9 Assessment of Lesion Severity (Intravascular Ultrasound, Optical Coherence Tomography, NIRS, and Beyond)

Sadik Raja Panwar, Anitha Rajamanickam, and Annapoorna Kini

Intravascular Ultrasound (IVUS)

IVUS is one of the new tools in our interventional armamentarium which is catheter based miniature ultrasound device which enables us to view the artery from inside. The oscillatory movement (expansion and contraction) of a piezoelectric transducer (crystal) in the IVUS when electrically excited produces sound waves which propagate through the different tissues and are reflected according to the acoustic properties of the tissue it travels through. These reflected sound waves are then transcribed into a three dimensional gray scale image.

Indications

- To determine lumen area, lesion complexity (e.g., plaque burden, calcification), and lesion length, especially in bifurcations lesions.
- To determine the severity of angiographically intermediate left main disease.
- To determine stent apposition, lesion coverage, and edge dissection post stent deployment.
  - To optimize stent expansion and prevent stent thrombosis or restenosis.
  - To assess for adequate stent expansion, especially in cases of in-stent restenosis and stent thrombosis.
  - To assess coronary vasculopathy in transplanted hearts.

S.R. Panwar, MD (✉) • A. Rajamanickam, MD • A. Kini, MD, MRCP, FACC
Department of Interventional Cardiology, Mount Sinai Hospital,
One Gustave Levy Place, Madison Avenue, New York, NY 10029, USA
e-mail: drsrpanwar@gmail.com; arajamanickam@gmail.com,
Anitha.Rajamanickam@mountsinai.org; Annapoorna.kini@mountsinai.org

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How it works

- IVUS catheters can either be a mechanical system rotating a single transducer or a multitransducer array that is activated sequentially to produce an image.
- Ultrasound waves from the IVUS catheter are reflected by the tissue to create a 360° tomographic image of the vessel wall from the intima to the media.
- IVUS resolution is 100–200 μm, showing the lumen–intima interface and, to a lesser degree, the interface between the media and intima.
- Unlike optical coherence tomography (OCT) imaging, IVUS does not require blood to be cleared from the vessel.

Limits

- Gives no physiologic evaluation of lesion severity.
- In the absence of FFR, it can be used to decide whether to stent an intermediate lesion, but the specificity of IVUS for obstructive lesions is suboptimal.
- May be difficult to pass the catheter across highly stenotic lesions or tortuous vessels.

Equipment and practical aspects

- ≥5F sheath.
- Heparin or bivalirudin for ACT >250 s.
- Engage target vessel and wire the lesion.
- Flush the IVUS catheter with saline.
- Administer 200 μg of intracoronary nitroglycerin.
- The blood vessel does not have to be cleared of blood for imaging to occur.
- Automated mechanical pullback is the best choice for precise imaging.
- Once the catheter pullback is completed, IVUS computer software can be used to determine minimal luminal area (MLA) of the lesion (Table 9.1).

Detailed discussion Interobserver variability in determining the severity of stenosis angiographically has been consistently demonstrated [1, 2]. IVUS provides more objective measurement of vessel size and lesion length and quality (Figs. 9.1, 9.2, 9.3, and 9.4), and can guide device selection (e.g., the need for rotablation or the use of a longer stent). IVUS-guided PCI leads to greater acute vessel gain, as well as better outcomes with respect to BMS restenosis and DES thrombosis [3, 4]. In our experience, IVUS

Table 9.1 IVUS numbers to remember

ACT >250 ms before IVUS catheter insertion
Left main MLA >6 mm^2 or non-left main MLA ≥4 mm^2, safe to defer stenting
MLA <4 mm^2 ≠ FFR <0.80, *but, in the absence of FFR*:
MLA <3 mm^2 in the proximal LAD correlates with FFR <0.80
MLA <2.75 mm^2 in the LAD after the second diagonal branch
MLA <2.4 mm^2 for non-LAD vessels may predict FFR <0.80
Intimal thickness >0.5 mm consistent with transplant coronary vasculopathy

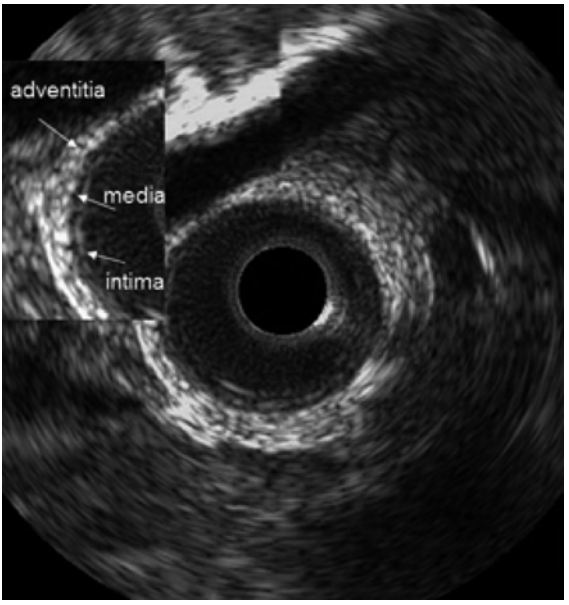


Fig. 9.1 Normal coronary artery

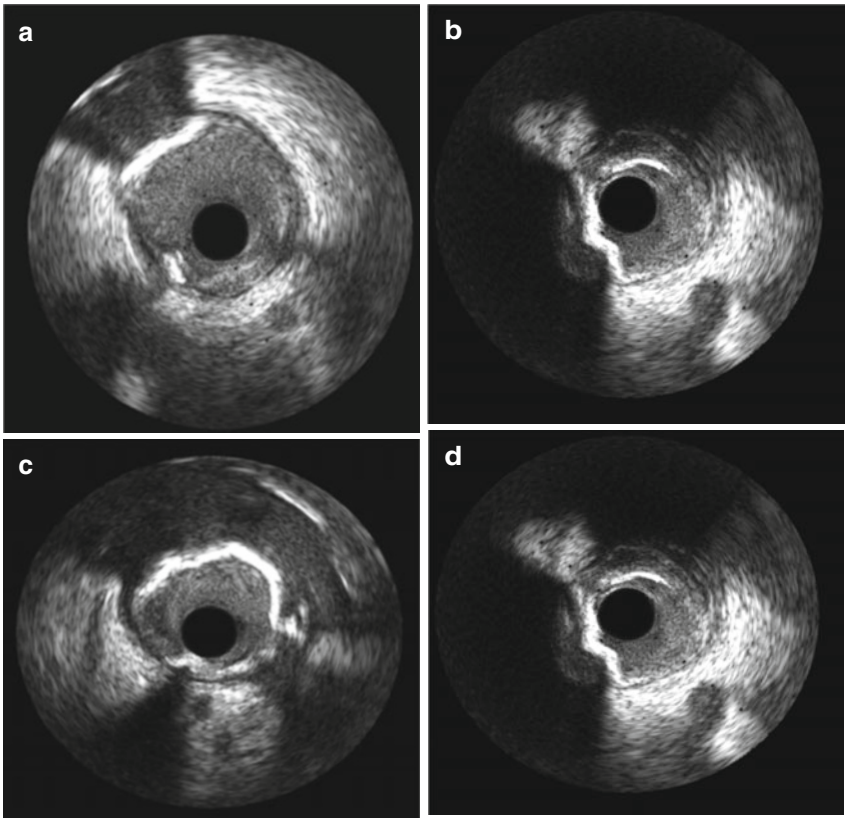


Fig. 9.2 Calcified plaque (hyperechoic) on IVUS

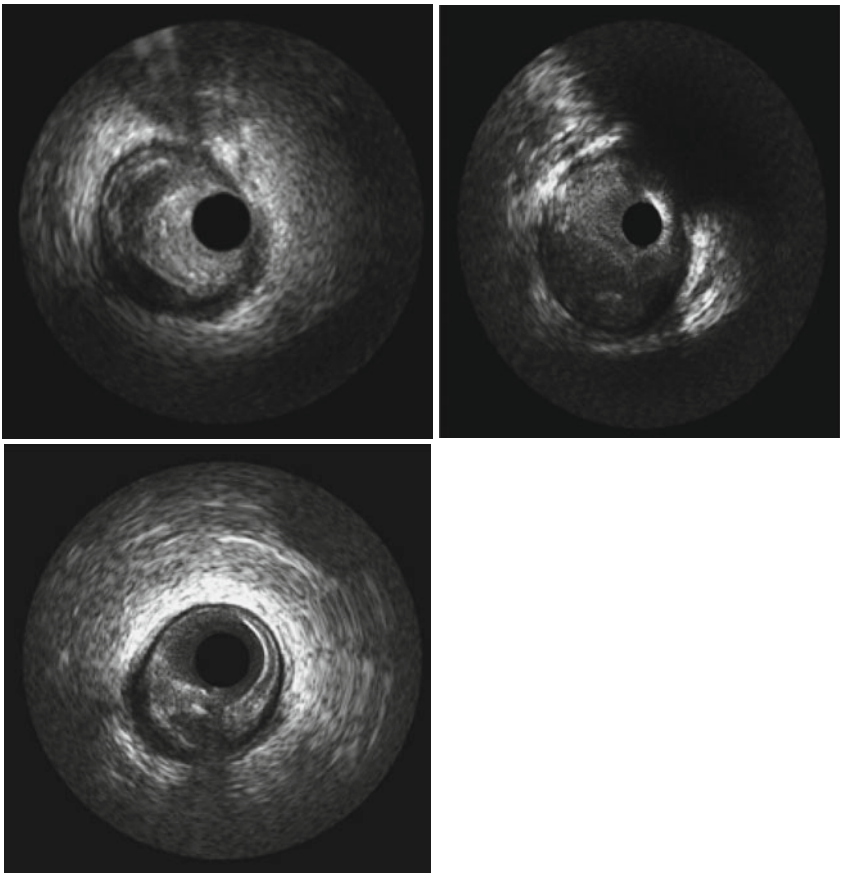


Fig. 9.3 Lipid pool (echolucent area within plaque) on IVUS

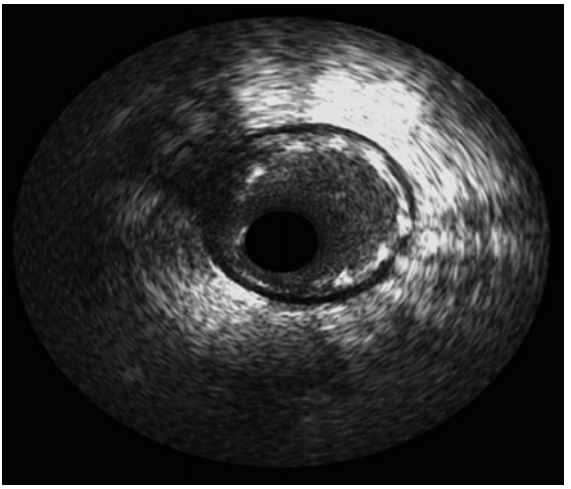


Fig. 9.4 Stented plaque by IVUS

evaluation of lesion length and quality can also reduce contrast use and ensure adequate lesion coverage. In the transplanted heart, IVUS is a sensitive tool for detection of coronary artery vasculopathy, typically defined as intimal thickness >0.5 mm. As IUS does not provide physiological assessment, FFR is the best modality to determine if an angiographically indeterminate lesion requires percutaneous intervention (PCI). The hemodynamic significance of a lesion depends on numerous variables (e.g., target vessel stenosis severity, lesion length, area of the viable myocardium supplied by the vessel), which are reflected by FFR, but are unaccounted for by IVUS. A rough guide to IVUS measurements that correlate to hemodynamically significant stenoses is listed in Table 9.1 [5, 6]. As FFR has not been validated in instent restenosis, IVUS may be used to guide therapy in angiographically indeterminate lesions (MLA of the left main >6 mm^2 or MLA ≥4 mm^2 in a non-left main vessel is the cuttoff criteria used for defining non-ischemic intermediate lesions in which stenting is safely deferred).

Optical Coherence Tomography (OCT)

Optical coherence tomography (OCT) is an newer intravascular imaging technology for evaluating the cross-sectional and three-dimensional (3D) microstructure of blood vessels at a resolution of approximately 10 μm. The underlying principle of OCT is based on the concept that structural information of the coronary vessel can be obtained by measuring the delay time of optical echoes reflected or backscattered from subsurface structures in biological tissues, OCT light is in the near-infrared (NIR) range, typically with wavelengths of approximately 1.3 μm, which are not visible to the human eye (Table 9.2). Because of its higher resolution than intravascular ultrasound (IVUS), OCT can characterize the superficial structure of the vessel wall in greater detail (Table 9.2). OCT cannot image through blood because blood attenuates light before it reaches the arterial wall. As a result, OCT images are acquired as blood is flushed from the field of view.

Table 9.2 Physical characteristics of FD-OCT versus IVUS

	FD-OCT	IVUS
Radiation type	Light	Ultrasound
Wavelength, μm	1.3	35–80
Frequency	20–45 MHz	190 THz
Resolution, μm	10–40	100–150
Penetration depth, mm	1–3	4–10
Field-of-view diameter, mm	15	7–10
Frame rate, frames/s	100	30
Pullback speed, mm/s	20	0.5–1
Plaque characterization	Yes	Yes
Fibrous cap measurement	Yes	No
Vessel remodeling	No	Yes
Blood removal required	Yes	No

How it works

- Infrared light emitted from an optical fiber in the imaging catheter is reflected by the coronary vessel tissue, allowing for characterization of vessel wall.
- Resolution is 10–20 μm, but tissue penetration is only 1–2 mm.

Limits

- Tissue penetration is limited, allowing for imaging of only the superficial structures.
- Left main and ostial lesions are not satisfactorily imaged as the blood cannot be cleared adequately.

Indications

- Assessment of plaque morphology (e.g., plaque erosion in ACS) (Figs. 9.5 and 9.6)
  - To determine stent apposition, lesion coverage, and edge dissection (Fig. 9.6)
  - To optimize stent expansion to prevent stent thrombosis or restenosis
  - To assess for adequate stent expansion, especially in cases of in-stent restenosis and stent thrombosis

Equipment and practical aspects

- ≥6F sheath.
- Heparin or bivalirudin for ACT >250 s.
- Engage target vessel and wire the lesion.

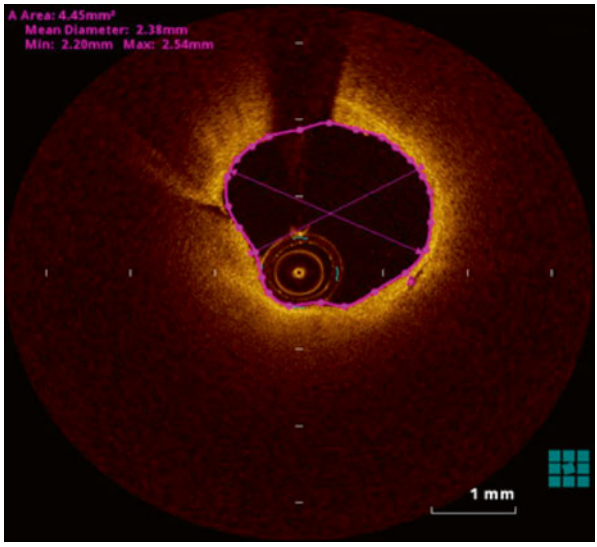


Fig. 9.5 OCT of an LAD lesion. Note the OCT catheter at 7 o'clock. In addition to highly accurate measurements of vessel diameter, lesion qualities can be assessed with greater accuracy than with IVUS

- Open the OCT catheter from packaging and flush the OCT catheter with attached 3 cc syringe using undiluted contrast to purge air from the catheter.
- Connect the catheter to the controller unit with a click.
- Administer 200 μg of intracoronary nitroglycerin.
- Back-load the guidewire through the OCT catheter and advance the distal tip of the catheter past the region of interest.
- Set the power injector according to the manufacturer's instructions (typically at least 3 cc/sec for a total volume of 12 cc for RCA and 4 cc/sec for a total volume of 14 cc for left coronaries (no more than 450 PSI).
- Check catheter position with a test injection.
- Once assured of position, activate the imaging catheter and inject 100 % contrast through the power injector.

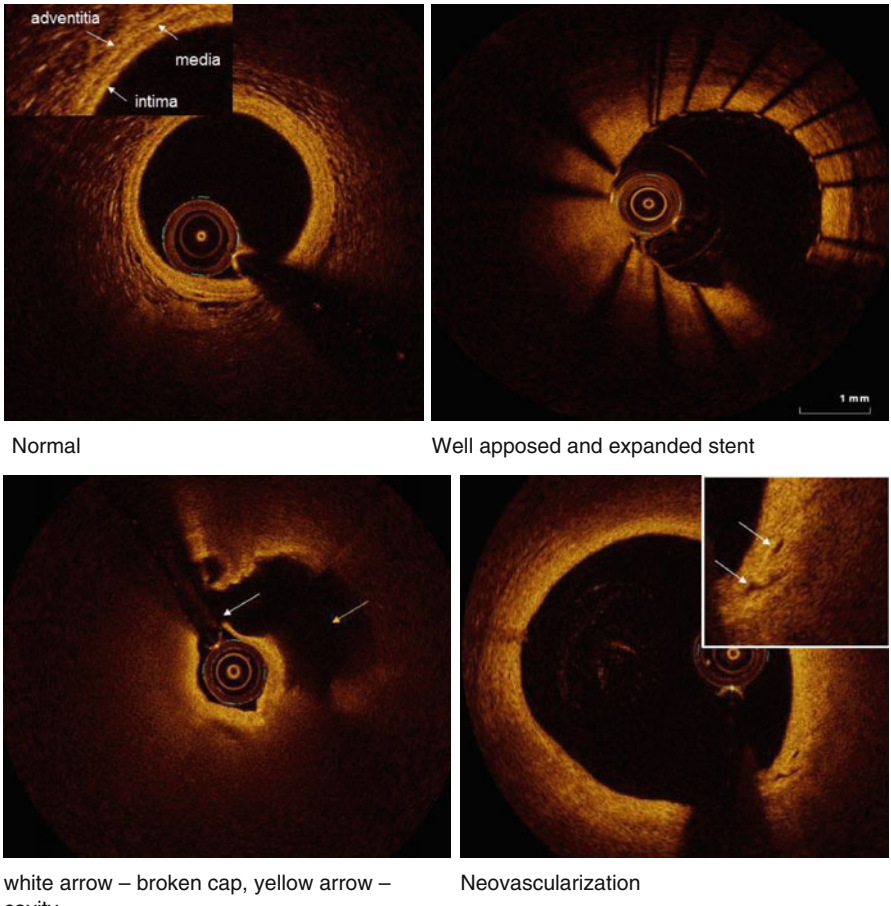
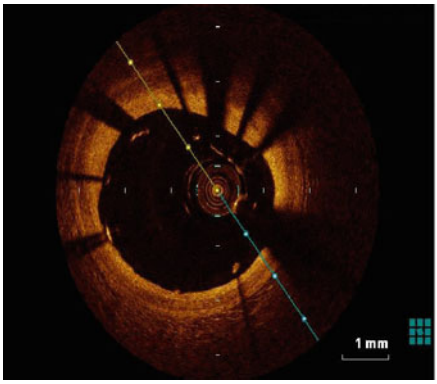
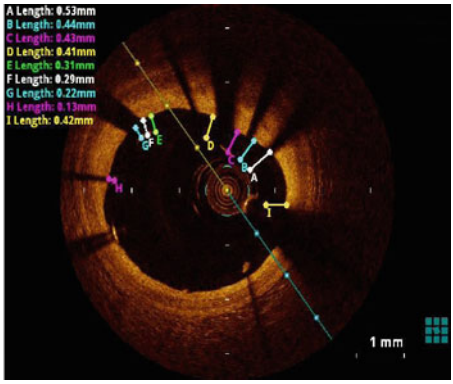


Fig. 9.6 Optical coherence tomography examples of normal vessel wall, plaque composition, thrombus, and findings after coronary stenting



Malapposition



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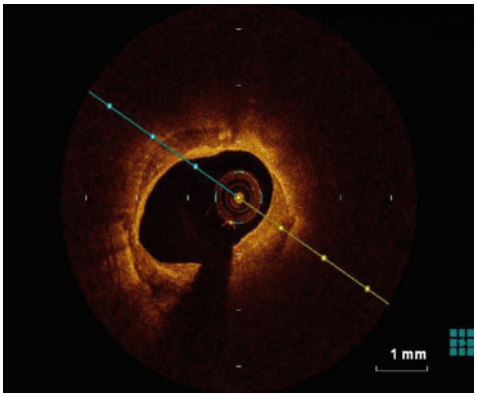
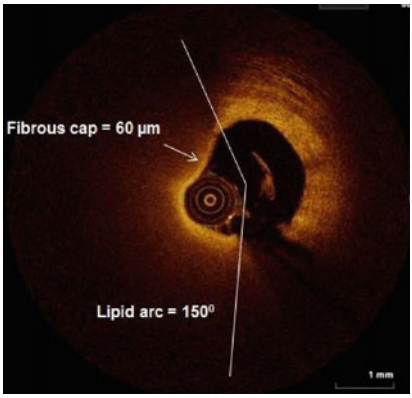
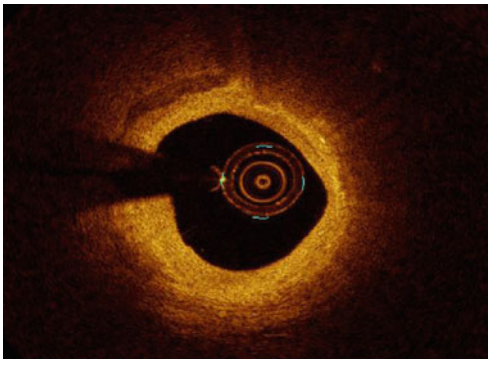


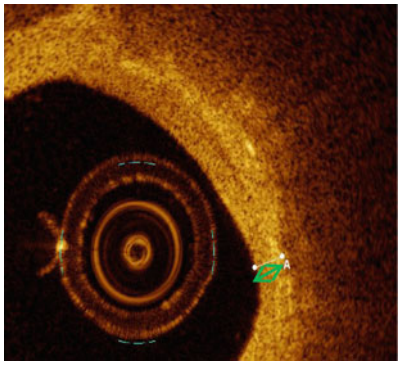
Calcified



Fibrous Cap

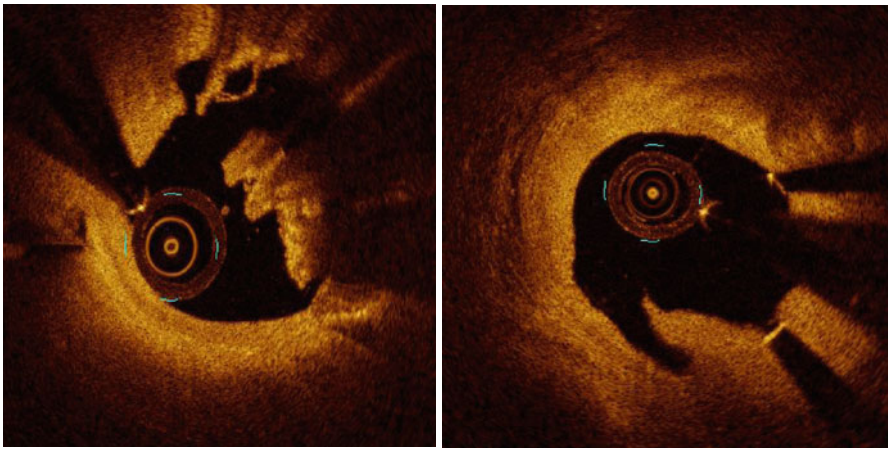


Fibroatheroma



Fibroatheroma

Fig. 9.6 (continued)



Thrombus Stent Edge Dissection

Fig. 9.6 (continued)

Detailed discussion OCT's high resolution means it is more sensitive than IVUS for plaque characterization and vessel anatomy (Figs. 9.5 and 9.6). At present, OCT is primarily a research tool, though there are data to suggest that adjunctive use of OCT in PCI may lead to better outcomes and can guide decision making in ACS [7, 8]. Nonetheless, a routine role for OCT in PCI has yet to be determined.

Near-Infrared Spectroscopy (NIRS)–Intravascular Ultrasound (IVUS) Imaging

Indications The Infraredx TVC Imaging System™ is intended for the detection of lipid core-containing plaques (LCPs) using near-infrared spectroscopy (NIRS) and intravascular ultrasound (IVUS) examination of the coronary arteries. The combination of NIRS with IVUS in a single catheter combines the benefit of NIRS to the benefits of IVUS.

How it works The TVC Imaging System utilizes diffuse reflectance near-infrared spectroscopy (NIRS), a classic method of analytical chemistry, to characterize the plaque for lipid content [1]. Diffuse reflectance spectroscopy requires scattering and absorption at different wavelengths of the light by the tissue. First, the combination

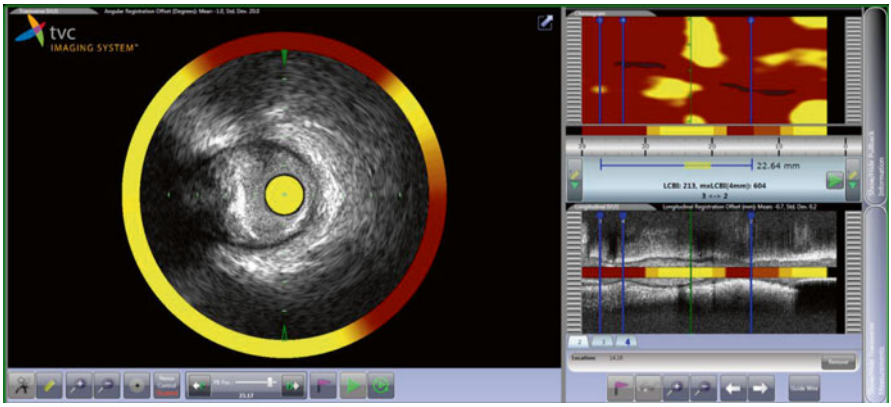


Fig. 9.7 TVC Composite™ view of co-registered near-infrared spectroscopy lipid core plaque with intravascular ultrasound. The chemogram displays low probability of lipid as red and high probability as yellow. The lipid core burden index (LCBI) indicates the amount of lipid in the scanned artery on a 0–1,000 scale

of scattering and absorption of near-infrared light by organic molecules in the arterial wall and plaque produces a unique chemical signature. Then, an algorithm analyzes the detected signal for signs of cholesterol and provide automated LCP detection without the need for manual image processing (Fig. 9.7). In contrast to OCT, NIRS can image through blood, as it does not need light to be directly reflected back to the detector [1].

Equipment TVC Insight Catheter

Minimum guide catheter	6 French (2 mm)
Maximum guidewire	0.014 (0.36)
Catheter crossing tip profile	3.2 French (1.1 mm)
Maximum imaging depth	16 mm
Catheter working length	120 mm
Operating frequency	40 MHz

Limitations NIRS–IVUS doesn't allow detection of non-superficial LCPs and LCPs in large vessels (more than 6 mm diameter) cannot visualize neovascularization [2].

NIRS–IVUS numbers to remember Patient with stable coronary artery disease who undergoes PCI of lesions with large lipid core plaques (maxLCBI4 mm ≥500 by NIRS) is associated with a 50 % risk of periprocedural MI [9] and a maxLCBI4 mm >400 in the culprit segment is considered significant with STEMI [10].

Table 9.3 Comparison of three intravascular imaging modalities for the detection of coronary lipid core plaque

	VHIVUS	OCT	NIRS–IVUS
Hybrid intravascular imaging	No	No	Yes
Axial resolution, um	200	10	100
Imaging through blood	++	–	++
Need for blood column clearance during image acquisition	No	Yes	No
Imaging through stents	No	Yes	Yes
Imaging through calcium	No	Yes	Yes for NIRS, no for IVUS
Imaging neovascularization	No	Yes	No
Detection of non-superficial LCPs	Yes	No	No
Evaluation of LCP cap thickness	+	++	*
Detection of thrombus	–	+	*
Expansive remodeling	++	–	++
Need for manual image processing for LCP detection	Yes	Yes	No

++ excellent, + good, – impossible, * potential under investigation, *VHIVUS* virtual histology intravascular ultrasound, *OCT* optical coherence tomography, *NIRS* near-infrared spectroscopy, *LCP* lipid core plaque

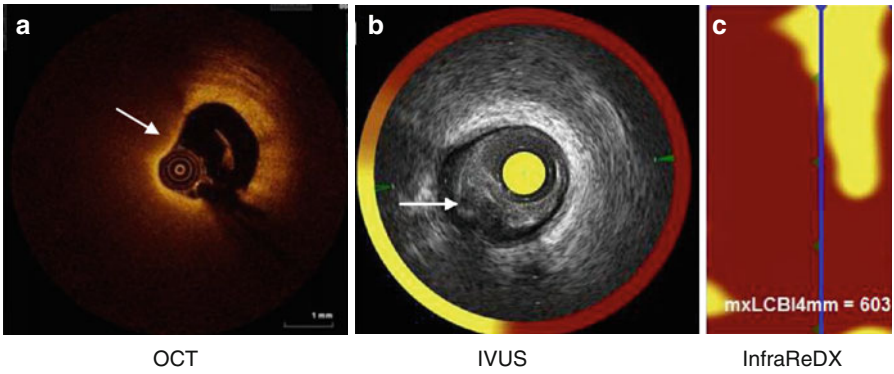


Fig. 9.8 OCT image of a thin-cap fibroatheroma (TCFA) lesion with a 60 μm fibrous cap (*arrow*) overlying a large lipid core (**a**). The lipid pool (*arrow*) is shown in the corresponding IVUS image (**b**). NIRS chemogram quantifies the lipid content of the lesion (**c**)

Multimodality imaging: correlation of OCT and NIRS–IVUS imaging Combined utilization of OCT and NIRS–IVUS allows to characterize the microstructural features of plaque morphology, such as fibrous cap thickness and neovascularization (OCT) and plaque lipid content (NIRS), and perform robust quantitative measurements of lumen, vessel, and plaque area (grayscale IVUS) in the same lesion (Table 9.3). Figure 9.8 shows an example of multimodality images of a thin-cap fibroatheroma lesion.

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