CT findings of bifurcation stent in phantom and patients: validation with micro CT

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Aims and objectives

Percutaneous coronary intervention for coronary bifurcation lesions has been associated with lower procedural success rates and worse clinical outcome compared with nonbifurcation lesions in the bare stent era (1). However, after the introduction of drug-eluting stents, extremely low rates of in-stent restenosis have been observed (2). Following several randomized controlled studies have indicated that coronary bifurcation lesions may be optimally treated using the optional side branch stenting strategy and the clinical outcomes after simple optional side branch stenting remained at least equal to the more complex strategy of planned stenting of both the main vessel and the side branch (3-7).

There are various techniques for bifurcation lesions and Crush or Culotte stenting are widely accepted techniques (8). Crush or Culotte stenting theoretically provides full scaffolding of the side branch (SB) ostium, but these approaches are associated with greater strut malapposition and higher rates of target lesion revascularization and myocardial infarction than provisional stenting (9). Studies including intravascular ultrasound assessment and in vitro bench deployment using micro computed tomography (CT) imaging have shown post-bifurcation stent morphology (9-12). Unfortunately, identifying post-stenting morphology using noninvasive modality has not been studied.

Coronary CT angiography has been reported to show promising results in luminal patency and stent fracture (13-15). Lim and colleagues found that coronary CT angiography depicts stent fractures in patients and phantoms, even those fractures that are not clearly depicted by conventional angiography (15). Based on the idea that CT angiography could demonstrate mechanical changes in stents, we hypothesized that post-bifurcation stent morphology evaluation could be possible on coronary CT angiography. Accordingly, we designed we designed out study to analyze post-bifurcation stent morphology in vitro on dual-source CT and validate those findings using micro-CT.
Methods and materials

Phantom Preparation

A silicon coronary artery phantom simulating main branch (MB) and side branch (SB) was prepared using a 3-D printer (Projet 3510 SD). An angle between MB and SB was 45 degree and wall thickness of the phantom was 1 mm. The MB diameter was 4.5 mm tapering to 3.5 mm and the SB diameter was 3.0 mm. Bifurcation stenting was performed by an experienced interventional cardiologist (Y.H.K, 8 years of experience) using a drug eluting stent (Sience Prime, Abbott). Crush, Cullotte, and T-stenting technique with final kissing balloon dilatation were performed in 4, 3 and 2 phantoms, respectively.

CT Imaging - Phantom

Total of 9 deployed phantoms were imaged using both micro-CT (SkyScan 1172, Bruker, Belgium, acquisition time 40 min, FOV 50 mm, spatial resolution <1µm) and second generation dual-source CT scanner (Somatom definition; Siemens Medical Solution, Forchheim, Germany). The micro-CT images were reconstructed with 27-um slice image and exported to the off line software (CTAn, Meshlab). Clinical CT images were reconstructed with OO-mm slice image and exported to the off line software (Syngovia). analyzed using CTAn (Bruker, Belgium) and MeshLab (freeware), and conventional CT images were analyzed using Syngovia (Siemens Medical Solutions, Erlangen, Germany).

CT Analysis

Parameters including crushed segment, floating strut, the location of the crushed segment, unintended gap and overlapped segment were defined in our study (figure 1). The definition of crushed segment was overlapping of the two layers of crushed SB stent struts in addition to a layer of MB struts on micro-CT (figure 2). Floating strut was defined as a malapposed and protruded strut into the lumen causing luminal narrowing (figure 2). The location of crushed segment was divided to two types; the angle between the center of MB and crushed segment from -45 degree to 45 degree defined as central and otherwise eccentric. When the center of crushed segment lined up straight with the SB stent it was classified as central and other than central, it was classified as eccentric (Figure 3). Unintended gap was defined as absence of stent strut between the MB and SB stent (Figure 4). In phantoms of Culotte stenting, additional parameter including overlapped segment was applied and its definition was circumferential overlapping of one layer of MB strut and one layer of SB strut.

Several parameters were measured in both micro-CT and dual source CT (figure 1). The length and perimeter of crushed segment, the minimal luminal area at the level of crushed segment, and SB ostium were measured. In phantoms with floating struts, the length of
floating strut and the minimal luminal area in MB and SB was measured. Additionally, the area of SB at non-crushed segment 1-cm distal to SB ostium was measured. In phantoms of Culotte stenting, the longest length and perimeter of overlapped segment, and the minimal luminal area at the level of overlapped segment were measured. The location of crushed segment, the presence of floating strut and unintended gap were compared between micro-CT and dual source CT. All CT image analyses were performed in a blinded manner by two independent observers.

**Statistical analysis**

Continuous variables were expressed as mean ± standard deviation, and categorical data were presented as percentages. To evaluate the agreement of measured parameters between micro-CT and dual source CT, Bland-altman plot was used. A statistical software package (MedCalc Software, Mariakerke, Belgium) was used to analyze the data.
**Fig. 1:** A. crushed segment, B. minimal luminal area at the level of crushed segment, C. side branch ostium, D. floating strut, E. minimal luminal area at side branch due to floating strut, F. minimal luminal area at main branch due to floating strut, G. side branch lumen

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**Fig. 2:** Crushed segment (arrow) and floating strut (arrowhead) on dual source CT and micro-CT.

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Fig. 3: Central location of crushed segment (arrows) and floating strut (arrowheads) causing luminal narrowing.

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**Fig. 4:** Unintended gap between the main branch and side branch stent.

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Results

Phantom

Crushed segment appeared as denser and thicker than non-crushed segment on dual source CT at the junction of MB and SB stent on either side (figure 2). Floating strut appeared as protruding of the stent on dual source CT (figure 2).

The classification of the location of crushed segment, presence of floating strut and unintended gap matched between micro-CT and dual source CT. Among 9 stents, 8 (89%) were central type, 4 (44%) had floating strut and 2 (22%) showed unintended gap.

Parameters measured in both micro-CT and dual source CT showed good correlation. According to the Bland-Altman plots of agreement, the length and perimeter of crushed segment and overlapped segment on dual source CT showed high agreement with micro CT (95% limits of Agreement = -3.2 to 3.8 mm; 95% CI = -0.74 to 1.32; 95% limits of Agreement = -2.5 to 3.6 mm; 95% CI = -0.50 to 1.57) (figure 5). Also, the minimal luminal area at the level of crushed segment, floating strut and overlapped segment, SB ostium, and non-crushed SB segment on dual source CT showed high agreement with micro CT (95% limits of Agreement = -1.5 to 1.6 mm; 95% CI = -0.22 to 0.26) (figure 5).
Fig. 5: A., B. Bland-Altman plot of the length and perimeter of crushed segment and overlapped segment between dual source CT and micro CT, C. Bland-Altman plot and scatter plot of the minimal luminal area at the level of crushed segment, floating strut and overlapped segment, side branch ostium, and non-crushed side branch segment between dual source CT and micro CT.

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Conclusion

The major findings of the study were 1) post-bifurcation stent morphology could be demonstrated on dual source CT which correlated well with micro-CT findings 2) Unexpected findings such as floating strut (44%), unintended gap (22%) and the eccentric location (11%) of crushed segment was observed in post-bifurcation stents. Several bench studies have demonstrated post-bifurcation stent morphology including crushed struts, jailed SB ostium, or gaps in stent coverage using micro-CT (16-18). Also, intravascular ultrasound and optical computed tomography have been widely used to visualize morphological characteristics of stent struts (19,20).

General idea of optional SB stenting has been proved to show not much benefit compared to provisional SB stenting in randomized controlled studies (3-5,7). The limitation of these studies is that the effect of post-bifurcation stent morphology on patient outcome has not been evaluated. Future study evaluating the significance of post-bifurcation morphological changes in correlation with clinical prognosis might be done and the findings of our study might be put into practice. Regarding the outcome, computational fluid dynamic simulations to evaluate flow-related processes leading to in-stent restenosis are being conducted (21,22). Further study on post-bifurcation stent morphology and local hemodynamic changes could be helpful in understanding the clinical impact of post-bifurcation stent morphology.

Clinical significance of morphological changes of the post-bifurcation stent is yet unclear, but characteristic such as the length and location of crushed segment, the presence of floating strut or unintended gap might potentially affect patient outcome. As shown in our study, coronary CT angiography could be useful in not only evaluating luminal patency but also morphological changes that could be potentially related to adverse clinical outcome after percutaneous coronary intervention. Also, patients showing unfavorable post-bifurcation stent morphology on coronary CT angiography could be more closely observed than the others to prevent undesirable events. However, current appropriate use criteria for cardiac CT does not include patient after percutaneous coronary intervention (23).

Several limitations of our study should be mentioned. 1) Even though we tried to simulate coronary bifurcation lesion, the silicone tube was not an anthropomorphic cardiac phantom and the phantom did not have features of atherosclerosis. It could have influenced the stent deployment. Also when the calcified plaque sets in plaque shifting phenomenon could take place and moreover it could be difficult to separate crushed segment or floating strut from calcified plaque. 2) We did not use intraluminal iodine contrast agent unlike coronary CT angiography. However, by applying the appropriate window width and center, this setting would not hinder the interpretation of the images in practice. 3) The number of phantoms was small.
In conclusion, the morphology of the post-bifurcation stent on dual source CT correlated well with that of micro-CT in the coronary artery phantom. Coronary CT angiography may be a feasible method for the evaluation of stent morphology in patients who underwent bifurcation stenting.
References


