Cardiac Cath Lab Basics: Indications, Complications, and Radiation Management

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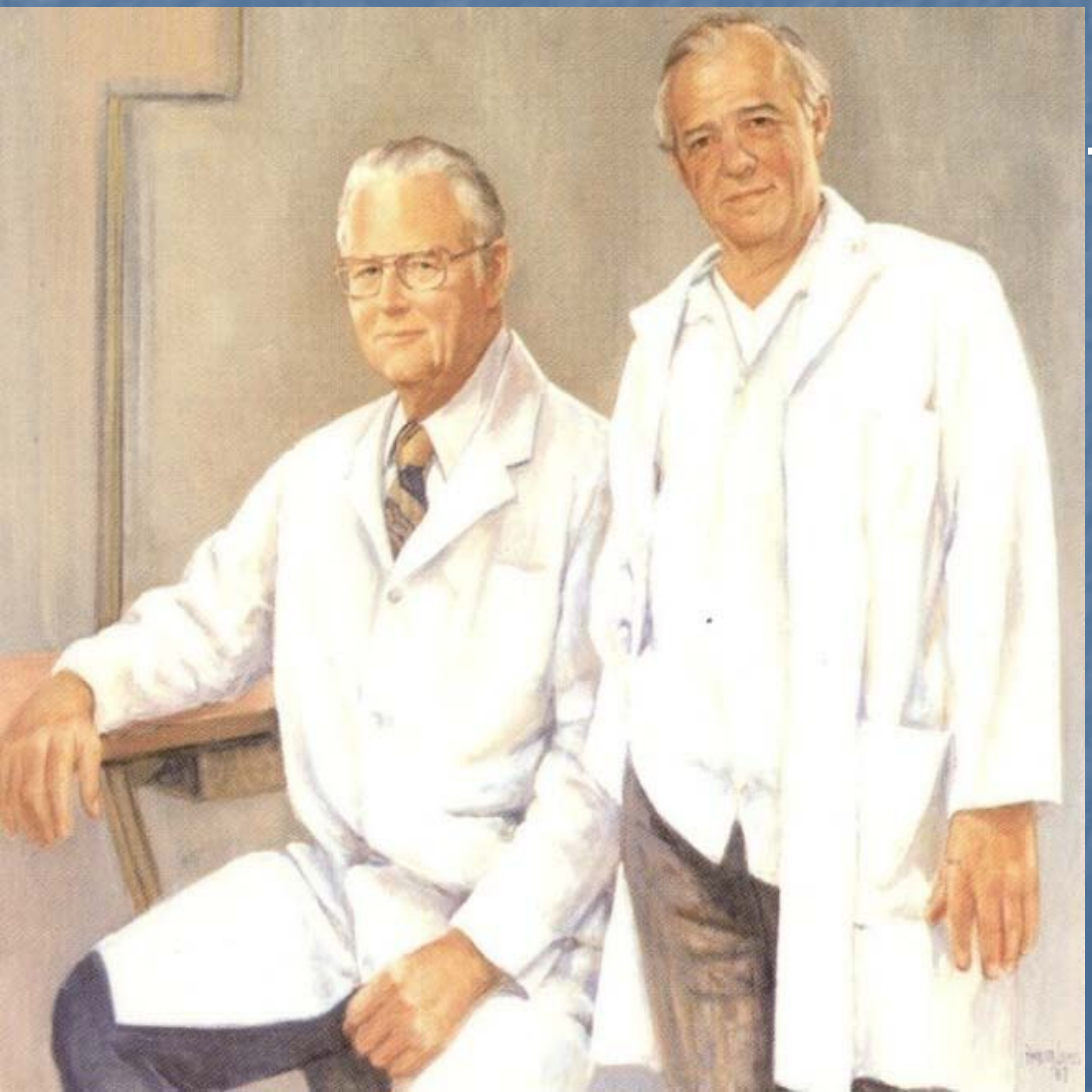
CONFLICT OF INTEREST: NONE

SCAI: Society for Cardiovascular Angiography and Interventions



Mission Statement

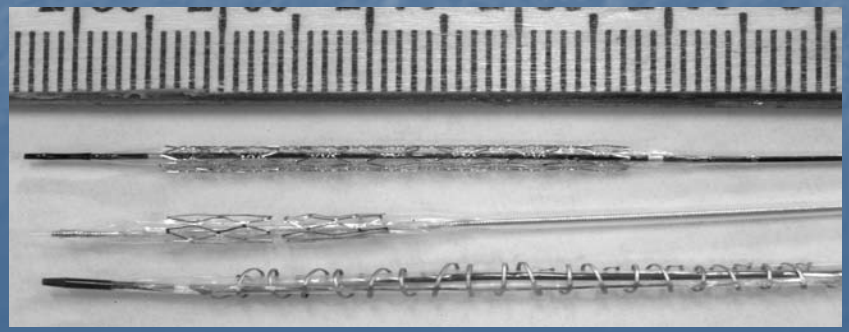
SCAI promotes excellence in invasive and interventional cardiovascular medicine through physician education and representation, and the advancement of quality standards to enhance patient care.

Lecture Outline

- **Historical Background**
- **Indications**
  - Diagnostic Testing for CAD
  - Appropriate Use Criteria (AUC): Dx Cath and Revascularization
- **Complications**
  - General Issues: Quality Improvement, Infection Control, and the High Risk Patient
  - Arterial Access
  - Iodinated Radiographic Contrast Agents
- **Radiation Management**
  - Radiation Physics
  - Radiation Safety Program in the Catheterization Lab

Historical Perspective Cardiac Catheterization/PCI

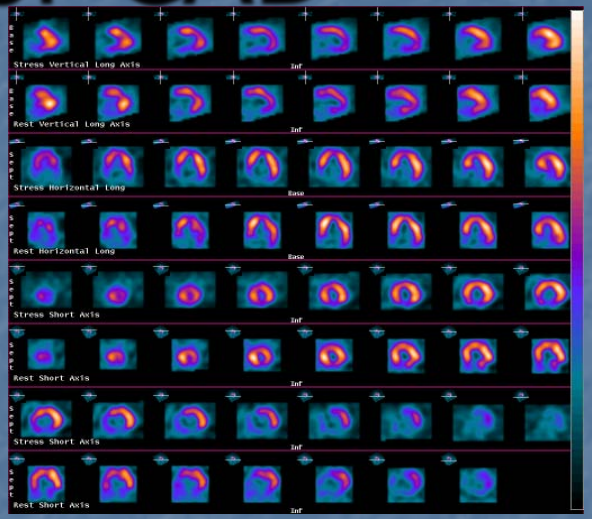
- 1929-Werner Forsmann, right heart catheterization
- 1959-Mason Sones, coronary cine-angiography
- 1967-Melvin Judkins, femoral catheters
- 1977- Andreas Gruentzig, PTCA
- 1994-first stent (US FDA approved)
- 2003-first DES (US FDA approved)

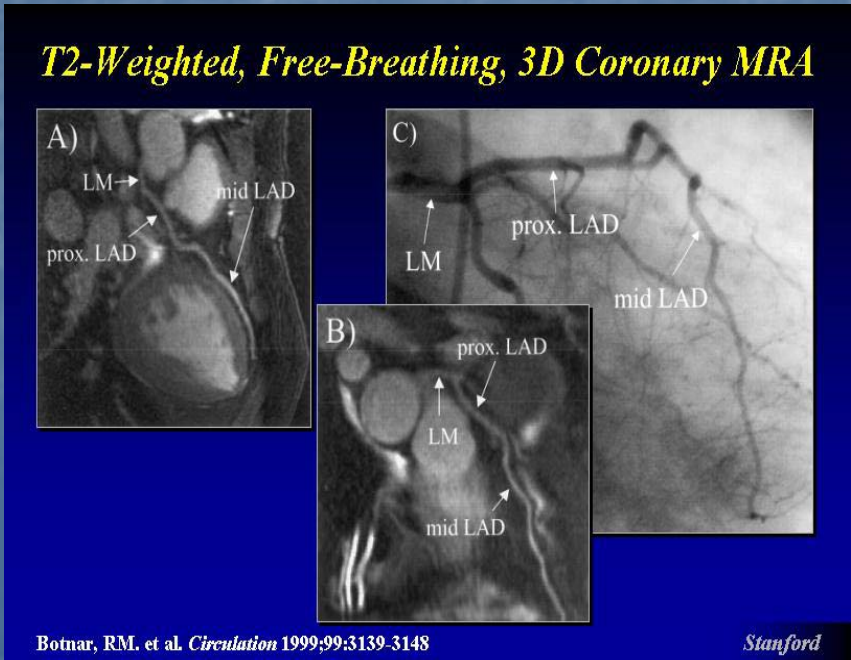


Indications for Cardiac Cath

Diagnostic Tests for CAD

- **Functional Testing**
  - Exercise tolerance test
  - Duke Treadmill score
- **Physiologic Testing**
  - Nuclear myocardial perfusion imaging
  - Echocardiographic imaging
- **Anatomic Testing**
  - MR and MDCT
  - Cardiac catheterization (still the gold standard)





INDICATIONS FOR DIAGNOSTIC CATHETERIZATION IN THE ADULT PATIENT

Coronary Artery Disease

- ***Symptoms***
- Unstable angina
- Postinfarction angina
- Angina refractory to medications
- Typical chest pain with negative diagnostic testing
- History of sudden death
- ***Diagnostic Testing***
- Strongly positive exercise tolerance test
- Early positive, ischemia in ≥ 5 leads, hypotension, prolonged ischemia into recovery
- Positive exercise testing following myocardial infarction
- Strongly positive Nuclear Myocardial perfusion test
- Increased lung uptake or ventricular dilation post stress
- Large single or multiple areas of ischemic myocardium
- Strongly positive stress echocardiographic study
- Decrease in overall ejection fraction or ventricular dilation with stress
- Large single area or multiple or large areas of new wall motion abnormalities

Valvular Disease

- ***Symptoms***
- Aortic stenosis with syncope, chest pain, or congestive heart failure
- Aortic insufficiency with progressive heart failure
- Mitral insufficiency or stenosis with progressive congestive heart failure symptoms
- Acute orthopnea/pulmonary edema post-infarction / acute mitral insufficiency
- ***Diagnostic Testing***
- Progressive resting LV dysfunction with regurgitant lesion
- ↓ LV function and/or chamber dilation with exercise

Adult Congenital Heart Disease

- ***Atrial Septal Defect***
- Age > 50 with evidence of coronary artery disease
- Septum primum or sinus venosus defects
- ***Ventricular Septal Defect***
- Catheterization for definition of coronary anatomy
- ***Coarctation of the Aorta***
- Detection of collaterals
- Coronary arteriography if increased age and/or risk factors are present

Other

- Acute MI therapy for considered primary PCI
- Mechanical complication post infarction
- Malignant cardiac arrhythmias
- Cardiac transplantation
- Pre-transplant donor evaluation
- Post transplant annual coronary artery graft rejection evaluation
- Unexplained congestive heart failure
- Research studies with Institutional Review Board review and patient consent

Appropriate Use Criteria, Diagnostic Catheterization May 2012

Chambers CE, ET AL. The Cardiac Catheterization Laboratory: Diagnostic and Therapeutic Procedures in the Adult Patient;

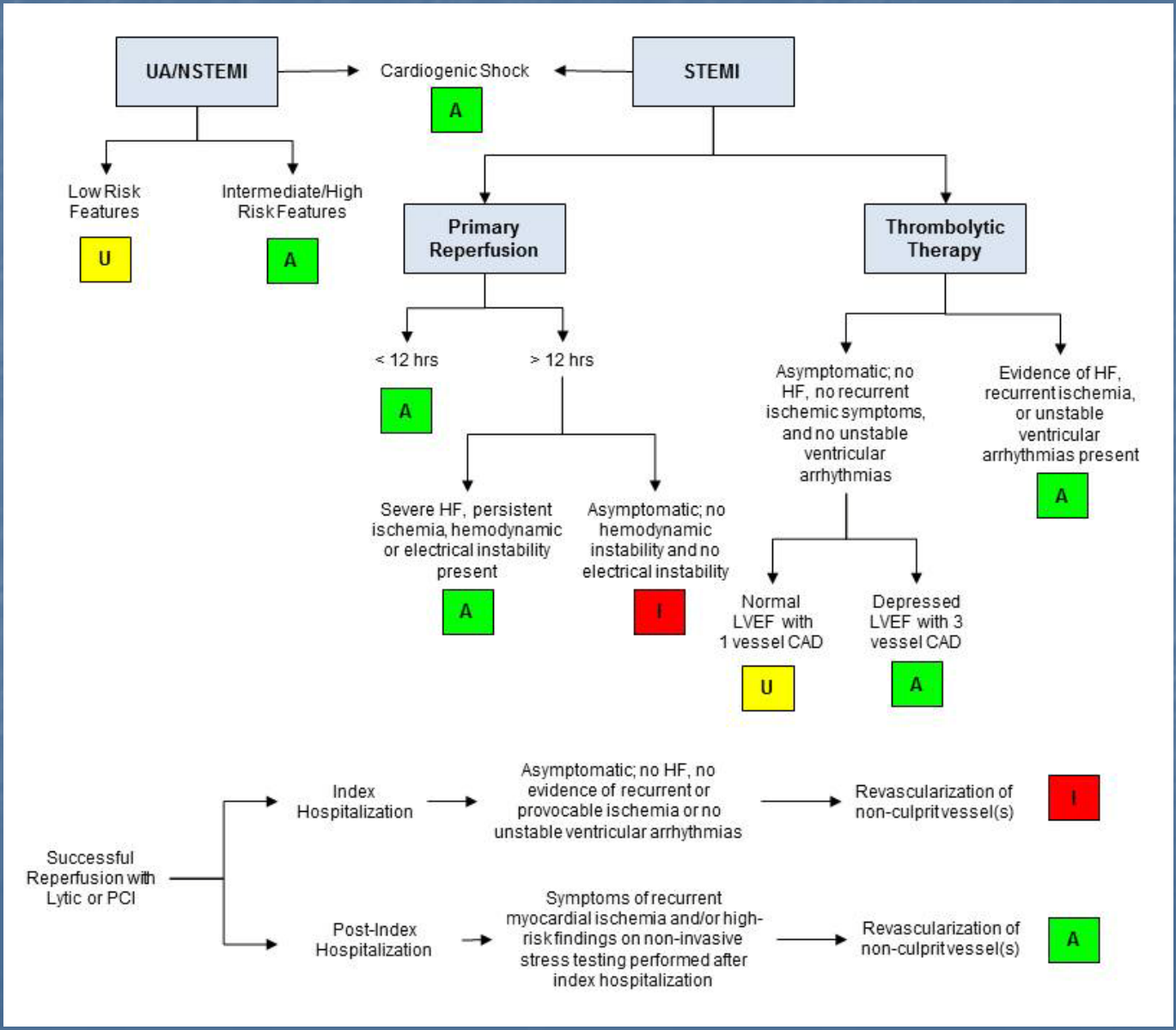
Kaplan, JA, Cardiac Anesthesia, 4th Edition, 41-94, 1999.

ACCF/SCAI/STS/AATS/AHA/ASNC 2012 Appropriateness Criteria for Coronary Revascularization

Appropriate Use Ratings by Low-Risk Findings on Noninvasive Imaging Study and Asymptomatic (Patients Without Prior Bypass Surgery)

Low Risk Findings on Noninvasive Study						Asymptomatic					
Symptoms Med. Rx						**Stress Test Med. Rx**					
Class III or IV Max Rx	U	A	A	A	A	High Risk Max Rx	U	A	A	A	A
Class I or II Max Rx	U	U	A	A	A	High Risk No/min Rx	U	U	A	A	A
Asymptomatic Max Rx	I	I	U	U	U	Int. Risk Max Rx	U	U	U	U	A
Class III or IV No/min Rx	I	U	A	A	A	Int. Risk No/min Rx	I	I	U	U	A
Class I or II No/min Rx	I	I	U	U	U	Low Risk Max Rx	I	I	U	U	U
Asymptomatic No/min Rx	I	I	U	U	U	Low Risk No/min Rx	I	I	U	U	U
Coronary Anatomy	CTO of 1 vz.; no other disease	1-2 vz. disease; no Prox. LAD	1 vz. disease of Prox. LAD	2 vz. disease with Prox. LAD	3 vz. disease; no Left Main	Coronary Anatomy	CTO of 1 vz.; no other disease	1-2 vz. disease; no Prox. LAD	1 vz. disease of Prox. LAD	2 vz. disease with Prox. LAD	3 vz. disease; no Left Main

Acute Coronary Syndromes



Appropriate Use Ratings by High-Risk Findings on Noninvasive Imaging Study and CCS Class III or IV Angina (Patients Without Prior Bypass Surgery)

High Risk Findings on Noninvasive Study						CCS Class III or IV Angina					
Symptoms Med. Rx						**Stress Test Med. Rx**					
Class III or IV Max Rx	A	A	A	A	A	High Risk Max Rx	A	A	A	A	A
Class I or II Max Rx	A	A	A	A	A	High Risk No/min Rx	A	A	A	A	A
Asymptomatic Max Rx	U	A	A	A	A	Int. Risk Max Rx	A	A	A	A	A
Class III or IV No/min Rx	A	A	A	A	A	Int. Risk No/min Rx	U	U	A	A	A
Class I or II No/min Rx	U	A	A	A	A	Low Risk Max Rx	U	A	A	A	A
Asymptomatic No/min Rx	U	U	A	A	A	Low Risk No/min Rx	I	U	A	A	A
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Appropriateness Criteria for Elective Use of the Bathroom Toilet Facilities

	Symptom Status				
Clinical Scenario	**Class 0: no symptoms**	**Class I: I might have to go**	**Class II: I need to go soon**	**Class III: I really really need to go soon**	**Class IV: I think I'm leaking**
Already chronically incontinent, wears Depends	A	A	A	A	A
Age >70, female, non-nulliparous	U	A	A	A	A
Age >70, female, nulliparous	U	U	A	A	A
Age >75, male, known prostate issues	U	U	A	A	A
Age >75, male, no known prostate issues	U	U	U	A	A
Age 50-75, heavy caffeine user	U	U	U	A	A
Age 50-75, no caffeine	I	I	U	A	A
Age <50, very nervous e.g. about to fill out PCI Appropriateness form	I	I	U	U	A
Age <50, no risk factors	I	I	U	U	U

COMPLICATIONS FROM THE CATHETERIZATION LAB

Left Heart

- ***Cardiac***
  - Death
  - Myocardial infarction
  - Ventricular fibrillation
  - Ventricular tachycardia
  - Cardiac perforation
- ***Noncardiac***
  - Stroke
  - Peripheral embolization
  - Air
  - Thrombus
  - Cholesterol
  - Vascular surgical repair
  - Pseudoaneurysm
  - A-V fistula
  - Embolectomy
  - Repair of brachial arteriotomy
  - Evacuation of hematomas
  - Contrast-related
    - Renal insufficiency
    - Anaphylaxis

Right Heart

- ***Cardiac***
  - Conduction abnormality
    - RBBB
    - Complete heart block (RBBB superimposed on LBBB)
  - Arrhythmias
  - Valvular damage
  - Perforation
- ***Non-cardiac***
  - Pulmonary artery rupture
  - Pulmonary infarction
  - Balloon rupture
  - Paradoxical (systemic) air embolus

Quality Assurance

- Mandatory Separate QA Program for the Cath Lab
  - Chaired by the Director
- Quality Indicators
  - Structural- credentialing
  - Outcome- signal event tracking with appropriate risk adjustment; will likely require participation in national data bases, ie NCDR
  - Process- patient management assessment through protocols
- Data Collection, Analysis and Practice Improvement
- NCDR
  - Benchmarking, risk adjustment
- ACE
  - Accreditation

Heupler FA, Chambers, CE et al. Guidelines for Internal Peer Review in the Cardiac Catheterization Laboratory.CCD 1997.

Klein LW, Uretsky BF, Chambers CE, et al. Quality Assessment and Improvement in Interventional Cardiology. A Position Statement of SCAI. Part I. Standards for Quality Assessment & Improvement in Interventional Card. CCI 2011.77; 927-35..

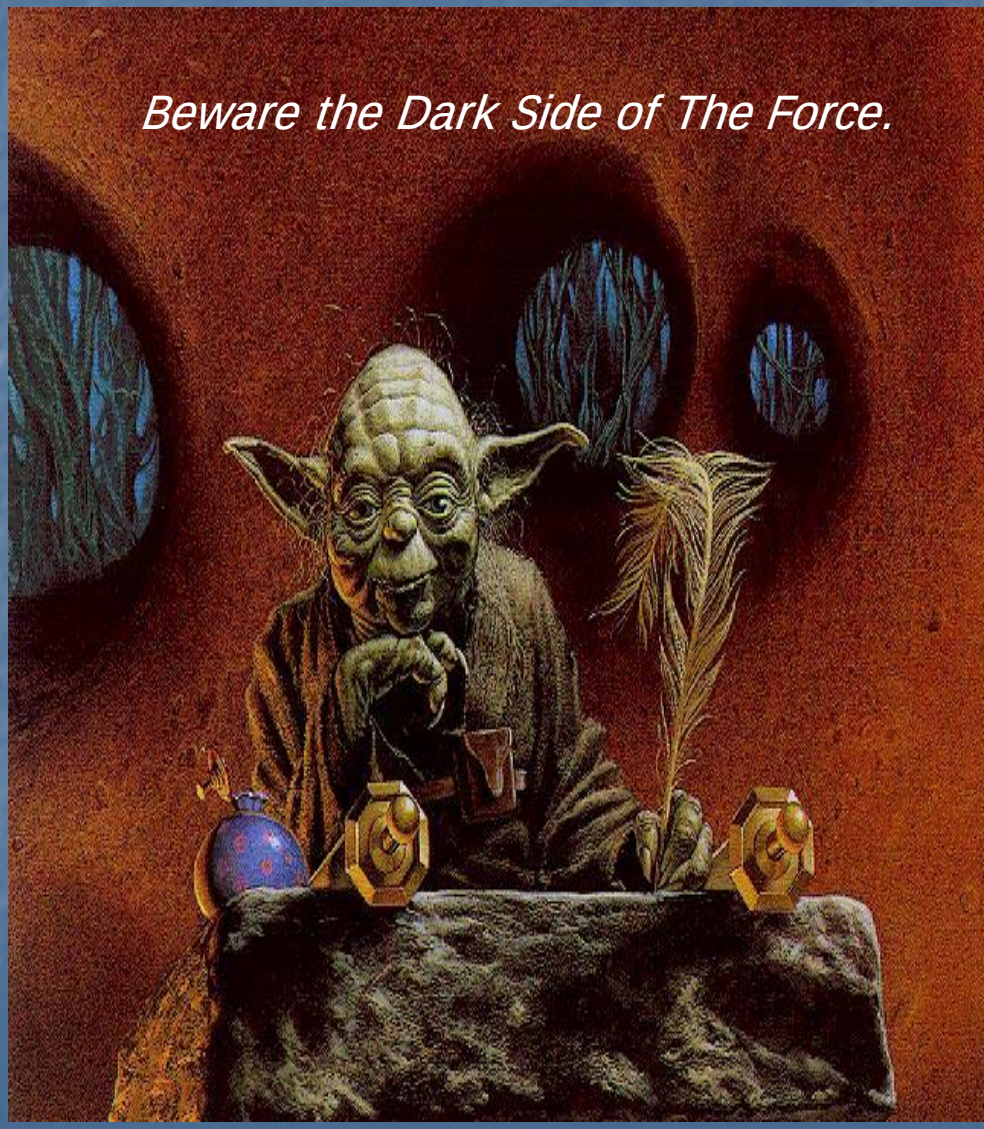
Infection Control in the Cardiac Catheterization Laboratory

- Low Incidence of Infection, Limited follow up
- Sanmore reported a series from 1991-98 with an infection rate of 0.11%, 1.7 days post procedure
- 4,000 post PTCA pts reported by Ramsdale with bacterial infection 0.64%, septic complication0.24%
- Skin site-electric not blade razor and 2% chlorhexidine
- Hat and Masks recommended
- Air Flow 15 exchanges per hour minimum.

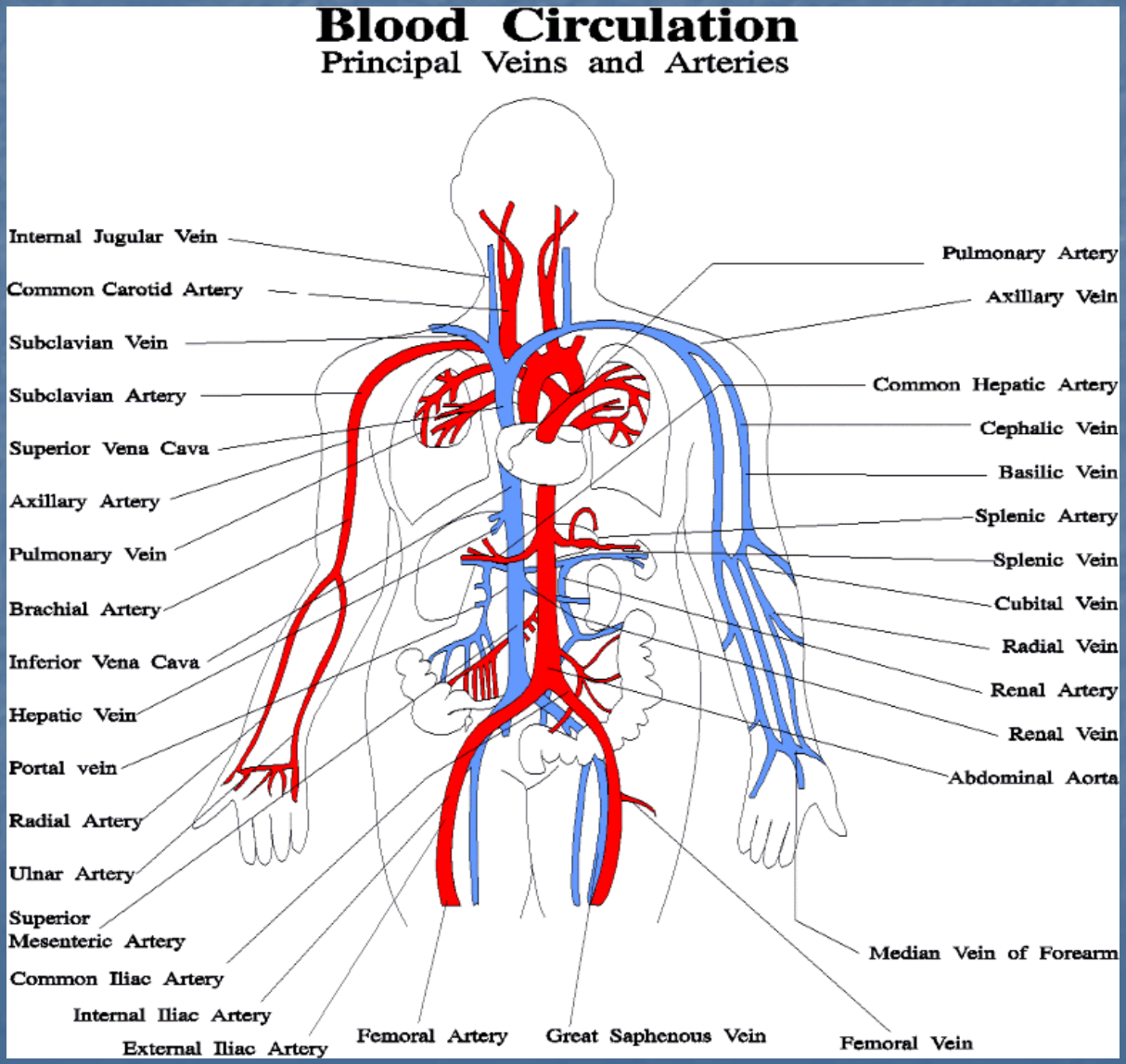
Chambers, CE et al. Infection Control Guidelines for the Cardiac Catheterization Laboratory. CCI 67:78-86.

IDENTIFICATION OF THE HIGH-RISK PATIENT

- Age
  - Infant <1yr
  - Elderly >70yrs
- Functional class
  - Mortality ↑ 10-fold for class IV patients compared with I and II
- Severity of coronary obstruction
  - Mortality ↑ 10-fold for left main disease compared with one- or two-vessel disease
- Valvular heart disease
  - As an independent lesion
  - Greater risk when associated with coronary artery disease
- Left ventricular dysfunction
  - Mortality ↑ 10-fold in patients with low EF (≤30%)
    - Further significant if LVEDP >2mmHg and BP < 100 mmHg
- Severe noncardiac disease
  - Renal insufficiency
  - Advanced peripheral and cerebral vascular disease
  - Severe pulmonary insufficiency
  - Insulin-requiring diabetes

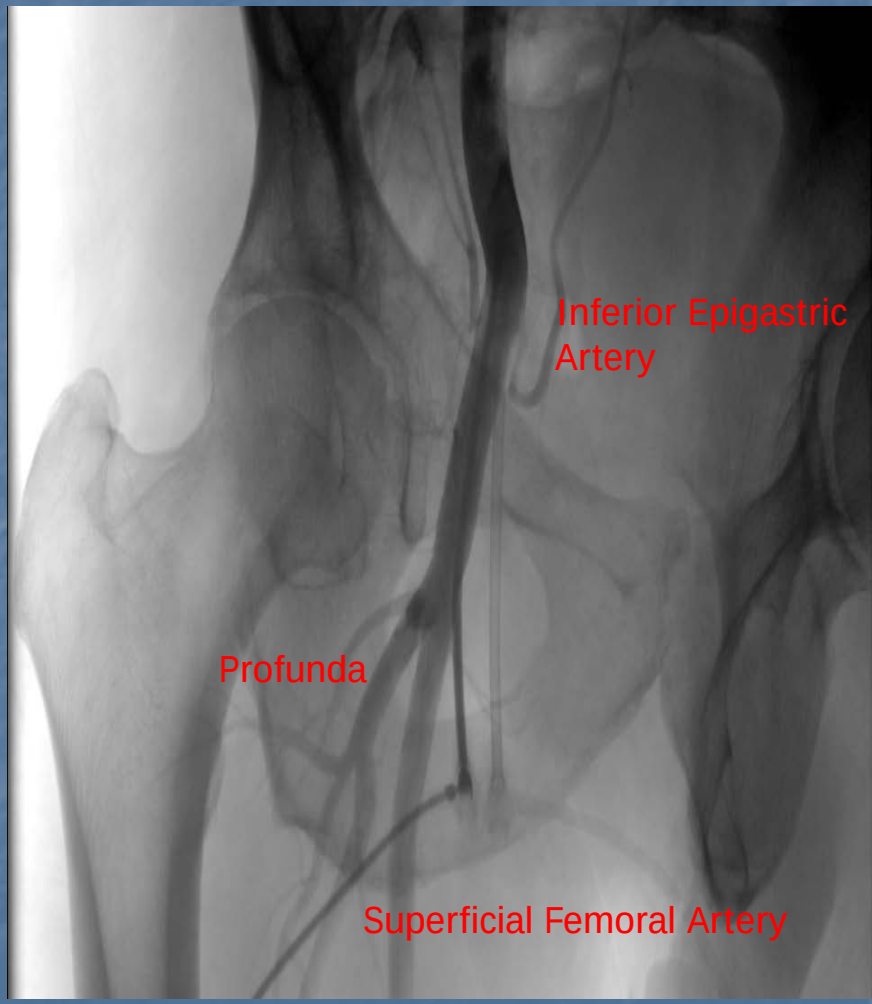


Access Site


Blood Circulation
Principal Veins and Arteries
Internal Jugular Vein
Common Carotid Artery
Subclavian Vein
Subclavian Artery
Superior Vena Cava
Axillary Artery
Pulmonary Vein
Brachial Artery
Inferior Vena Cava
Hepatic Vein
Portal vein
Radial Artery
Ulnar Artery
Superior Mesenteric Artery
Common Iliac Artery
Internal Iliac Artery
External Iliac Artery
Femoral Artery
Great Saphenous Vein
Femoral Vein
Median Vein of Forearm
Pulmonary Artery
Axillary Vein
Common Hepatic Artery
Cephalic Vein
Basilic Vein
Splenic Artery
Splenic Vein
Cubital Vein
Radial Vein
Renal Artery
Renal Vein
Abdominal Aorta

Femoral Artery

- Know landmarks
  - Inguinal ligament- anterior superior iliac spine to pubic tubercle
  - FA crosses inguinal ligament approximately 1/3 from medial aspect of ligament
  - Needle/sheath should enter the FA 2-3 cm below the inguinal ligament
    - 95% pt have femoral bifurcation below upper border of femoral head
  - Role of fluoroscopic identification of landmarks and/or ultrasound
- Vascular Complications
  - One of the most common complications of catheterization and single greatest source of morbidity
    - 0.5 – 0.6% rate



Vascular Complications

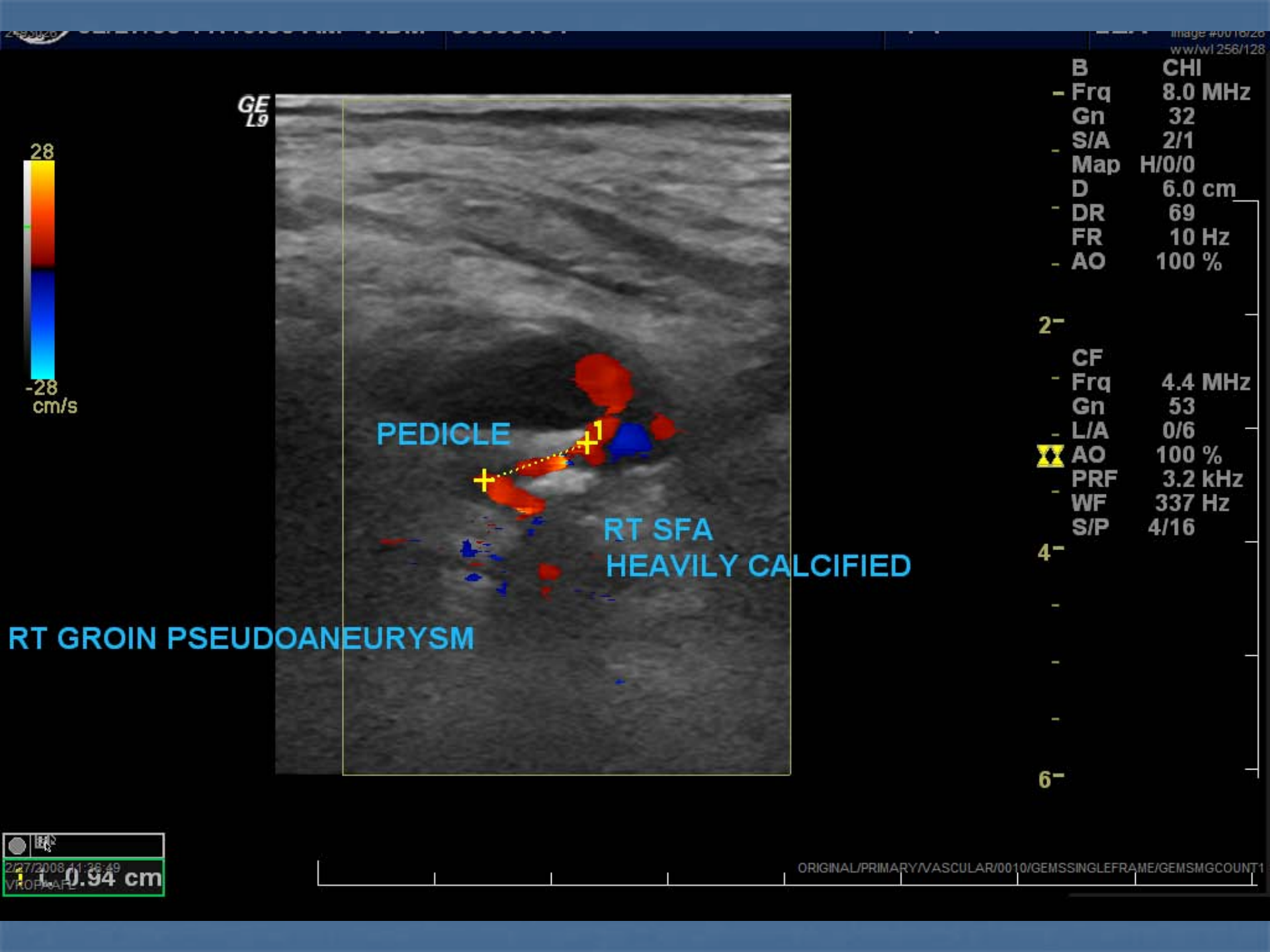
- Distal Embolization
- Dissection
- Hematoma
- Retroperitoneal Hemorrhage
- Pseudoaneurysm
- AV fistula formation

Vascular Complications

- Hematoma
  - Blood in soft tissues
  - Tender mass
  - NCDR CathPCI Registry, defined as drop in Hct of >= 10% or hemoglobin drop of >= 3g/dL
  - May cause femoral or lateral cutaneous nerve compression, take weeks to months to resolve
  - Compression is treatment.
- Retroperitoneal Hemmorhage
  - Femoral artery punctured above inguinal ligament
  - Signs/symptoms: hypotension, tachycardia, flank pain, drop in Hct
  - Diagnosis: CT scan or abdominal U/S, H &P
  - Rx: IVF resuscitation, blood products, bed rest
    - If artery lacerated, peripheral angioplasty with covered stent

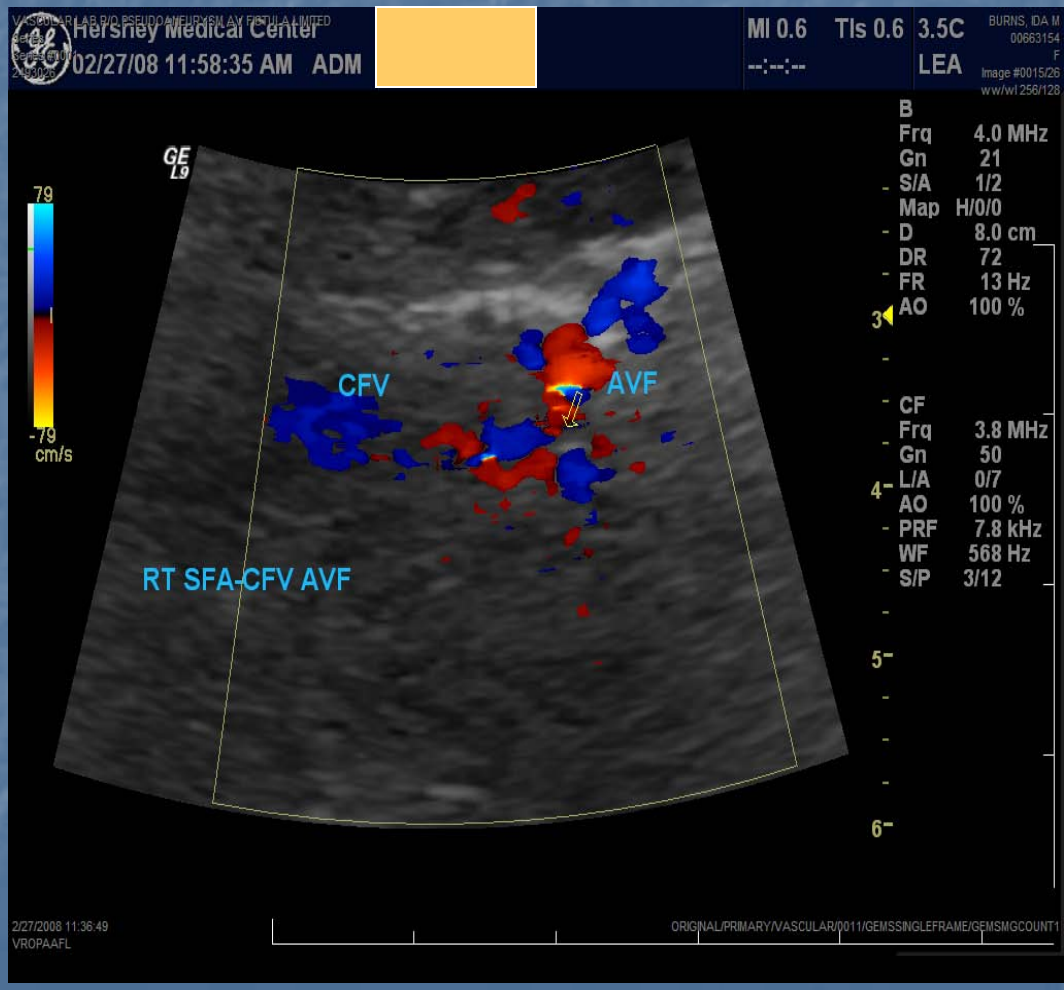
Vascular Complications

- Pseudoaneurysm
  - Hematoma in continuity with lumen
  - Dx: pulsatile mass; bruit; Duplex U/S
  - All but the smallest (<2 cm) tend to rupture
  - Rx: Vascular Surgery
    - U/S guided compression of narrow neck (30 -60 min)
    - Inject with procoagulants/coils
  - Proper techniques
    - Puncture common femoral artery
      - Superficial femoral/profunda arterial punctures are more likely to result in pseudoaneursym formation due to smaller caliber and lack of bony structure for compression
    - Use landmarks (anterior superior iliac crest and pubic symphysis)
    - Ultrasound guidance


GE
L9
28
-28
cm/s
PEDICLE
RT SFA
HEAVILY CALCIFIED
RT GROIN PSEUDOANEURYSM
B CHI
Frq 8.0 MHz
Gn 32
S/A 2/1
Map H/0/0
D 6.0 cm
DR 69
FR 10 Hz
AO 100 %
CF
Frq 4.4 MHz
Gn 53
L/A 0/6
AO 100 %
PRF 3.2 kHz
WF 337 Hz
S/P 4/16
2
4
6
0.94 cm
ORIGINAL/PRIMARY/VASCULAR/0010/GEMSSINGLEFRAME/GEMSMGCOUNT1

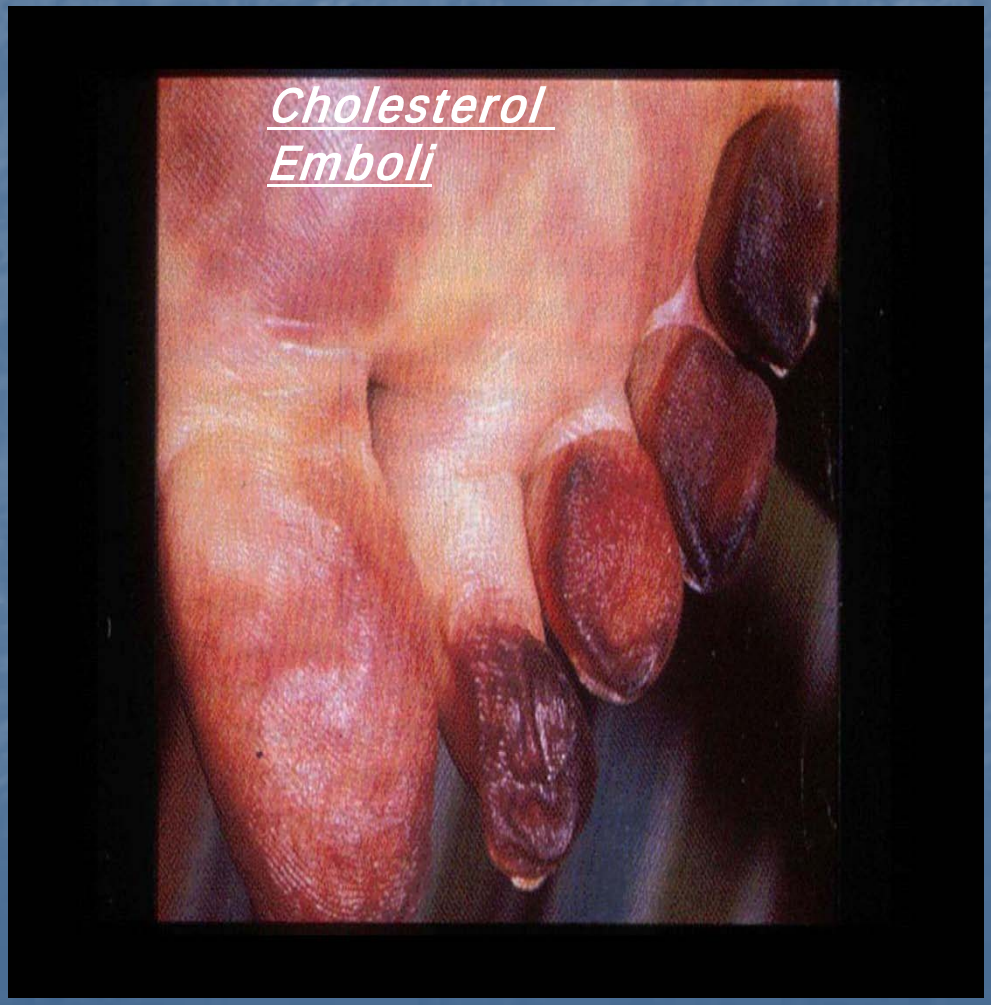
Vascular Complications

- AV fistula
  - Due to ongoing bleeding from arterial puncture site that enters venous puncture site
  - Signs/Sx: bruit
  - 1/3 close within 1 yr spontaneously
  - Rx: surgical repair



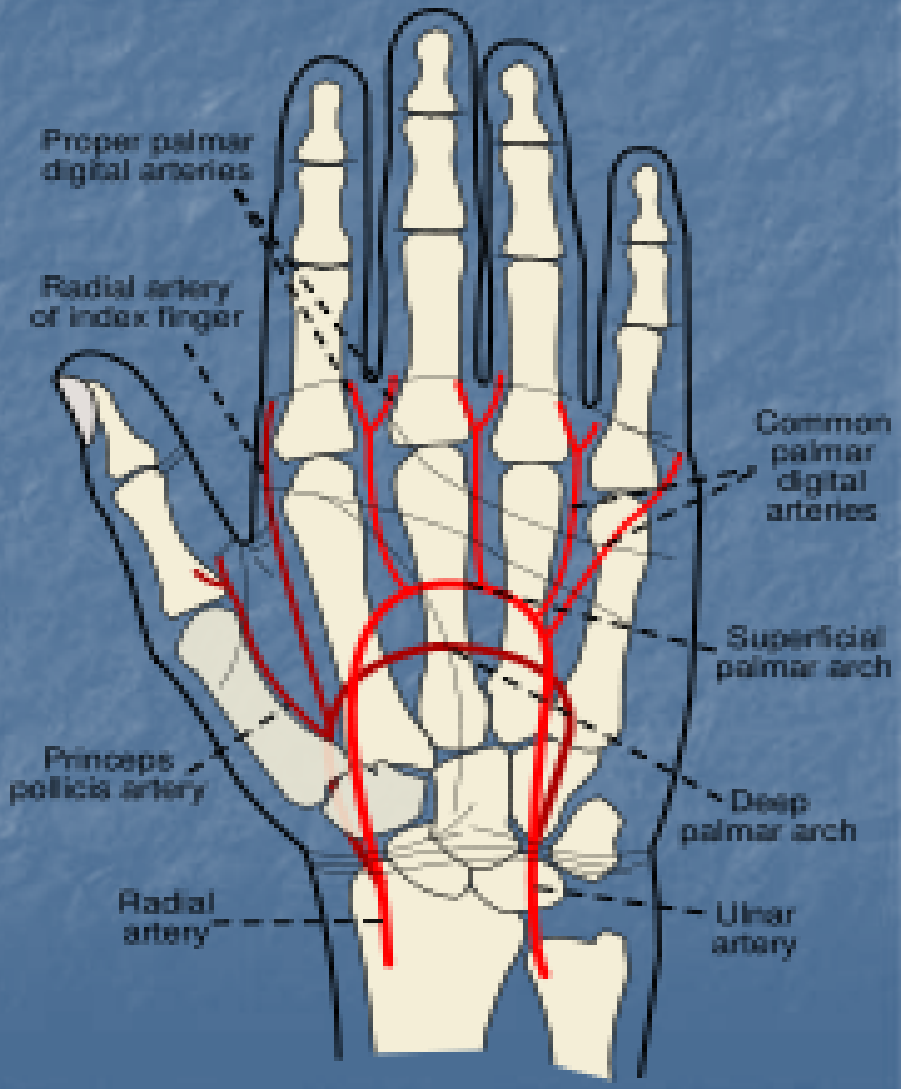
Vascular Complications

- Cholesterol emboli
  - Renal Insufficiency identified week(s) later
  - Livedo reticularis
  - Necrotic toes
  - Eosinophilia
  - Crystals on bx



Radial (Brachial) Approach

- Check Allen Test
- Use local anesthetic to make small wheal
- Make knick with scalpel
- Approx 1 cm proximally from styloid process
- After placement of sheath, vasodilator to help prevent spasm



Radial (Brachial) Approach

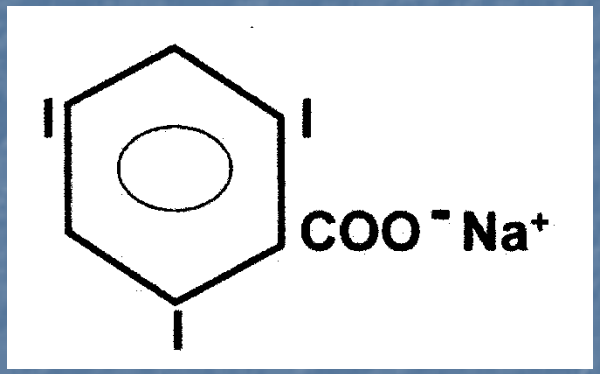
- To avoid sheath thrombosis, heparin 3000 to 5000 units IV recommended
- Complications:
  - arterial aneursym, compartment syndrome, infection, nerve injury, skin necrosis, thrombosis, hematoma, vascualr injury
  - AV Fistula (left)
  - Radial artery occlusion/thrombosis
    - 10.5% pt had no RA blood flow at 7 day f/u*

Pulikal GA et al, *Circulation* 2005;111:e99

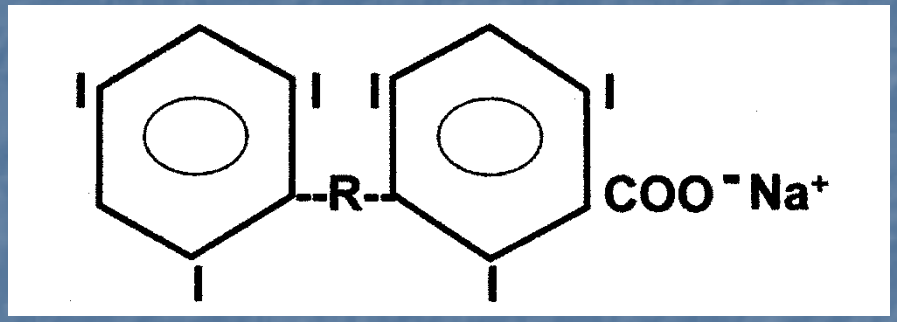
*Sanmartin et al. "Interruption of blood flow during compression and radial artery occlusion after transradial catheterization. CCI 70(2): 185-9, 2007.

Radiographic Contrast Media

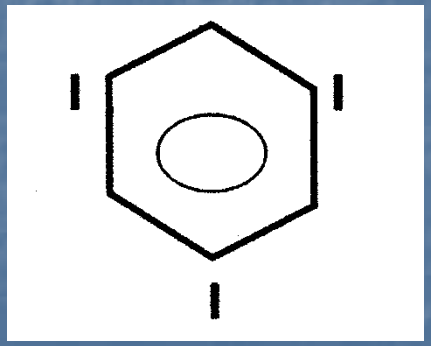
Classification is based upon the agent's ability to *dissociate* (ionic) or *not dissociate* (nonionic) into ionic particles



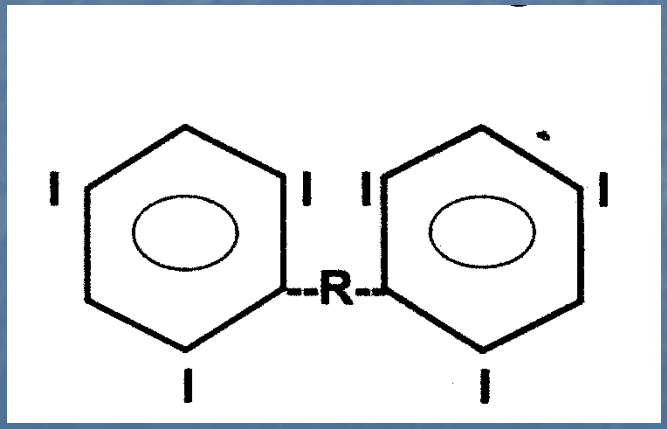
Ionic **Monomer**



Ionic **Dimer**



Nonionic **Monomer**



Nonionic **Dimer**

Radiographic Contrast Media

Product	Type	Concentration (mgI/mL)	Osmolality (mOsm/kg H_2O)
Monomers			
iohexol (*Omnipaque*)	non-ionic	350	844
iopamidol (*Isovue*)	non-ionic	370	796
ioxilan (*Oxilan*)	non-ionic	350	695
iopromide (*Ultravist*)	non-ionic	370	774
ioversol (*Optiray*)	non-ionic	350	792
Dimers			
iodixanol (*Visipaque*)	non-ionic	320	290
ioxaglate (*Hexabrix*)	ionic	320	600

Kozak M, Robertson BJ, Chambers, CE. Cardiac Catheterization Laboratory: In: Kaplan, JA, ed. Kaplan's Cardiac Anesthesia. 5th ed., p. 307, 2006

"Allergic" Reactions to RCM

- Differentiate **Chemotoxic** from **Anaphylactoid**
- *Anaphylactoid not anaphylactic* since non-IgE medicated , therefore no skin tests are available or invitro tests to detect potential allergic rxns
- Allergy to "fish" is unrelated to RCM allergy since the presence of iodine in fish and contrast media is not a common antigenic factor.
- A trial administration of a small dose of contrast may well not detect potential reactions to the therapeutic dose.
- Incidence of Repeat Anaphylactoid Contrast Reactions
  - Without prophylaxis- 44%
  - With steroid and diphenhydramine-5%
  - With steroids, diphenhydramine, and non-ionic contrast-0.5%

Reisman RE. Anaphylaxis, in *Allergy and Immunology, AM Coll of Physicians, 1998*

Anaphylactoid Reaction Prophylaxis

- Prednisone: 50 mg po 6pm, midnight, and 6 AM prior to catheterization.
  - Most important dose likely the one >12 hrs prior.
- Diphenhydramine: 50mg, given IV on call
- Non-ionic contrast used.
- Limited role for H_2 blockers and ephedrine.
  - Should not use H_2 without H_1.
  - Ephedrine not proven beneficial in the cardiac pt.
- Emergent procedures, limited data:
  - Hydrocortisone, 200 mg IV q 4 hrs, until procedure .

Goss JE, Chambers CE, Heupler. Systemic Anaphylactoid Rxns to RCM/ CCD 1995. 34: 88-104.

Therapy for Anaphylactoid Reactions

- **Minor-Uticaria, with or without Skin Itching**
  - No therapy
  - Diphenhydramine, 25-50mg IV
  - Epinephrine 0.3 cc of 1:1,000 solution sub-Q q 15 min up to 1 cc
  - Cimetadine 300 mg or ranitadine 50 mg in 20 cc NS IV over 15 mins

- **Facial/Laryngeal Edema**
  - Call anesthesia
  - Assess airway
    - O2 mask, Intubation, Tracheostomy tray
  - Mild-Epinephrine sq

    Moderate/Severe: Epi-IV 0.3 cc of 1:1,000 solution sub-Q q 15 min, 1 cc
  - Diphenhydramine 50 mg IV
  - Hydrocortisone 200-400 mg IV
  - Optional: H2 blocker

- **Bronchosapsm**
  - Oxygen
  - Mild- albuterol inhaler, 2 puffs
  - Moderate-Epinephrine 0.3 cc of 1:1,100 sub-Q up to 1 cc
  - Severe-Epinephrine IV as bolus 10 micrograms/min then infusion 1 to 4 micrograms/min
  - Diphenhydramine 50 mg IV
  - Hydrocortisone 200-400mg IV
  - Consider H2 blocker

- **Hypotension/Shock**
  - Epinephrine IV boluses
  - Large volumes 0.9% NS (1-3 l)
  - CVP, PA catheter
  - Airway, intubation as needed
  - Diphenhydramine 50 mg IV
  - Hydrocortisone 400mg IV
  - If unresponsive…
    - H2 blocker
    - Dopamine/nor epinephrine

2011 PCI Guidelines
3.3 Anaphylactoid Reactions Recommendations

- **Class I**

  1. Patients with prior evidence of an anaphylactoid reaction to contrast media should receive appropriate steroid and antihistamine prophylaxis prior to repeat contrast administration . ***(Level of Evidence B)***

- **Class III: No Benefit**

  1. In patients with prior history of allergic reactions to shellfish or seafood, anaphylactoid prophylaxis for contrast reaction is not beneficial. ***(Level of Evidence: C)***

Pre-procedural Clinical Risk Factors for Contrast Induced Nephropathy

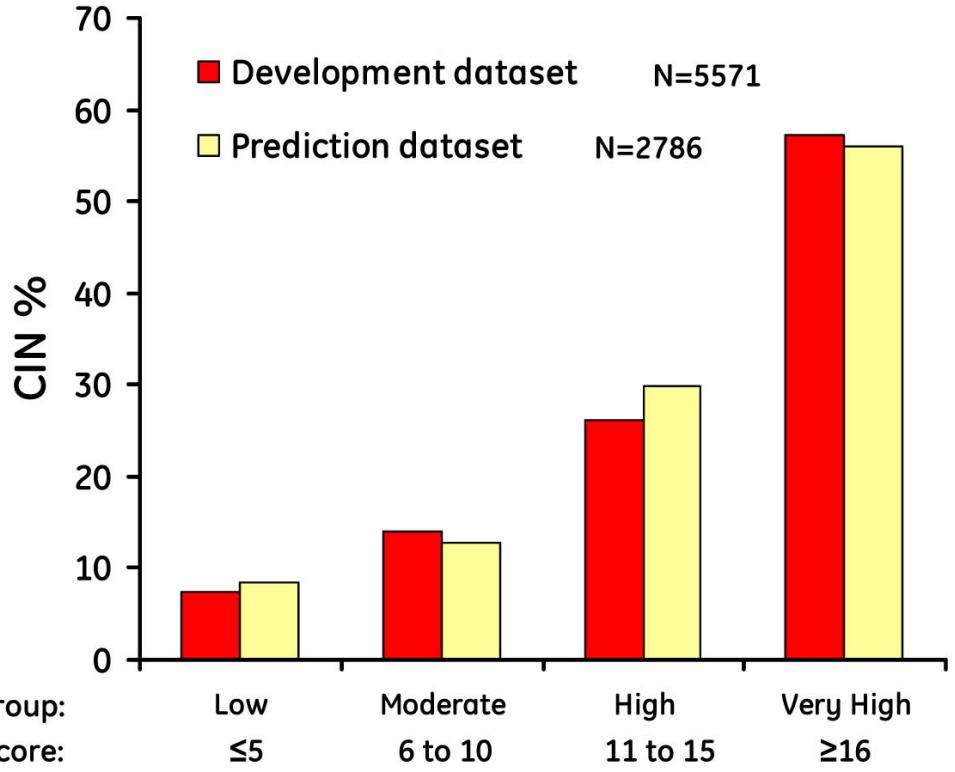
- **Modifiable Risk Factors**
  - Contrast volume
  - Hydration status
  - Concomitant nephrotoxic agents
  - Recent contrast administrations
- **Non-modifiable Risk Factors**
  - Diabetes/Chronic kidney disease
  - Shock/hypotension
  - Advanced age (> 75 yrs)
  - Advanced congestive heart failure

Klein LW, Sheldon MA, Brinker J, Mixon TA, Skeldiong K, Strunk AO, Tommaso CL, Weiner B, Bailey SR, Uretsky B, Kern M, Laskey W . The use of radiographic contrast media during PCI: A focused review. Cathet Cardiovasc Int 2009; 74: 728-46

Multi-factorial Predictors of CIN

A Risk Score for Prediction of CIN

Multivariate Predictors	
Hypotension	5 points
IABP use	5 points
CHF	5 points
SCr >1.5 mg/dL (>132 µmol/L)	4 points
Age >75 y	4 points
Anemia	3 points
DM	3 points
Contrast volume	1 point/100 mL



CIN, contrast-induced nephropathy; DM, diabetes mellitus; IABP, Intra-aortic balloon pump

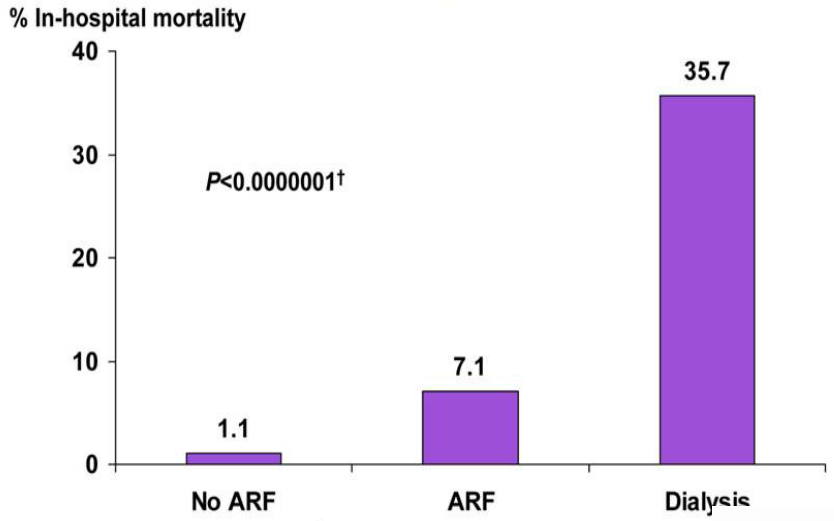
Mehran R et al. *J Am Coll Cardiol.* 2004;44:1393-1399.

PENN STATE heart & vascular INSTITUTE

The Society for Cardiovascular Angiography and Interventions SCAI

Mortality with CIN

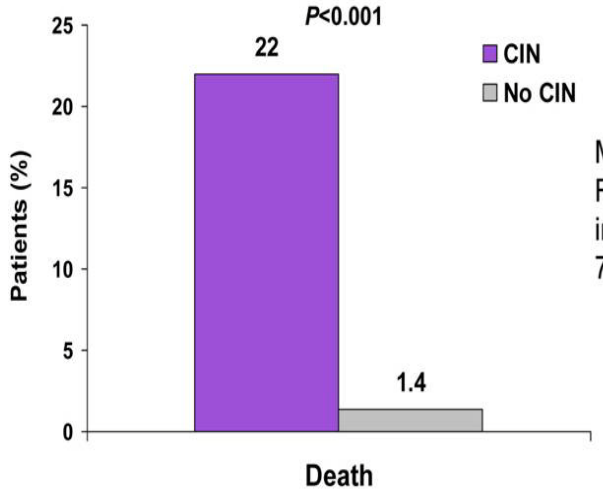
Acute Renal Failure (ARF)*: In-hospital Mortality



*ARF defined as SCr >25% from baseline; †*P* value for differences between proportions

McCullough PA et al. *Am J Med.* 1997;103:368–375.

In-hospital Death After PCI in Patients With CIN*



Mayo Clinic Registry included 7586 patients

*CIN defined as SCr >0.5 mg/dL

Rihal CS et al. *Circulation.* 2002;105:2259-2264.

Reducing Risk for CIN

- Identify Risk
  - Low risk; eGFR > 60 ml/1.73 m2
    - Optimize hydration status.
  - High risk; eGFR < 60 ml/1.73 m2
    - Schedule outpatient for early arrival and/or delay procedure time to allow time to accomplish the hydration.

- Pre-Procedure
  - Hydration
    - Normal Saline preferred over D5 ½ normal
    - Sodium Bicarbonate, mixed reviews
  - Medications
    - NSAID stop if possible
    - N-acetylcysteine, mixed reviews, no clear benefit
- Procedure
  - CrCl to contrast ratio
  - Contrast
    - Volume, repeat stuides
    - Type-mixed reviews
- Post Procedure
  - Hydration, Normal Saline and PO

Schweiger MJ, Chambers CE, Davidson CJ, et al. Prevention of CIN.CCI 2007, 69:135-40

2011 PCI Guidelines
3.2 Contrast-Induced Acute Kidney Injury Recommendations

Class I

1. Patients should be assessed for risk of contrast-induced AKI before PCI. *(Level of Evidence: C)*
2. Patients undergoing cardiac catheterization with contrast media should receive adequate preparatory hydration . *(Level of Evidence: B)*
3. In patients with chronic kidney disease (creatinine clearance <60cc/min), the volume of contrast media should be minimized . *(Level of Evidence: B)*

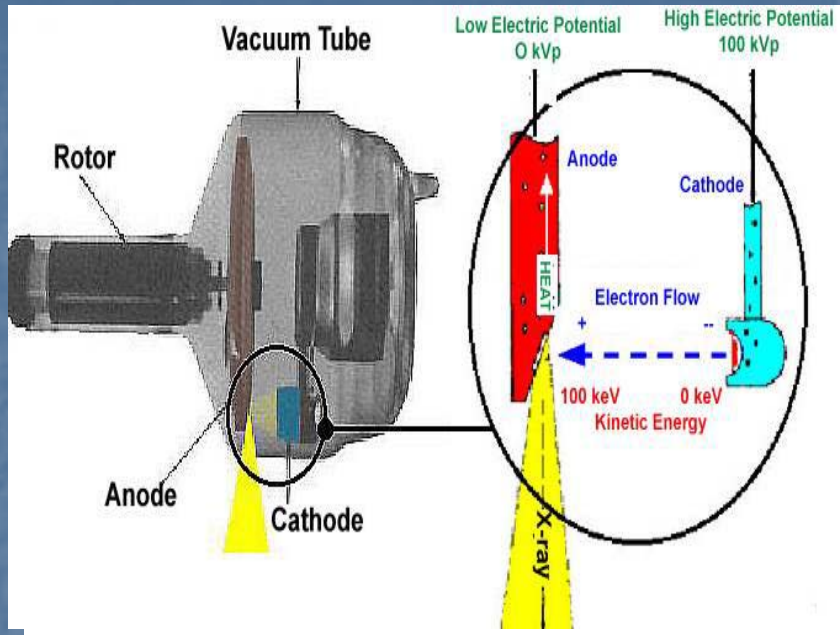
Class III: No Benefit

1. Administration of N-acetyl-L-cysteine is not useful for the prevention of contrast-induced AKI . *(Level of Evidence: A)*

Radiation Management in the Cardiac Catheterization Laboratory

Principles of X-ray Image Formation

- X-ray generation is inefficient *<1%* of the electrical energy is converted to X-rays. >99% heat.
- Cathode current (m A) = **number** of X-ray photons
  - Increasing mA increases absorption and increases patient dose.
- Tube voltage (k Vp) = **energy** of X-ray photons
  - Increasing kVp decreases absorption, and reduces patient exposure.



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ACCF/AHA/HRS/SCAI FLUOROSCOPY CLINICAL COMPETENCE STATEMENT

ACCF/AHA/HRS/SCAI Clinical Competence Statement on Physician Knowledge to Optimize Patient Safety and Image Quality in Fluoroscopically Guided Invasive Cardiovascular Procedures

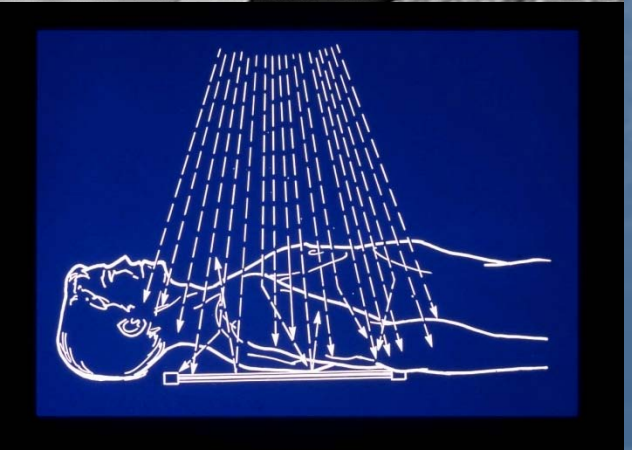
A Report of the American College of Cardiology Foundation/ American Heart Association/American College of Physicians Task Force on Clinical Competence and Training

ACCF/AHA/HRS/SCAI Clinical Competence Statement…JACC 2004. Vol.44, 2259-82

X-ray Image Formation

- Scattered radiation
  - Principal source of exposure to the patient, staff.
  - Increases with field size & intensity of X-ray beam.
- Image Noise
  - Noise decreases as the X-ray dose increases.
  - Point-to-point variations in brightness is called *image noise*.
  - Noise should be apparent in fluoroscopic imaging.
- Ideal X-ray imaging balances the requirements for contrast, sharpness, and patient dose.
  - Optimal X-ray imaging requires a kVp (peak tube voltage) that produces the best balance of image contrast, and patient dose.

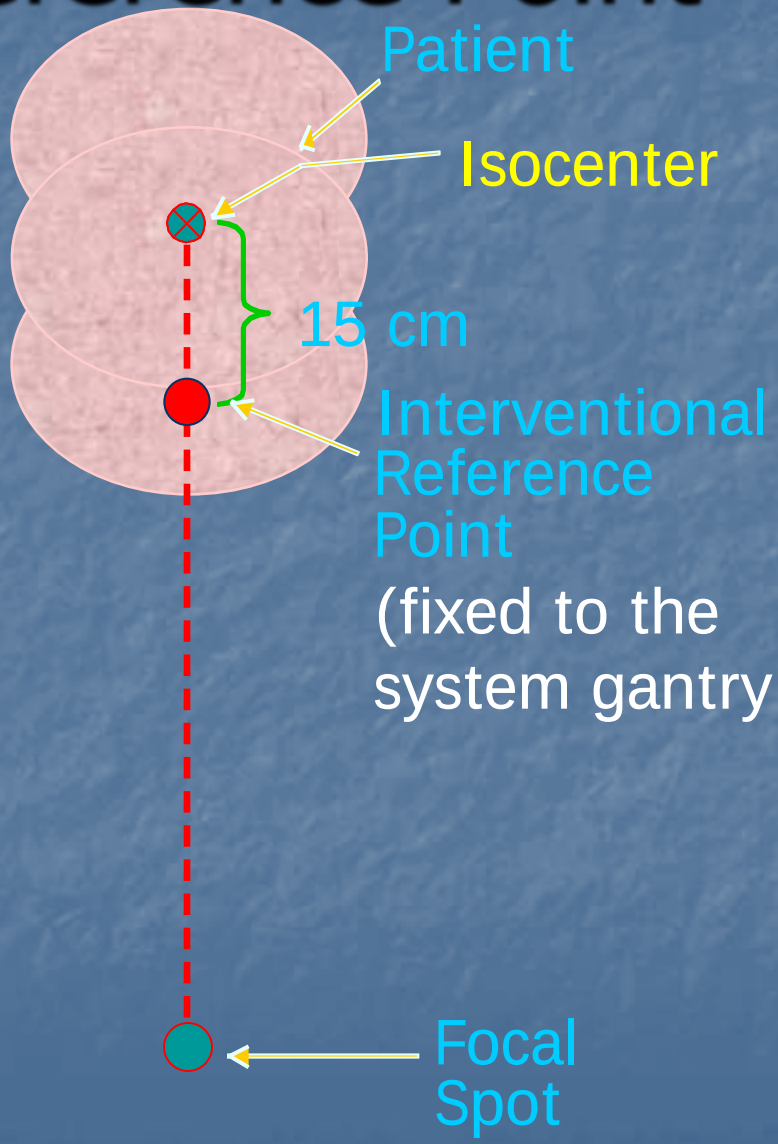
Patient Dose Assessment



- ***Fluoroscopic Time*** ***least*** **useful.**
- ***Total Air Kerma at the Interventional Reference Point*** *($K_{a,r}$, Gy)* is the x-ray energy delivered to air 15cm from for **patient dose burden for deterministic skin effects.**
- ***Air Kerma Area Product (P_{KA}, $Gycm^2$)*** is the product of air kerma and x-ray field area. ***P_{KA}*** **estimates potential stochastic effects (radiation induced cancer).**
- ***Peak Skin Dose*** (PSD, Gy) is the maximum dose received by any local area of patient skin. N**o current method to measure PSD, it can be estimated if air kerma and x-ray geometry details are known. Joint Commission Sentinel event, >15 Gy.**

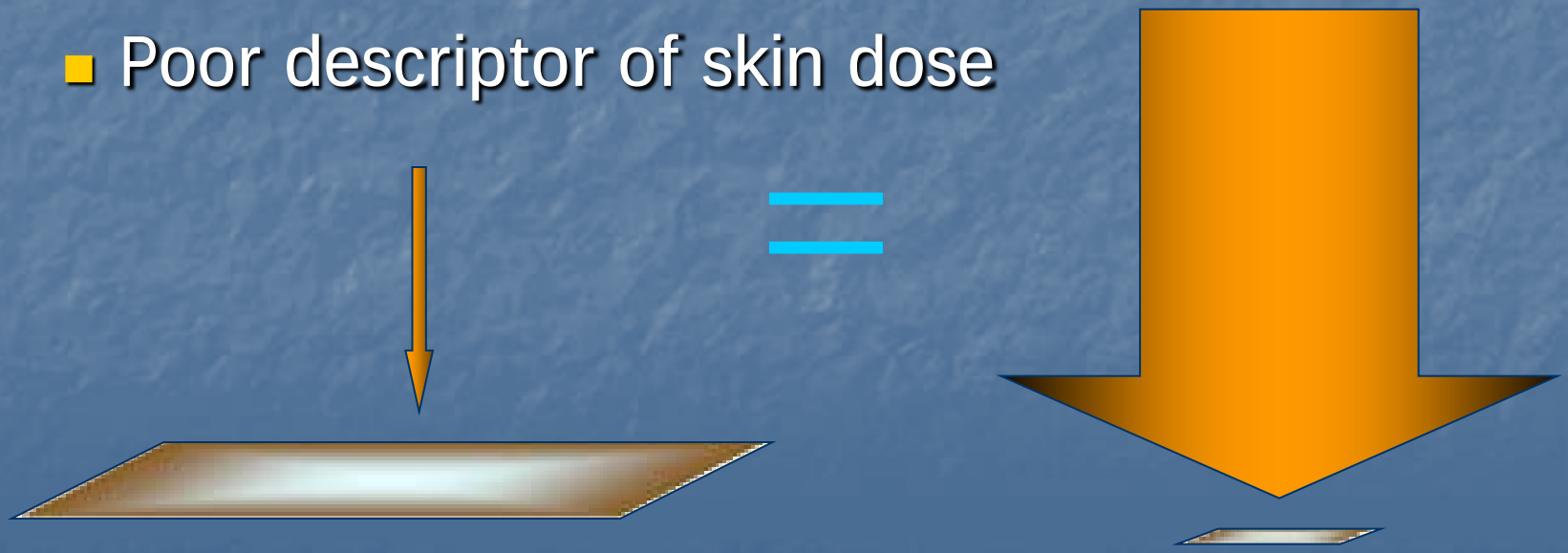
Total Air Kerma at the Interventional Reference Point

- a/k/a Reference Air Kerma, Cumulative Dose
- Measured at the IRP, may be inside, outside, or on surface of patient
- Iso-center is the point in space through which the central ray of the radiation beam intersects with the rotation axis of the gantry.



Air Kerma-Area Product (P_{KA})

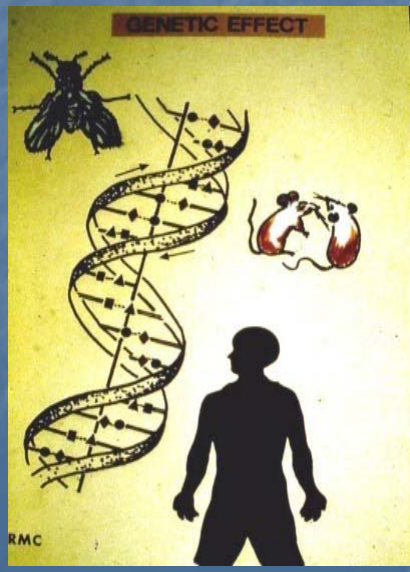
- Also abbreviated as KAP, DAP
- Dose **X** area of irradiated field *(*Gy·cm²)
- Total energy delivered to patient:
  - ***Good indicator of stochastic risk***
  - Poor descriptor of skin dose



Biologic Effects of Radiation

- **Deterministic injuries**
  - When large numbers of cells are damaged and die immediately or shortly after irradiation. Units-Gy.
  - There is a threshold dose of visible toxicity post procedure ranging from erythema to skin necrosis.

- **Stochastic injuries**
  - When a radiation damaged cell, the cell descendents become clinically important. The higher the dose, the more likely this process.
  - There is a linear non-threshold dose identifiable for radiation-induced neoplasm and heritable genetic defects. This is in units of Sv.



Clinical Determinants of Radiation Dose in PCI

- **1800 PCI pts with total air Kerma at IRP ($K_{a,r}$, Gy) estimate PSD.**
- **Patient, procedural, and operator imaging practices impacted dose.**
- **The pt's size influenced dose, emphasizing the need for specific size based x-ray programs to address the relationship between dose and image quality.**
- **Pts with PVD/ CABG got higher doses; CRI and DM, no difference.**
- **Procedural complex influen. dose: CTO and Cx PCI increased dose.**
- **156 radial approach with no dose increase.**
- **Fellows 97% case; higher volume attending had lower pt dose.**
- **It is essential to develop a culture of radiation safety.**
- **From1997 to 2009, there was a 55% reduction in PCI patient dose at Mayo clinic.**
- **Formal training is required on x-ray systems and radiation safety.**
- **Pre-procedure dose planning & techniques for dose reduction during procedure.**

Fetterly et al, JACC Int, March 2011:4, 336-43 Chambers JACC Int March 2011:4,344-6

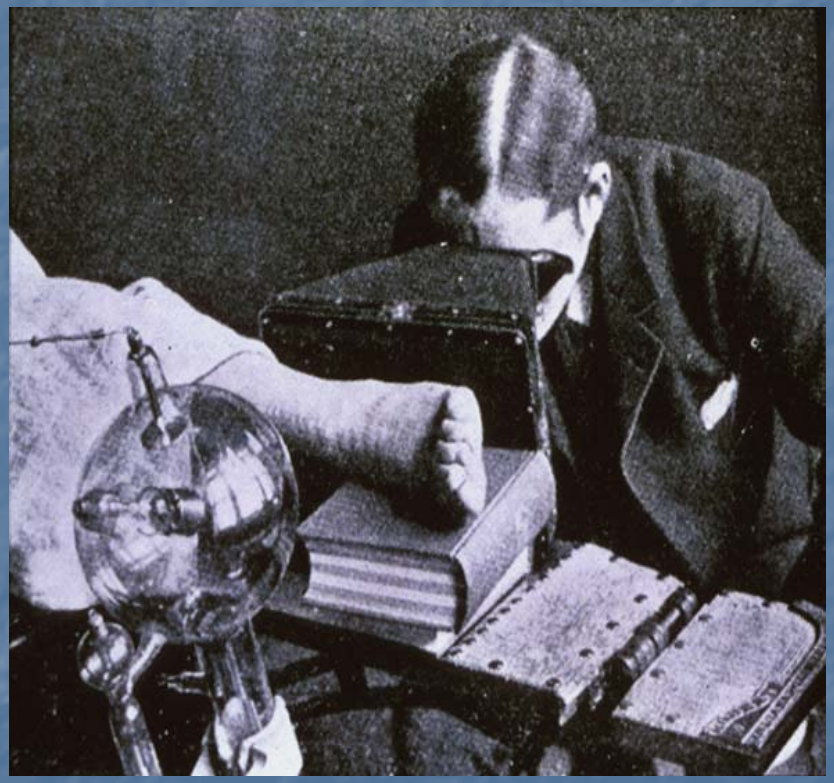
Determinants of Patient X-ray Dose

- **Equipment**
- **Procedure/Patient**
  - Obese patient
  - Complex/long case
- **Operator**
  - Equipment use
  - Dose awareness
  - Procedure technique

Chambers CE et al. Radiation Safety Program for the Cardiac Catheterization Laboratory. Cath and Card Interv. 2011 77: 510-514.

Imaging Equipment

- Purchase X-ray units with sophisticated dose-reduction and monitoring features.
- Maintain X-ray equipment in good repair and calibration.
- Utilize the ***Medical Physicist*** to assess dose and image quality.



The Procedure/Patient

- **As patient size increases…**
  - Image quality poor
  - Input dose of radiation increases exponentially
  - Scatter radiation more
- **As complexity increases…**
  - Increase fluoro/cine time
  - Steep angles/single port
  - Repeat proced. (30-60 days)

Radial Artery Access as a Predictor of Increased Radiation Exposure During Dx Cath

- Lang, 195 dx caths and 102 PCI, all elective
  - Experienced operators; dosimeters for exposure; Fluoroscopy time and DAP for patient “dose”.
  - Operator: Dx:100%; PCI- 51%for radial compared to femoral
  - Patient approx.15% increase cath, no change PCI
- Mercuri, retrospective analysis of 5,954 dx caths
  - 23% increased in Measured Air Kerma for radial compared to femoral

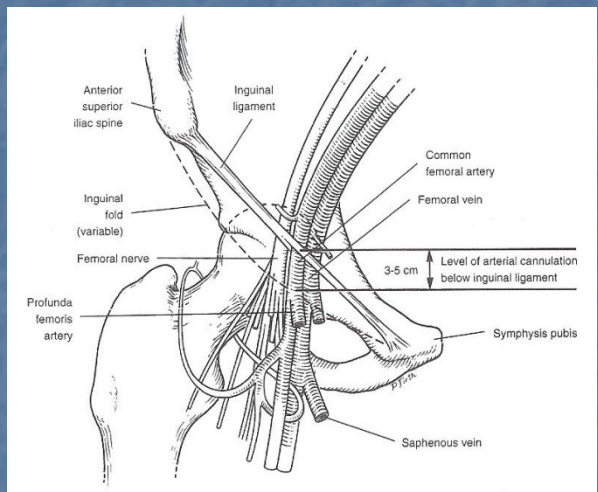
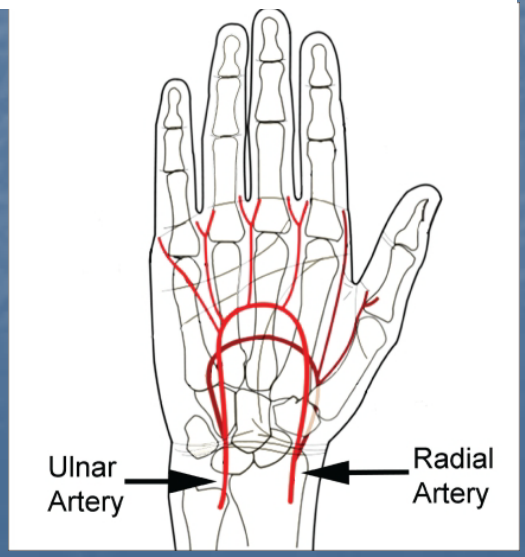


Fig. 2-1 Inguinal anatomy and guidelines for correct vascular access. (From Kulick DL, Rahimtoola SH, eds. *Techniques and applications in interventional cardiology*. St Louis, MO: Mosby, 1991: 2.)

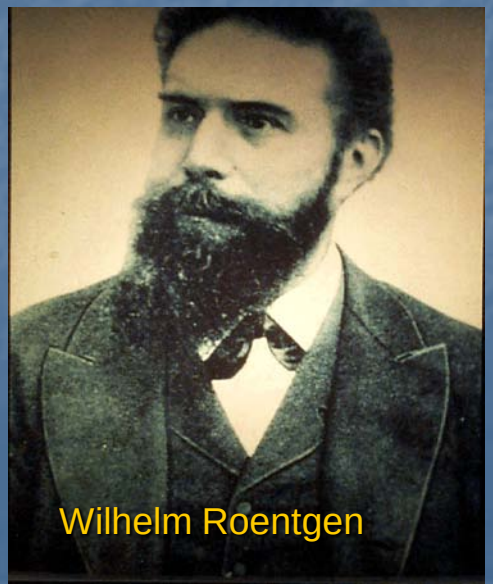


Lang, et al. CCI, 67, Jan 2006: 67, 12-16

Mercuri, et al. JACC INT, 4, March 2011: 347-352

Operator Radiation Dose Management

- **Justification of Exposure-** benefit must offset risk
- **ALARA-As Low As Reasonably Achievable**
- **Training**
- **Optimizing Patient Dose-** From Onset Of Procedure
- **Radiation Safety Program-** CCI Paper


Wilhelm Roentgen

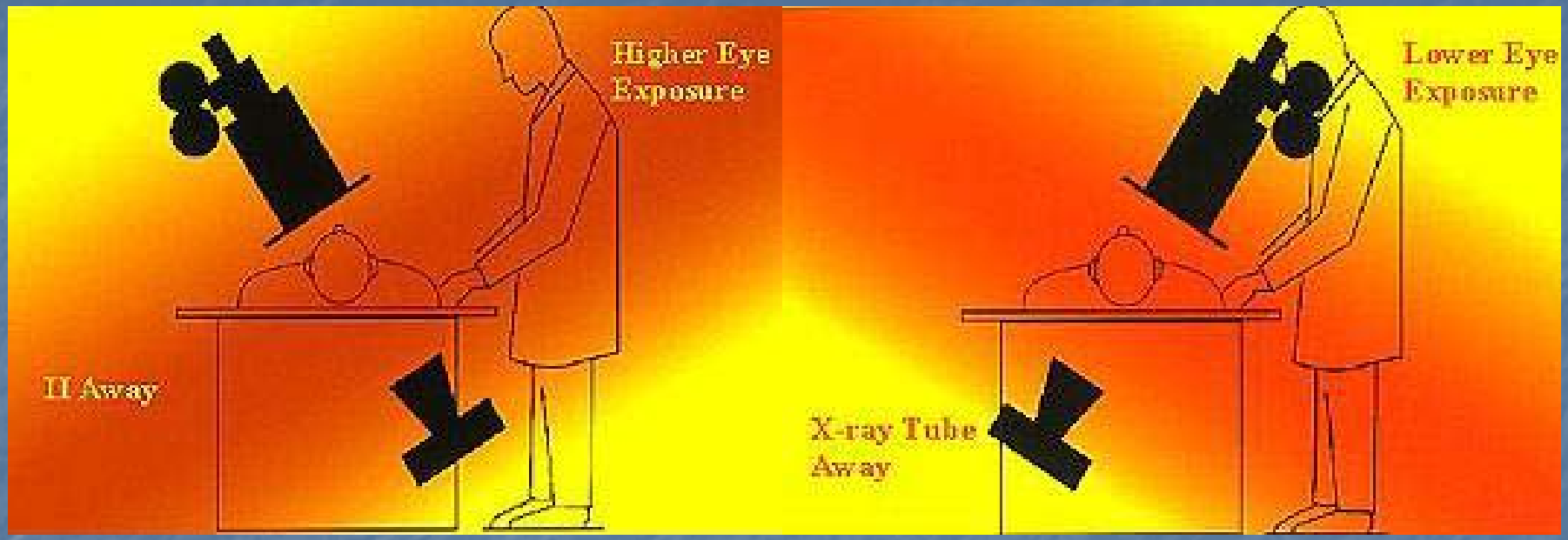
Pre-Procedure Issues

- ***Assessment of Risk***
  - The obese patient
  - complex PCI/CTO
  - repeat procedures within 30-60 days
  - other radiation-related procedures
- ***Informed Consent Components***
  - procedures are performed using x-ray ionizing radiation
  - these x-rays are delivered to help guide the equipment as well as to acquire images for long term storage
  - your physicians will deliver the dose required for the procedure
  - although risk is present, this rarely results in sig. injury
  - in complex cases, local tissue damage may occur that may require additional follow up and treatment.

Procedure Related Issues to Minimize Exposure to Patient and Operator

- Utilize radiation only when imaging is necessary
- Minimize use of cine
- Minimize use of steep angles of X-ray beam
- Minimize use of magnification modes
- Minimize frame rate of fluoroscopy and cine
- Keep the image receptor close to the patient
- Utilize collimation to the fullest extent possible
- Monitor radiation dose in real time to assess patient risk/benefit during the procedure

Tube Position and Scatter

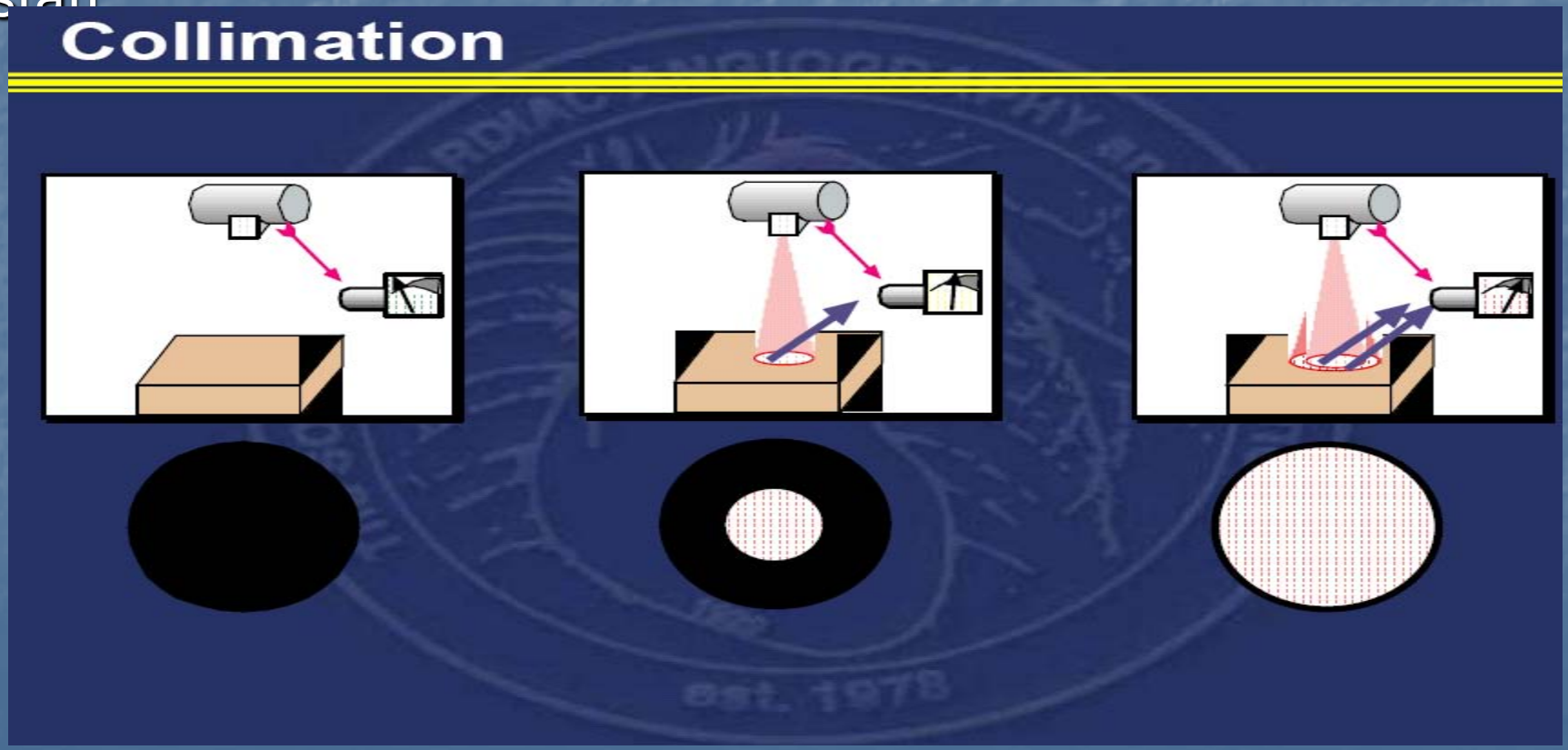


The scatter profile tilts as the x-ray tube is moved from the posterior to the anterior projection or when the tube is moved toward the cranial or caudal projections. Higher head and eye exposure occurs during oblique angle projections when the x-ray tube is tilted toward the operator or staff (II away). Radiation exposure decreases when the tube is tilted away (II toward). If given the option, stay on the II side.

Note: scatter is still directed toward the waist regardless of tube tilt.

Collimators

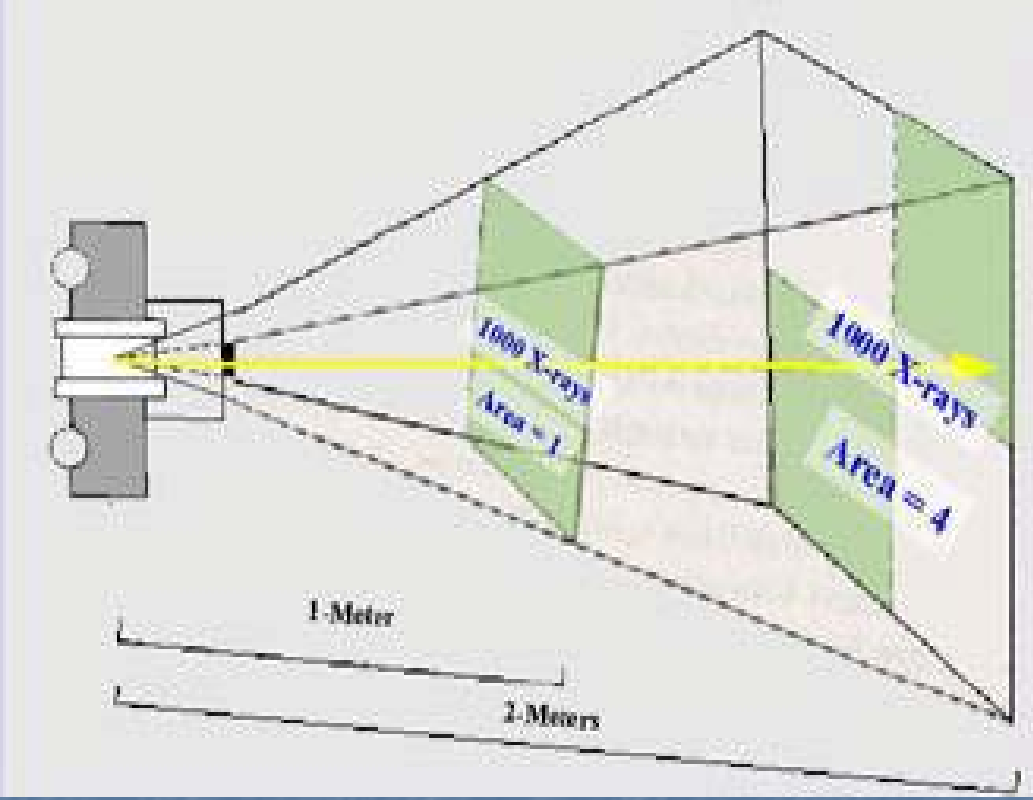
- Collimators are incorporated into the X-ray tube port .
- They adjust the beam size to the minimum required for the imaging task.
- Collimators therefore reduce scatter to other body parts and staff



Procedure Related Issues to Specifically Minimize Exposure to Operator

- Use and maintain appropriate protective garments
- Maximize distance of operator from X-ray source and patient
- Keep above-table and below-table shields in optimal position at all times
- Keep all body parts out of the field of view at all times

Inverse Square Law



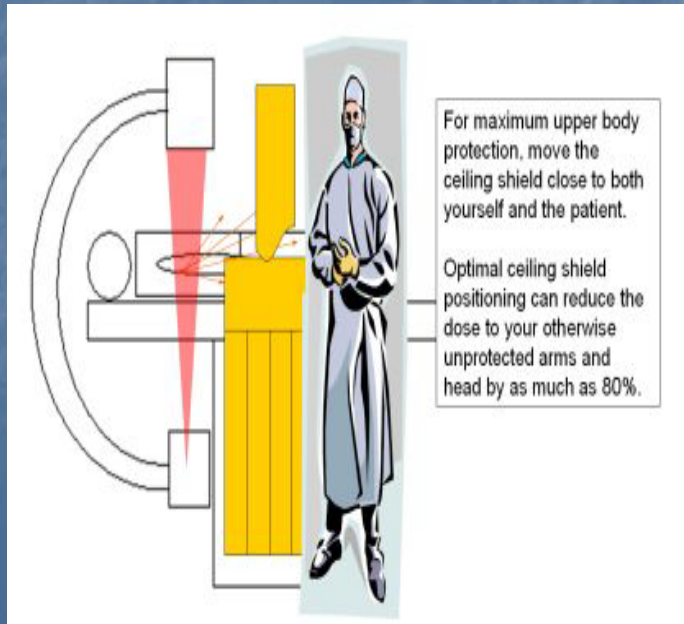
$$I_1 / I_2 = (d_2)^2 / (d_1)^2$$

This relationship shows that doubling the distance from a radiation source will decrease the exposure rate to 1/4 the original.

Staff Radiation Protection

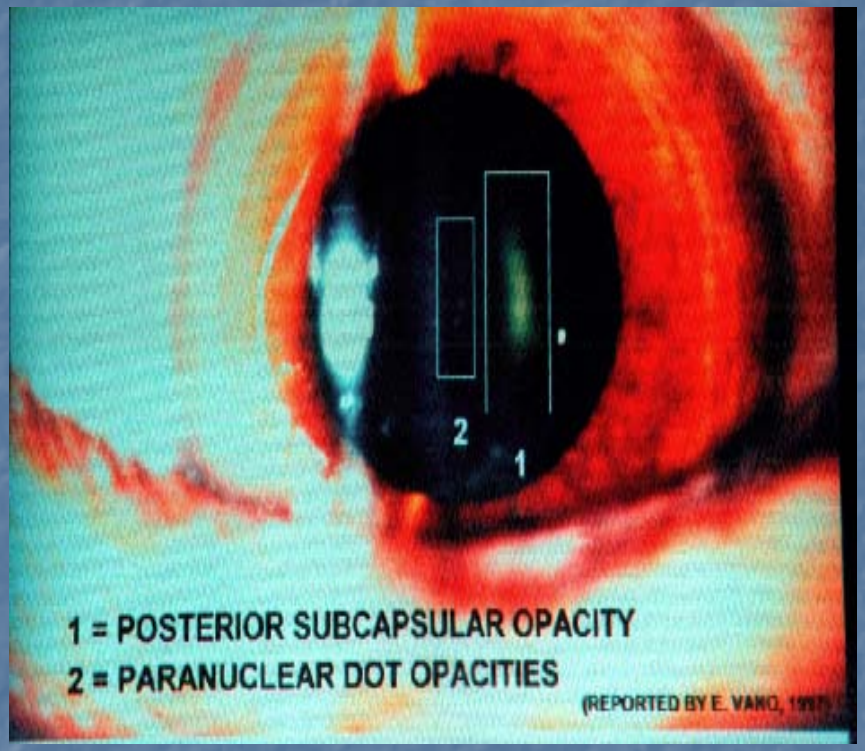
- Shielding
  - Lead>90%;Proper care of aprons
  - Thyroid shielding; <40 yo
  - Glasses-0.25 mm; must fit
  - Portable: above/below table shielding
  - Drapes (Bismuth-barium).
  - Distance (Inverse square law)
- Effective Dose / Procedure
  - 0.02-30.2 *u*SV for Dx Cath
  - 0.17-31.2 *u*Sv for PCI
  - 0.29-17.4 *u*Sv- implantable device
  - 0.24-9.6 *u*Sv for ablation
  - 2-4 mSv/yr interven. cardiologist

Joint Inter-Society Task Force on Occupational Hazards in the Interventional Laboratory.



Staff Exposure Limits

- Whole Body
  5 rem (50 mSv)/yr
- Eyes
  15 rem (150 mSv)/ yr
- Pregnant Women
  50 mrem (0.5 mSv)/mo
- Public
  100 mrem (1.0 mSv)/yr

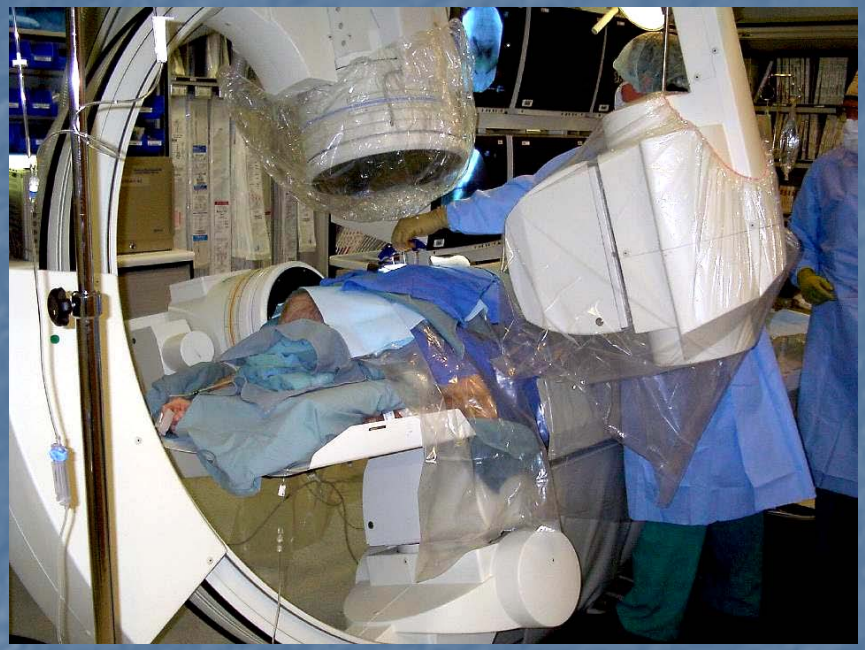


Cataract in eye of interventionist after repeated use of over table x-ray tube

www.ircp.org

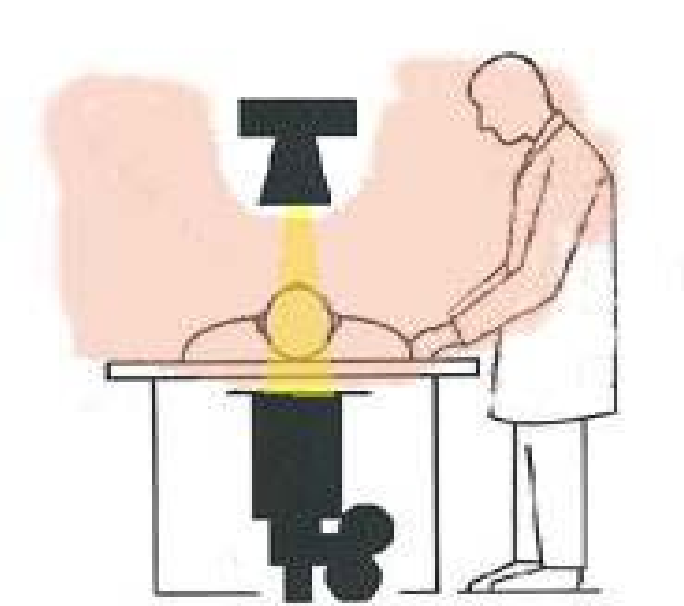
Procedure Related Issues to Minimize Exposure to Patient

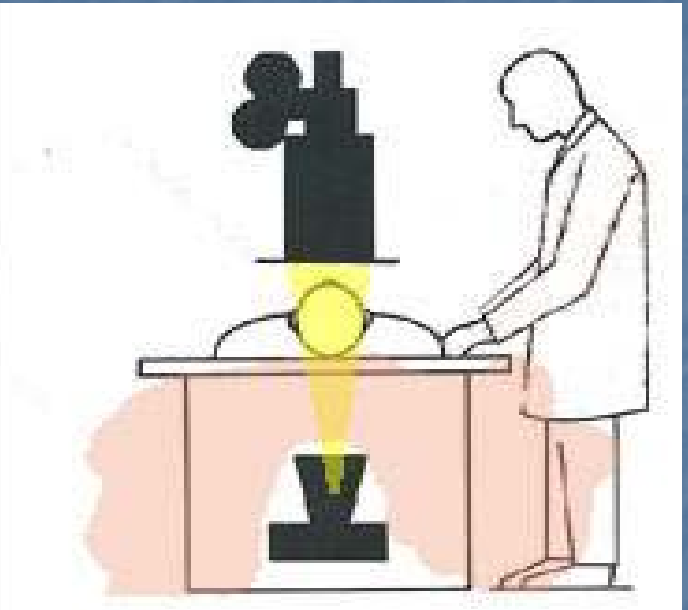
- Keep table height as high as comfortably possible for operator
- Vary the imaging beam angle to limit exposure to any 1 skin area
- Keep patient's extremities out of the beam



Protecting the patient will protect the staff and visa, versa

X-Ray Tube Position





The position of the x-ray tube determines the scatter pattern. Higher exposure occurs when the tube is in the lateral or anterior projection. A bi-plane system routinely uses a second x-ray unit in the lateral position.

Post Procedure Issues

- ***Cardiac Catheterization Reports*:** include Fluoro Time, Total Air Kerma at the Interventional Reference Point (IRP) ($K_{a,r,}$, Gy) , and/or Air Kerma Area Product (P_{KA} ,$Gycm^2$) .
- ***Chart Documentation*** for procedures of $K_{a,r} \geq 5$ Gy.
- ***Follow up*** at 30 day is required for $K_{a,r}$ of 5-10 Gy can be done as either a phone call or visit.
- ***For $K_{a,r} > 10$ Gy:*** a detailed analysis by a qualified physicist.
- ***PSD > 15 Gy:*** contact risk management within 24 hrs.
- ***Staged Procedures***: remember to consider prior dose.

Risk Management of Skin Effects in Interventional Procedures

- Individualized management by an experienced radiation wound care team should be provided for wounds related to high dose radiation.
- For any patient exposed to significant high dose, > 10 Gy, not only is medical follow-up essential, full investigation of the entire case is desirable to minimize the likelihood of such an event being repeated.

2011 PCI Guidelines
3.1 Radiation Safety Recommendation

Class I

Cardiac catheterization laboratories should routinely record relevant patient procedural radiation dose data (e.g.., total air kerma at the interventional reference point ($K_{a,r}$), air kerma area product (P_{KA}), fluoroscopy time, number of cine images), and should define thresholds with corresponding follow-up protocols for patients who receive a high procedural radiation dose. ***(Level of Evidence: C)***

Final Thoughts