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

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Tapered coronary artery lesions (TCALs) are often seen clinically, optimal stenting of TCALs remains challenging. 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 505 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 ± 0.34 versus 3.08 ± 0.33, P = 0.004) was smaller and diameter stenosis (11.7 ± 4.0% versus 9.0 ± 4.8%, P = 0.003) was higher in MSS group than COS group. At 1-year follow-up, in-stent MLD (2.76 ± 0.38 mm versus 2.65 ± 0.60 mm, P = 0.003) was reduced, LLL (0.20 ± 0.26 mm versus 0.42 ± 0.48 mm, P = 0.001), diameter stenosis (24.02 ± 20.94% versus 19.68 ± 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 ≥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 data, (4) severe renal insufficiency (eGFR <30 mL/min), (5) hematopoietic disorders (platelet count <100 × 10^9/L or >700 × 10^9/L, leukocyte count <3 × 10^9/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 undergone 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), Then the 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 non-compliant 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. Intra-procedural 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 (%) | 81 (54.0%)     | 74 (49.3%)         | 0.488    |
| Stable angina pectoris   | 51 (34.0%)         | 47 (31.3%)         | 0.0712   |
| Unstable angina pectoris | 18 (12.0%)         | 25 (16.7%)         | 0.323    |
| NSTEMI                   | 150 (100%)         | 150 (100%)         | 1.000    |
| Antiplatelet therapy, n (%) | 5 (3.3%)         | 5 (3.3%)           | 1.000    |

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

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.

| Lesion locations, n (%) | Modified (n = 150) | Standard (n = 150) | P values |
|-------------------------|--------------------|--------------------|----------|
| 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    |
| ∆D                      | 0.83 ± 0.12        | 0.86 ± 0.14        | 0.333    |
| Diameter stenosis percentage, % |
| Calcified lesion, n (%) | 6 (4.0%)           | 6 (4.0%)           | 1.000    |
| Chronic total occlusion, n (%) |
| 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: ∆D, 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    |
| ∆D               | 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,%| 11.68 ± 4.01       | 9.00 ± 4.81        | 0.003    |
| In-stent         | 8.67 ± 0.94        | 8.56 ± 1.14        | 0.597    |
| In-edge          |                    |                    |          |
| **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,%| 19.68 ± 11.75      | 24.02 ± 20.94      | 0.028    |
| In-stent         | 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%)         | 0.026    |
| IER              | 5 (3.3%)           | 5 (3.3%)           | 1.000    |

Abbreviations: QCA, Quantitative angiography analysis; ∆D, 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%) | 0.022   |
| 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%)        | 0.026   |
| 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.

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Conflict of interest
The authors declare no conflict of interest.

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