NC balloon number, n (%)	1.22 ± 0.47	1.78 ± 0.55	0.000
Maximal pressure, ATM	17.4 ± 2.6	17.2 ± 2.4	0.645
Residual stenosis ≥20%, n (%)	5 (3.3%)	3 (2.0%)	0.723
TIMI flow ≤3, n (%)	2 (1.3%)	2 (1.3%)	1.000
Edge dissection ≥type C*, n (%)	4 (2.7%)	2 (1.3%)	0.684
Edge bailout stenting*, n (%)	4 (2.7%)	2 (1.3%)	0.684
Angiographic success, n (%)	145 (96.7%)	147 (98.0%)	0.723
Procedural time, min	43.98 ± 18.23	64.52 ± 20.01	0.000
Radiation dosage, mGy	508.51 ± 360.24	803.8 ± 464.12	0.000
Contrast volume, mL	134.8 ± 92.50	204.00 ± 88.76	0.000
Treatment cost per lesion, RMB	28325.18 ± 8632.71	42925.24 ± 15369.05	0.000

Abbreviations: ΔD, proximal-distal diameter difference; LAD, left anterior descending artery; LCX, left circumflex artery; LM, left coronary main stem; NC, Non-compliance; RCA, right coronary artery; TCAL, tapered coronary artery lesion.

Note: *, Edge dissection was defined as dissection that occurred in 5-mm distal or proximal to the stent edge; bailout stenting was only indicated as dissection ≥type C in the distal or the proximal edge.

match a long tapered vessel by stepping up the size of multiple stents. However, clinical outcomes afforded by overlapping BMS have been proven inferior to those treated with a single BMS primarily due to increased TLR [31–34]. Overlapping stents with first generation DESs could effectively reduce restenosis by strongly inhibiting neointimal hyperplasia [35–39] However, clinical outcomes remain controversial. A pooled analysis of five studies on overlapping sirolimus-DESs has revealed that the rates of ischemic end-points and revascularization are similar to those of a single sirolimus-DES, and that revascularization is significantly reduced compared with a BMS [40]. By contrast, a study comparing overlapping DESs, non-overlapping DESs, and a single DES implanted in a vessel has demonstrated that overlapping DESs are associated with impaired angiographic and long-term clinical outcomes, including death or MI [41]. The discrepancy could be partly explained by the delayed vascular healing and impaired endothelialization caused by increased drug concentrations and polymer burden because impaired endothelialization is particularly pronounced at overlapped-stent sites [42]. Additionally, an experimental study has shown more neutrophils, eosinophils, and fibrin deposition at the sites of overlapping DESs than at those of non-overlapping DESs and BMSs. This finding suggests the inflammation of impaired vascular healing at DES overlapping sites [43]. Overall, these data suggest that a single long stent may be better than multiple overlapping stents for the treatment of long lesions or TCALs. Obviously, a long tapered stent may be more suitable for the fixation of long TCALs. Nevertheless, tapered or long-tapered stents are not extensively used clinically because of their limited availability.

Table 3. QCA measurements at baseline, post-procedure and follow-up.

	Modified (n = 150)	Standard (n = 150)	*P* values
Baseline			
Lesion length, mm	30.60 ± 4.48	31.08 ± 4.81	0.607
RVD, mm			
Proximal	3.17 ± 0.37	3.24 ± 0.47	0.401
Distal	2.33 ± 0.26	2.38 ± 0.34	0.459
ΔD	0.83 ± 0.12	0.86 ± 0.14	0.333
MLD, mm	0.53 ± 0.22	0.56 ± 0.25	0.468
Diameter stenosis, %	80.56 ± 8.45	79.82 ± 8.55	0.664
Post-procedure			
MLD, mm			
In-stent	2.96 ± 0.34	3.08 ± 0.33	0.004
In-edge	2.13 ± 0.26	2.18 ± 0.33	0.456
Diameter stenosis, %			
In-stent	11.68 ± 4.01	9.00 ± 4.81	0.003
In-edge	8.67 ± 0.94	8.56 ± 1.14	0.597
Follow-up at 1-year			
MLD, mm			
In-stent	2.76 ± 0.38	2.65 ± 0.60	0.003
In-edge	2.03 ± 0.37	2.01 ± 0.50	0.702
LLL, mm			
In-stent	0.20 ± 0.26	0.42 ± 0.48	0.001
In-edge	0.09 ± 0.26	0.17 ± 0.44	0.048
Diameter stenosis, %			
In-stent	19.68 ± 11.75	24.02 ± 20.94	0.028
In-edge	12.68 ± 11.83	14.54 ± 21.07	0.588
Binary restenosis, %	15 (10.0%)	28 (18.7%)	0.047
ISR	10 (6.7%)	23 (15.3.0%)	0.026
IER	5 (3.3%)	5 (3.3%)	1.000

Abbreviations: QCA, Quantitative angiography analysis; ΔD, proximal-distal diameter difference; IER, in-edge restenosis; ISR, in-stent restenosis; LLL, late lumen loss; MLD, minimal lumen diameter; RVD, reference vessel diameter.

4.2 Promising outcomes of modified stenting with single long stent for TCALs

Considering the inconsistent outcomes of overlapping stents and the limited availability of long tapered stents, most treatment of TCALs involve the use of the conventional tubular long stent. Theoretically, the expandability of conventional tubular stents has a maximum limit despite an open-cell design. Further dilation with larger balloons and higher pressure inevitably deforms the stent structure and disrupt the stent polymer, thereby leading to likely unfavorable outcomes [6–10, 44, 45]. Apart from the use of overlapping multiple stents or tapered stents, this dilemma remains unsolved.

In the present study, we used an MSS characterized by two key points: First was the selection of a larger stent based on the mean distal and proximal RVD instead of the distal RVD to obtain a larger expandable lumen and to more effectively adapt the tapered anatomy of TCALs without deformation the stent platform; The second key point was stepwise stent deploying by initially inflating with a low pressure of about 6 atm (much lower than the nominated pressure). This process was followed by reinflating with the nominated pressure or a higher one after pulling back the stent balloon by 1–2 mm to avoid distal edge dissection caused by deploying an oversized stent. As shown in our study, the stent selected using such a standard was larger than that using the conventional one. Our study further showed that the MSS achieved better clinical outcomes than OSMS, as evidenced by the lower rate of MACE at 1 year, less use of stents, and lower cost of treatment with similar rates of immediate angiographic success.

5. Limitations in our study

Several limitations of this work merit to be addressed. First, this study was a single- center case-control type with a relatively small sample size rather than a nonrandomized trial, which could limit the confirmatory conclusions. Second, only QCA data without other data of intravascular imaging (IVUS, OCT) or functional assessment (FFR) were available, so some relevant data may have been lost. Third, the mean difference of 0.8 mm between the proximal and distal vessel diameter can't represent absolutely typical TCALs in all cases. Fourth, the stent length was around 2 mm shorter in

Table 4. MACE and its individual components at follow-up.

	Modified (n = 150)	Standard (n = 150)	*P* values
MACE in hospital, n (%)	10 (6.7%)	12 (8.7%)	0.665
Non-Cardiac death, n (%)	0 (0.0%)	0 (0.0%)	1.000
Cardiac death, n (%)	0 (0.0%)	0 (0.0%)	1.000
Non-Q-wave MI, n (%)	10 (6.7%)	12 (8.7%)	0.665
Q-wave MI, n (%)	0 (0.0%)	0 (0.0%)	1.000
Stent thrombosis, n (%)	0 (0.0%)	0 (0.0%)	1.000
Urgent TLR/TVR, n (%)	0 (0.0%)	0 (0.0%)	1.000
In-stent TLR/TVR*	0 (0.0%)	0 (0.0%)	1.000
In-edge TLR/TVR*	0 (0.0%)	0 (0.0%)	1.000
In-segment TVR*	0 (0.0%)	0 (0.0%)	1.000
MACE at 1-year follow-up, n (%)	18 (12.0%)	34 (22.7.0%)	0.022
Non-cardiac death, n (%)	0 (0.0%)	0 (0.0%)	1.000
Cardiac death, n (%)	0 (0.0%)	0 (0.0%)	1.000
Non-Q-wave MI, n (%)	3 (2.0%)	6 (4.0%)	0.501
Q-wave MI, n (%)	0 (0.0%)	0 (0.0)	1.000
Stent thrombosis, n (%)	0 (0.0)	0 (0.0%)	1.000
TLR/TVR, n (%)	15 (10.0%)	28 (18.7%)	0.047
In-stent TLR/TVR*	10 (6.7%)	23 (15.3.0%)	0.026
In-edge TLR/TVR*	5 (3.3%)	5 (3.3%)	1.000

Abbreviations: MACE, major cardiac adverse events; TLR/TVR, target vessel/lesion revascularization.

Note: *, In-stent or in-edge revascularization was defined as TLR, in-segment revascularization as TVR.

MSS group than COS group, which might affect comparison of outcomes between groups. Fifth, potential confounders or selection bias that may have affected the outcomes cannot be completely ruled out despite the comparable baseline clinical and procedural characteristics between the groups after propensity score matching. Therefore, future large-scale randomized trials are warranted to validate our results.

6. Conclusions

Compared with the conventional overlapped stenting, the proposed MSS for the treatment of TCALs has similar angiographic success, fewer TLRs, and lower treatment cost.

Author contributions

DK—data collection and analysis, data interpretation, drafting manuscript, final critical revision of the manuscript and final approval. XH—data collection and analysis, data interpretation, drafting manuscript, final critical revision of the manuscript and final approval. CL—data collection and analysis, data interpretation. LC—designer of the study, data analysis, data interpretation, drafting manuscript, final critical revision of the manuscript and final approval.

Ethics approval and consent to participate

The Ethics Committee of Fujian Medical University Union Hospital approved this study. The approval number is 2021KY055. All patients gave written informed consent.

Acknowledgment

The authors thank the catheterization laboratory staff for their enthusiasm in supporting the study, also all the peer reviewers for their opinions and suggestions.

Funding

This work was supported by the National Natural Science Foundation of China (Grant No. 81670332); the National Natural Science Foundation of China (Grant No. 82020108015); Startup Fund for scientific research, Fujian Medical University (Grant No. 2019QH1078).

Conflict of interest

The authors declare no conflict of interest.

References

[1] Roach MR, MacLean NF. The importance of taper proximal and distal to Y-bifurcations in arteries. Frontiers of Medical and Biological Engineering. 1993; 5: 127–133.

[2] Zhang L, Xu D, Liu X, Wu X, Ying Y, Dong Z, *et al.* Coronary artery lumen diameter and bifurcation angle derived from CT coronary angiographic image in healthy people. Zhonghua Xin Xue Guan Bing Za Zhi. 2011; 39: 1117–1123. (In Chinese)

[3] Banka VS, Baker HA, Vemuri DN, Voci G, Maniet AR. Effectiveness of decremental diameter balloon catheters (tapered balloon). The American Journal of Cardiology. 1992; 69: 188–193.

[4] Timmins LH, Meyer CA, Moreno MR, Moore JE. Mechanical modeling of stents deployed in tapered arteries. Annals of Biomedical Engineering. 2008; 36: 2042–2050.

[5] 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. 2019; 15: 90–98.
[6] Foin N, Sen S, Allegria E, Petraco R, Nijjer S, Francis DP, *et al.* Maximal expansion capacity with current DES platforms: a critical factor for stent selection in the treatment of left main bifurcations? EuroIntervention. 2013; 8: 1315–1325.
[7] Basalus M, van Houwelingen K, Ankone M, Feijen J, von Birgelen C. Micro-computed tomographic assessment following extremely oversized partial postdilatation of drug-eluting stents. EuroIntervention. 2010; 6: 141–148.
[8] Guérin P, Pilet P, Finet G, Gouëffic Y, N'Guyen JM, Crochet D, *et al.* Drug-eluting stents in bifurcations: bench study of strut deformation and coating lesions. Circulation: Cardiovascular Interventions. 2010; 3: 120–126.
[9] He R, Zhao L, Silberschmidt VV, Liu Y. Mechanistic evaluation of long-term in-stent restenosis based on models of tissue damage and growth. Biomechanics and Modeling in Mechanobiology. 2020; 19: 1425–1446.
[10] He R, Zhao LG, Silberschmidt VV, Liu Y, Vogt F. Finite element evaluation of artery damage in deployment of polymeric stent with pre- and post-dilation. Biomechanics and Modeling in Mechanobiology. 2020; 19: 47–60.
[11] Chu WW, Kuchulakanti PK, Torguson R, Wang B, Clavijo LC, Suddath WO, *et al.* Impact of overlapping drug-eluting stents in patients undergoing percutaneous coronary intervention. Catheterization and Cardiovascular Interventions. 2006; 67: 595–599.
[12] Honda Y, Muramatsu T, Ito Y, Sakai T, Hirano K, Yamawaki M, *et al.* Impact of ultra-long second-generation drug-eluting stent implantation. Catheterization and Cardiovascular Interventions. 2016; 87: E44–E53.
[13] Kitabata H, Loh JP, Pendyala LK, Badr S, Dvir D, Barbash IM, *et al.* Safety and efficacy outcomes of overlapping second-generation everolimus-eluting stents versus first-generation drug-eluting stents. The American Journal of Cardiology. 2013; 112: 1093–1098.
[14] Claessen BE, Smits PC, Kereiakes DJ, Parise H, Fahy M, Kedhi E, *et al.* Impact of lesion length and vessel size on clinical outcomes after percutaneous coronary intervention with everolimus- versus paclitaxel-eluting stents pooled analysis from the SPIRIT (Clinical Evaluation of the XIENCE V Everolimus Eluting Coronary Stent System) and COMPARE (second-generation everolimus-eluting and paclitaxel-eluting stents in real-life practice) Randomized Trials. JACC: Cardiovascular Interventions. 2011; 4: 1209–1215.
[15] Naidu SS, Krucoff MW, Rutledge DR, Mao VW, Zhao W, Zheng Q, *et al.* Contemporary incidence and predictors of stent thrombosis and other major adverse cardiac events in the year after XIENCE V implantation: results from the 8,061-patient XIENCE V United States study. JACC: Cardiovascular Interventions. 2012; 5: 626–635.
[16] Waksman R, Kirtane AJ, Torguson R, Cohen DJ, Ryan T, Räber L, *et al.* Correlates and outcomes of late and very late drug-eluting stent thrombosis: results from DESERT (International Drug-Eluting Stent Event Registry of Thrombosis). JACC: Cardiovascular Interventions. 2014; 7: 1093–1102.
[17] Ullrich H, Münzel T, Gori T. Coronary Stent Thrombosis- Predictors and Prevention. Deutsches Ärzteblatt International. 2020; 117: 320–326.
[18] Jain RK, Chakravarthi P, Shetty R, Ramchandra P, Polavarapu RS, Wander GS, *et al.* One-year outcomes of a BioMime^{TM} Sirolimus-Eluting Coronary Stent System with a biodegradable polymer in all-comers coronary artery disease patients: the meriT-3 study. Indian Heart Journal. 2016; 68: 599–603.
[19] Podolec J, Niewiara Ł, Baran J, Pieniążek P, Żmudka K. First in Poland, unique 60-mm long single drug eluting tapered stent implantation in a patient with unstable angina. Kardiologia Polska. 2017; 75: 78.
[20] Valero E, Consuegra-Sánchez L, Miñana G, García-Blas S, Rodríguez J, Moyano P, *et al.* Initial experience with the novel BioMime^{TM} 60 mm-long sirolimus-eluting tapered stent system in long coronary lesions. EuroIntervention. 2018; 13: 1591–1594.
[21] Zivelonghi C, van Kuijk JP, Nijenhuis V, Poletti E, Suttorp MJ, van der Heyden JAS, *et al.* First report of the use of long-tapered sirolimus-eluting coronary stent for the treatment of chronic total occlusions with the hybrid algorithm. Catheterization and Cardiovascular Interventions. 2018; 92: E299–E307.
[22] Patted SV, Jain RK, Jiwani PA, Suryavanshi S, Raghu TR, Raveesh H, *et al.* Clinical Outcomes of Novel Long-Tapered Sirolimus-Eluting Coronary Stent System in Real-World Patients with Long Diffused De Novo Coronary Lesions. Cardiology Research. 2018; 9: 350–357.
[23] Podolec J, Skubera M, Niewiara Ł, Podolec M, Pieniążek P, Bartuś K, *et al.* Clinical experience with 12-month follow-up in patients after implantation of a novel long-tapered sirolimus drug-eluting stent. Postępy w Kardiologii Interwencyjnej. 2019; 15: 46–51.
[24] Thygesen K, Alpert JS, Jaffe AS, Chaitman BR, Bax JJ, Morrow DA, *et al.* Executive Group on behalf of the Joint European Society of Cardiology (ESC)/American College of Cardiology (ACC)/American Heart Association (AHA)/World Heart Federation (WHF) Task Force for the Universal Definition of Myocardial Infarction. Fourth Universal Definition of Myocardial Infarction. Circulation. 2018; 138: e618–e651.
[25] Mauri L, Hsieh W, Massaro JM, Ho KKL, D'Agostino R, Cutlip DE. Stent thrombosis in randomized clinical trials of drug-eluting stents. The New England Journal of Medicine. 2007; 356: 1020–1029.
[26] Jurado-Román A, Abellán-Huerta J, Requena JA, Sánchez-Pérez I, López-Lluva MT, Maseda-Uriza R, *et al.* Comparison of Clinical Outcomes Between Very Long Stents and Overlapping Stents for the Tretment of Diffuse Coronary Disease in Real Clinical Practice. Cardiovascular Revascularization Medicine. 2019; 20: 681–686.
[27] Park DW, Kim YH, Song HG, Ahn JM, Kim WJ, Lee JY, *et al.* Comparison of everolimus- and sirolimus-eluting stents in patients with long coronary artery lesions: a randomized LONG-DES-III (Percutaneous Treatment of LONG Native Coronary Lesions With Drug-Eluting Stent-III) Trial. JACC: Cardiovascular Interventions. 2011; 4: 1096–1103.
[28] Lee PH, Lee S, Yun S, Bae J, Ahn J, Park D, *et al.* Full Metal Jacket with Drug-Eluting Stents for Coronary Chronic Total Occlusion. JACC: Cardiovascular Interventions. 2017; 10: 1405–1412.
[29] Tan CK, Tin ZL, Arshad MKM, Loh JKK, Jafary FH, Ho HH, *et al.* Treatment with 48-mm everolimus-eluting stents: Procedural safety and 12-month patient outcome. Herz. 2019; 44: 419–424.
[30] Yue X, Guo J, Zhang J, Cao C, Zhang Z, Shen D, *et al.* Evaluation of Mechanical Performances of Stents with 38 mm Length in Long Lesion. BioMed Research International. 2020; 2020: 2594161.
[31] Haude M, Erbel R, Straub U, Dietz U, Schatz R, Meyer J. Coronary vessel stent implantation in patients with symptomatic dissections following balloon dilatation. Zeitschrift Fur Kardiologie. 1990; 79: 843–849. (In German)
[32] Kastrati A, Elezi S, Dirschinger J, Hadamitzky M, Neumann FJ, Schömig A. Influence of lesion length on restenosis after coronary stent placement. The American Journal of Cardiology. 1999; 83: 1617–1622.
[33] Kobayashi Y, De Gregorio J, Kobayashi N, Akiyama T, Reimers B, Finci L, *et al.* Stented segment length as an independent predictor of restenosis. Journal of the American College of Cardiology. 1999; 34: 651–659.
[34] Serruys PW, Foley DP, Suttorp MJ, Rensing BJWM, Suryapranata H, Materne P, *et al.* A randomized comparison of the value of additional stenting after optimal balloon angioplasty for long coronary lesions: final results of the additional value of NIR stents for treatment of long coronary lesions (ADVANCE) study. Journal of the American College of Cardiology. 2002; 39: 393–399.
[35] Moses JW, Leon MB, Popma JJ, Fitzgerald PJ, Holmes DR, O'Shaughnessy C, *et al.* Sirolimus-eluting stents versus standard stents in patients with stenosis in a native coronary artery. The

New England Journal of Medicine. 2003; 349: 1315–1323.
[36] Schofer J, Schlüter M, Gershlick AH, Wijns W, Garcia E, Schampaert E, *et al.* Sirolimus-eluting stents for treatment of patients with long atherosclerotic lesions in small coronary arteries: double-blind, randomised controlled trial (E-SIRIUS). The Lancet. 2003; 362: 1093–1099.
[37] Aoki J, Ong AT, Rodriguez Granillo GA, McFadden EP, van Mieghem CA, Valgimigli M, *et al.* "Full metal jacket" (stented length > or = 64 mm) using drug-eluting stents for de novo coronary artery lesions. American Heart Journal. 2005; 150: 994–999.
[38] Tsagalou E, Chieffo A, Iakovou I, Ge L, Sangiorgi GM, Corvaja N, *et al.* Multiple Overlapping Drug-Eluting Stents to Treat Diffuse Disease of the Left Anterior Descending Coronary Artery. Journal of the American College of Cardiology. 2005; 45: 1570–1573.
[39] Degertekin M, Arampatzis CA, Lemos PA, Saia F, Hoye A, Daemen J, *et al.* Very long sirolimus-eluting stent implantation for de novo coronary lesions. The American Journal of Cardiology. 2004; 93: 826–829.
[40] Kereiakes DJ, Wang H, Popma JJ, Kuntz RE, Donohoe DJ, Schofer J, *et al.* Periprocedural and late consequences of overlapping Cypher sirolimus-eluting stents: pooled analysis of five clinical trials. Journal of the American College of Cardiology. 2006; 48: 21–31.
[41] Räber L, Jüni P, Löffel L, Wandel S, Cook S, Wenaweser P, *et al.* Impact of stent overlap on angiographic and long-term clinical outcome in patients undergoing drug-eluting stent implantation. Journal of the American College of Cardiology. 2010; 55: 1178–1188.
[42] Finn AV, Nakazawa G, Joner M, Kolodgie FD, Mont EK, Gold HK, *et al.* Vascular responses to drug eluting stents: importance of delayed healing. Arteriosclerosis, Thrombosis, and Vascular Biology. 2007; 27: 1500–1510.
[43] Finn AV, Kolodgie FD, Harnek J, Guerrero LJ, Acampado E, Tefera K, *et al.* Differential response of delayed healing and persistent inflammation at sites of overlapping sirolimus- or paclitaxel-eluting stents. Circulation. 2005; 112: 270–278.
[44] Ng J, Foin N, Ang HY, Fam JM, Sen S, Nijjer S, *et al.* Overexpansion capacity and stent design model: an update with contemporary DES platforms. International Journal of Cardiology. 2016; 221: 171–179.
[45] Chen S. Rethinking overdilation of drug-eluting stents: an effective "loose end". EuroIntervention. 2013; 8: 1235–1239.