IVUS Fundamentals and Techniques

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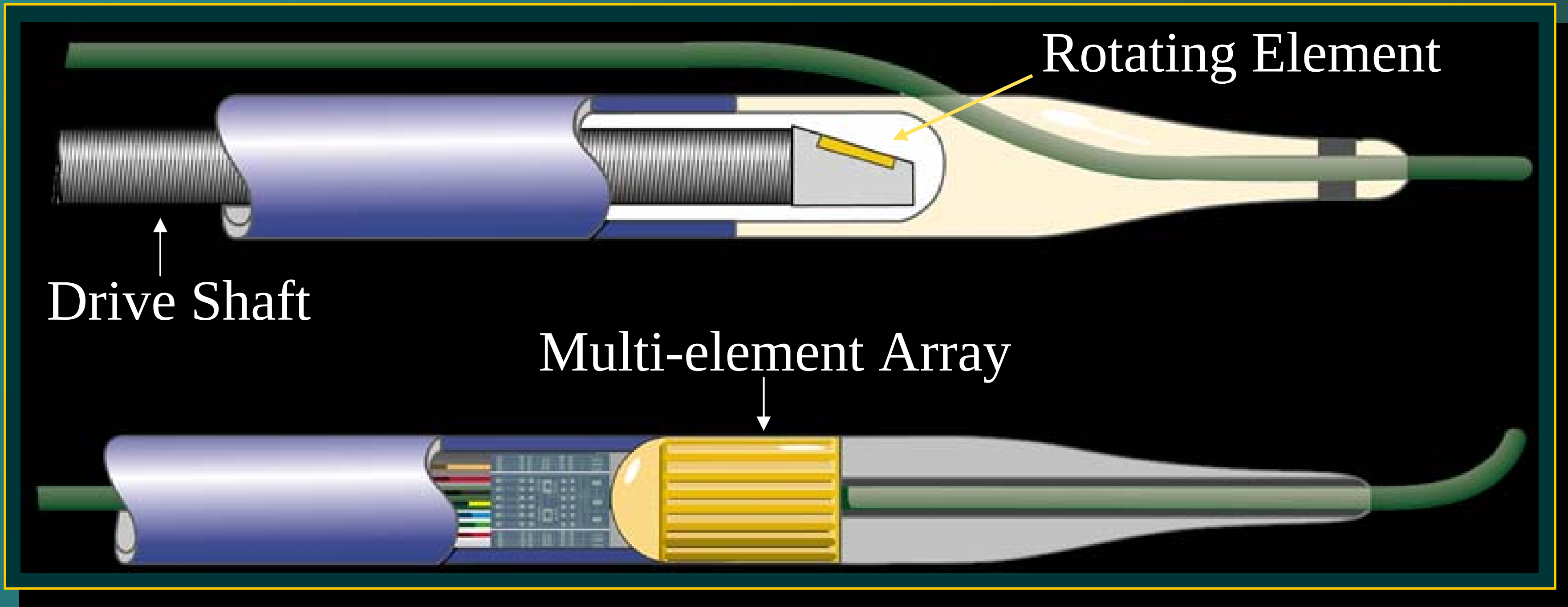
- **An IVUS image is not identical to histology.**
- **Ultrasound images are produced by passing an electrical current through the transducer that expands and contracts to produce sound waves**
- **Ultrasound is reflected at interfaces between tissues or structures of different density.**
- **After reflection from tissue, ultrasound waves return to the same transducer to create an electrical impulse that is then converted into the image.**
- **The IVUS greyscale image is derived from the *amplitude* of the reflected signal, not its *radiofrequency*. A white image means that more of the signal is reflected and the amplitude is greater; a black image means that less of the signal is reflected and the amplitude is less.**

There are two types of imaging systems: Rotating Transducer and Electronic Array



There are differences in catheter handling, system controls, and image presentation; however, both produce similar useful clinical information

Near Field and Far Field

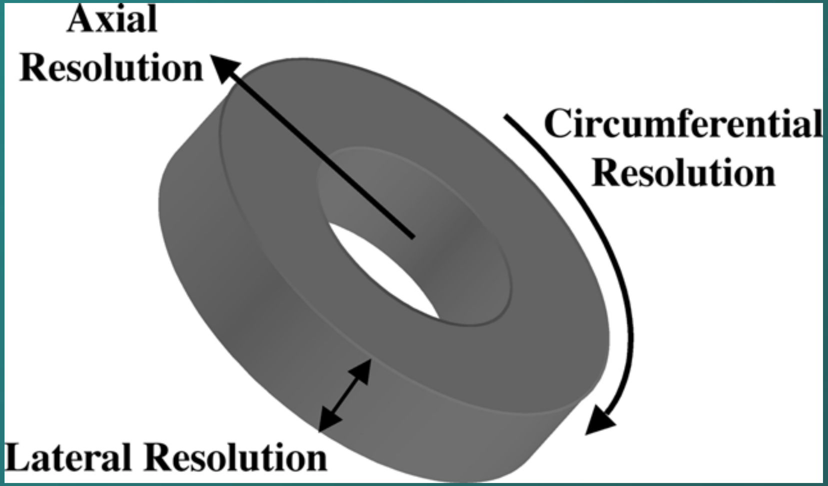
- The IVUS beam remains fairly parallel for a distance (Near Field) and then begins to diverge (Far Field).
- Image quality is better in the Near Field than in the Far field.
- The length of the near field is expressed by the equation $L = r^2 / \lambda$, where L is the length of the near field, r is the radius (aperture) of the transducer, and λ is the wavelength.

- Spatial resolution
- Contrast resolution

Spatial Resolution

- Ability to discriminate small adjacent objects
  - For IVUS, the typical resolution is 80-100 microns axially and 200-250 microns laterally
- Ultrasound cannot reliably detect or measure a structure that is smaller than its resolution.
- Resolution affects the sharpness of an image, the distinctness of the borders, and the reproducibility of the measurements.
- Resolution increases as transducer frequency increases; resolution decreases as transducer frequency decreases.
- Resolution is better in the Near Field than in the Far fField
- Focusing the transducer also improves resolution within the focused zone; however, the beam then diverges and resolution suffers.

Axial resolution - along the ultrasound beam (or radius of the artery)



Circumferential resolution - along the circumference of the artery - is affected by NURD

Lateral resolution - along the long axis of the artery - is affected by pullback and beam width

Penetration

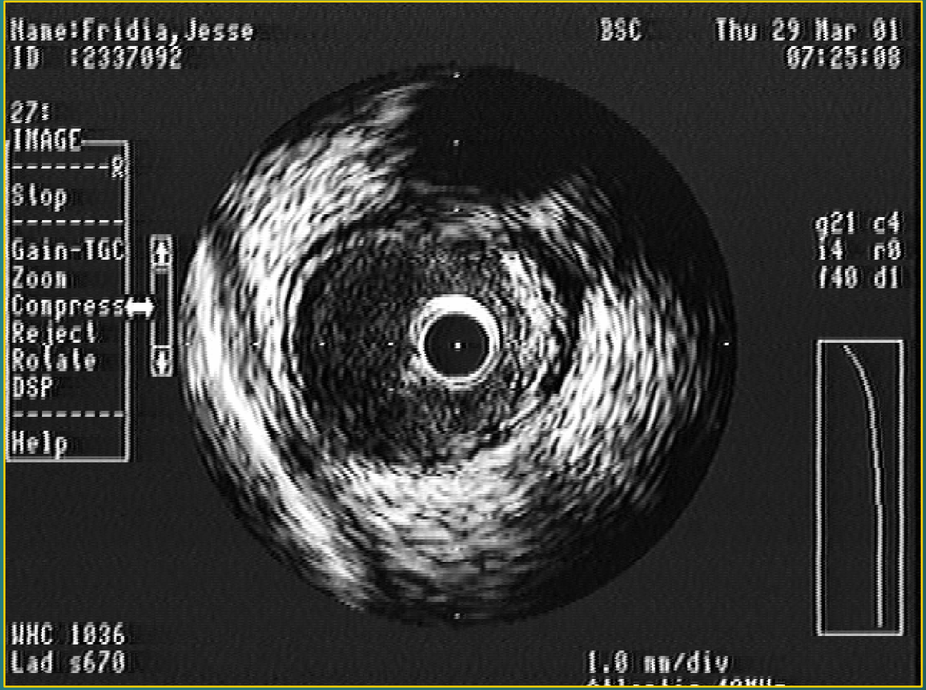
- Penetration depends on power output, aperture, and design of the transducer and on imaging frequency. . .
- Penetration is inversely related to frequency
  - The higher the transducer frequency, the less the penetration
  - The lower the transducer frequency, the greater the penetration

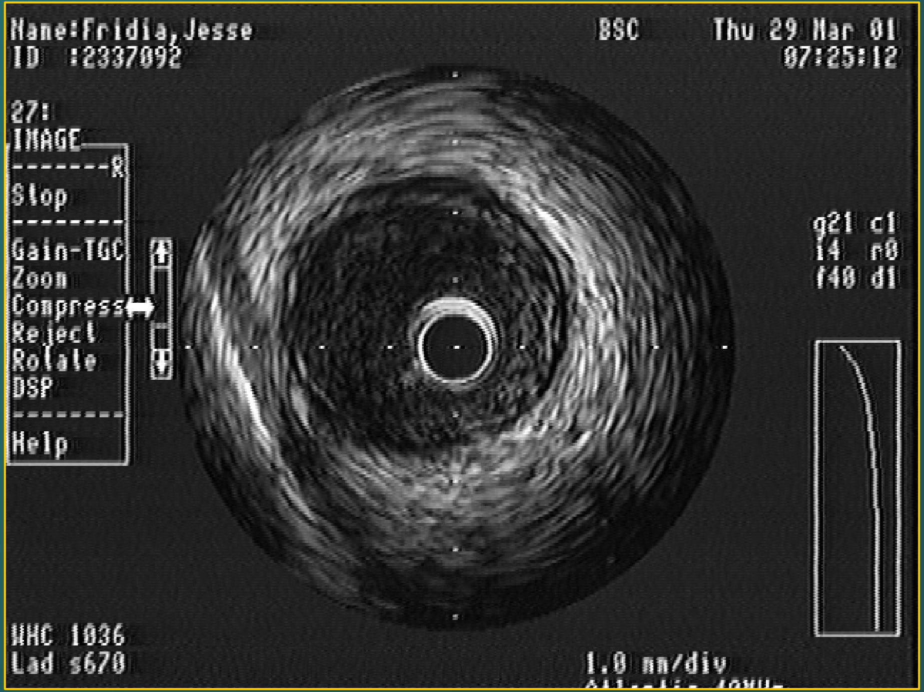
Transducer Selection

- Larger transducers with lower frequencies are better for examination of large vessels because they create a deeper Near Field, have greater penetration, and resolution is not as critical.
- Smaller transducers with higher frequencies are used for small vessels where resolution is more critical and penetration is less important
- Theoretically, you should select the highest frequency transducer that will adequately penetrate the vessel. In practice, you choices are limited by the what is commercially available.

Contrast Resolution

- Contrast resolution = dynamic range = the number of shades of grey that can be differentiated between the weakest and the strongest targets.
  - The greater the dynamic range, the broader the range of reflected signals (from weakest to strongest) that can be detected, displayed, and differentiated
- Low dynamic range images appear “black and white” with only a few “in between” gray-scale levels – in other words, they appear “contrasty”
- High dynamic range images have more shades of grey and can differentiate more different tissue types and more structural elements.





Low dynamic range **High dynamic range**

Blood Speckle

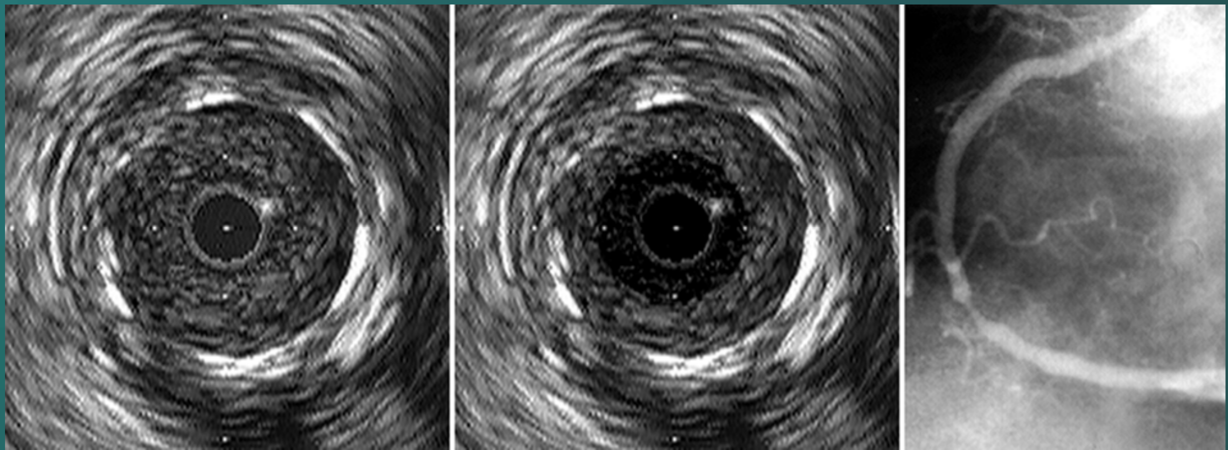
- The intensity of the blood speckle increases exponentially with
  - The frequency of the transducer: the higher the frequency, the greater the resolution; and the smaller the targets that are seen
  - Stasis (because of red cell clumping or rouleaux formation) - most evident when the catheter is across a tight stenosis. In fact, static blood can be more echodense than plaque.

Controls

- Other than the overall gain settings, adjusting the various system controls should be ***kept to a minimum***.
  - Overall gain is useful in correcting for a weak transducer and in imaging a very large vessel with poor penetration. However, if the transducer is very weak, it is better to just get a new catheter and send the weak one back to the manufacturer.
  - Overall gain that is set too low limits the detection of low-amplitude signals.
  - Overall gain that is set too high causes all tissue to appear too bright and limits dynamic range.
- *Zoom* or *depth* or *scale* should be set so that the entire external elastic membrane is on the screen throughout the length of the vessel.

Time Gain Compensation (TGC)

- The *TGC* curve adjusts the image brightness at fixed distances from the catheter. The best TGC curves are flat.
- Increasing the far-field intensity slightly is useful in imaging large vessels.
- Excessive reduction in near field intensity to reduce blood speckle, ring down, or other near field artifacts can also blank out tissue and artificially produce a lumen. If blood speckle can be seen in the lumen, it is less likely that near-field tissue will be blanked out.



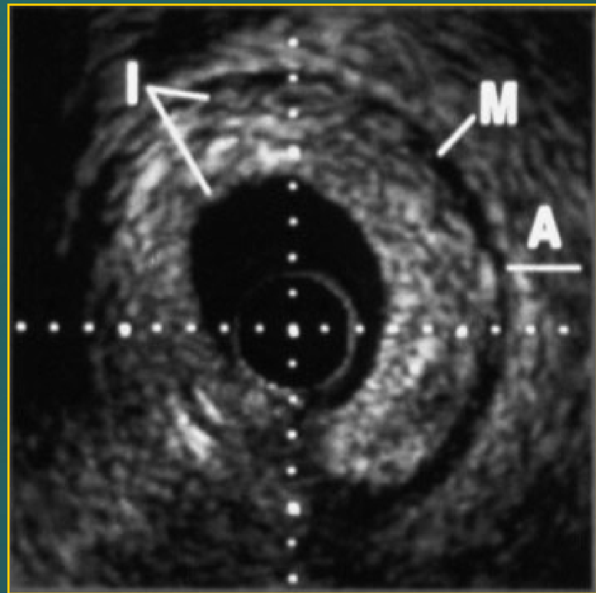
Only a small percentage of the emitted signal returns to the transducer to create the image. The amplitude of the reflected signal depends on

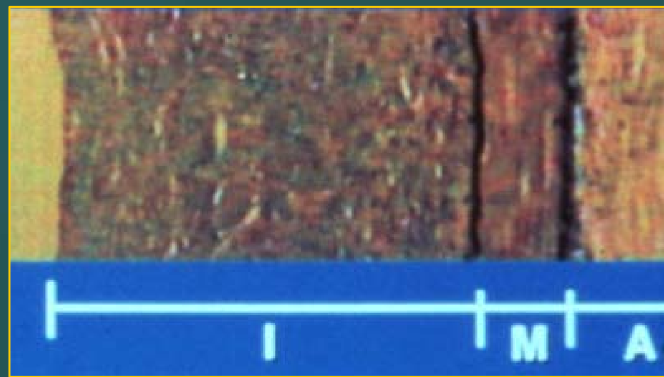
- Amplitude of the *transmitted* signal
- Distance from the transducer to the target
- Angle of the signal relative to the target
- Density (or reflectivity) of the tissue.
- Attenuation of the signal as it passes through tissue
  - As the wave passes through many tissue interfaces, the energy is attenuated (reduced). Attenuation is a function of the number and characteristics of the tissue interfaces as well as some scattering and absorption

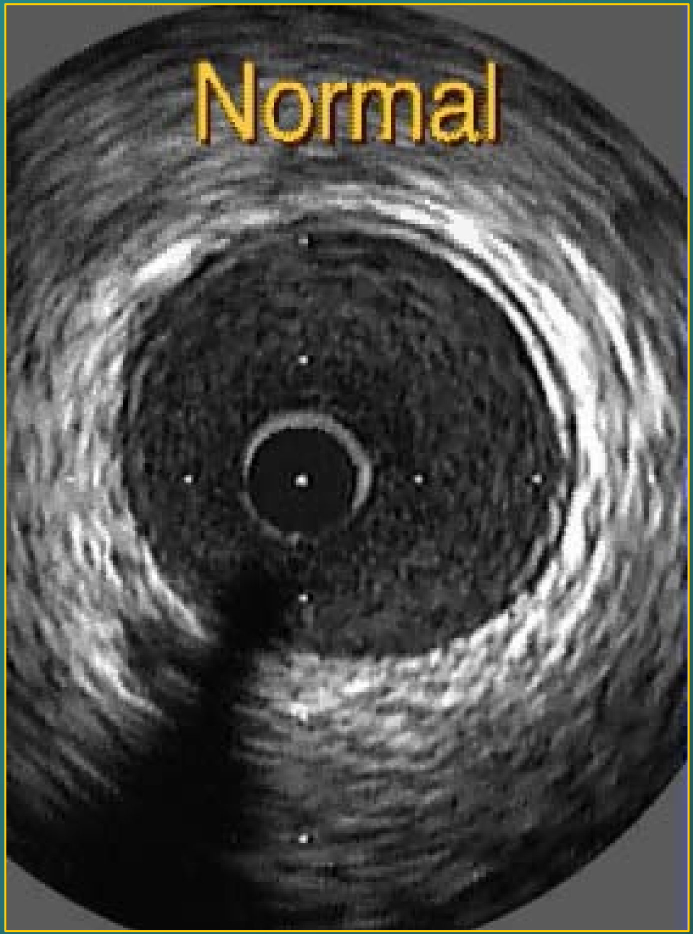
Intima, Media, and Adventitia

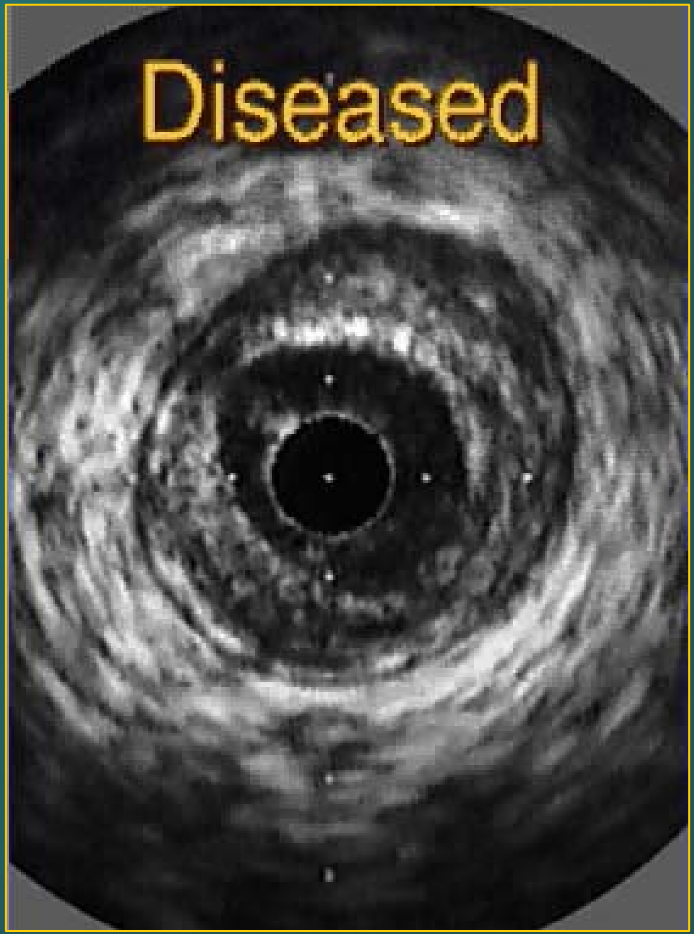
- In normal arteries, the material that most strongly reflects ultrasound is collagen. The reflectivity of collagen is 1000 times that of muscle.
  - The adventitia of coronary arteries has high collagen content and is, therefore, echoreflective.
  - The media of coronary arteries has a low collagen content, is mostly muscular, and is typically echolucent.
- The internal elastic membrane separates the intima from the media. Fibrous changes in the media make it difficult to identify the internal elastic membrane and image and quantify the media as a distinct structure.

- **Intimal disease** (plaque) is dense and will appear 'white'
- **Media** is made of homogeneous smooth muscle cells and does not reflect ultrasound (appears dark)
- **Adventitia** has 'sheets' of collagen that reflect a lot of ultrasound (appears white)






Normal


Diseased

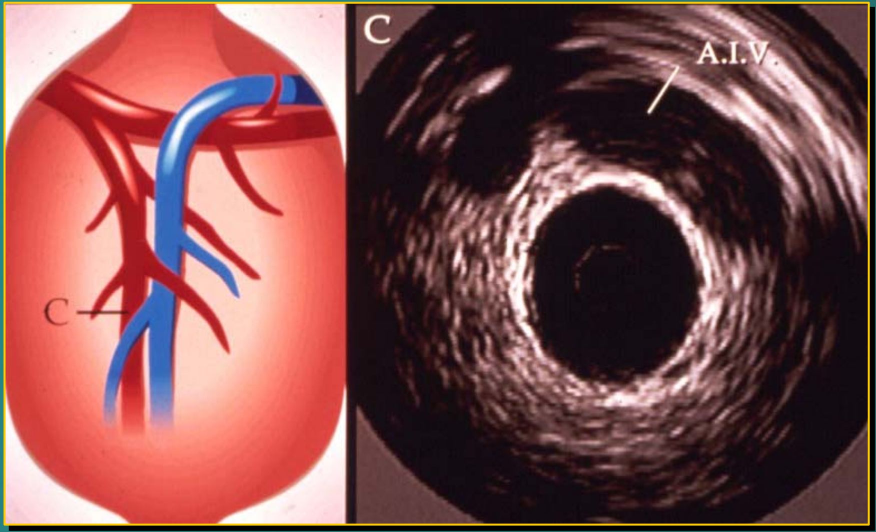
Principles of Measurements

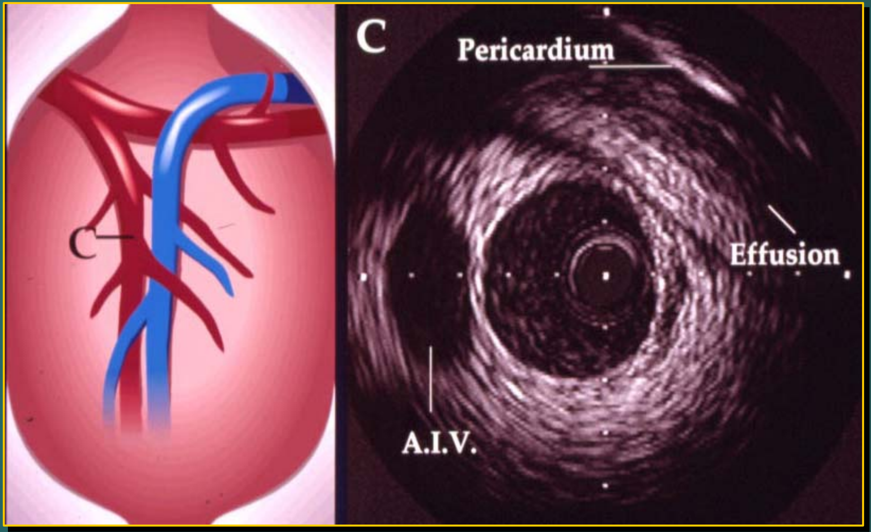
- Measurements made at the leading edge of an IVUS target are accurate and reproducible while measurements at the trailing edge are inconsistent and frequently yield erroneous results.
- Measurements should be performed relative to the center of mass of the lumen or artery, not relative to the center of the IVUS catheter.
- During clinical IVUS imaging of *non-stented lesions*, there are only two distinct boundaries that have consistent histologic correlates: the lumen-intima (or lumen/plaque) interface and the media-adventitia interface (or external elastic membrane=EEM).
- In stented vessels there can be three boundaries: EEM, stent, and lumen dimensions.
- We report plaque&media or atheroma measurements because we cannot separate the plaque from the media.

Spatial Orientation

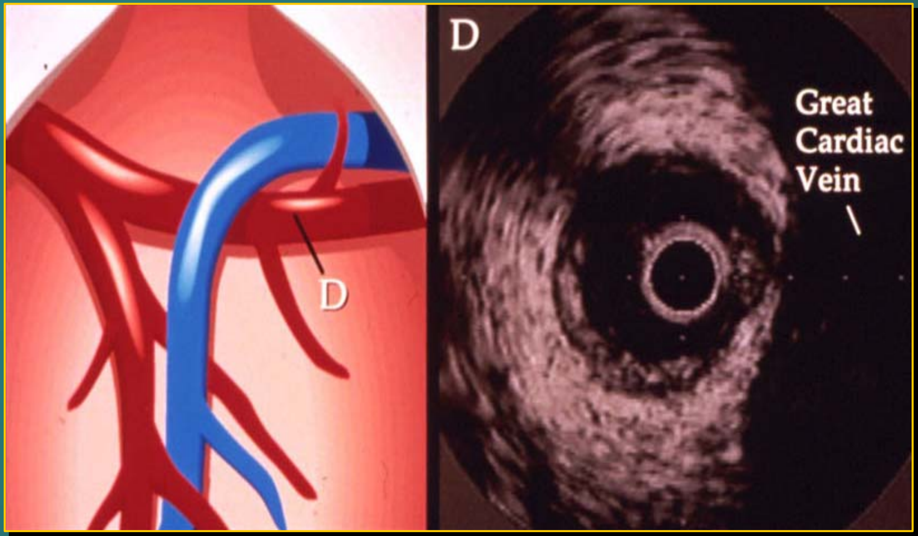
- There is no absolute (anterior versus posterior, left versus right) *rotational* orientation of the image.
- Instead, side branches are used during clinical IVUS imaging; and the image is described as if viewing the face of a clock.
- With some systems, images can be rotated electronically to produce a consistent orientation as an electronic aid to interpretation.
- Perivascular landmarks are also important references for both axial position and rotational orientation within the vessel. These landmarks include the pericardium, muscle tissue, and the venous system.

LAD

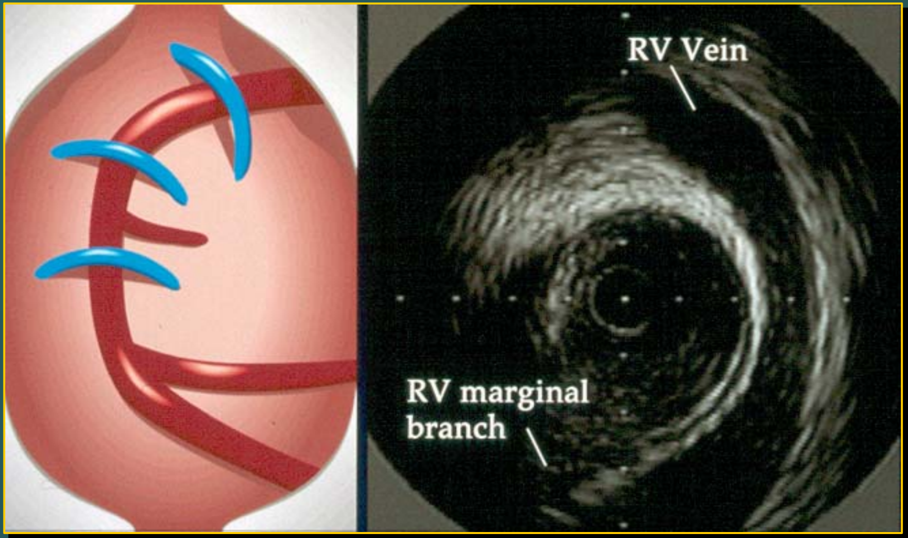

C
C
A.I.V.


C
C
Pericardium
Effusion
A.I.V.

LCX


D
D
Great
Cardiac
Vein

RCA


RV Vein
RV marginal
branch

Safety

- Hausmann et al., Circulation 1995;91:623-30
  - 2207 IVUS studies in 28 centers
  - Spasm occurred in 2.9%. Complications other than spasm occurred in 0.4% that were related to IVUS and in 0.6% that had a possible relationship to IVUS (10 acute occlusions, 1 embolism, 5 dissections, 1 arrhythmia, and 1 thrombus). Major events occurred in 0.25% (2 myocardial infarction and 3 emergency CABG).
- Gorge et al., JACC 1996;27:155A.
  - 7085 IVUS studies at 51 centers
  - 10 (0.1%) major complications other than spasm (7 dissection, 1 thrombus, 1 VF, 1 severe unresponsive spasm)
- Batkoff et al., CCD 1996;38:238-41.
  - 718 IVUS studies at 12 centers
  - 8 (1.1%) major complications (4 spasm, 2 dissections, 2 guide wire entrapments)

Artefacts

- Nearfield Artefacts
  - Ringdown
  - Blood speckle. Flushing contrast or saline through the guiding catheter may clear the lumen and help to identify tissue borders.
- Motion Artifacts
  - NURD (Non-Uniform Rotation Distortion) - only mechanical scanners
  - Axial (antegrade and retrograde) catheter motion with each cardiac cycle - both mechanical and phased array scanners
- Side lobes
  - More problematic with phased array scanners
- Transducer position artefacts - more important in larger vessels
  - Catheter obliquity
  - Catheter eccentricity
  - Vessel curvature

Essentials of an IVUS Program

- Director
- Dedicated Technicians, Nurses, and/or Fellows
- Image acquisition protocols and standards
- Identify ways to make imaging more efficient and effective
- Reports
- Housekeeping issues

Director

- Overall responsibility for clinical IVUS service including standards, protocols, and education

Dedicated Technicians*, Nurses, and/or Fellows

- Knowledge of imaging systems, catheters, and imaging protocol(s)
- Dedicated personnel are immediately available and flow of procedure and patient care not interrupted
  - System and catheter preparation
  - System controls and image optimization
  - Annotation
  - Make measurements, interpret images, and provide feedback to physician during procedure
- Care of systems, video tapes, CDs, etc.
- Keep procedure logs
- Generate reports

* Technicians often “run” an echo lab, why not an IVUS service

Imaging Procedure - I

- Remember to give heparin prior to inserting guidewire and IVUS catheter – avoid thrombosis
- Remember to give intracoronary NTG prior to imaging – avoid spasm
- Remember to disengage guiding catheter when imaging aorto-ostial lesions – avoid confusing the guiding catheter with the ostium

Imaging Procedure - II

- Standard image acquisition protocols needed for
  - Viewing, understanding, and comparing studies at a later date
  - Serial IVUS analysis
  - Multicenter studies (often have their own protocol)
- Accurate voice annotation
- Label studies completely
  - Vessel (e.g., LAD) and lesion location (e.g., proximal)
  - Device use
  - Temporal relationship between imaging run and procedure (e.g., pre-intervention, post-stent #1, etc.)
- Perform complete imaging runs back to aorto-ostial junction
  - Free look at proximal vessel and at LMCA if imaging LAD/LCX
- Motorized pullback

Motorized Pullback

- 0.5mm/sec is recommended
- Advantages
  - Steady, slow transducer pullback to avoid imaging any segment too quickly and avoid skipping any segment
  - Ability to concentrate on images without having to worry about catheter manipulation
  - Length measurements
  - Volume measurements
  - Reproducible image acquisition for multicenter and serial studies
- Disadvantages
  - Potentially inadequate examination of important regions of interest because transducer does not remain long at any one specific site in the vessel

Manual Pullback

- Advantages
  - Ability to concentrate on specific regions of interest by pausing the pullback at a specific location
- Disadvantages
  - Can skip over pathology by pulling the transducer too quickly
  - No length or volume measurements
  - Antegrade and retrograde catheter movement can be confusing when study is reviewed at a later date
  - Impossible to pull transducer slowly and uniformly

Imaging Efficiency and Effectiveness

- Perform imaging run(s), remove IVUS catheter, and make measurements from video tape or digital replay, NOT during live imaging
  - Less patient ischemia
  - More efficient use of cath lab time
  - Additional measurements can easily be made and additional questions easily answered
- Display images on angiographic monitors
  - Superior monitors
  - Get IVUS system away from table
  - Requires separate roadmap or reference monitors

Basic Report

- Patient demographics
- Indications
- Brief description of IVUS procedure
  - Equipment
  - Artery(s) imaged
- Basic findings
  - Basic measurements (e.g., MLA, MSA, plaque burden, etc.)
  - Notable morphology (e.g., plaque rupture, thrombus, calcium, dissection, intramural hematoma, etc.)
- Changes in therapy because of IVUS imaging
- IVUS-related complications and consequent therapy

Comprehensive Report

- In addition to information contained in Basic Report. .
- Pre-intervention and/or post-intervention quantitative analysis of three cardinal images slices: distal reference, lesion, proximal reference
  - EEM CSA
  - Lumen CSA
  - Plaque&media CSA and plaque burden
  - Area stenosis
  - Stent measurements
  - Lesion length

Reference

Mintz GS, Nissen SE, et al. American College of Cardiology Clinical Expert Consensus Document on Standards for Acquisition, Measurement, and Reporting of Intravascular Ultrasound Studies. *J Am Coll Cardiol* 2001;37:1478-1492

Mintz GS. *Intracardiac Ultrasound*. Taylor and Francis. 1995