Cardiac Imaging

Three-Dimensional Coronary Tomographic Reconstructions Using *In Vivo* Intracoronary Optical Frequency Domain Imaging in the Setting of Acute Myocardial Infarction: The Clinical Perspective

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Optical coherence tomography (OCT) is a light-based imaging modality with superior spatial resolution (~15 μm) compared to other intracoronary imaging systems currently used *in vivo*, such as intravascular ultrasonography (~100 μm) and angioscopy (~150 μm). OCT technology uses a similar algorithm as intravascular ultrasound (IVUS) to reconstruct two-dimensional (2-D) tomographic images, measuring the time delay of the reflected infrared light beam from the biological tissues. The earlier time-domain OCT technology has been replaced by frequency-domain OCT (FD-OCT); more recently, optical frequency domain imaging (OFDI), a variant of FD-OCT, has been introduced. OFDI is an intravascular imaging modality that is capable of obtaining higher frame rates (up to 160/s) and pull-back speeds (up to 40 mm/s). It is these technical components that define the resolution of 3-D tomographic reconstructions from the 2-D post-processed images.

The major contributions of 2D FD-OCT technology in conventional clinical practice are the following: 1) characterization of the initial stages of atherosclerosis (pathological intimal thickening) and plaque composition (fibrous, fibrofatty, calcific); 2) evaluation of cap thickness (thin cap vs. thick cap fibroatheroma); 3) visualization of plaque complications (erosion, ulceration, rupture); 4) identification of thrombus; and 5) evaluation of stent implantation post intervention (strut apposition, edge dissection, tissue prolapse) and at follow up (strut coverage, late acquired malapposition, in-segment restenosis).

3-D OFDI reconstructions from their respective 2-D images were first described by Tearney et al[1] for the visualization of metallic stents; more recently Okamura et al[2] demonstrated the potential for this technology in the evaluation of jailed side-branches associated with implantation of a bioresorbable vascular scaffold. Subsequent reports have described the potential use of this technology in the setting of acute coronary syndromes.[3] In brief, the major imaging findings that may enhance the decision making process during interventional procedures and confirm the need of a real-time application of this technology are the following: 1) assessment of the flow divider and high resolution visualization of the spatial-distribution of the stent struts covering the side

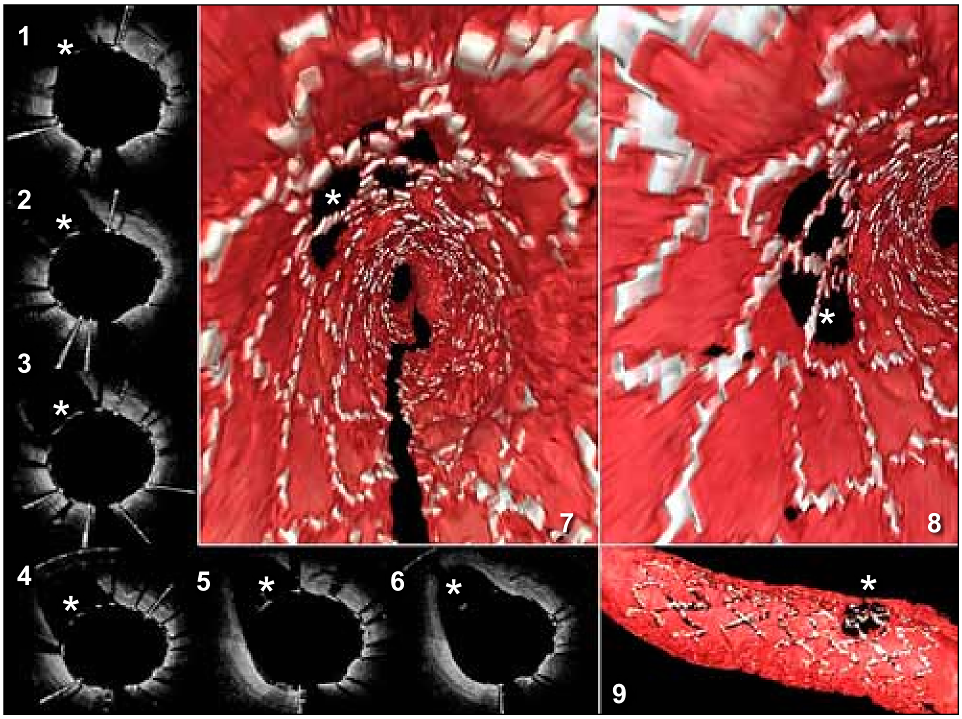

Figure 1. Three-dimensional reconstruction of a jailed side branch.
Three-dimensional post processed reconstruction, demonstrating the jailing of the side branch - a large diagonal branch - after implantation of a Biolimus-A9 eluting stent, in fly-through (Panels 7, 8) and longitudinal views (Panel 9). Two-dimensional optical coherence tomography (OCT) frames (Panels 1, 2, 3, 4, 5, 6) illustrate the region of interest (white asterisks).
The OCT pullback was performed with the TERUMO (Terumo, Corporation, Tokyo, Japan) imaging system. *: Side branch jailing

branch, after main-branch stenting[4] (Figure 1); 2) assessment of pre/peri-procedural thrombus formation (Figure 2); and 3) evaluation of the stent strut apposition/malapposition (Figure 3).

Bifurcation stenting is a challenging subset of coronary interventions with less satisfactory clinical outcomes compared to the management of simple lesions.[5] In the setting of side-branch jailing, recent evidence from benchwork studies suggests the crossing and post-dilatation of the distal cells of the implanted device to clear the struts in the jailed side-branch orifice. Real-time 3-D OCT clinical application appears

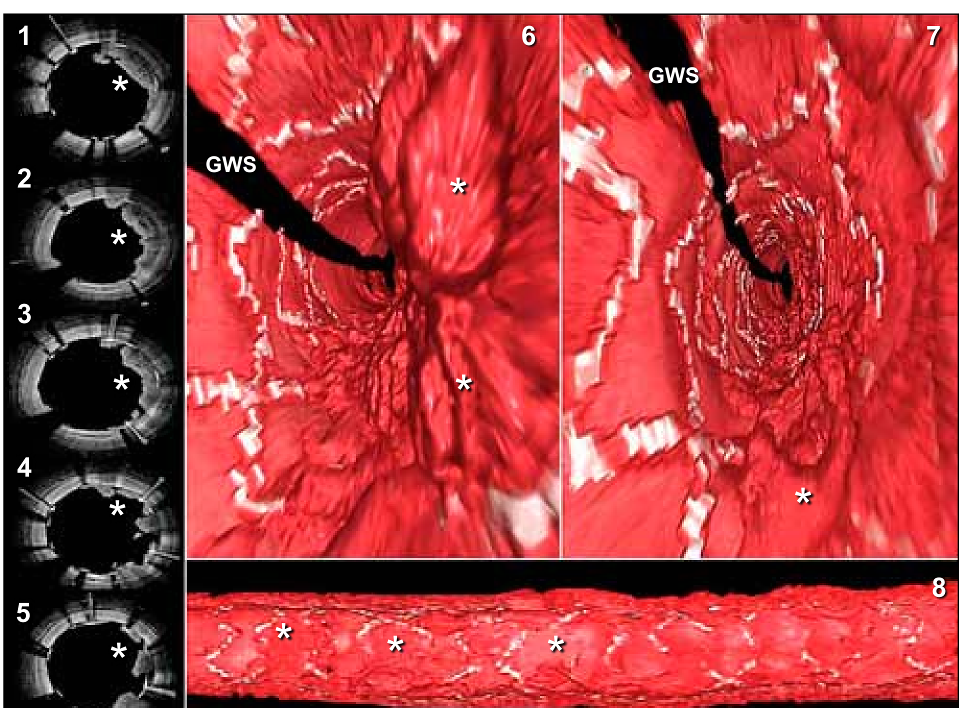

Figure 2. Three-dimensional reconstruction of thrombus.
Three-dimensional post processed reconstruction, demonstrating the thrombus burden covering the metallic struts of an implanted Biolimus-A9 eluting stent, in fly-through (Panels 6, 7) and longitudinal views (Panel 8). The two-dimensional optical coherence tomography (OCT) still frames (Panels 1, 2, 3, 4, 5) illustrate the region of interest (white asterisks).
The OCT pullback was performed with the TERUMO (Terumo, Corporation, Tokyo, Japan) imaging system.
GWS – guide wire shadow.
*: Thrombus

to have the potential to accurately guide the interventional cardiologist in performing distal cell post-dilatation and restoring the optimal TIMI flow that may influence the patient's clinical outcome.

The evaluation of pre/periprocedural thrombus formation in the setting of acute coronary syndromes is a clinical subset where real-time 3-D OFDI may appear helpful. Real-time 3-D visualization and quantification of thrombus to guide further aspiration thrombectomy may have a future potential role; aspiration thrombectomy has been shown to improve angiographic TIMI flow, myocardial perfusion and subsequent blush score, and has been associated with a possible reduction in the incidence of major adverse cardiac events.[6,7] Gonzalo et al recently demonstrated the potential of the fusion of tissue characterization with 3-D OFDI technology.[8] Further improvements are required for precise tissue component quantification, as is currently done using IVUS virtual histology (VH); fusion of 2D FD-OCT with IVUS-VH has also recently been shown to be feasible.[9] The potential clinical benefit of fusion imaging will be to accurately visualize plaque components during stent implantation in order to allow full coverage of the lesion. This concept, however, remains unproven, though tissue composition has been shown to be directly related to stent healing, thrombosis and tissue protrusion.

Stent malapposition, either post-intervention or as a late acquired phenomenon, has been incriminated in the pathophysiology of several mechanisms of stent thrombosis. Stent thrombosis has an incidence rate of 0.5-2% and is associated with a high mortality (approximately 45%).

2-D OFDI is currently the imaging modality of choice to visualize incomplete stent apposition. 3-D visualization of the malapposed struts with identification of the underlying mechanism (e.g. underlying thrombus, calcified plaque) may potentially add further to the clinical management of such cases. Conversely, IVUS is unable to visualize thrombus, with the detection of incomplete stent apposition being made on the grounds of an educated guess.

3-D off-line post-processed vascular tomographic reconstructions are for the moment time consuming, as they have to be performed manually. Off-line bitmap sequences are generated from prior 2-D OFDI imaging, each strut is manually detected in each cross section and specific volume rendering software is used for reconstruction with operator-dependent output. Automated strut identification and volume rendering to generate real-time OCT in the catheterization laboratory will potentially allow for immediate 3-D constructions that will guide the operator to the area of interest, where further scrutiny can be undertaken with 2-D imaging.

With the advent of high resolution intravascular

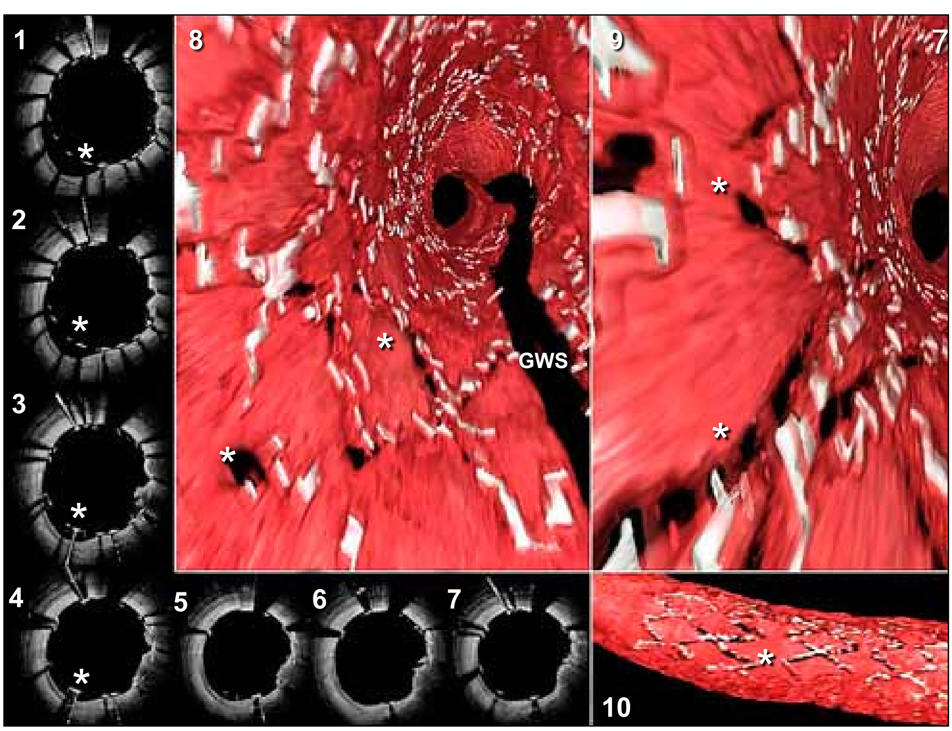

Figure 3. Three-dimensional reconstruction of incomplete stent apposition.
Three-dimensional post processed reconstructions, demonstrating the incomplete apposition (ISA) of the Biolimus-A9 eluting stent in fly-through (Panels 8, 9) and longitudinal views (Panel 10). Malapposed struts are systematically accompanied by a thin wall shadow. The two-dimensional optical coherence tomography (OCT) still frames (Panels 1, 2, 3, 4, 5, 6, 7) illustrate the region of interest (white asterisks).
The OCT pullback was performed with the TERUMO (Terumo, Corporation, Tokyo, Japan) imaging system.
GWS – guide wire shadow.
*: ISA

imaging, the treatment of coronary artery disease has changed, as we understand more about the anatomy, the physiology and the behavior of the treated lesions.

Real time 3-D post-processed OFDI appears to have the potential to guide percutaneous coronary intervention, and the application of this technology in the catheterization laboratory is eagerly expected from the industry. Images with better than the existing resolution (Figures 1, 2, 3) are expected, as the development of 2-D OFDI with faster pullback and frame rates is under intense research. Further development and innovation in this field is required for the patient's clinical benefit.

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