

Introduction to Physics and Applications of Vascular Imaging

ACMP 2009 Annual Meeting

Medical Physics Applications in Cardiac and Vascular Imaging

David E. Hintenlang, Ph.D.
DABR, FACMP

University of Florida
Gainesville, FL

Vascular Imaging Development

- 1896
 - Vascular image of amputated hand
 - Mixture of salts used for contrast
- 1920's
 - Femoral and cranial imaging developed
 - Sodium bromide contrast
- Rapid development continues
 - From 1979-2002: 479% increase

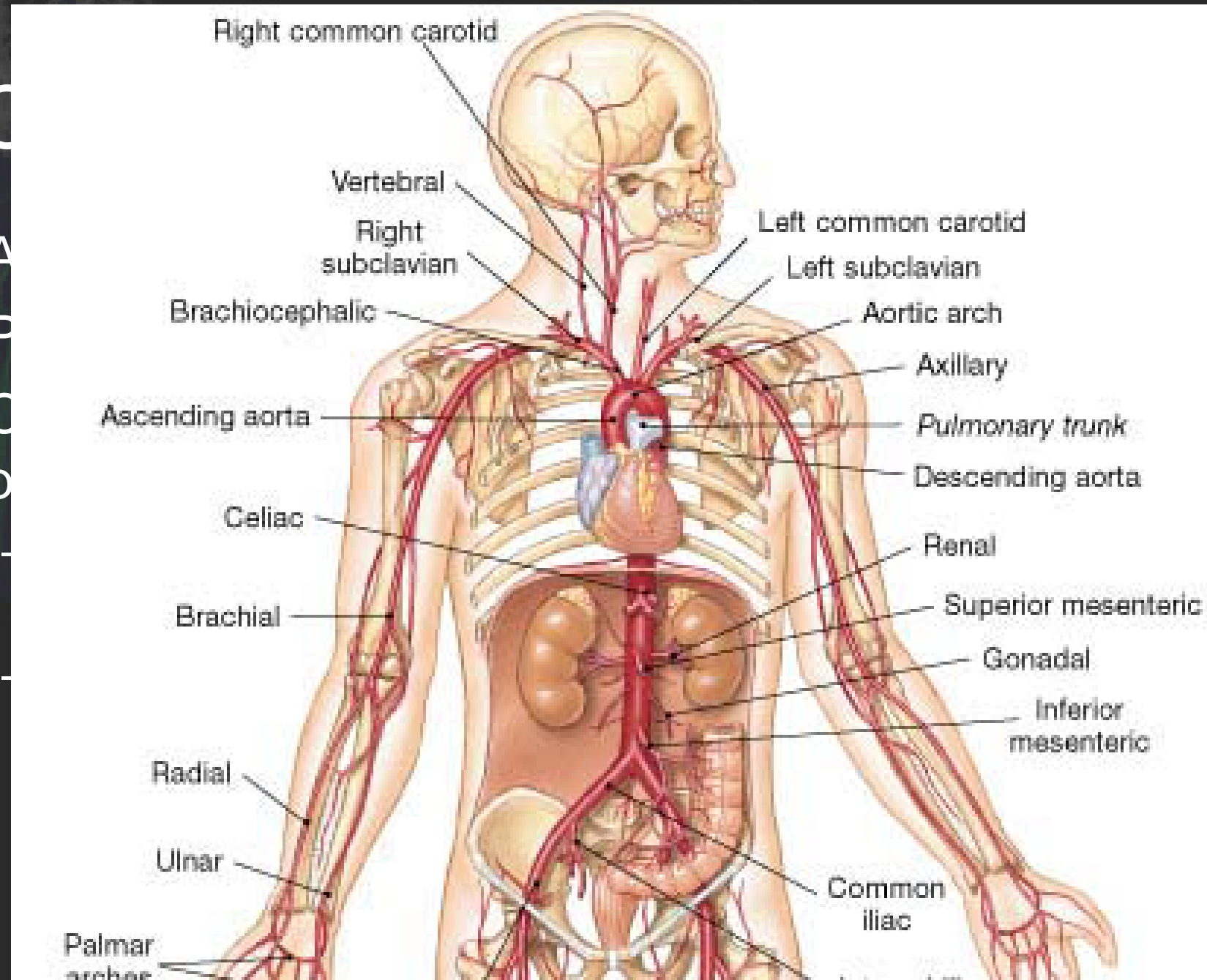
Cardiovascular disease (CVD)



- 34.2 % of the deaths in the US attributed to CVD
- More than 4 million in-patient CVD associated procedures per year using x-ray imaging
- Fluoroscopic based imaging has been the traditional “gold standard”
- New technologies:
 - MR
 - CT
 - PET/SPECT
 - Ultrasound

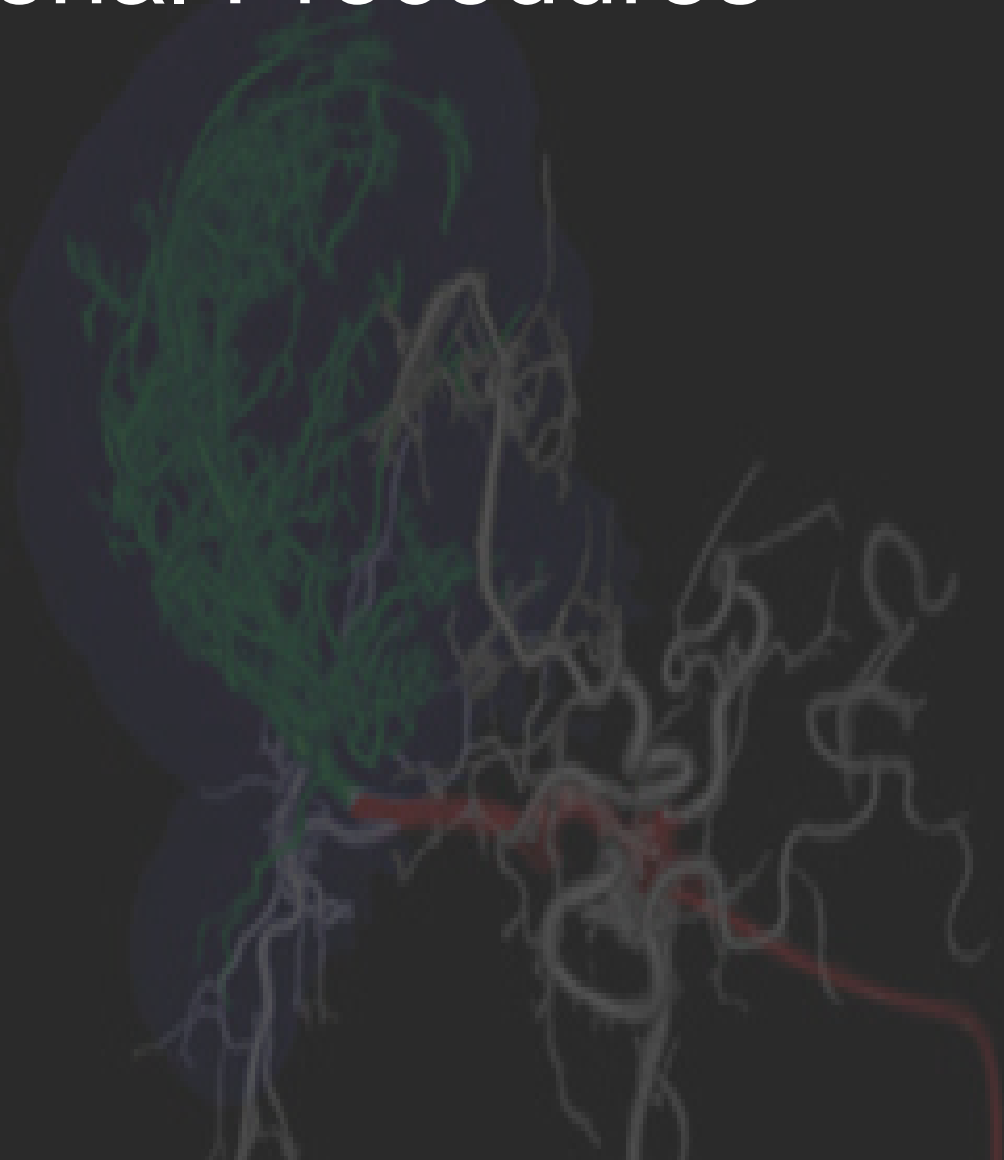
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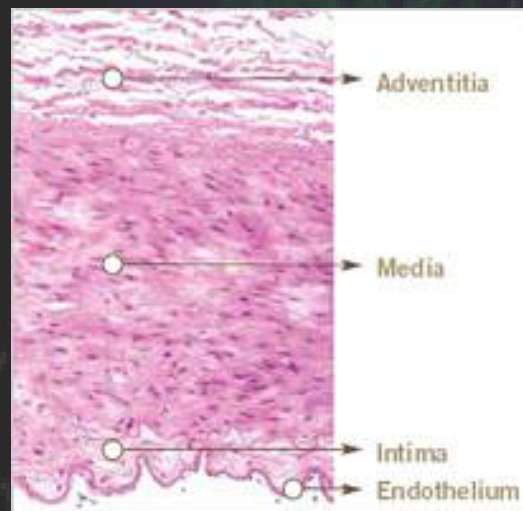
Vascular Disease and Interventional Procedures

- Coronary Disease
- Aneurisms
- Stroke
 - Hemorrhagic
 - Ischemic
- Artherosclerosis
 - Carotid
 - Coronary
 - Renal
 - Peripheral (PAD)



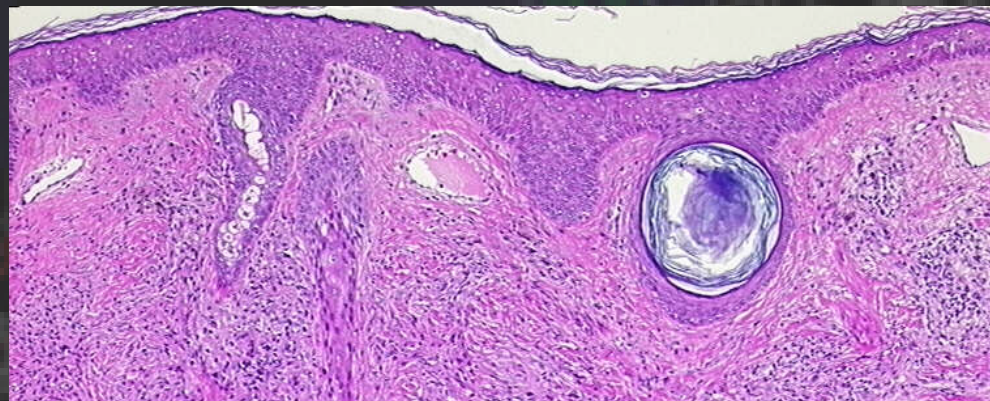
Progression of Artherosclerosis

- Buildup of plaques accelerates with aging
- Blood Vessel
 - Intima – endothelial cells
 - Media – smooth muscle fiber
 - Adventitia – connective tissue and blood vessels



Plaque progression:

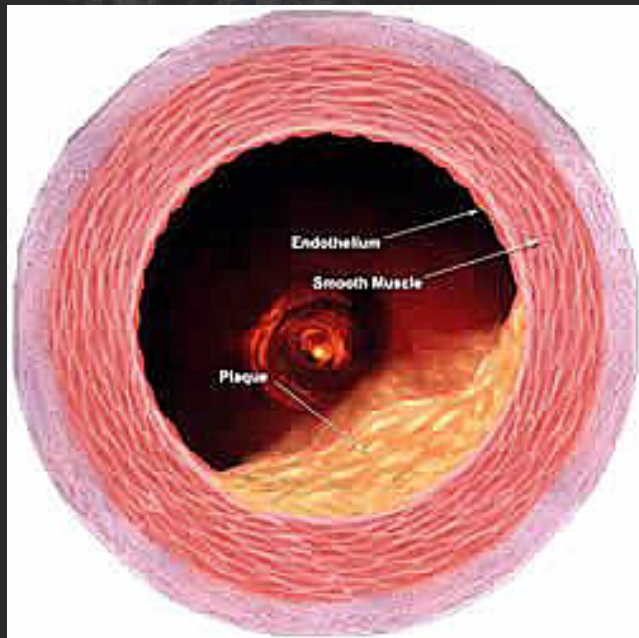
- LDL cholesterol accumulates on arterial wall when nitric oxide production is impaired
- Endothelial cells signal white blood cells
- White blood cells penetrate the intima and trigger an inflammatory response
- Macrophages consume LDL cholesterol to become fat laden “Foam cells”



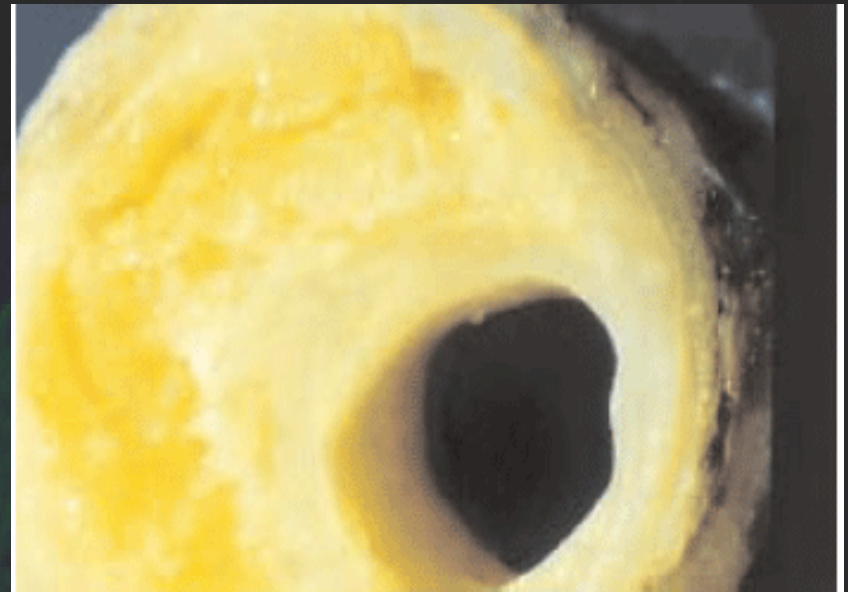
- Foam cells form a fatty streak – early sign of atherosclerotic plaque.



- Plaques trap calcium, cholesterol, platelets and cellular debris
- Continues to grow & develops a fibrous cap
- Substances released from foam cells may destabilize the cap, allowing rupture
 - Thrombus or emboli may occur
 - May result in heart attack or stroke

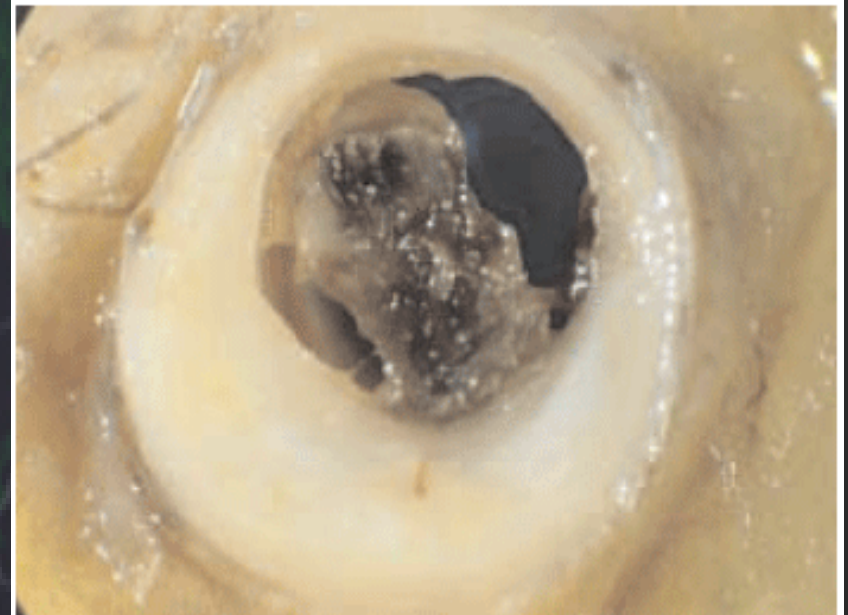


Stable Plaque



A

Thrombosis adherent to the surface of a plaque



Diagnostic Studies

- Coronary angiography
 - Arterial/venous blockage
 - Evaluate heart valve function
 - Ventricular aneurisms
 - Electrophysiology
- Utilizes contrast and DSA techniques
- Evaluation of stroke
 - Hemoragic/ischemic
 - CT/MR
- Echo Cardiography

Therapeutic Procedures

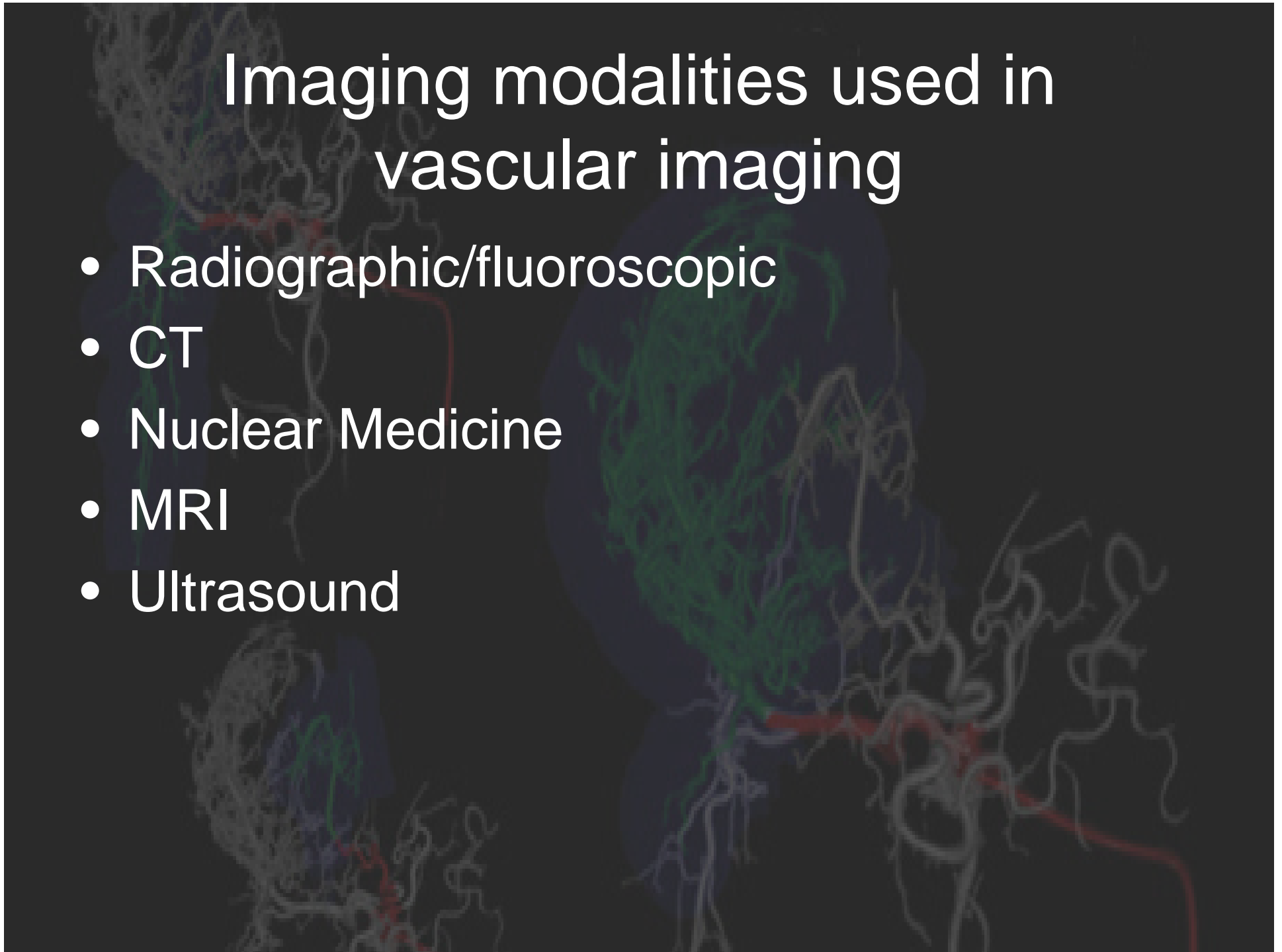
- Use real-time imaging methods
- Guide catheters and tools through vessels
- Remove & treat disease non-invasively
- Examples:
 - Compress plaques
 - Percutaneous Transluminal Angioplasty (PTA)
 - Balloon Angioplasty
 - Remove plaques
 - RF Ablation
 - Stenting and stent/filter replacement
 - Opening stenotic heart valves
 - Embolization of aneurisms
 - Chemoembolization
 - Transjugular Intrahepatic Portosystemic Shunt (TIPS)

Features of interventional imaging

- Visualize anatomy
- Visualize catheters and tools
- Provide real-time imaging
 - Frame rates typically at least 6 fps
- Moderate spatial resolution
- Minimize radiation dose/time of procedure
- ACR recommends fixed equipment over portable

Imaging modalities used in vascular imaging

- Radiographic/fluoroscopic
- CT
- Nuclear Medicine
- MRI
- Ultrasound



Fluoroscopic Guided Procedures

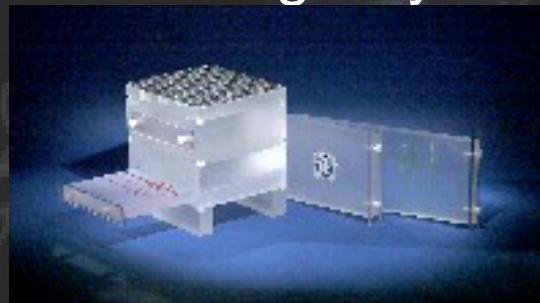
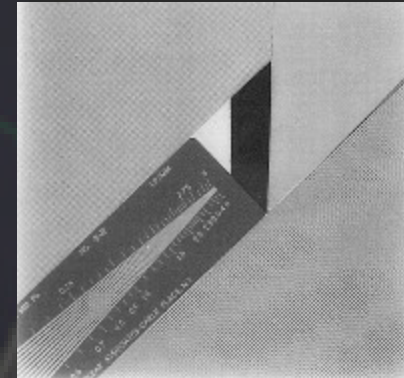
- Has long been the “Gold Standard”
 - Perhaps being replaced by CTA?
- Remains the most widely used modality
- Commonly Procedures
 - Arterial and venous occlusions
 - Carotid artery stenosis
 - Pulmonary embolisms
 - Acute limb ischemia
 - Arterial stenosis
 - Cerebral aneurisms
 - Arterial venous malformations

Issue for fluoroscopic guided procedures

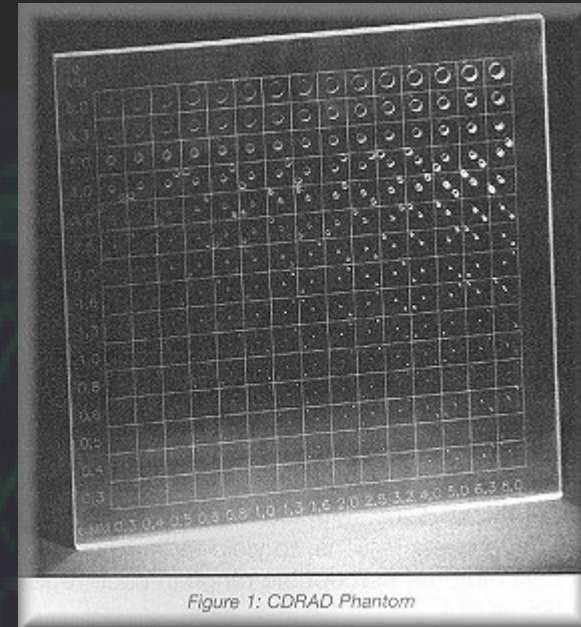
- Use of ionization radiation
 - Skin injury
 - Patient dose tracking
 - Training of non-radiologists
- Visualization of catheters & tools
- Visualization of anatomy
 - Contrast agents

Evaluating Image Quality

- Cardiac digital imaging QC
 - Fluke and Nuclear Associates
 - Spatial resolution
 - Density & contrast
 - Uniformity of focus
 - Includes contrast objects, line pair, copper mesh
- DSA Phantom
 - Permits optimization of digitally subtracted images



- Contrast detail phantoms



- NEXT Phantoms
 - Copper plate
 - Lead plate
 - Image quality tool

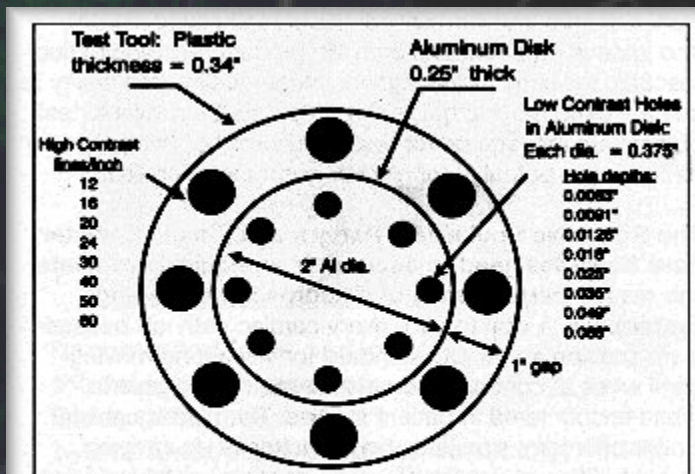


Diagram of the Fluoroscopic Image Quality Test Object used for the upper GI tract fluoroscopic survey illustrates the high-contrast wire-mesh patterns and the aluminum (Al) disk with holes for low-contrast evaluation.

Skin Injury



U.S. Food and Drug Administration



Department of
Health and
Human Services

CENTER FOR DEVICES AND RADIOLOGICAL HEALTH

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FDA Public Health Advisory: Avoidance of Serious X-Ray-Induced Skin Injuries to Patients During Fluoroscopically-Guided Procedures

(We encourage you to copy and distribute this Advisory)

September 30, 1994

To: Healthcare Administrators
 Risk Managers
 Radiology Department Directors
 Cardiology Department Directors

The Food and Drug Administration (FDA) Center for Devices and Radiological Health (CDRH) has received reports of occasional, but at times severe, radiation-induced skin injuries to patients resulting from prolonged, fluoroscopically-guided, invasive procedures. Procedures typically involving extended fluoroscopic time are:

- percutaneous transluminal angioplasty (coronary and other vessels),
- radiofrequency cardiac catheter ablation,
- vascular embolization,
- stent and filter placement,
- thrombolytic and fibrinolytic procedures,
- percutaneous transhepatic cholangiography,
- endoscopic retrograde cholangiopancreatography,
- transjugular intrahepatic portosystemic shunt,
- percutaneous nephrostomy,

www.fda.gov/cdrh/fluor.html

Skin Damage Thresholds

Effect	Dose
Temporary Epilation	3 Gy
Main Erythema	6 Gy
Moist desquamation, ulceration, necrosis	15-20 Gy

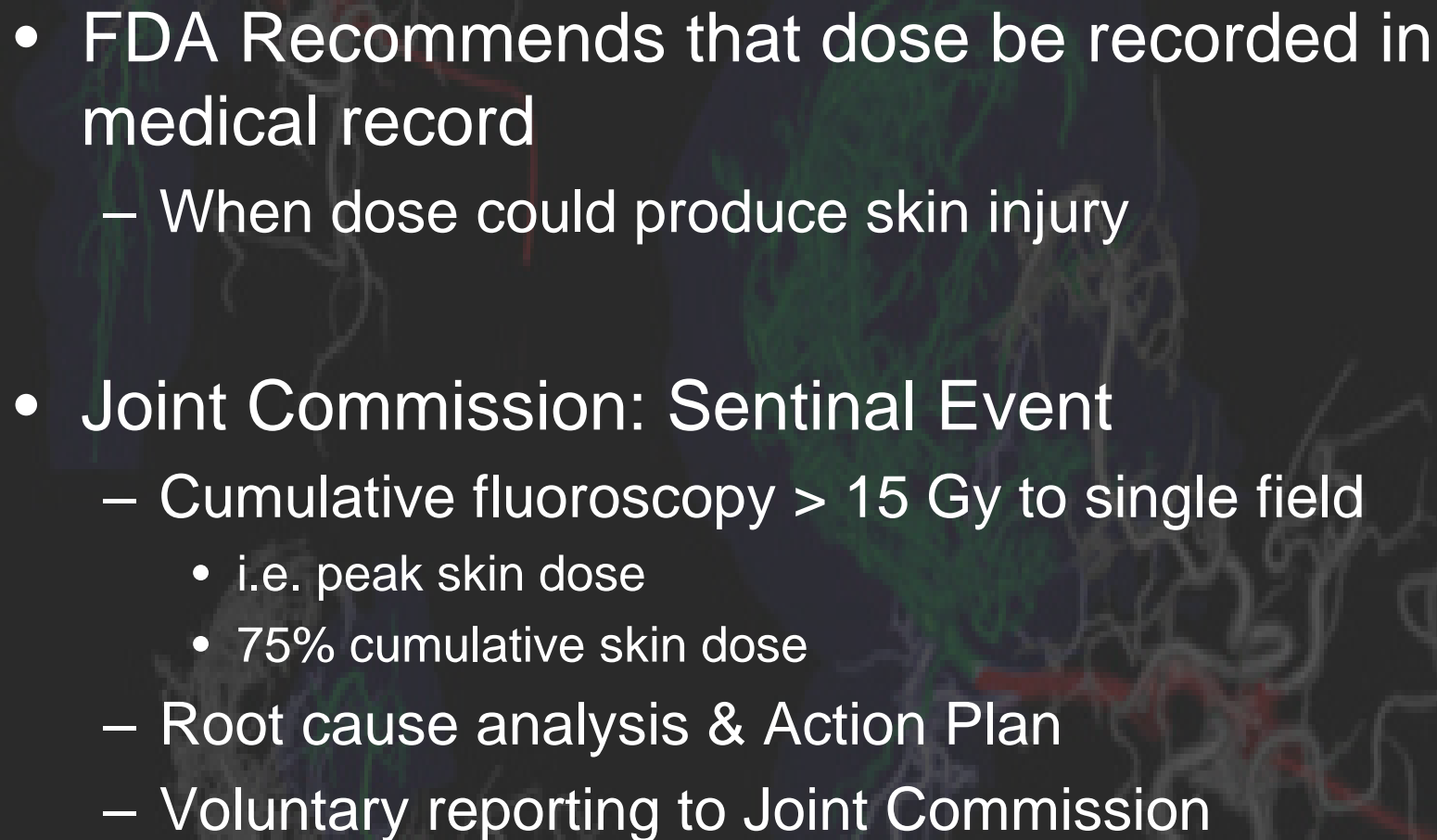




Henry MF Maender, JL, Shen Y, Tschen JA, Subrt P, Schmidt JD, Hsu S, Fluoroscopy induced chronic radiation dermatitis: A report of three cases, Dermatology Online Journal, 15 (1) 3, **January 2009**

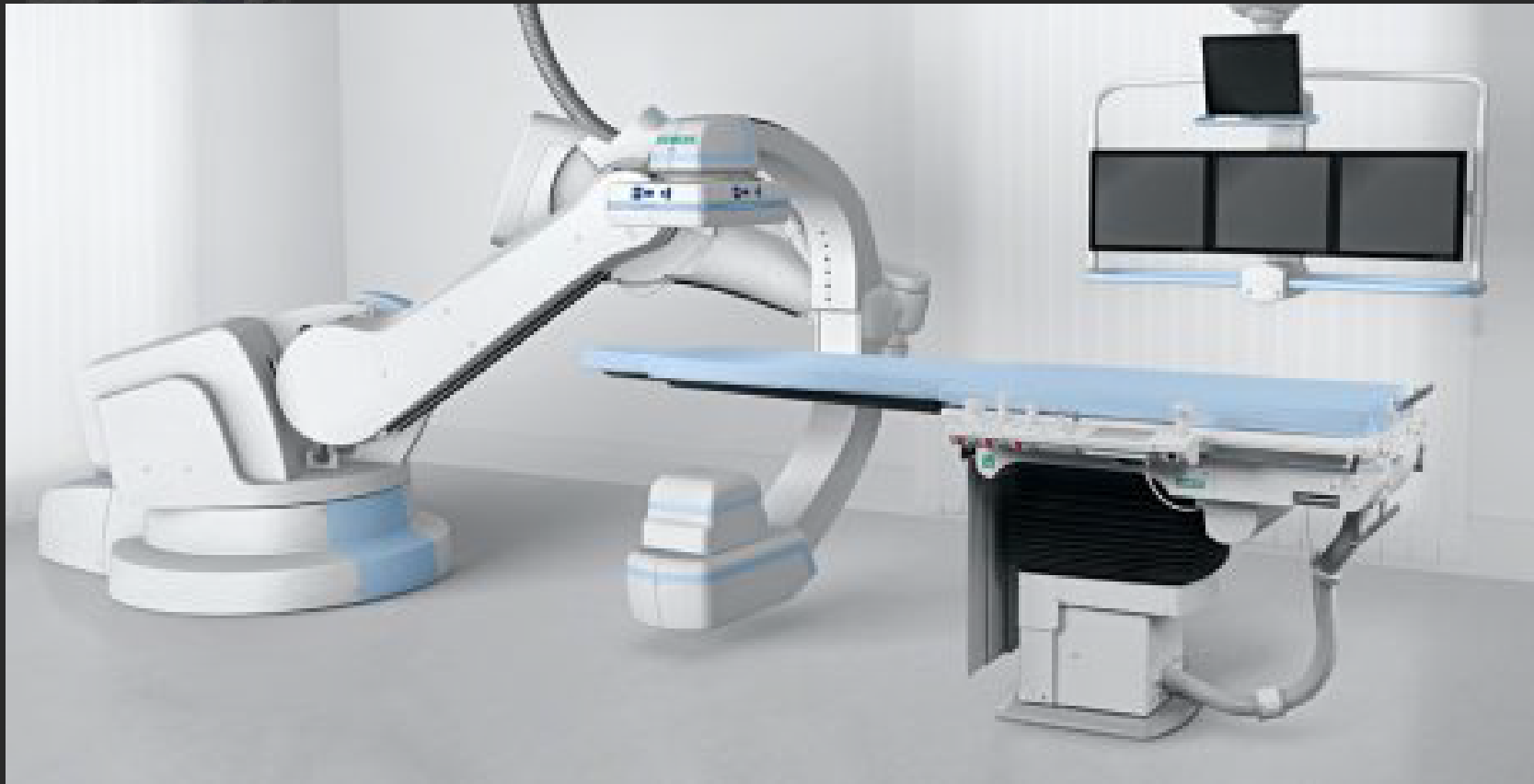
Dose Monitoring

- Fluoroscopy time
- Dose-area product (DAP)
- Cumulative dose at reference point (RP)
- Direct measurement of peak skin dose
 - Integrated measurements, i.e. TLD or Film
 - Real-time : i.e. MOSFETS or FOC
- Software reconstruction
 - DAP & table/tube positions

- 
- FDA Recommends that dose be recorded in medical record
 - When dose could produce skin injury
 - Joint Commission: Sentinal Event
 - Cumulative fluoroscopy > 15 Gy to single field
 - i.e. peak skin dose
 - 75% cumulative skin dose
 - Root cause analysis & Action Plan
 - Voluntary reporting to Joint Commission

Dose Reduction

- Copper Filtration
 - Lowers patient skin dose
 - Filtration may change with frame rate
 - High frame rates result in lower exposure at detector, hence some filtration may be removed.



- Current dose reduction techniques = fast repositioning

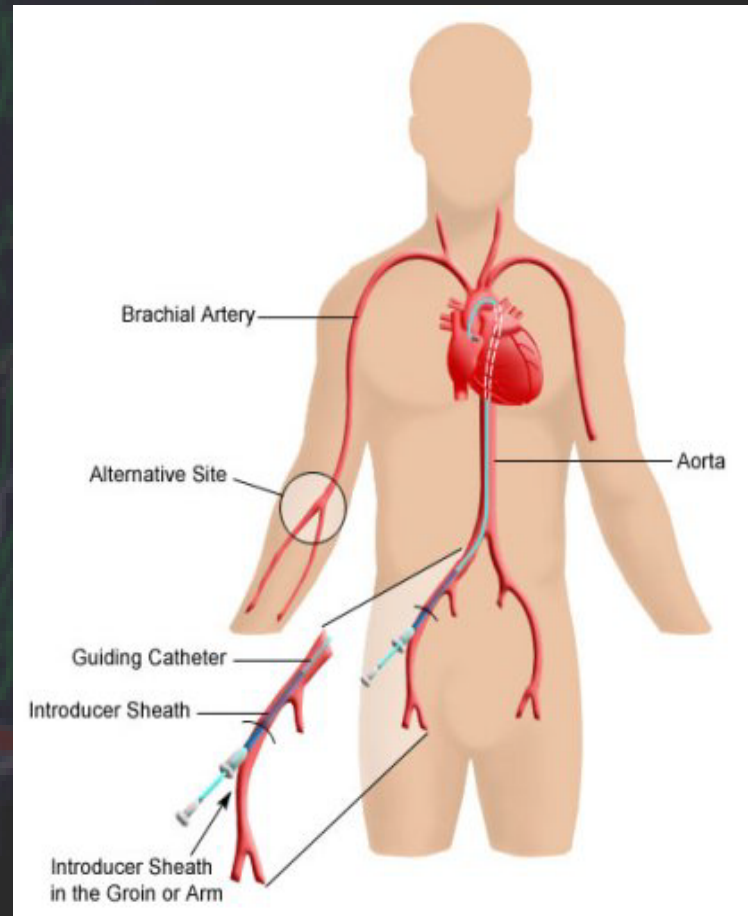
Training of non-Radiologists

- Credentialing programs

Tune in next hour.....

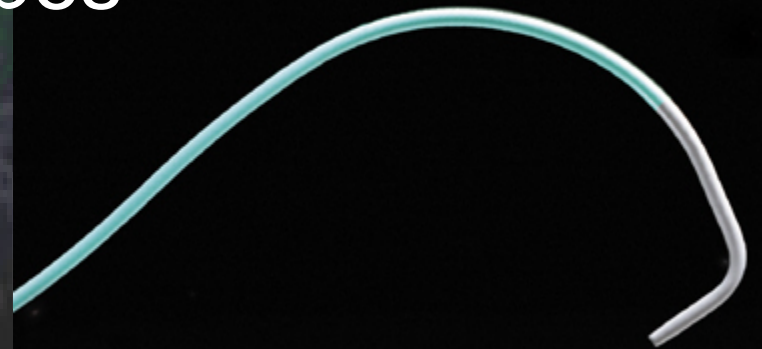
Visualization of Catheters, etc.

- Thin plastic usually hard to distinguish
- Standard procedure uses a guidewire introduced through a sheath
- Catheter slides over guide wire to correct location
- Guidewire pulled out & contrast may be injected



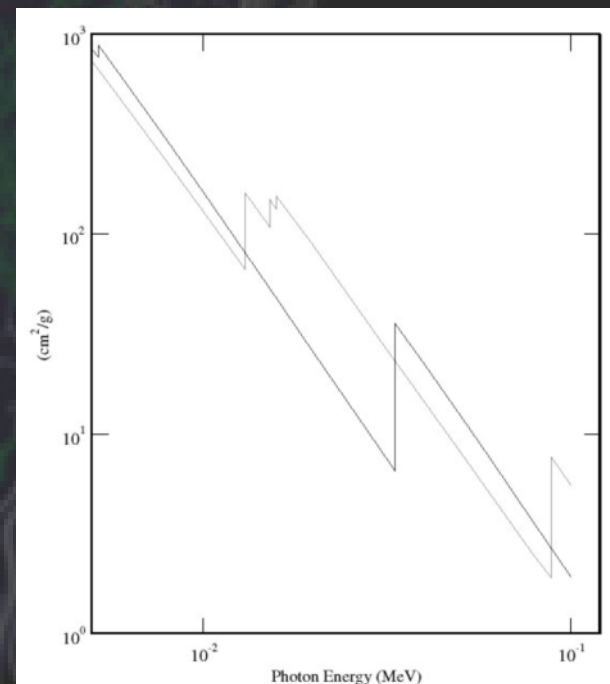
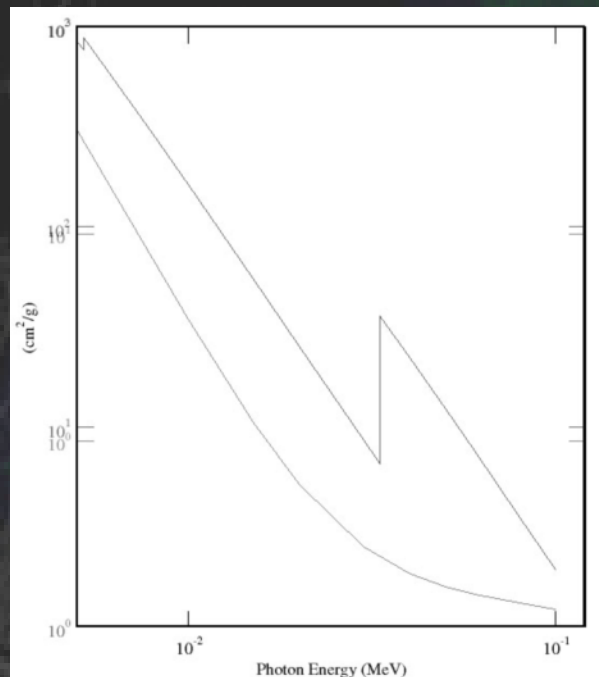
Catheter features

- Tungsten layering at distal tip for visualization
- Marked every 5-10 cm for positioning
- Soft-tip, but stiff enough to push and control
- Variety of sizes and shapes

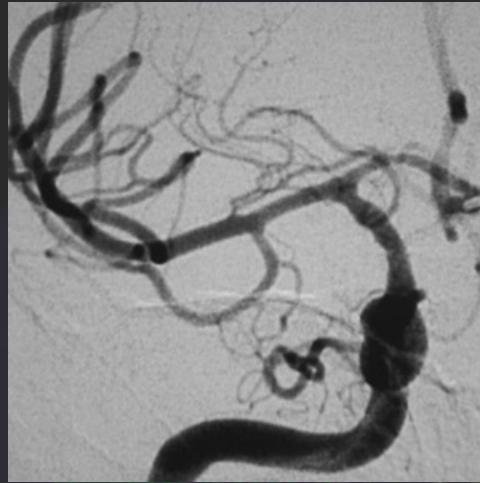


Visualization of Anatomy

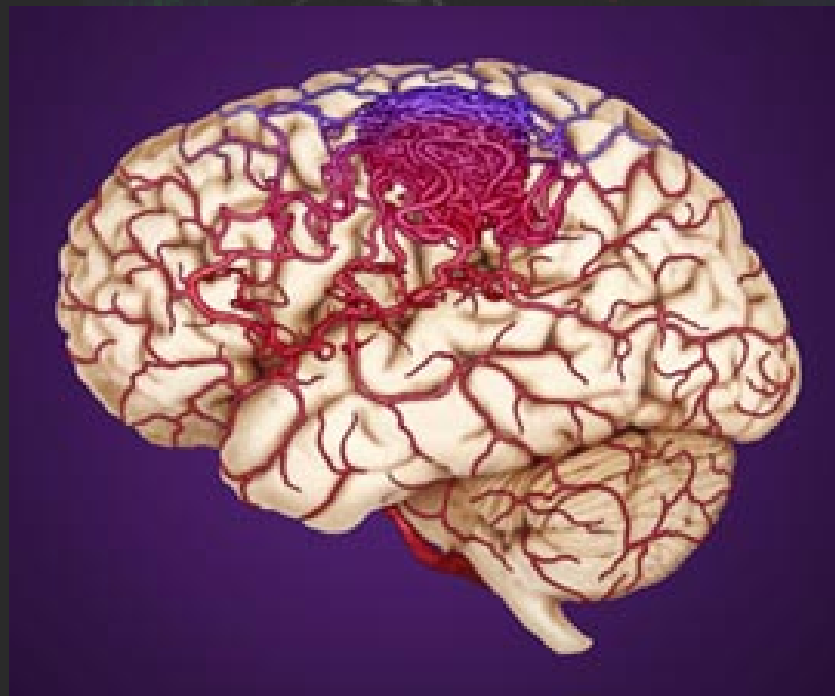
- Contrast agents injected intravenously
- Typically iodine component provides enhanced absorption



- Combined with DSA provides visualization of vessels



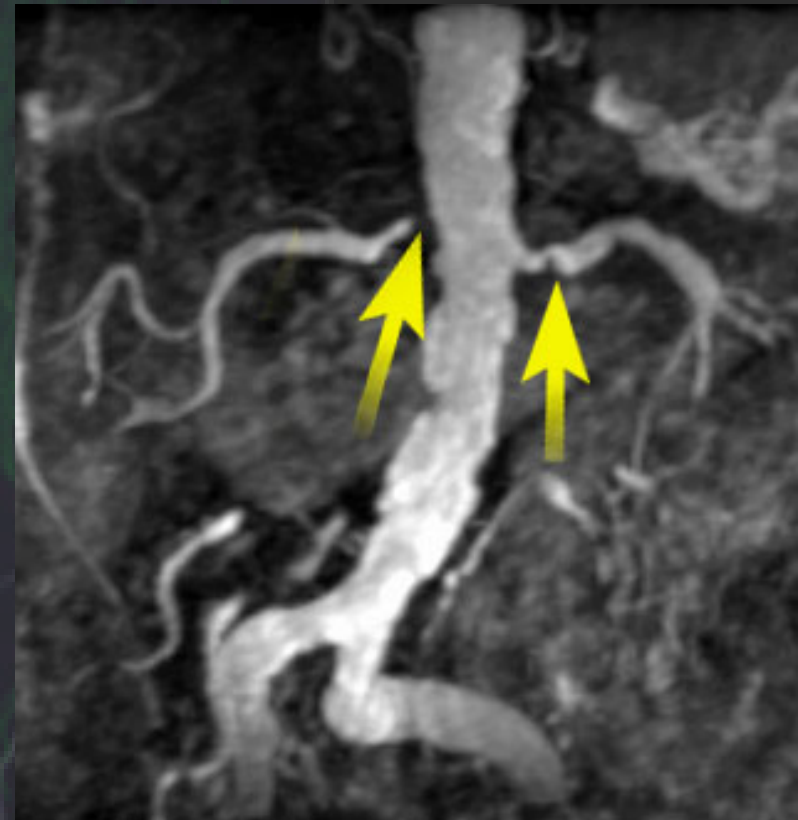
Arteriovenous Malformation (AVM)



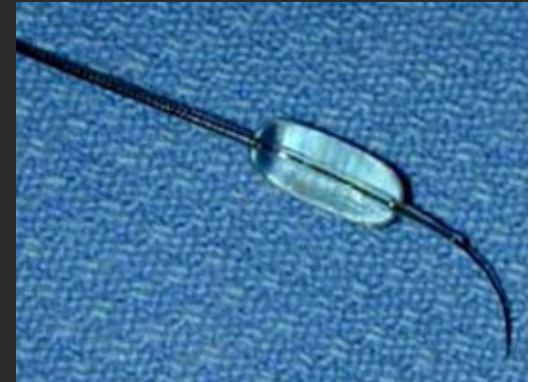
Normal Renal Vessels



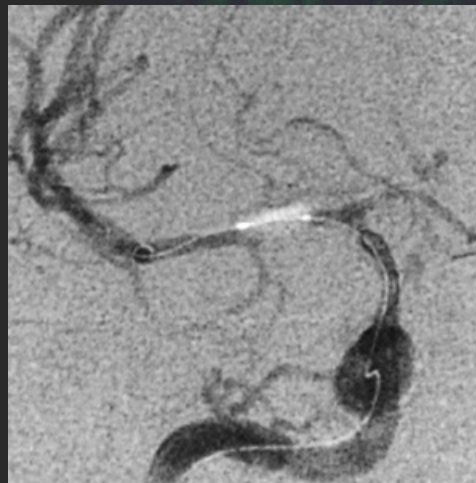
Atherosclerotic Vessels



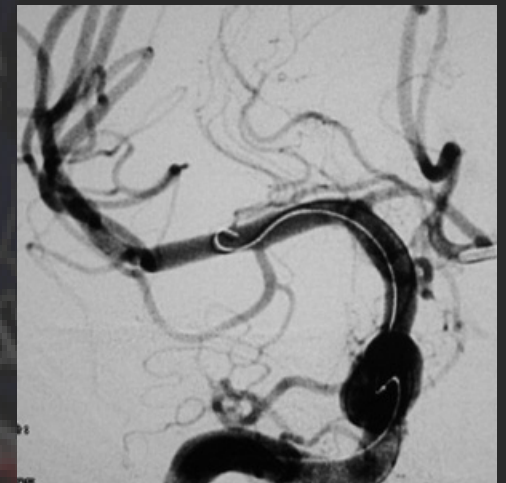
Angioplasty



Before Treatment



During Treatment
(Balloon Inflated)



After Treatment

Contrast Media & Patient Risks

- ACR Manual on Contrast Media, ACR 2008
- At risk for adverse reactions
 - Allergies
 - Diabetes
 - Renal failure
 - Cardiac conditions
- Ionic vs Non-Ionic
 - Ionic: higher osmolarity and greater risk of side effects
 - Non-Ionic: lower osmolarity and less risk of side effects
- Adverse Reactions
 - Mild to moderate: 5-12% of patients
 - Severe : < 0.1% non-ionic and < 0.2% ionic
 - No fatalities in 170,000 pts examined

Plaque ablation techniques

- Rotablation
- Laser ablation
 - Limited by restenosis
- Intervascular Brachytherapy
- Drug eluting stents (DES)
- RF ablation
- Ultrasound ablation

Vascular Ultrasound Imaging



- External transducers
 - Peripheral
 - Carotid
 - TTE
- Internal transducers
 - TEE
 - IVUS

Ultrasound Techniques

- Utilize reflection of ultrasonic waves off of tissue inhomogeneities
- No ionizing radiation risks
- Inherently real-time
- Short distances for intravascular applications use high frequencies ($\sim 20\text{-}40$ MHz)

- Blood flow quantification and processing for enhanced image quality
- Contrast for perfusion studies

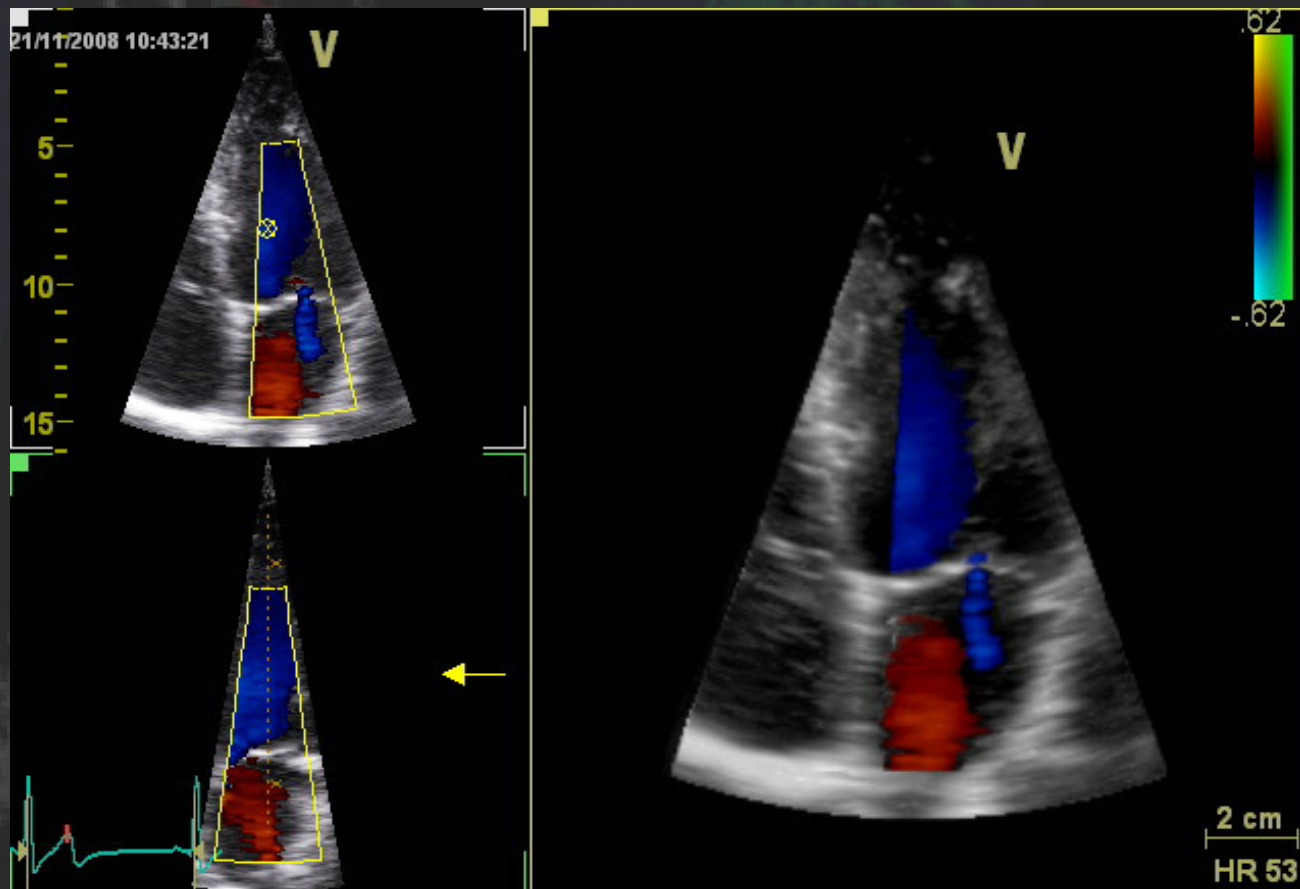
Carotid bifurcation



Echocardiography

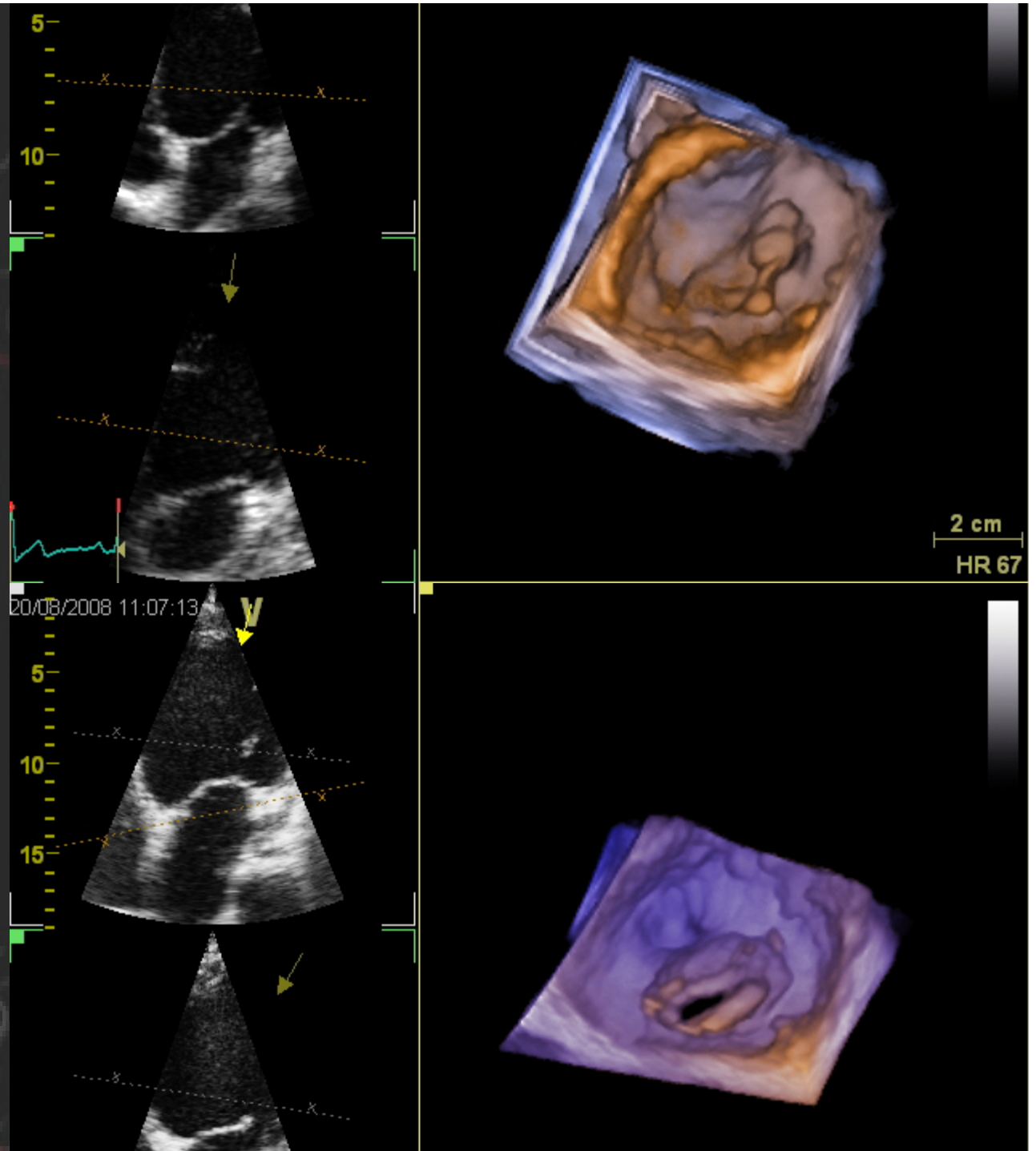
- Transthoracic echocardiograms (TTE)
 - Can reasonably assess heart valve motion and degree of heart muscle contraction.
 - Wave must transmit across skin, fat, ribs, and lungs
- Transesophageal echocardiograms (TEE)
 - Transducer located in esophagous behind heart
 - Improved transmission and image quality over TTE
 - Evaluates chamber condition and functioning of valves, aortic aneurisms, septum defects, clots, tumors, etc.

- Incorporation of Doppler for blood flow direction and quantification



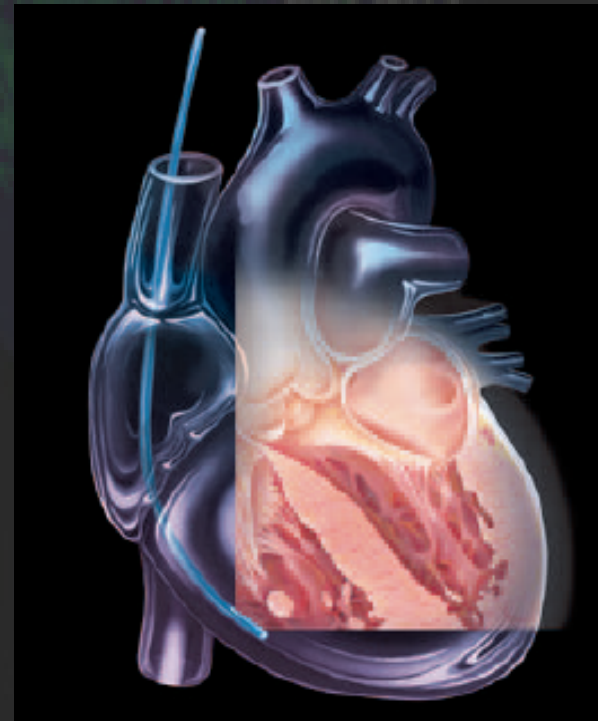
- 4-D Cardiac

- Mitral stenosis



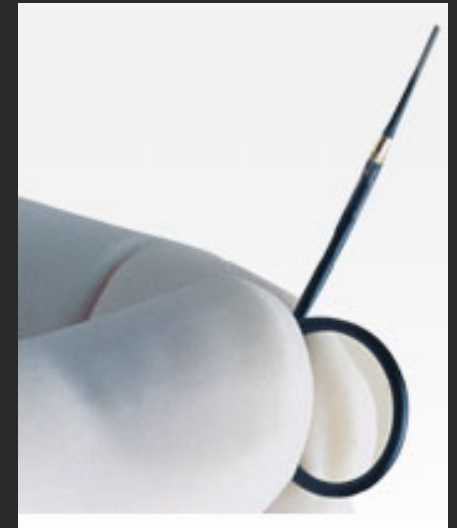
In-heart echocardiology

- Siemens Acuson
- Sterile, one use catheters
- Range to 15 cm
 - Low frequency
 - Lower spatial resolution
- Alternative to TEE
- Siemens Sequoia
 - 64 element phased array
 - 7 mm aperture
 - 10-5 MHz
 - Doppler capability
 - 110 cm catheter



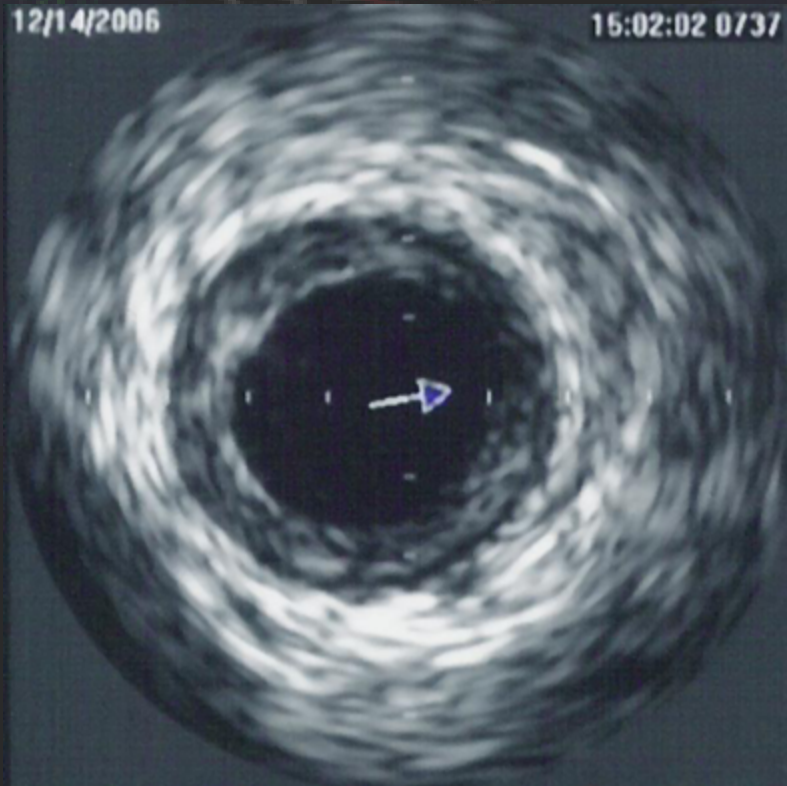
Intravascular Ultrasound (IVUS)

- Development initiated in late 1980's
- Useful for assessing drugs and post-stenting restenosis
- Performed in conjunction with angiography
- Transducer ~ 1mm at end of catheter
- Multi-element transducer allows 360° radial scanning
- Images vessel and plaque morphology
 - Permits evaluation of stability
- Most commonly used in coronary arteries



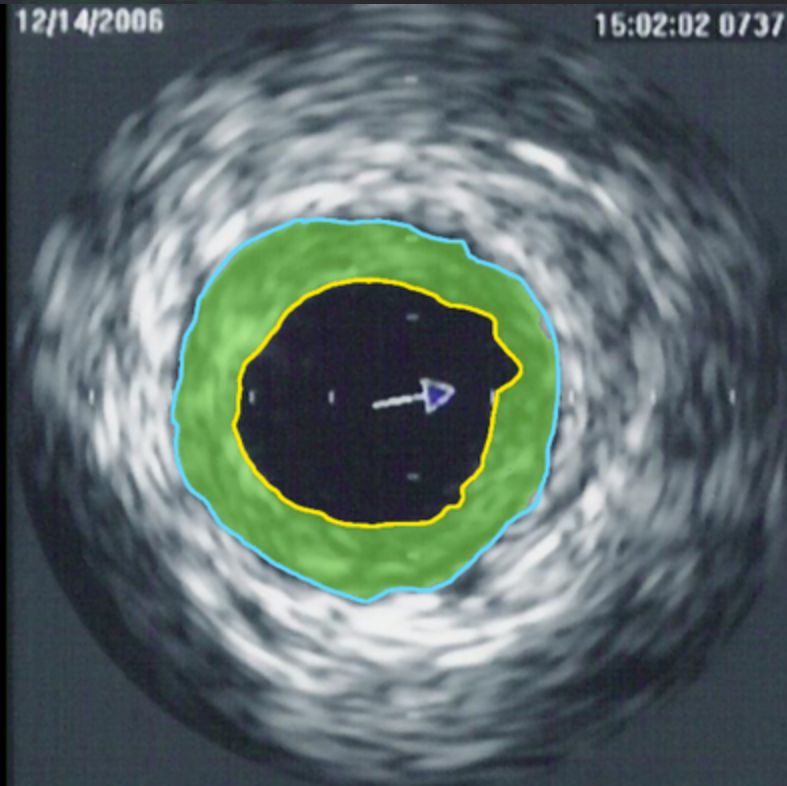
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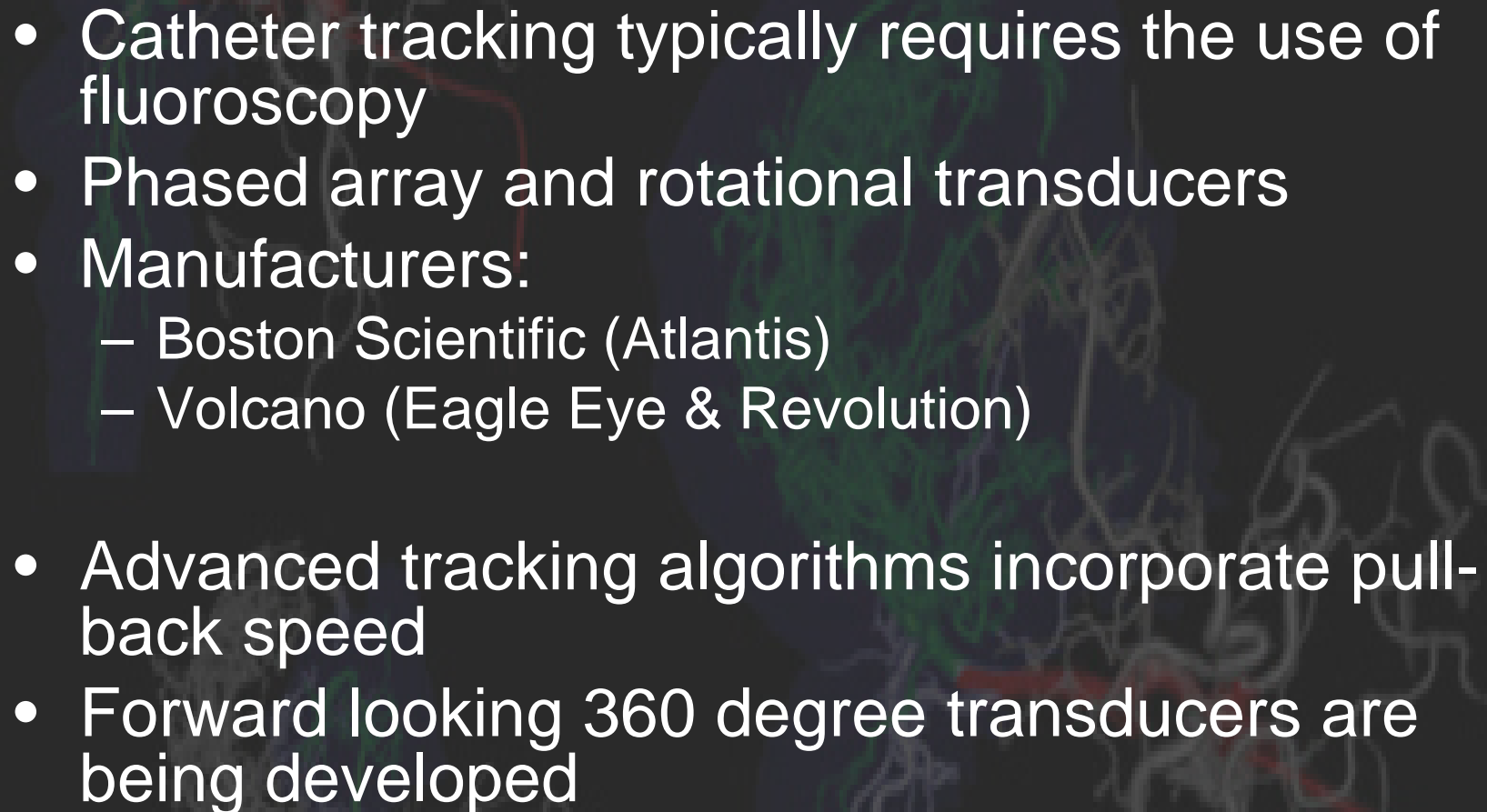
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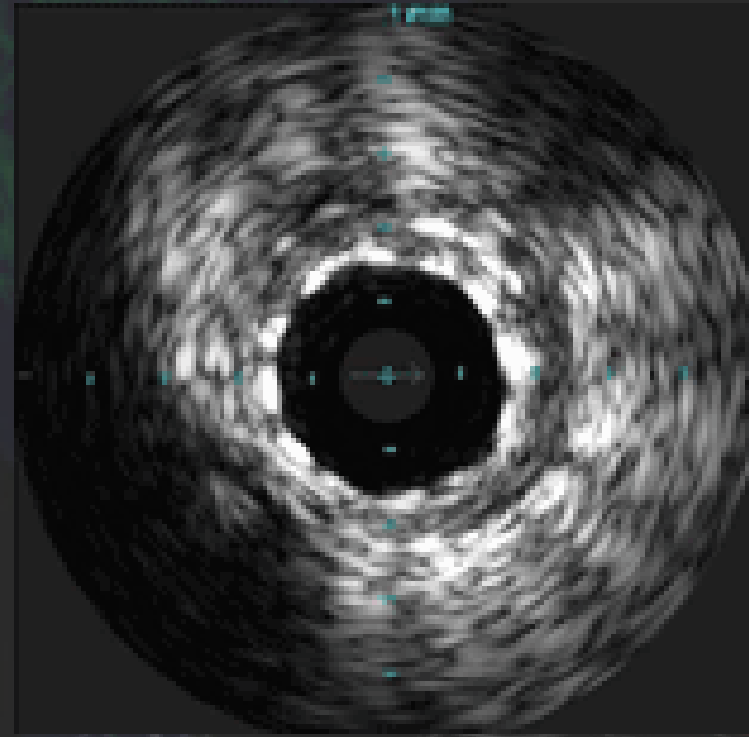
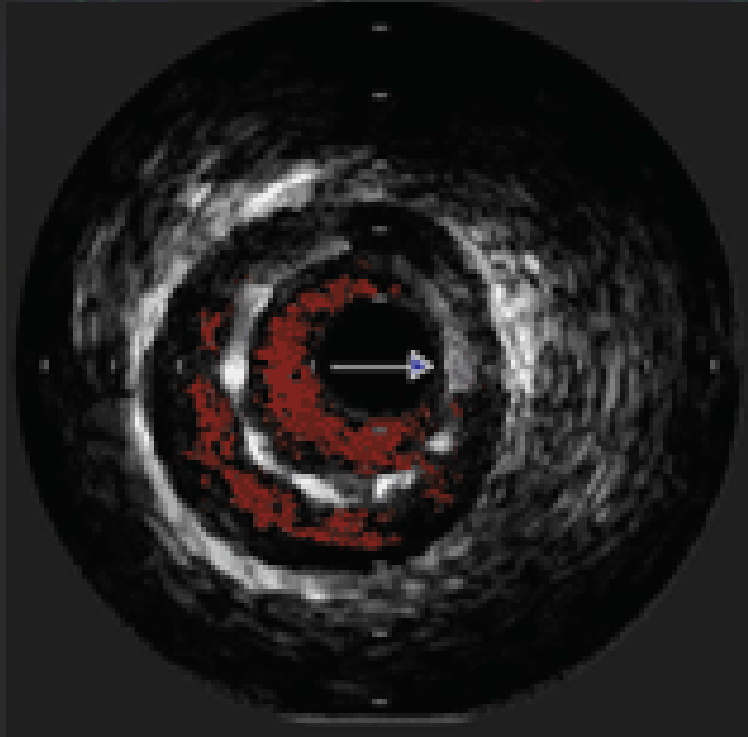
Comparisons with angiography

- Advantages
 - No radiation risk
 - Provides direct visualization of plaque
 - Better visualization of remodeling (vs restenosis)
- Disadvantages
 - Longer procedure
 - Increased risk due to catheter
 - Still expensive

- 
- Catheter tracking typically requires the use of fluoroscopy
 - Phased array and rotational transducers
 - Manufacturers:
 - Boston Scientific (Atlantis)
 - Volcano (Eagle Eye & Revolution)
 - Advanced tracking algorithms incorporate pull-back speed
 - Forward looking 360 degree transducers are being developed

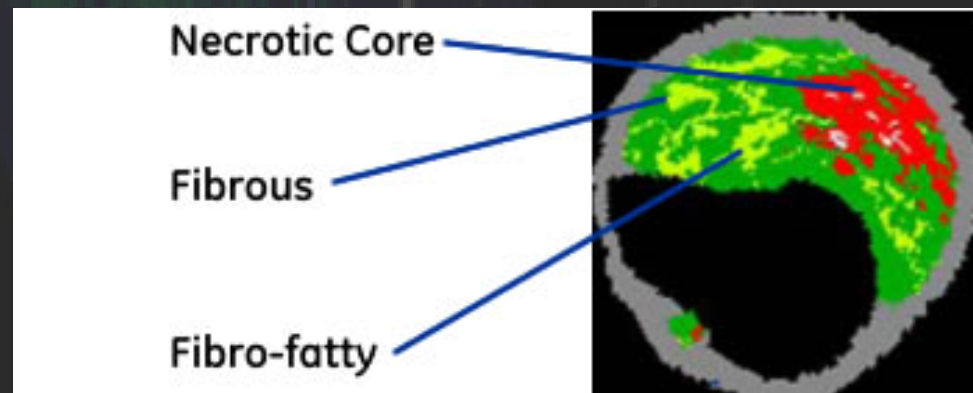
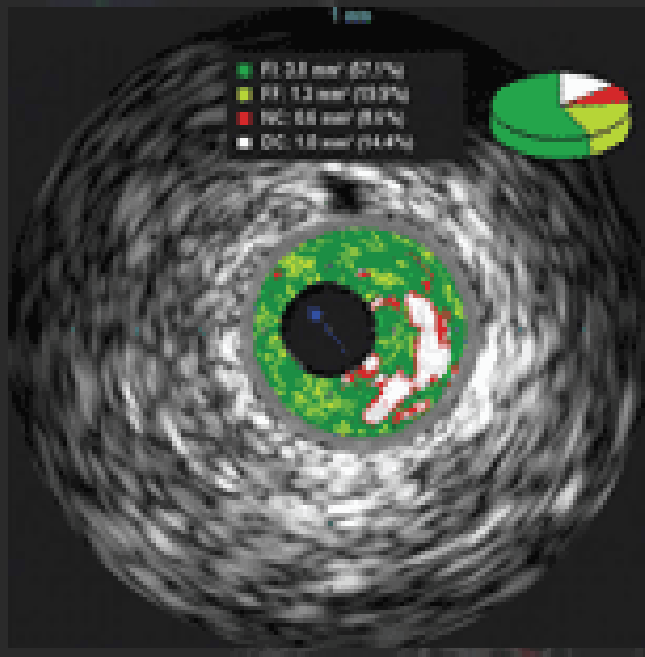
IVUS

- Verification of stent placement and full extension



Volcano IVUS

- Automated segmentation of plaques:
 - Fibrous
 - Fibrous-fatty
 - Necrotic
 - Dense Calcium



Volcano VH IVUS

- 
- Rapid development & applications of IVUS continues
 - Discrimination and quantitative evaluation of plaque composition
 - Integration with modern angiographic labs

Summary

- Fluoroscopic imaging continues to evolve and integrate new technologies
- A variety of other new technologies may supplant fluoroscopy as the standard
 - Detailed image quality of vascular structures
 - Increasingly quantitative analysis
 - Coronary MRI
 - SPECT / PET
 - CT