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Original article

# Eccentric morphology of jailed side-branch ostium after stent crossover in coronary bifurcation lesions: A three-dimensional optical coherence tomographic analysis

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ABSTRACT

*Background:* Angiographic stenosis of a jailed side-branch ostium is usually observed after a single-stent crossover at coronary bifurcation lesions. However, the stenosis severity is typically overestimated due to the limited information obtained from two-dimensional morphology by angiography. We evaluated the actual stenosis of jailed side-branch ostium using three-dimensional (3D) optical coherence tomography (OCT).
*Methods:* Using 3D reconstructions of OCT data, we analyzed minimal lumen area (MLA) and eccentricity of the jailed side-branch ostium in 41 patients who were treated with single stent crossover at coronary bifurcation lesions and subsequently underwent serial OCT follow-up.
*Results:* The MLA of jailed side-branch ostium calculated from quantitative coronary angiography (QCA) assuming a circular lumen markedly decreased after stent implantation ($1.73 \pm 1.22$ mm$^2$ pre-intervention to $0.84 \pm 0.91$ mm$^2$ post-intervention, $p < 0.001$). However, the MLA of jailed side-branch ostium measured at post-intervention by 3D-OCT ($2.67 \pm 1.75$ mm$^2$) was significantly larger than that measured by QCA ($p < 0.001$). There were no statistically significant changes in MLA of jailed side-branch ostium based on 3D-OCT measurements during the follow-up ($2.35 \pm 1.50$ mm$^2$ at 3–6 months post-intervention; $2.44 \pm 1.27$ mm$^2$ at 1–2 years post-intervention, $p = 0.098$). The shapes of the jailed side-branch ostium were nearly elliptical (mean eccentricity index: $2.97 \pm 1.27$ post-intervention; $2.79 \pm 1.17$ at 3–6 months post-intervention; $2.59 \pm 1.02$ at 1–2 years post-intervention).
*Conclusions:* Compared to 3D-OCT measurements, QCA measurements overestimated the jailed side-branch ostial stenosis after single stent crossover due to eccentric morphology from orthogonal projection in coronary angiography. Significant changes in the MLA of jailed side-branch ostium by 3D-OCT were not observed during the follow-up.


## Introduction

Coronary bifurcation lesions remain a therapeutic challenge to percutaneous coronary intervention due to high complication and restenosis rates, particularly at the side-branch ostium [1,2]. Simple stent implantation across the side-branch has been preferred to treat bifurcation lesions because the double-stenting technique in both the main vessel and side-branch resulted in higher rates of complications and poor clinical outcomes [3–5]. However, in bifurcation lesions treated with simple single-stent implantation, jailed side-branch ostial stenosis is frequently observed in coronary angiography and compromised side-branches are a serious concern after single-stent implantation across the large-sized side-branch. However, a previous study that used pressure wire reported that jailed side-branch stenosis in angiographic evaluation was not always functionally impaired [6]. Coronary angiography typically overestimates the severity of side-branch ostial stenosis in most lesions treated with single-stent implantation

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of the main vessel across the side-branch [7], and most jailed side-branch lesions do not have functionally significant stenosis [8,9]. The purpose of this study was to determine the reason for discrepancies between angiographic stenosis and actual stenosis after single crossover stent implantation at coronary bifurcation lesions. Therefore, we evaluated the morphological features and the area of the jailed side-branch ostium using three-dimensional (3D) optical coherence tomography (OCT).

## Materials and methods

### *Study patients*

From January 2011 to November 2013, non-consecutive patients who underwent single-stent crossover at coronary bifurcation lesions and three serial OCT examinations (post-intervention, 3–6 month follow-up, and 1–2 year follow-up) were retrospectively enrolled from the OCT registry database of our institute. Additional inclusion criteria were: 1) A side-branch ostium with a minimum lumen diameter $\geq$2 mm and lesion length $<$10 mm by visual estimation, and 2) thrombolysis in myocardial infarction flow grade 3 in the side-branch after stent implantation into the main vessel. Patients who had angiographically visible thrombi or a history of any previous intervention at the side-branch before OCT examination were excluded. A total of 50 patients were enrolled during the study period; however, nine patients were excluded due to poor image quality or wire artifacts of the 3D-OCT images. Thus, a total of 41 lesions in 41 patients were available for final analysis. Among 41 lesions, 4 lesions were true bifurcation (medina classification: 1.0.1, 0.1.1). A second guide wire was used for protecting side-branch in 4 lesions, but none of the lesions underwent kissing balloon inflation. This study protocol was approved by the Institutional Review Board of our institution, and adhered to the Declaration of Helsinki. All patients provided written informed consent. Coronary stent implantation of the bifurcation lesions with drug-eluting stents was performed using conventional techniques and a single-stent crossover strategy. Unfractionated heparin was administered at an initial bolus of 100 IU/kg, with additional boluses administered during the procedure to achieve an activated clotting time of 250–300 s. Dual anti-platelet therapy (aspirin and clopidogrel) was recommended to all patients for $>$12 months after drug-eluting stent implantation.

### *Quantitative angiography analyses*

Quantitative coronary angiography (QCA) analyses were performed by a single expert analyst in an independent core laboratory (Cardiovascular Research Center, Seoul, Korea) using an offline computerized QCA system (CASS system, Pie Medical Imaging, Maastricht, Netherlands). Quantitative angiographic parameters in the side-branch were measured before and after single-stent crossover; reference vessel diameter, minimal lumen diameter (MLD), and percent diameter stenosis were measured. The minimal lumen area (MLA) of side-branch ostium by QCA (MLA-QCA) was calculated using the equation $\pi \times (\text{MLD}/2)^2$ based on the assumption that the lumen of the side-branch ostium is circular. The assumption for calculating MLA from QCA is classic but instinctively acceptable and has been employed in previous studies [10–12].

### *OCT procedure, 3D-OCT reconstruction, and analyses*

OCT imaging of the main vessel was serially performed three times (immediately post-intervention, 3–6 months post-intervention, and 1–2 year post-intervention) in all patients using a frequency-domain OCT system (C7-XR OCT Imaging System, LightLab Imaging, Inc., St. Jude Medical, St. Paul, MN, USA). In this study, OCT cross-sectional images were generated at a rate of 100 frames/s while the fiber optic probe was withdrawn at a speed of 20 mm/s within the stationary protective sheath. All OCT images were analyzed at a core laboratory (Cardiovascular Research Center) by analysts who were blinded to patient and procedural information.

Because of limitations in understanding and assessing the 3D geometry of the side-branch ostium with direct side-branch imaging after main vessel stent implantation, we evaluated the jailed side-branch ostium from images obtained during OCT imaging of the stented segment of the main vessel rather than directly during OCT imaging of the side-branch through the main vessel stent struts. The cross-sectional OCT images were processed using the free software Image Processing and Analysis in Java (Image J) [13] and then imported into a 3D volume-rendering program (OsiriX 3.9.4, The OsiriX Foundation, Geneva, Switzerland) [14]. Next, 3D images around the bifurcation lesion of the main vessel, including the side-branch ostium, were reconstructed (Fig. 1C,D). The cross-sectional image of side-branch ostium perpendicular to the expected blood flow direction was selected and the MLA (MLA-OCT) was measured using the multi-planar reconstruction viewer supported in the OsiriX volume-rendering program (Fig. 1E,F). Minimal and maximal diameters of the side-branch ostium were measured to calculate the eccentricity index (maximal diameter/minimal diameter). The degree of eccentricity indexes of side-branch ostia were defined as group 1 (1.0–1.5), group 2 (1.5–2.5), group 3 (2.5–3.5), group 4 (3.5–4.5), and group 5 (4.5–5.5). Additionally, we analyzed the shape of side-branch ostium.

### *Statistical analyses*

Statistical analyses were performed using the GraphPad Prism for Windows version 5.01 (GraphPad Software, San Diego, CA, USA). Comparisons between groups were analyzed using Student's *t*-tests, paired *t*-tests, or repeated analyses of variance (ANOVA) with Bonferroni's post hoc tests. Correlations between the post-intervention MLA-OCT and the pre- or post-intervention MLA-QCA were analyzed using Spearman's correlation coefficient. A *p*-value of $<$0.05 was considered statistically significant. All values are expressed as the mean $\pm$ standard deviation (SD) for continuous variables or as the number and percentage for categorical variables.

## Results

The baseline clinical and angiographic characteristics of 41 patients with 41 bifurcation lesions are summarized in Tables 1 and 2, respectively. There was a significant positive correlation between post-intervention MLA-OCT with post-intervention MLA-QCA ($r = 0.78$, $p < 0.001$; Fig. 2A) and pre-intervention MLA-QCA ($r = 0.83$, $p < 0.001$; Fig. 2B). The MLA-QCA significantly decreased from $1.73 \pm 1.22$ mm$^2$ pre-intervention to $0.84 \pm 0.91$ mm$^2$ post-intervention (average percent change: $-54.0\%$, $p < 0.001$; Fig. 3). However, the post-intervention MLA-OCT ($2.67 \pm 1.75$ mm$^2$) was significantly greater than the post- or pre-intervention MLA-QCA ($p < 0.001$, respectively). There were no statistically significant changes in MLA-OCT during the follow-up ($2.35 \pm 1.50$ mm$^2$ at 3–6 months post-intervention; $2.44 \pm 1.27$ mm$^2$ at 1–2 years post-intervention, $p = 0.098$; Fig. 3). Fig. 4 shows the eccentricity index and the shape of the jailed side-branch ostium that were evaluated with 3D-OCT after single-stent implantation in the main vessel. The mean eccentricity indices were $2.97 \pm 1.27$ post-intervention, $2.79 \pm 1.17$ at 3–6 months post-intervention, and