How Do OCT and IVUS Differ?

A comparison and assessment of these modern imaging modalities.

BY JOSHUA WAGGONER, MD, AND MARC D. FELDMAN, MD, FACC, FSCAI

Optical coherence tomography (OCT) is a new, light-based, intravascular imaging technique that provides high-resolution, cross-sectional images of coronary artery anatomy. OCT image acquisition is analogous to intravascular ultrasound (IVUS), except it uses near-infrared light instead of ultrasound. This use of light gives OCT an approximate 10-fold higher resolution than IVUS (10–15 µm compared to 100–150 µm), allowing for increased ability to visualize vessel wall anatomy, characterize plaque, and assist with short- and long-term follow-up of coronary interventions.

Recent advances in OCT technology have allowed faster image acquisition, precluding the need for proximal balloon occlusion and making it easier and safer to use. This ease in acquisition has led many to believe that OCT will replace IVUS as the gold standard for intravascular imaging. However, OCT remains inferior to IVUS in regard to its depth of penetration (1.5 mm compared to 5 mm), which limits its ability to assess plaque burden and vessel remodeling, and in its inability to image ostial disease (eg, unable to clear blood in the ostium). This article focuses on the different uses of OCT and its advantages and limitations compared to IVUS.

PLAQUE CHARACTERIZATION

Arterial Morphology

OCT has proven to be a powerful tool in visualizing coronary anatomy. Due to its superior resolution, OCT has the ability to identify pathology that could be missed by IVUS. For example, intimal thickening is an early phase of atherosclerosis and provides important prognostic information.[1-6] IVUS imaging can only indirectly measure intimal thickness due to its inability to identify the internal elastic lamina and, therefore, the intima media border.[7] OCT is more accurate in measuring intima media thickness than IVUS and can visualize intimal thickness, intimal hyperplasia, and the internal and external elastic lamina.[8,9] However, in the presence of heavy plaque burden, OCT lacks the depth of penetration to visualize the external elastic lamina, whereas IVUS easily can.[10] Thus, plaque burden, an important predictor of clinical outcome, is more readily quantitated with IVUS.

Plaque Composition

Both IVUS and OCT have shown effectiveness in characterizing plaque composition. Originally, conventional IVUS was limited in its assessment of plaque composition to fibrofatty, calcified, or "soft." However, new applications of IVUS, such as integrated backscatter, wavelet analysis, and virtual histology, have allowed IVUS to characterize plaques as lipid, fibrous tissue, calcification, or necrotic core with high accuracy.[11-15] The effectiveness of OCT in this arena was first described in 2002, when Yabushita et al showed that OCT is highly sensitive and specific at characterizing plaque type.[16]

OCT's superior resolution—its ability to see plaque microstructures and tissues adjacent to calcium—makes it superior to both grayscale IVUS and radiofrequency IVUS in characterizing plaque type.[8,17-19] This superiority is especially apparent when identifying lipid-rich plaques.[17,18] However, OCT's limited depth of penetration precludes the full visualization of large plaques and causes OCT to occasionally misclassify thick-capped plaques as fibrous or fibrocalcific.[17] IVUS, on the other hand, can accurately quantify large lipid pools and visualize the entire vessel wall, even in the presence of large plaque burden.[10,17]

Plaque Vulnerability

Rupture and subsequent thrombosis of coronary plaque is believed to be the cause of most acute coronary syndromes based on autopsy studies.[20-22] Therefore, identifying plaque features that impart vulnerability has emerged as a potential tool in preventing acute coronary syndromes. Pathohistologically, vulnerable plaques have been described as hypocellular, lipid-rich with necrotic cores, and covered by a thin cap (< 65 µm). OCT and IVUS have different strengths when evaluating vulnerability. OCT is superior to IVUS in visualizing thin caps

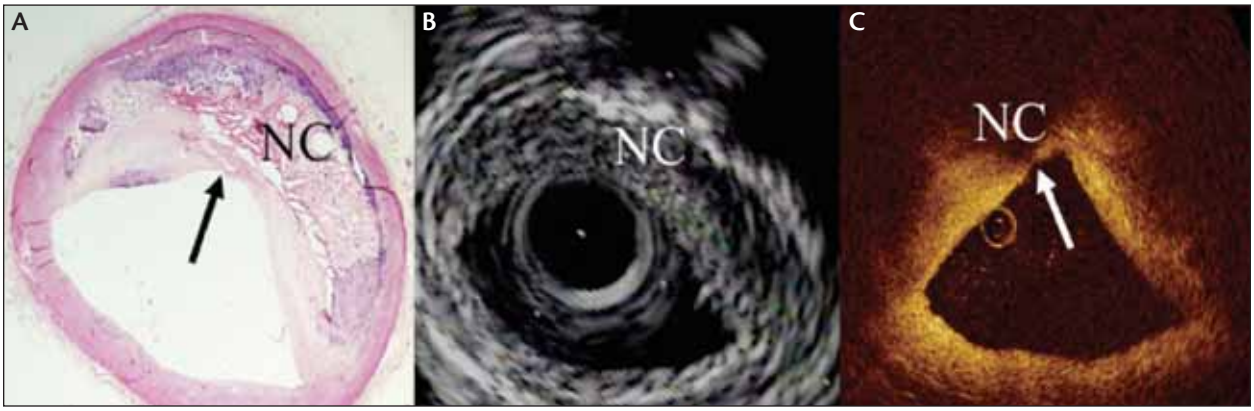

Figure 1. Representative images of thin-cap fibroatheroma by histology, IVUS, and OCT. Histology reveals a hypocellular necrotic core (NC) with an overlying thin cap (< 65 µm) (A). An IVUS image of thin-cap fibroatheroma shows the hypoechoic lesion around the calcification. However, it is impossible to visualize the thin fibrous cap (B). In the OCT image, the NC is visualized as a signal-poor region with diffuse borders, and the fibrous cap is the signal-rich layer from the coronary artery lumen to the inner border of the underlying NC, as measured at its minimum thickness. Therefore, it is possible for OCT to identify thin-cap fibroatheroma (C). Thin fibrous cap (arrows). Reprinted with permission from Kume T et al. Frequency and spatial distribution of thin-cap fibroatheroma assessed by 3-vessel intravascular ultrasound and optical coherence tomography: an ex vivo validation and an initial in vivo feasibility study. *Circ J.* 2009;73:1086–1091.[23]

(Figure 1)[8,24] and has even shown the ability to visualize cap composition, which can influence cap stability. For example, both collagen content and macrophage density are important markers of cap structural integrity.[25-31] Tearney et al found that OCT has the potential to quantify cap macrophage content,[32] although the specificity of this finding is unclear, and microcalcifications are known to have a similar appearance.[33] Several groups have also shown OCT's ability to quantify cap collagen content and smooth muscle density with the use of polarization-sensitive OCT.[34,35] Moreover, OCT has better accuracy in identifying lipid-rich plaques,[17-19] and it can visualize and qualify intracoronary thrombus as being platelet or red blood cell predominant.[10,36]

However, due to its depth of resolution, IVUS can assess plaque burden and vessel remodeling (important components of vulnerability), whereas OCT cannot. Additionally, OCT has the propensity to misinterpret signal-poor regions in the deeper vessel wall as a necrotic core, which can lead to false labeling of plaques as vulnerable.[23] Due to these differing strengths, some contend that the use of combined IVUS and OCT to evaluate plaque vulnerability is superior to any one technique alone.[37,38]

VESSEL SIZE

Several studies have been performed comparing luminal measurements between OCT and IVUS, with conflicting results. Kawase et al performed measurements on stented pig arteries and reported no differences in lumen areas and volumes between the two imaging techniques.[39] However, several other studies performed in stented arteries have found minimal to no correlation between the two modalities for luminal measurements.[40-42] In these studies, OCT is consistently found to have smaller minimal lumen area measurements than IVUS. One possible reason for this discrepancy is the superior ability of OCT to visualize the lumen-intima interface compared with IVUS,[9] therefore allowing OCT to visualize the true lumen dimensions and causing IVUS to overestimate.

Supporting this theory is the fact that IVUS is known to overestimate lumen area compared to quantitative angiography measurements.[43-45] Another possible explanation for this discrepancy is the fact that most of these studies were performed with time-domain OCT, which requires proximal balloon occlusion. Balloon occlusion causes a decrease in coronary perfusion pressure that is not compensated by continuous flush injection, therefore causing partial vessel collapse.

In support of this hypothesis, Gonzalo et al showed that acquisition technique appears to have an impact on lumen measurements.[46] This study found greater differences in minimal lumen area measurements between IVUS and OCT with balloon occlusion than between IVUS and OCT without balloon occlusion (Figure 2). Further complicating this issue, they also found that both IVUS and OCT (with either acquisition technique) overestimate lumen area compared with histology. The proposed explanation is removal of water content from histology specimens causing vessel shrinkage and thereby falsely lowering luminal areas. Due to OCT consistently underestimating lumen area compared with IVUS,

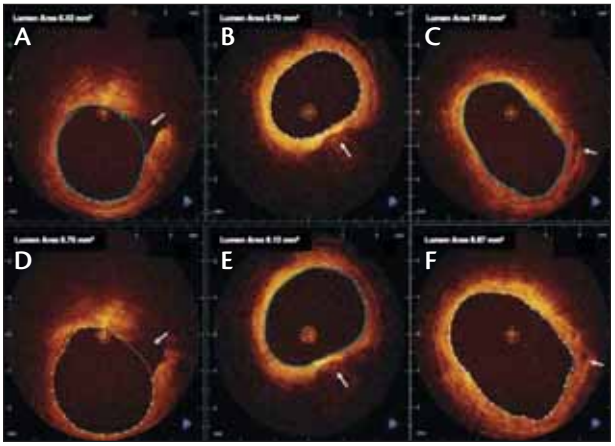

Figure 2. Examples of differences in lumen measurements between OCT with and without balloon occlusion. This figure shows corresponding images acquired with occlusion (A–C) and without occlusion (D–F). The white arrows indicate the landmarks used in the study for matching of the pullbacks (side branches in A and C and calcium spot in B). In all examples, the lumen dimensions are smaller in the pullback acquired with occlusion. Reproduced with permission from Gonzalo N, Serruys PW, Garcia-Garcia HM, et al. Quantitative ex vivo and in vivo comparison of lumen dimensions measured by optical coherence tomography and intravascular ultrasound in human coronary arteries. *Rev Esp Cardiol.* 2009;62:615–624.[46]

caution should be used before using literature-validated IVUS parameters to assess lesion significance by OCT. Further studies are needed to both validate OCT lumen measurements and to correlate OCT measurements with lesion significance.

USE IN PERCUTANEOUS CORONARY INTERVENTION

IVUS has been the gold standard for intravascular imaging during percutaneous intervention and monitoring the vascular response to coronary stenting. However, the low resolution of IVUS and the nature of sound-based imaging limit the ability to accurately assess fine architectural changes and vascular responses to coronary stents.[39] Furthermore, the ability to study the vessel wall adjacent to the struts is impeded by the bright signal reflection of the metal struts.[39] Due to its higher resolution and the fact that most of the relevant structures during this evaluation are located within OCT's depth of penetration (< 500 µm), OCT has the potential to be superior to IVUS in this specific patient population.[47]

Stent Apposition

Incomplete stent apposition is defined as separation of at least one stent strut from the vessel wall.[48] Several

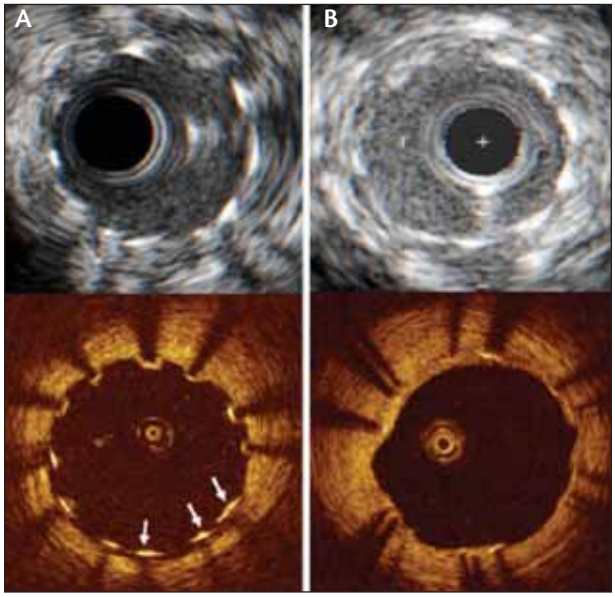

Figure 3. Corresponding IVUS (top) and OCT (bottom) images of a stented coronary artery. OCT images immediately after stent placement show small-sized stent malappositions (white arrows) that IVUS cannot visualize (A). Follow-up OCT images show that the surfaces of the malapposed struts are covered by neointima and therefore may be a benign finding (B). With kind permission from Springer Science+Business Media: *Clin Res Cardiol,* Serial changes of minimal stent malapposition not detected by intravascular ultrasound: follow-up optical coherence tomography study, 99, 2010, 639–644, Kim et al, Figure 2.[49]

IVUS studies have suggested a possible correlation between incomplete stent apposition and subsequent stent thrombosis.[50-52] Recent studies have shown that very-small-sized stent malappositions can be detected by OCT,[53,54] and further studies have proven its superiority to IVUS in detecting them.[55,56] However, the long-term clinical implications of stent malapposition discovered by OCT are not clearly understood.

In an OCT study, Kim et al found that the surfaces in almost all minimally malapposed struts were covered by neointima and, therefore, are unlikely to cause clinically significant thrombosis (Figure 3).[49] Furthermore, they found that minimal stent malapposition, which is not detectable by IVUS, may disappear or decrease in follow-up and may be benign.[49] In contrast, Ozaki et al discovered that thrombus was seen in a significantly greater proportion of stent struts that were characterized as malapposed by OCT at 10-month follow-up.[56] To further elucidate whether these stent malappositions visualized by OCT bear any clinical consequences, more large, long-term prospective studies will be necessary.

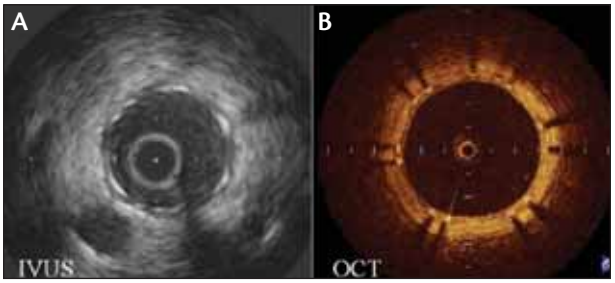

Figure 4. Corresponding IVUS and OCT images obtained at the same distance from a major side branch 6 months after stent placement. The insufficient resolution of IVUS prohibits visualization of neointima, whereas the OCT images clearly show that all struts are covered. Matsumoto D et al. Neointimal coverage of sirolimus-eluting stents at 6-month follow-up: evaluated by optical coherence tomography. *Eur Heart J.* 2007;28(8):961–967, by permission of Oxford University Press.[53]

Intimal Coverage After Drug-Eluting Stent Implantation

IVUS has been used extensively to assess neointimal coverage months after percutaneous coronary intervention.[57] However, drug-eluting stents inhibit neointimal proliferation to such an extent that it may not be detectable by IVUS.[58-60] On the other hand, the higher resolution of OCT allows for the visualization and measurement of thin layers of tissue growth covering stents.[61,62] In a 6-month follow-up of 34 patients with drug-eluting stents, Matsumoto et al found that 65% of the struts were covered by a thin neointima undetectable by IVUS (< 100-µm thickness), with a median tissue thickness of 52 µm (Figure 4).[53] Further studies have shown that OCT is superior to IVUS in detecting a small amount of in-stent neointima.[42]

Due to its high resolution, in addition to quantifying neointimal hyperplasia (NIH) thickness, OCT can also be used for qualitative assessments of NIH (to determine if it is homogeneous, heterogeneous, or layered).[63] This could help in understanding the mechanism of in-stent restenosis. An attempt to use IVUS to assess different NIH morphology resulted in disappointing results. Kwon et al found that IVUS cannot distinguish patterns of NIH morphology when < 15% of the lumen cross-sectional area is occupied.[64]

Furthermore, IVUS measurements only had a moderate correlation with OCT results, and the assessments differed in approximately 30% of lesions.[64] Histological validation of these measurements has not been performed, and the long-term prognostic implications are unknown, but this assessment remains a promising area of future research.

Complications in Percutaneous Coronary Intervention

IVUS imaging has played an important role in understanding failure and optimizing outcomes after stent implantation. However, the lack of resolution and artifacts caused by stent struts make visualization of small morphologic changes in vessel structure after stent implantation difficult. In contrast, the high resolution of OCT allows the visualization of these small defects, such as tissue prolapse and small-edge dissections, with improved accuracy over IVUS.[55,65] Although the clinical implications of these findings are unclear, the ability of OCT to clearly visualize these phenomena will allow researchers to further study their impact on clinical outcomes.

BIODEGRADABLE STENTS

The recent results of the ABSORB trial and the subsequent European approval of the first biodegradable everolimus-eluting stent (Absorb BVS, Abbott Vascular, Santa Clara, CA) is potentially ushering in a new era in interventional cardiology. However, with this new technology come new challenges pertaining to imaging of these new stents. The Absorb stent is translucent and radiolucent, thus making visualizing these stents with traditional modalities difficult. The potential of OCT to quantitatively assess strut thickness and biodegradation makes it an ideal imaging modality for monitoring these stents.

Recent studies have proven the ability of OCT to precisely characterize stent apposition and stent strut coverage and to demonstrate structural changes in the bioresorbable drug-eluting stent over time (Figure 5).[66] Furthermore, a head-to-head study comparing the ability to measure stent length proved OCT superior to both IVUS and quantitative coronary angiography, and its measurements correlate well with the known length.[67]

In the ABSORB trial, OCT was able to show serial changes in the optical properties of the struts over time,[68,69] hypothesized to be reflecting the bioresorption process. However, in a follow-up study attempting to validate this hypothesis, Onuma et al found that OCT might not be sensitive enough to determine polymer degradation because of a lack of correlation between OCT images and histology.[69] Given these findings, OCT will likely be the imaging modality of choice when assessing biodegradable stents.

ARTIFACTS

Both IVUS and OCT are prone to artifacts during image acquisition. Certain artifacts are shared by both IVUS and OCT, whereas others are unique to their respective imaging technique. IVUS catheters are afflicted by artifacts related to sound-based imaging

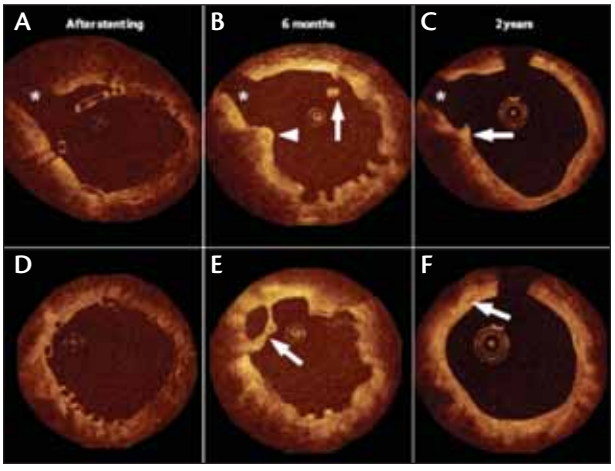

Figure 5. Serial assessment of bioabsorbable stent struts by OCT in the ABSORB study. OCT allows the visualization of incomplete stent apposition (arrow in B), with resolution over time (arrow in C), and apparent stent absorption at 2 years (A–C). OCT images show complete stent strut apposition immediately after stenting followed by late acquired incomplete stent apposition at 6 months (arrow in E) and smooth endoluminal lining with barely discernable stent struts at 2 years (arrow in F) (D–F). Reprinted from *The Lancet,* 373, Serruys PW et al, A bioabsorbable everolimus eluting coronary stent system (ABSORB): 2-year outcomes and results from multiple imaging methods, 897–910, Copyright (2009), with permission from Elsevier.[68]

(ring down and blood speckle), whereas OCT experiences artifacts that are unique to light-based imaging (saturation artifact and artifacts related to residual blood in the artery). The artifacts shared by both techniques are mostly related to mechanical issues, such as motion artifacts and nonuniform rotational distortion (mechanical IVUS). OCT's smaller profile and simplified rotational mechanics make it less susceptible to these mechanical artifacts.

A recent study using a phantom model found that OCT experienced less nonuniform rotational distortion than IVUS, particularly in a more tortuous vessel.[70] Interestingly, the artifacts seen by OCT due to eccentric wire position, such as sunflower and merry-go-round effect, likely occur with rotational IVUS, but the resolution of OCT allows clearer visualization of these image misrepresentations.

CONCLUSION

Although the resolution of OCT allows for superior ability to characterize plaques, assess vessel size, and provide short- and long-term follow-up of coronary stenting, its use does not completely eliminate the need for IVUS imaging technologies. Due to the superior depth of penetration of IVUS, its use is still necessary to characterize and measure plaque burden, assess vessel remodeling, and view deep vascular structures, such as coronary adventitia. ■

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