Intravascular Ultrasound

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Presentation Overview

1. Patient presentation, RG
2. Overview of intravascular ultrasound (IVUS)
3. Patient RG workup, diagnosis, and treatment
4. Utility and clinical indications of IVUS
5. Research uses of IVUS
6. Recent advancements and future directions of IVUS
7. Summary
Patient RG

- RG is a 73 year old gentleman with classic angina on exertion.

- Coronary angiography at an outside hospital showed significant coronary lesions in the left anterior descending (LAD), left circumflex (LCx), and elsewhere.

- There was a question of a left main coronary artery (LMCA) lesion in the left coronary ostium but it could not be adequately visualized by angiography.

- He was referred to the Beth Israel Deaconess Medical Center (BIDMC) for possible coronary artery bypass grafting (CABG) versus percutaneous coronary intervention (PCI).
Our patient RG: Left coronary artery branches on coronary angiogram

Green arrows demonstrate luminal narrowings in the LAD and LCx.
Our patient RG: Additional view of left coronary artery branches on coronary angiogram

Green arrow demonstrates a luminal narrowing in the LCx.
Our patient RG: View of the LMCA on coronary angiogram

Green arrow points to a possible lesion in the ostium of the LMCA. However it could not be adequately visualized on coronary angiography given the catheter insertion.
Our patient RG: Treatment considerations

- Given the distal coronary artery lesions and a question of a LMCA lesion, PCI and CABG were both considered as possible treatment options. Thus RG was referred to BIDMC for further evaluation of the LMCA.
- IVUS was selected as the modality of choice to evaluate the LMCA.
- A general overview of IVUS follows before we look at the images from our patient RG.
Intravascular Ultrasound (IVUS) overview

- IVUS uses a miniature ultrasound transducer affixed to a flexible intravascular catheter to visualize arteries. There are 3 different devices in use:
  
  - **Mechanical catheter:**
    - A single transducer rotates (1800rpm) to visualize a vessel in cross section.
    - Typically a 40MHz transducer with a resolution of ~100-150 microns is used.
    - The drive shaft has limited flexibility and is difficult to advance into distal coronary vessels.

  - **Phased array catheter:**
    - Multiple transducer elements are mounted along the circumference of the catheter tip to visualize a vessel in cross section.
    - It requires complex software to combine images, and typically images are of lower quality than with a mechanical catheter.
    - The catheter is more flexible than a mechanical catheter.

  - **Timed pullback ‘sled’:**
    - A device to pullback the catheter at a slow, fixed speed. Allows creation of a longitudinal image of the vessel in any plane.
Images of IVUS devices

1. http://www2.bostonscientific.com/med_specialty/deviceDetail.jsp?task=tskBasicDevice.jsp&sectionId=4&relId=3,126,127,128&deviceId=12016&uniqueId=MPDB3359
3. Image courtesy of BIDMC
IVUS image of a coronary artery with a calcified lesion

- The general principles of ultrasonography apply to IVUS.

- **Catheter**: Middle of image
- **Blood**: Cellular, leading to backscatter, speckled pattern.
- **Intima**: Normally 1-2 cell layers and echoic. Enlarges in atherosclerotic disease.
- **Media**: Homogenous smooth muscle, minimal echogenicity.
- **Adventitia**: Numerous parallel collagen fibers, creating echogenic surfaces.
- **Calcium**: Highly echogenic with distal shadowing.
Back to our patient RG: IVUS imaging

• An IVUS catheter was advanced several millimeters in the LAD, and a timed pullback through the LAD, LMCA, and into the aorta was performed. One reconstructed longitudinal image and then several selected cross sectional images follow.
Our patient RG: Longitudinal view of the proximal LAD and LMCA on IVUS (bottom image)
Our patient RG: Several millimeters distal in the LAD

image courtesy of BIDMC
Our patient RG: More proximal in the LAD

image courtesy of BIDMC
Our patient RG: Proximal LAD
Our patient RG: LAD and LCx bifurcation
Our patient RG: Distal LMCA
Our patient RG: Mid LMCA

Small LMCA lesion

image courtesy of BIDMC
Our patient RG: Proximal LMCA

Calcified LMCA lesion

image courtesy of BIDMC
Our patient RG: Ostium of the LMCA
Our patient RG: Additional view of the LMCA ostium with contrast

Calcified LMCA lesion

Aorta
Our patient RG: Additional view of the Proximal/Ostium LMCA with contrast

Calcified LMCA lesion

image courtesy of BIDMC
Our patient RG: LMCA lumen cross sectional areas

Mid-LMCA: ~14 mm²

Ostium of LMCA: ~5-7 mm²

Normal ≈ 15 mm²

Images courtesy of BIDMC
Our Patient RG: Treatment

• Given the lesion in the ostium of the LMCA, RG was referred for CABG.

• A discussion of the utility and clinical indications of IVUS follows.
Specific advantages of IVUS over other imaging modalities

- Detailed assessment of plaque morphology and size
- Determination of plaque composition, in particular calcium versus collagen
- Measurement of intimal thickness
- Measurement of both intraluminal and extraluminal vessel diameters
Clinical Indications

Class IIA indications according to the ACC/AHA taskforce:

- **Diagnostic**
  - Following angiography to evaluate a coronary obstruction that is difficult to image.
  - To assess coronary calcium when adjunctive rotational atherectomy is contemplated.
  - To assess plaque location and circumferential distribution in anticipation of directional coronary atherectomy.

- **Interventional (post-stenting)**
  - Following percutaneous intervention (PCI) after a suboptimal angiographic result.
  - Following stenting to assess adequacy of deployment (extent of stent apposition and minimal luminal diameter).
  - To determine the mechanism of in-stent restenosis to guide therapy.

Class IIB indications (ACC/AHA taskforce):

- To assess a symptomatic patient with no evidence of significant coronary disease on angiography.
- Following diagnostic angiography to assess lesion characteristics to aid in device selection.
- Following cardiac transplantation to aid in assessment of coronary disease.

(Smith SC et al., 2006)
Research History and Utility (1)

• IVUS was first developed in the 1980s and has contributed greatly to our understanding of coronary disease processes.

• Natural history of coronary atherosclerosis
  – Confirmed the presence of disease beginning in the 2nd and 3rd decades of life, well before symptom onset. (Tuzcu EM et al., 2001)
  – Demonstrated that atherosclerosis is a diffuse process rather than focal. (Mintz GS et al., 1995)
  – Demonstrated that outward expansion (remodeling) occurs in the early phases of coronary atherosclerosis prior to luminal narrowing. (Schoenhagen P et al., 2001)
  – Distinguished various types of lesions with different risk implications. For example that lesions with expansive remodeling generally contain greater amounts of metalloproteinases and are more likely to result in acute coronary syndrome (ACS) than lesions with constrictive remodeling, which are more likely to result in stable angina pectoris. (Naghavi M, et al. 2003)
  – Helped define plaque vulnerability (eg. thin cap with a large lipid core). (Nicholls SJ et al., 2006)
Research History and Utility (2)

• Mechanisms and prevention of restenosis
  – Demonstrated that there are 3 distinct mechanisms contributing to restenosis after PCI – arterial recoil, vessel remodeling, and neointimal formation. (Weissman NJ, 2008)
  
  – Helped determine distinct forms of post cardiac transplant vasculopathy. A donor-transmitted mechanism leading to focal intimal thickening, and an acquired mechanism injury leading to diffuse intimal thickening. (Eisen HJ and Ross H, 2008)
  
  – Validated the beneficial impact of antiproliferative agents on the progression of restenosis after PCI. (Nicholls SJ et al., 2006)
• Secondary prevention
  – Plaque progression by IVUS is becoming a primary end point in a number of clinical trials. While there is significant research to suggest that changes in coronary atheroma seen on IVUS are linked to clinical outcome, definitive proof is lacking.
  – Provided strong evidence that aggressive LDL-C lowering strategies with atorvastatin halted plaque progression. (Nissen SE et al., 2004 (1))
  – Demonstrated a continuous relationship between changes in C-reactive protein levels and atheroma volume. (Nissen SE, et al., 2005)
  – Demonstrated that infusing reconstituted HDL led to plaque regression. (Chiesa G and Sirtori CR, 2003)
  – Revealed a continuous relationship between lowering of systolic blood pressure and plaque volume, suggesting that improved blood pressure control even within the normal range (<140 mmHg) might lead to significant clinical benefit. (Nissen SE et al., 2004 (2))
  – Determined that some compounds under development appear to have a negative influence on plaque progression and should not be used clinically. Pactimibe, an inhibitor of A:cholesterol acyltransferase is an example. (Nicholls SJ et al., 2006)
Recent Technologic Advancements (1)

**Luminal surface:**

- 5% glucose injection has been used as negative contrast to eliminate backscatter from blood cell. This allows a more detailed assessment of luminal surface, in particular for investigation of plaque fracture and dissection. (Honye J et al., 1999)
Recent Technologic Advancements (2)

Plaque composition:

- Integrated Backscatter (IB) IVUS – A technique under development that analyzes the IB signal from the transmitted radiofrequency (RF) signal to determine and color code plaque composition. (Kawasaki M et al., 2005)
Recent Technologic Advancements (3)

Plaque composition:
- Virtual Histology (VH) IVUS – A technique that measures both amount of returning RF signal and distortion of the RF signal to determine plaque composition. (Nair A et al., 2002)
Future Directions

- Research needs to correlate IVUS findings with clinical outcomes.

- IB IVUS and VH IVUS may help further define plaque composition to better evaluate plaque vulnerability, indications for therapy, and efficacy of prevention measures.

- IVUS used in combination with assessment of plaque temperature, compressibility, and optical coherence tomography may help evaluate for inflammation and atheroma stress points most at risk for rupture.

- IVUS used in conjunction with non-invasive imaging modalities under development including MR and CT imaging of coronaries may help follow atherosclerosis non-invasively when possible.
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