The Changing Landscape of Cardiovascular Imaging

Samuel E. Lewis, M.D., M.S.E.E., F.A.C.C., DABNM

Charles Dickens

"It was the best of times, it was the worst of times …

it was the age of wisdom, it was the age of foolishness; it was the epoch of belief, it was the epoch of incredulity; it was the season of Light, it was the season of Darkness; it was the spring of hope, it was the winter of despair; we had everything before us, we had nothing before us; we were all going directly to Heaven, we were all going the other way."

Cost / Benefit

Who pays?

For what?

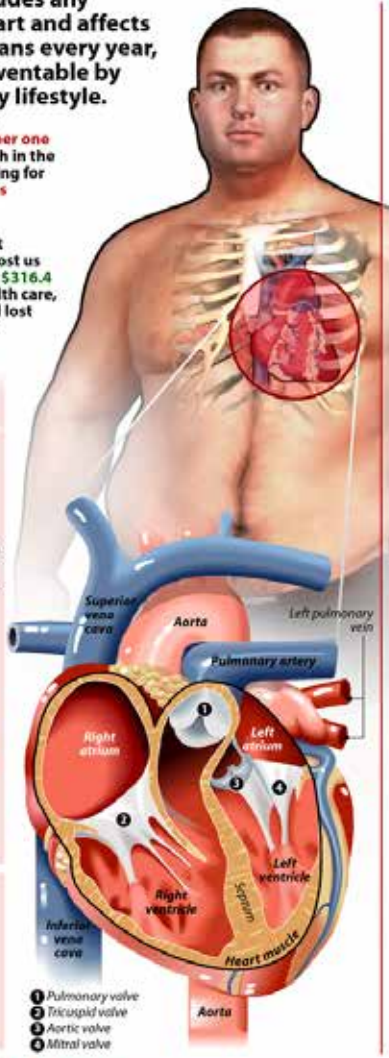
When?

Heart Disease

Heart disease includes any disorder of the heart and affects millions of Americans every year, yet it is highly preventable by following a healthy lifestyle.

It is the number one cause of death in the U.S., accounting for 36% of deaths annually.

In 2010, heart disease will cost us an estimated $316.4 billion in health care, medicine and lost productivity.



COMMON RISK FACTORS FOR HEART DISEASE INCLUDE:

TO SCREEN FOR RISK FACTORS, HAVE YOUR DOCTOR:

- Test your blood pressure with a pressure cuff
- Test your blood cholesterol level
- Compute/discuss your Body Mass Index (BMI)

HOW TO LOWER YOUR RISK

- Quit smoking
- Exercise
- Eat your fruits and vegetables
- Avoid salt and fatty foods
- Limit alcohol
- Get regular medical exams

And, if applicable:

- Take blood-pressure-lowering meds (for people with high blood pressure)
- Monitor your blood sugar level (for diabetics)

TYPES OF HEART DISEASE

Coronary heart disease
Blocked or clogged arteries limit blood flow to the heart and starving it of oxygen and nutrients.

Arrhythmia
The heart beats irregularly.

Heart failure
The heart can't pump as powerfully as it needs to in order to supply the body with oxygen and nutrients, causing the heart muscles to overwork and weaken.

Heart valve disease
One of more of the hearts' valves — which control blood flow into and out of the heart — doesn't work.

Cardiomyopathy
An enlarged or abnormally stiff or thick heart, causing the heart to pump weaker than normal and sometimes leading to heart failure or arrhythmia.

Pericarditis
An inflammation of one or more layers of the pericardium, a thin membrane that lines the heart.

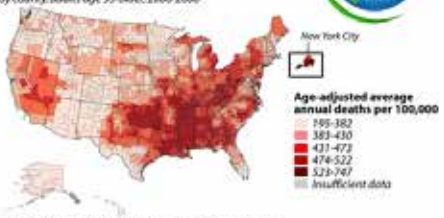
Aorta disease
A portion of the aortic wall weakens and balloons out, forming an aneurysm.

Vascular disease
Heart disease is often related to diseases of the circulatory system, including arteries, veins and lymph vessels, or blood disorders.

FAST FACTS

- Heart disease is the **leading cause of death** in the U.S.
- It is the **leading cause** for **both men and women,** and the deaths are **split evenly** across gender.
- Every **34 seconds** in the U.S., someone has a **heart attack.** Every **minute,** someone dies from **heart disease.**
- About **79 million** Americans have some form of **cardiovascular disease.**

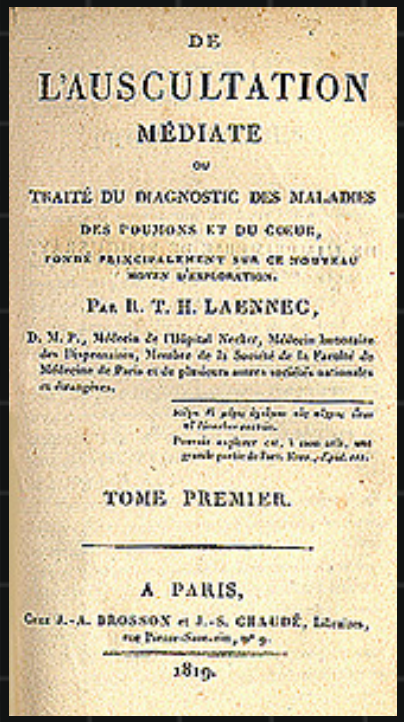
Heart disease death rates in the U.S.
by county, adults age 35-older, 2000-2006



SOURCE: National Vital Statistics System and U.S. Census Bureau

SOURCES: American Heart Association; WebMD; Centers for Disease Control and Prevention; National Heart Lung and Blood Institute

Rene T. H. Laennec



DE

L'AUSCULTATION

MÉDIATE

OU

TRAITÉ DU DIAGNOSTIC DES MALADIES

DES POUMONS ET DU COEUR,

FONDÉ PRINCIPALEMENT SUR CE NOUVEAU

MOYEN D'EXPLORATION.

PAR R. T. H. LAENNEC,

D. M. P., Médecin de l'Hôpital Necker, Médecin honoraire des Dispensaires, Membre de la Société de la Faculté de Médecine de Paris et de plusieurs autres sociétés nationales et étrangères.

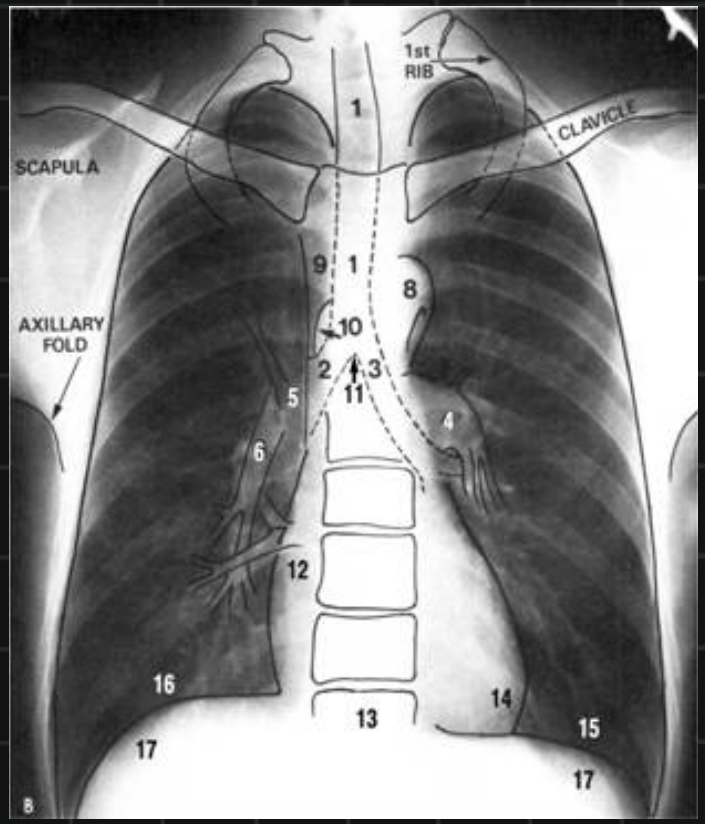
TOME PREMIER.

A PARIS,

CHEZ J.-A. BROSSON et J.-S. CHAUDÉ, Libraires, rue Pierre-Sarrazin, n° 9.

1819.

William Conrad Roentgen and Radiography



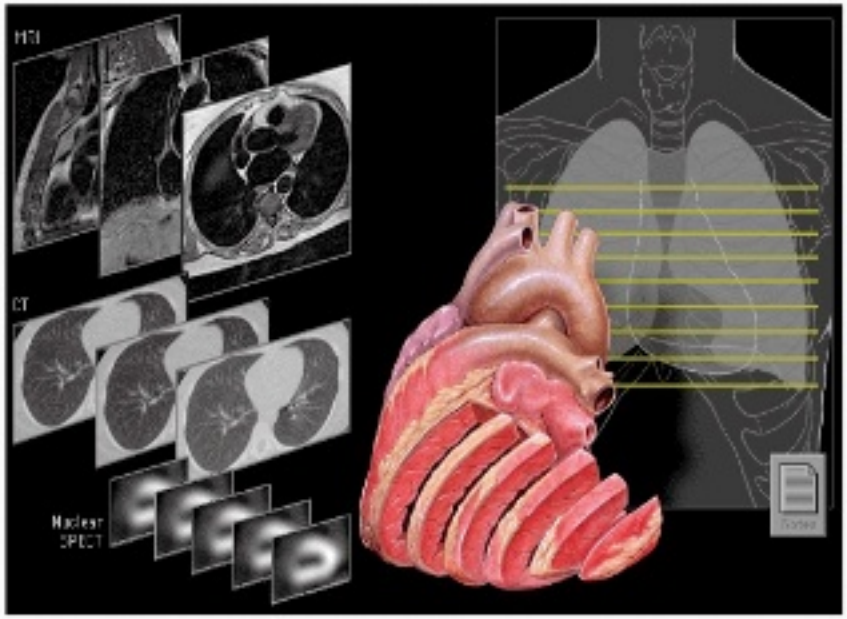
1895

Cardiac Imaging

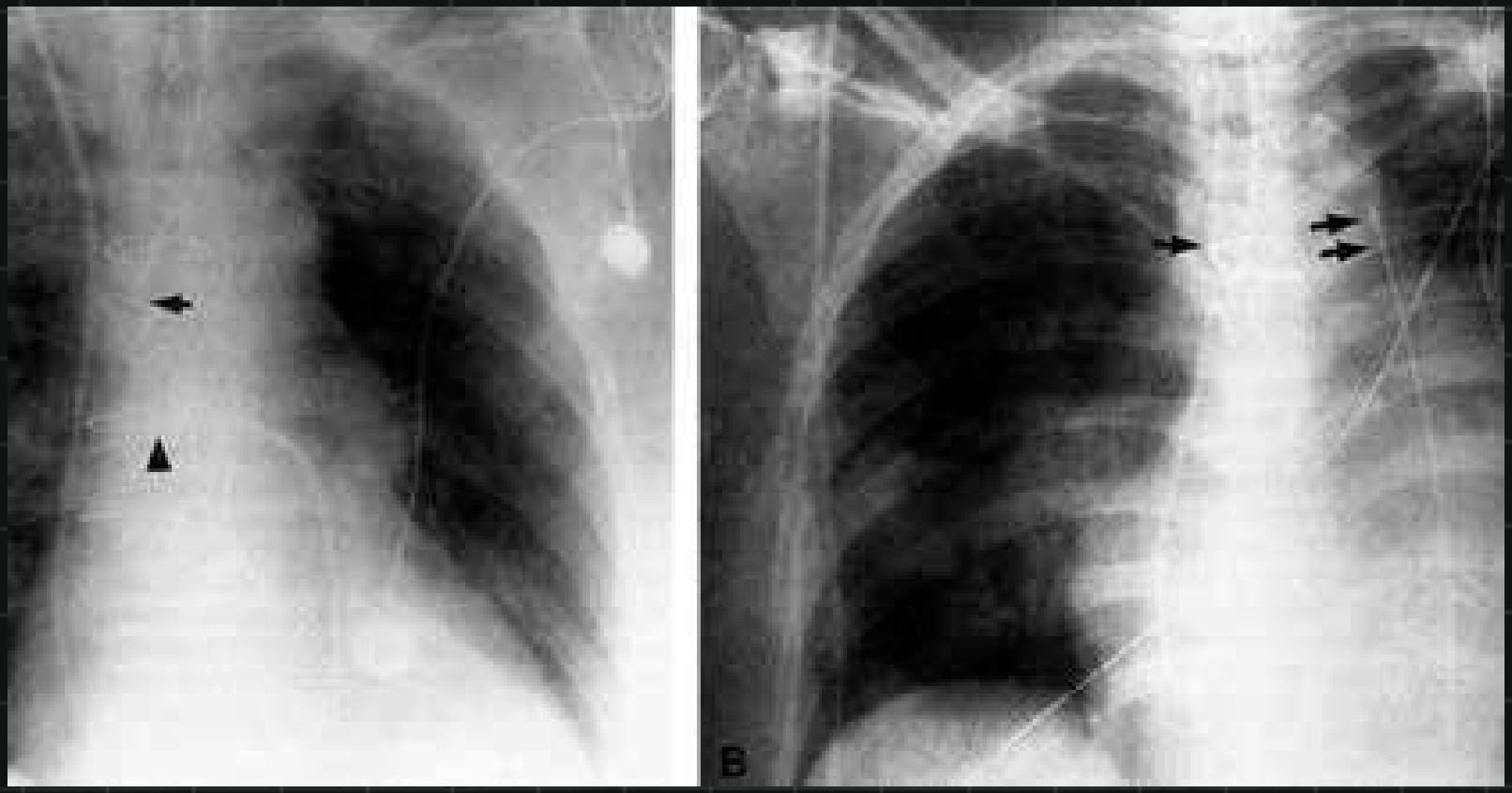
- Imaging of the heart is done for the following reasons:
  - To see the size and shape of the heart
  - To see the pumping and flow of blood to various parts of the body
  - To see the activity of the valves
  - To know the condition and activity of the walls of the heart
  - To see the circulation to the heart itself

Imaging Modalities Used

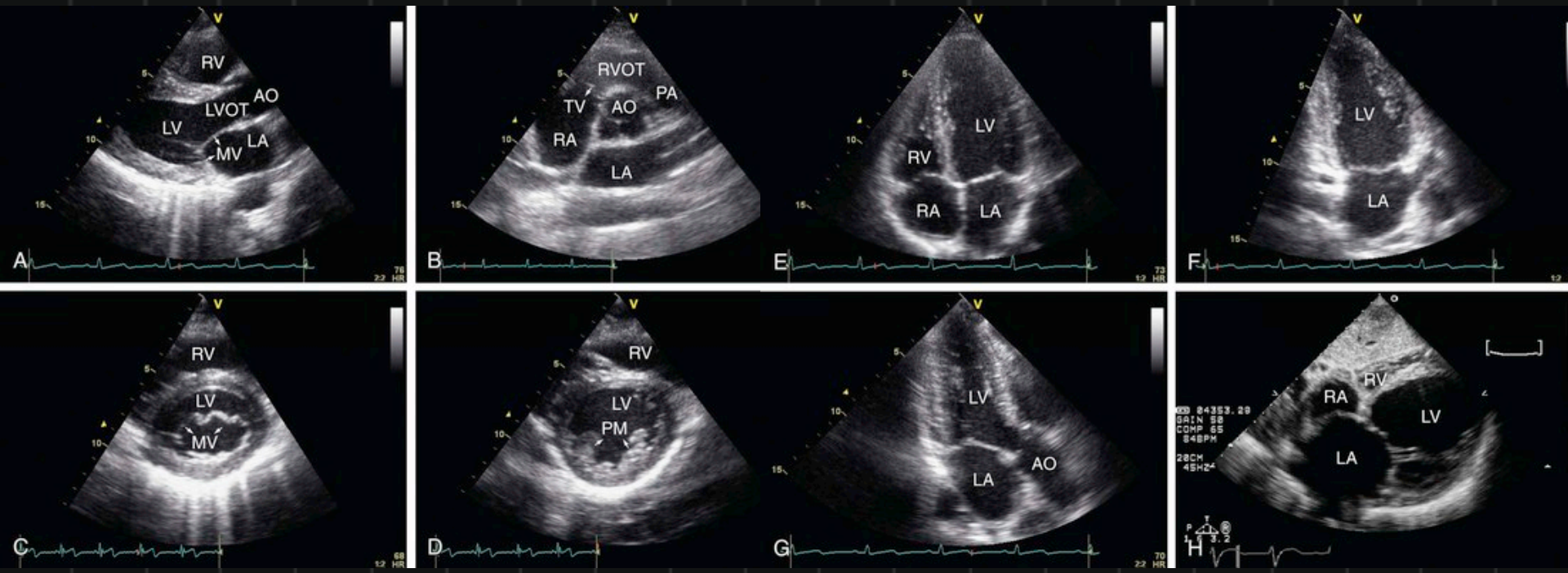
- Chest X-Rays
- Echocardiography
- Computed Tomography
- MRI
- Nuclear Medicine
- Angiocardiography



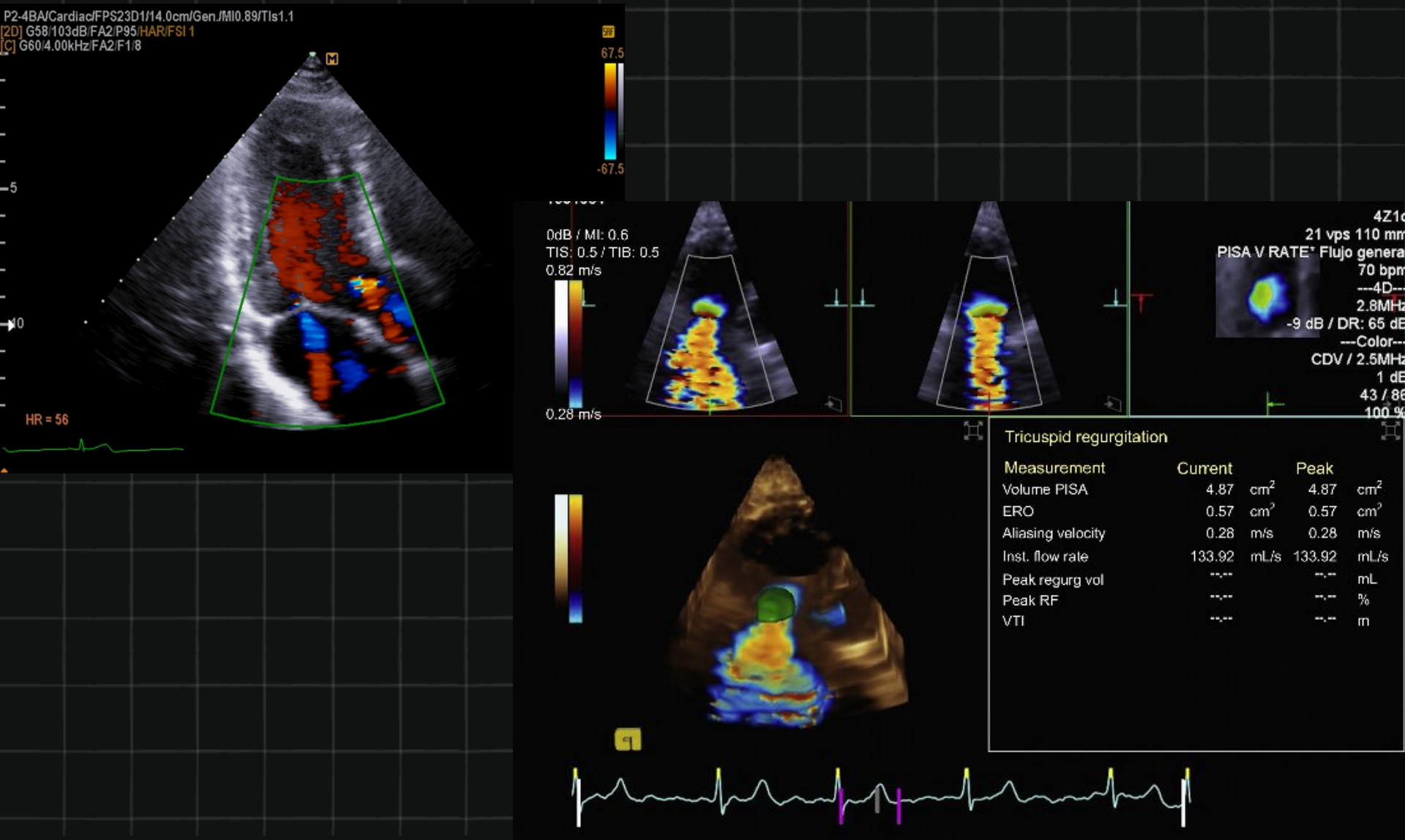
Radiography



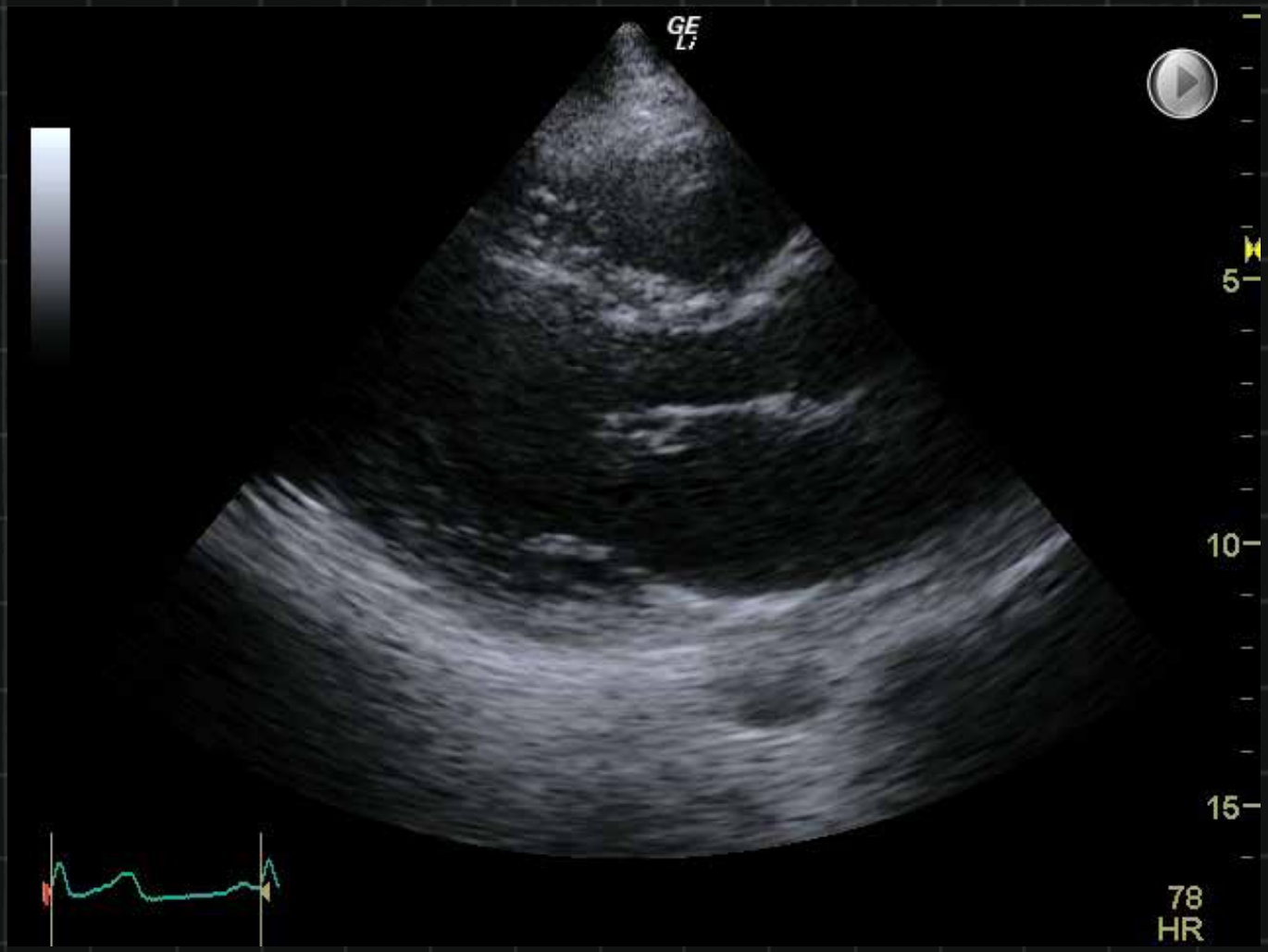
Echocardiography



Color Doppler for Valve Dysfunction

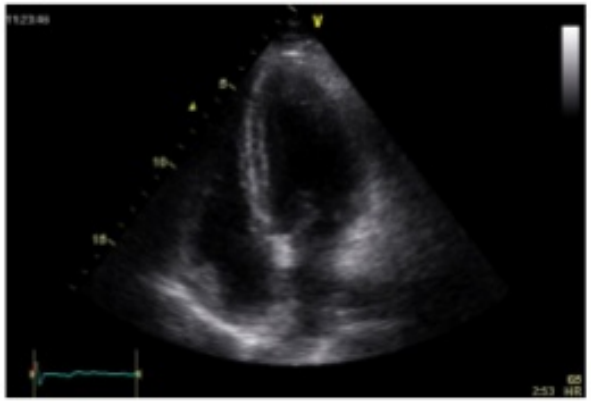


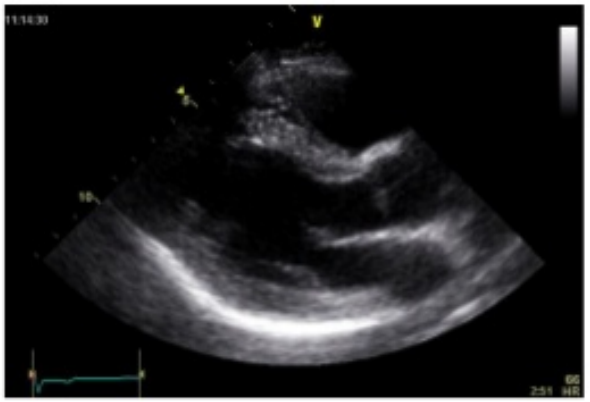
Echocardiography for Masses

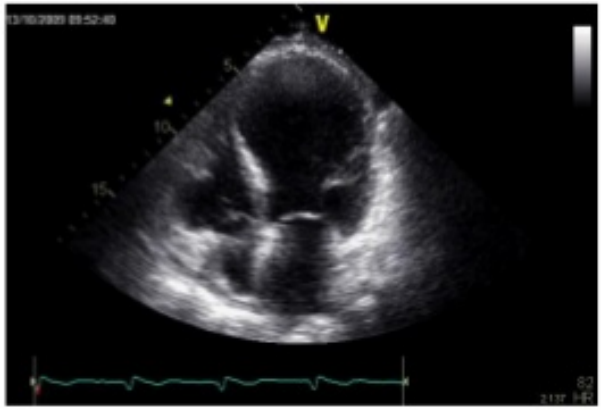


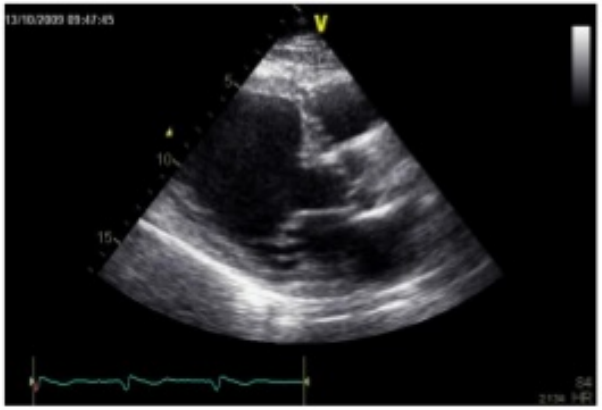
Stress Echo for Inducible Segmental Dysfunction

Regional Wall Motion Assessment









From: U.S. Hospital Use of Echocardiography: Insights From the Nationwide Inpatient Sample

J Am Coll Cardiol. 2016;67(5):502-511. doi:10.1016/j.jacc.2015.10.090

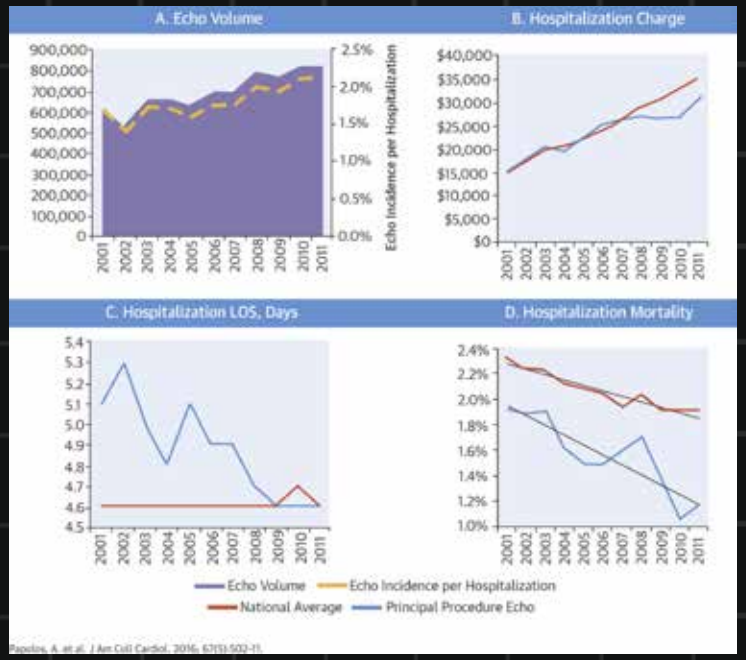


Figure Legend:

U.S. Hospital Trends in Echo Use: 2001 to 2011

(A) Annual national volume (shaded area) and incidence (dashed line) of echocardiography (echo) use per hospitalization. (B) Average charge of hospitalization in which echo was coded as the principal procedure performed versus the national average. (C) Average length of hospitalization in which echo was coded as the principal procedure performed versus the national average. (D) Incidence of inpatient mortality of hospitalizations in which echo was coded as the principal procedure performed versus the national average. LOS = length of stay.

Myocardial Contrast Echocardiography Perfusion Imaging

- Late 1990s – MCE will soon be a daily clinical reality threatening nuclear cardiology because promising single-center trials claimed near biblical levels of accuracy
- Plagued with technical and interpretive problems
- James D. Thomas, M.D. editorial – “Still Waiting After All These Years”
- “ I get tired of waiting, wondering if you were ever coming around” – Taylor Swift

From: U.S. Hospital Use of Echocardiography: Insights From the Nationwide Inpatient Sample

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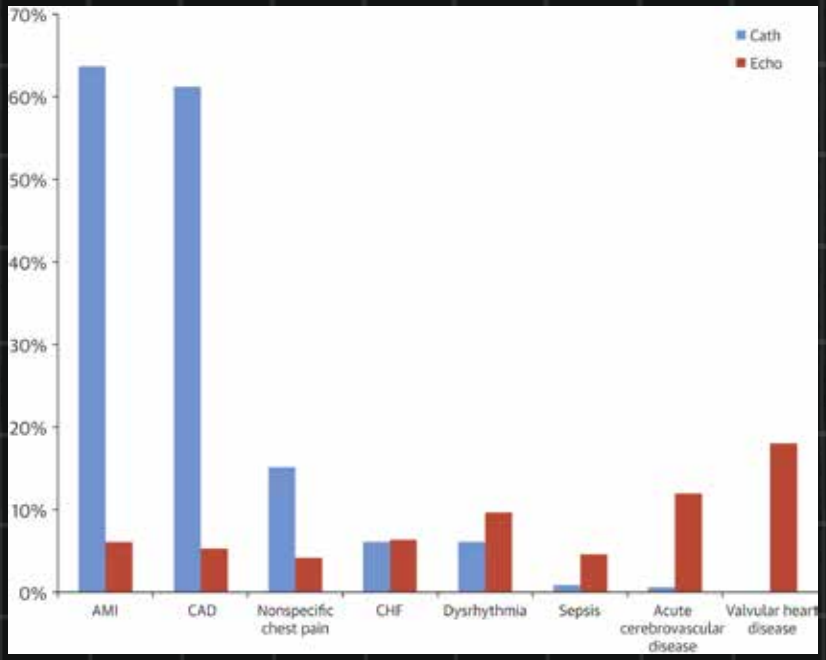


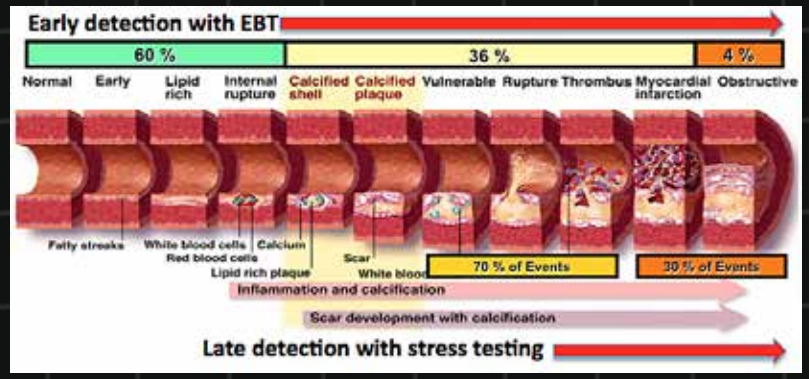
Figure Legend:

Sample Rates of Diagnostic Cardiac Catheterization and Echo by Admission Diagnosis

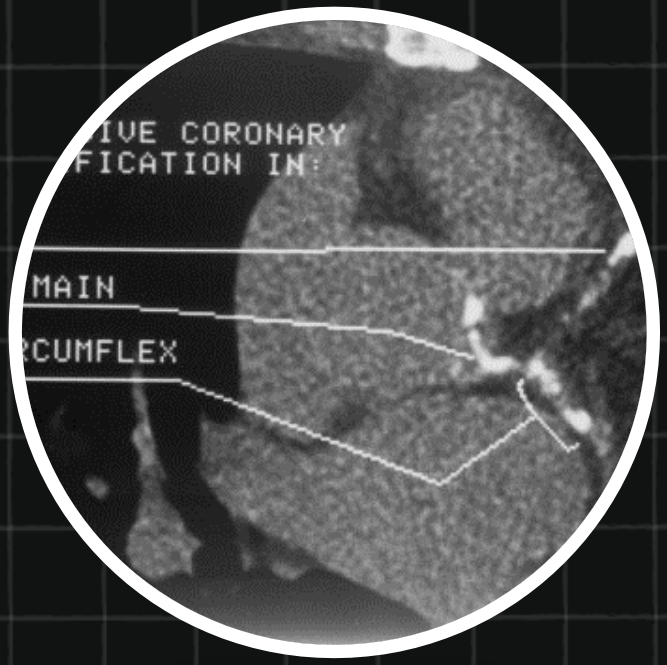
AMI = acute myocardial infarction; CAD = coronary artery disease; Cath = cardiac catheterization; CHF = congestive heart failure; Echo = echocardiography.

Portable Echocardiography

EBCT Calcium Imaging



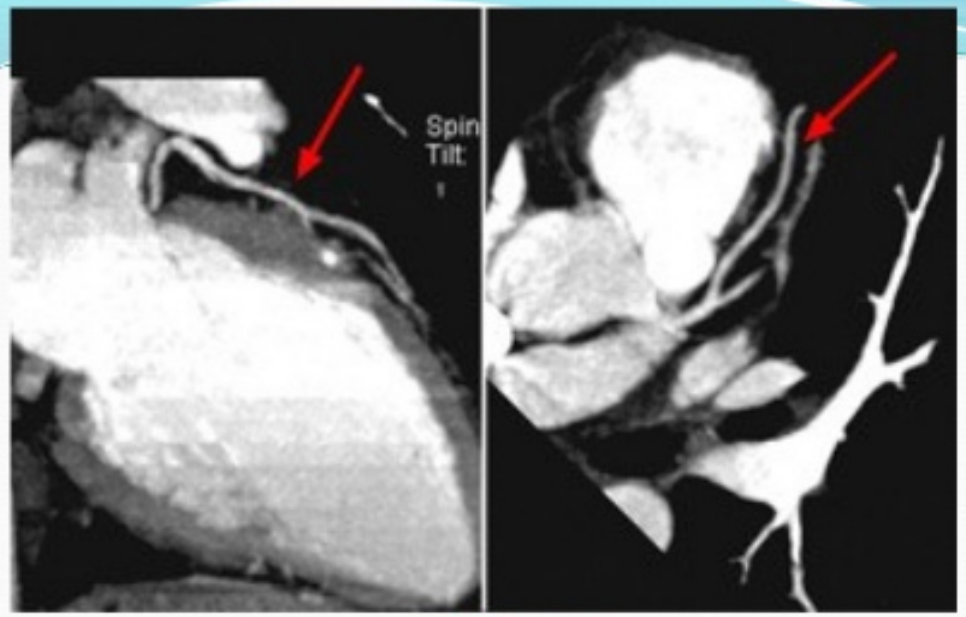
CT Calcium Scoring



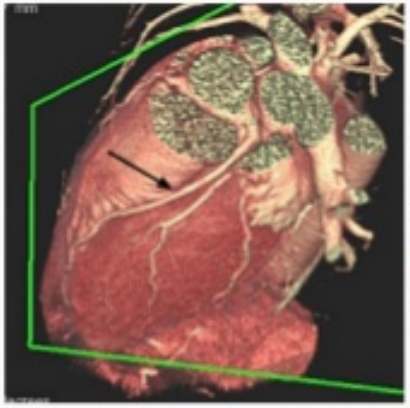
Calcified atherosclerotic plaque burden as a surrogate marked for coronary atherosclerosis. Calcium is NOT present within the wall of a normal coronary artery.

Rule of thumb: testing for inducible ischemia generally not indicated for total calcium scores < 400

CTA



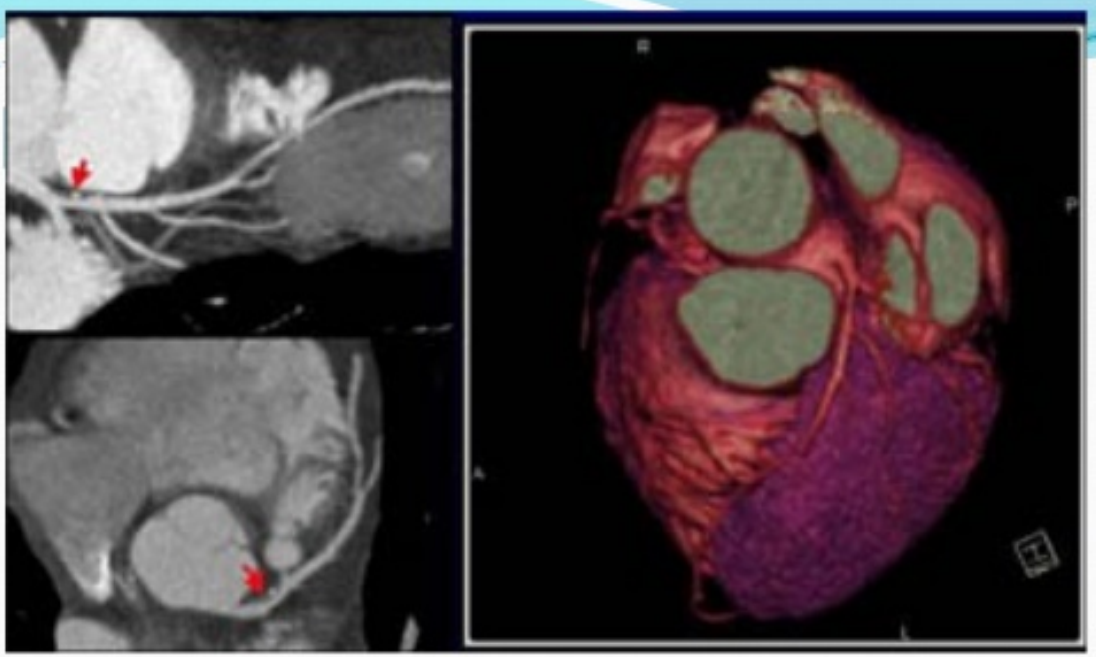
- The two MDCT views above show that the left coronary artery (red arrows) and its side branches are normal



- This 3D MDCT view is looking down on top of the left ventricle
- It shows a normal coronary artery (black arrow

CTA

CT A



- CC- Patient with mild hyperlipidemia and atypical chest pain
- Curved reconstructions of the left anterior descending coronary artery show just beyond its origin, a plaque [arrows] consisting largely of “soft” non-calcified (gray) material but with a small central calcification (white)

CTA

- Patient with equivocal stress test results and atypical chest pain
- Curved reconstructions of the left anterior descending coronary artery and a dynamic 3D surface reconstruction demonstrate a long, densely calcified atherosclerotic plaque [arrows] resulting in significant narrowing of the artery

Limitations of CTA

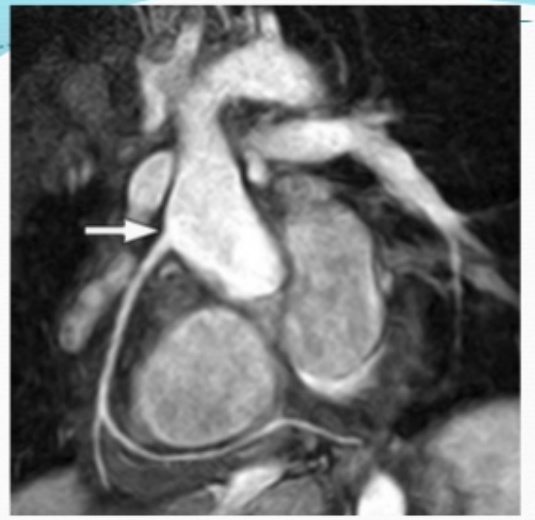
Relatively high radiation exposure

Most studies require HR limitation (beta-blockade)

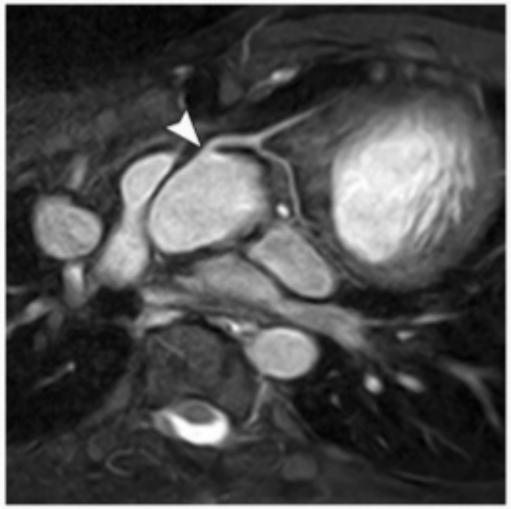
Magnetic Resonance Imaging

- Used to identify abnormalities in the
  - Heart muscles- weakness , aneurysm, thickening
  - Valves
  - Coronary arteries
  - Great vessels for any abnormality
  - Presence of tumors, thrombus

Cardiac MRI

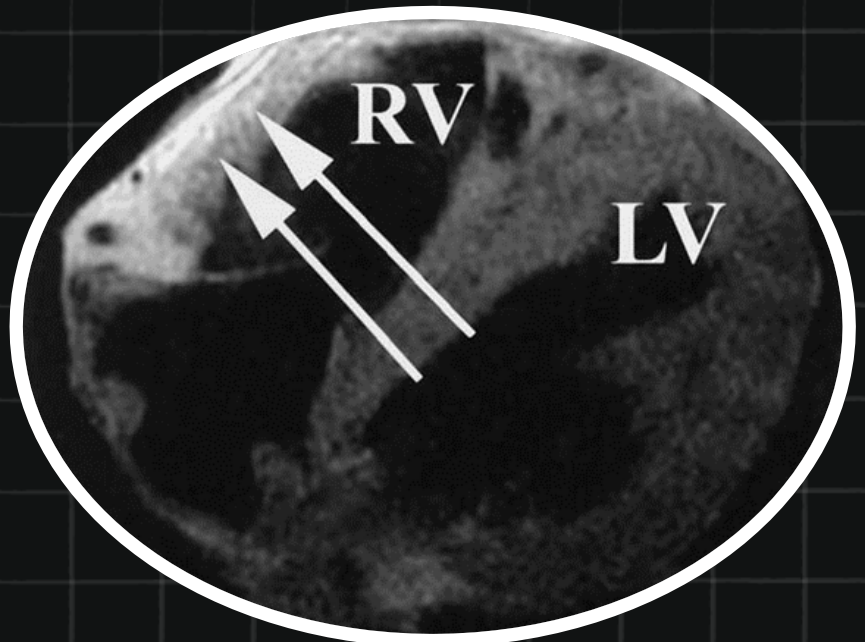


RIGHT CORONARY ARTERY

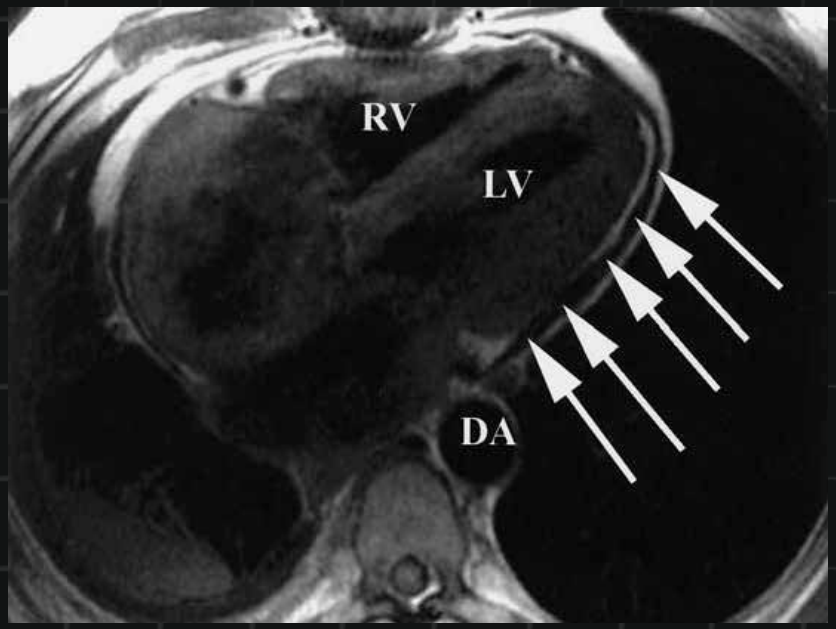


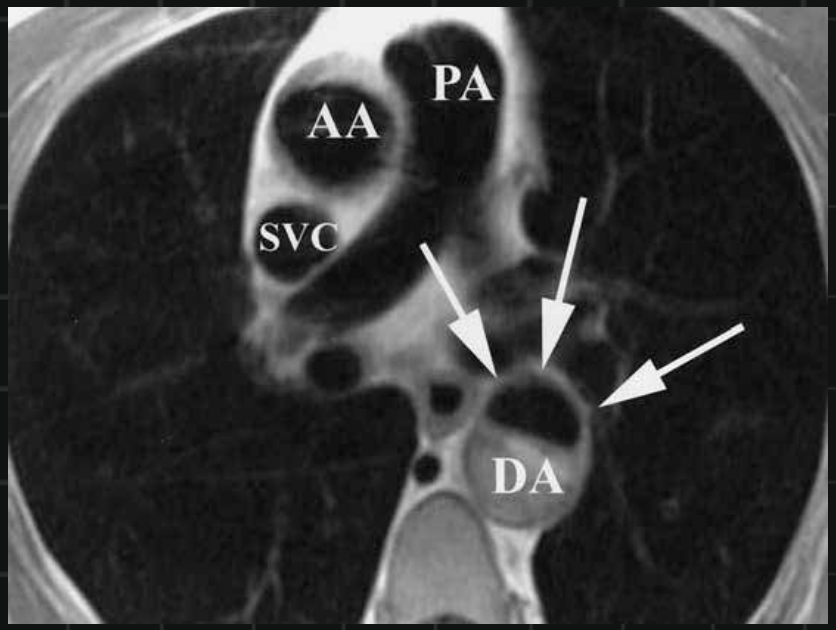
LEFT CORONARY ARTERY

Limitations: gorgeous example images not realized in clinical practice



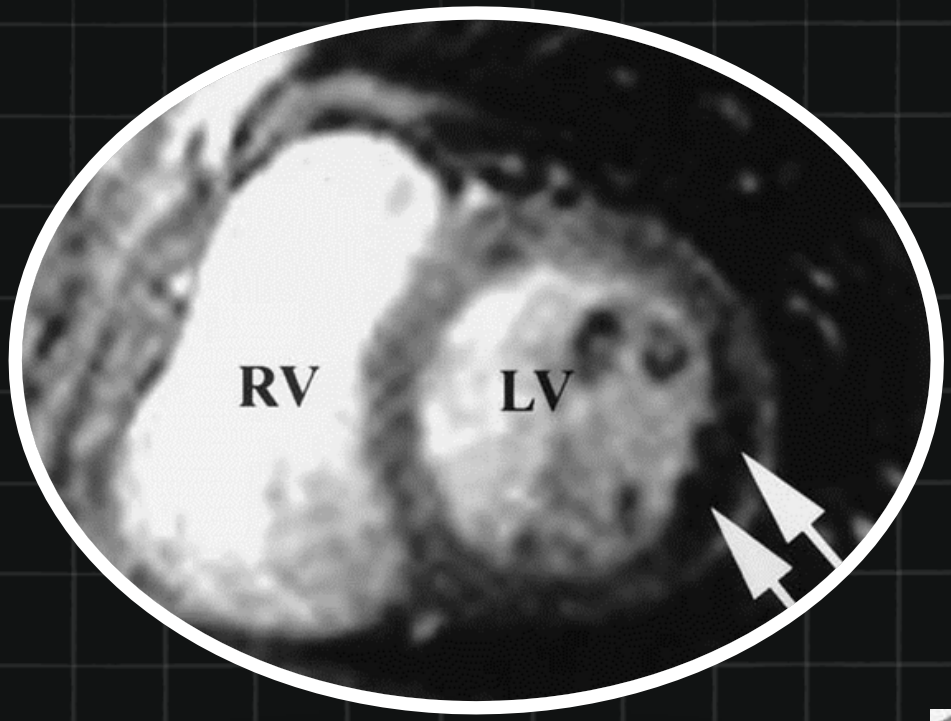
Bright RV consistent with fatty deposits of arrhythmogenic RV dysplasia





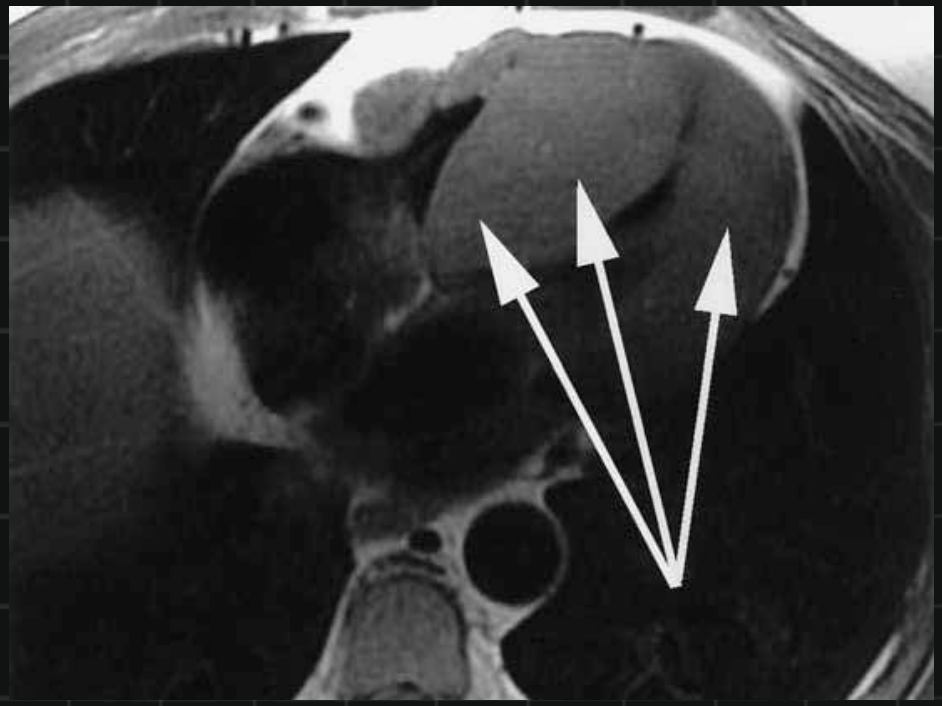
Dissection in the descending thoracic aorta with high signal i
the false lumen because of thrombus

MRI Black Blood Imaging



First pass contrast imaging showing lateral wall hypoperfusion

Severe concentric LVH in HCM

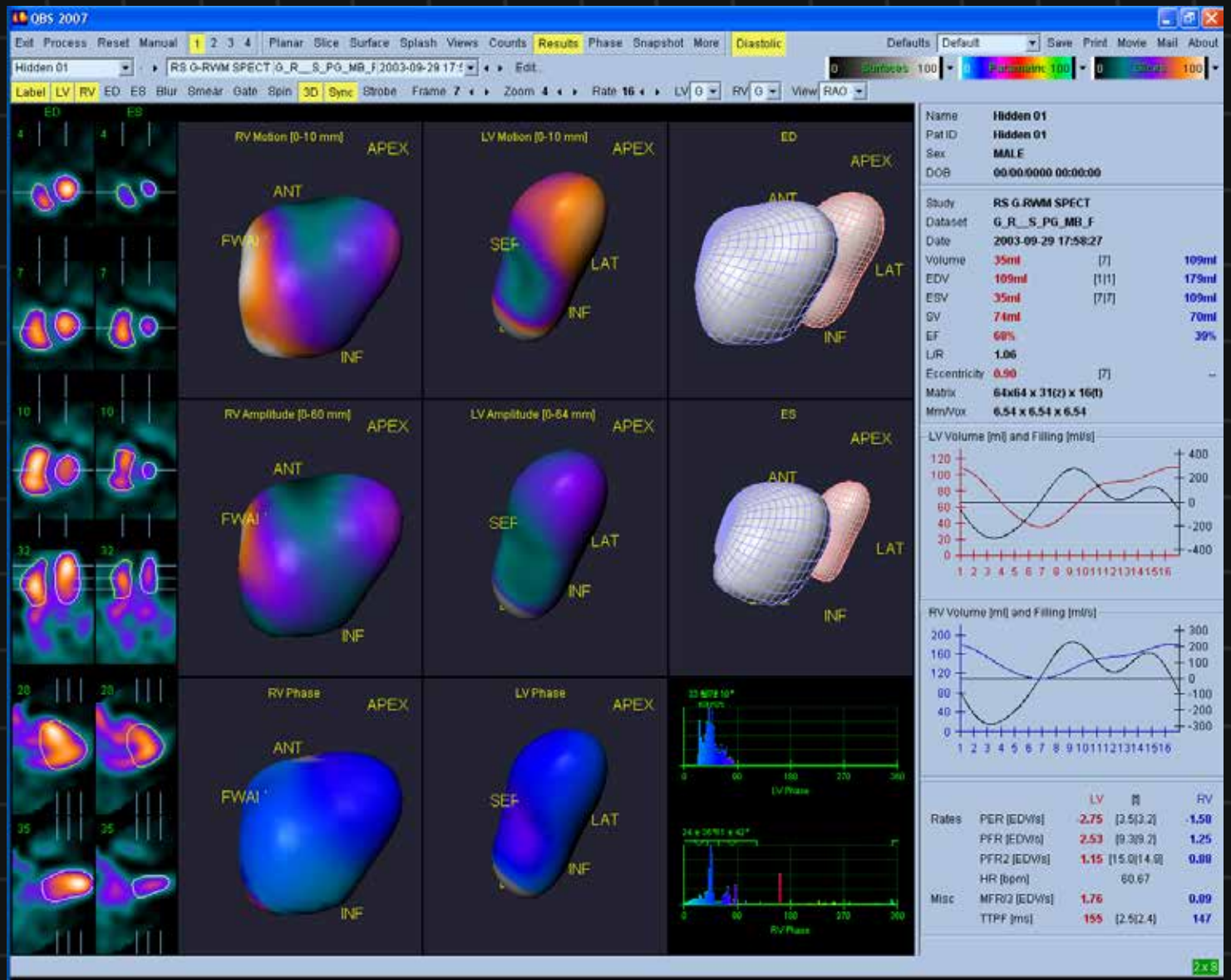


Cardiac MRI Evaluation of Scar

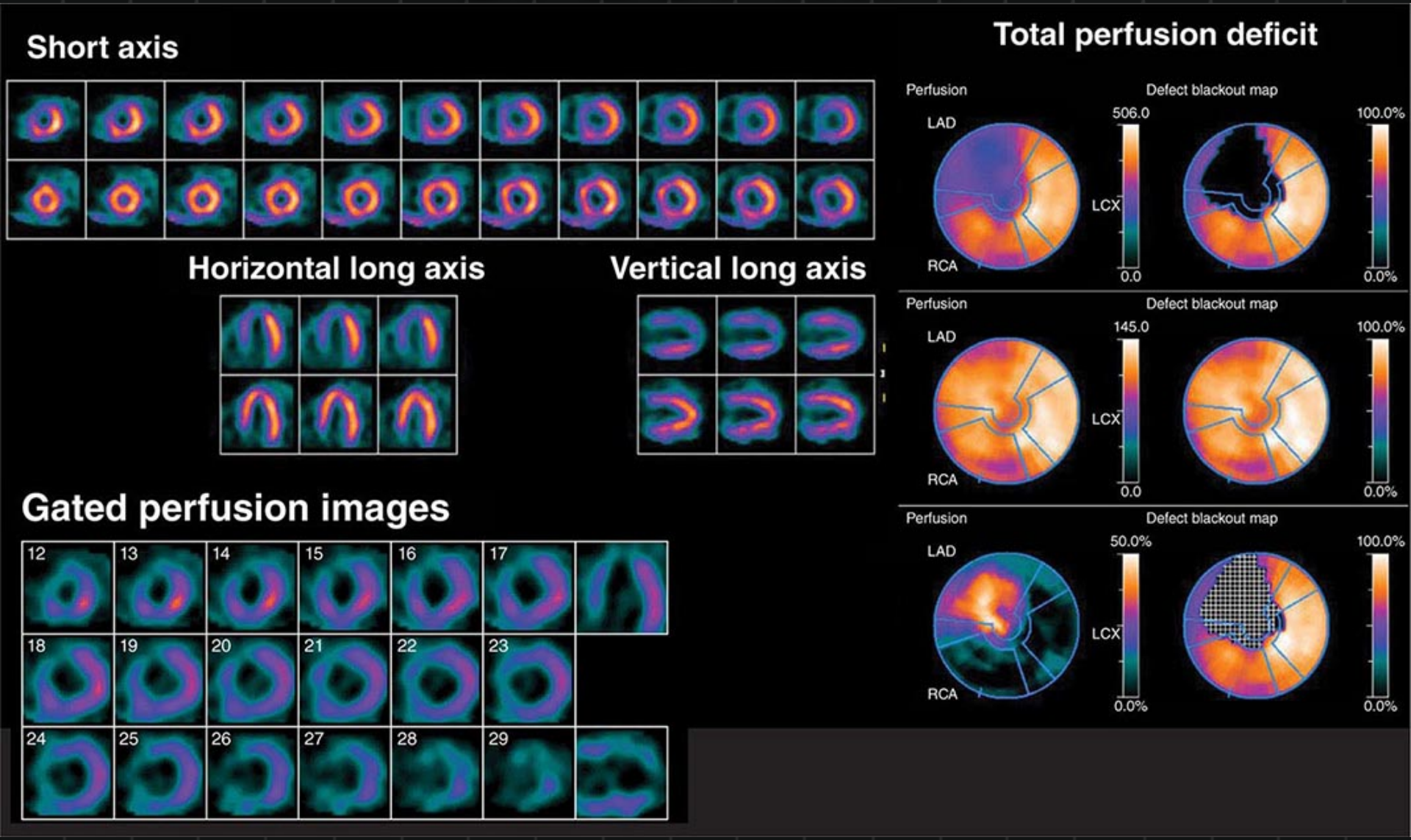
Nuclear Cardiology

- Radionuclide ventriculography
- SPECT MPI
- PET – MPI
- PET metabolic imaging (FFA / glucose)
- PET pre/post-synaptic nervous system
- PET plaque characterization
- PET angiogenesis

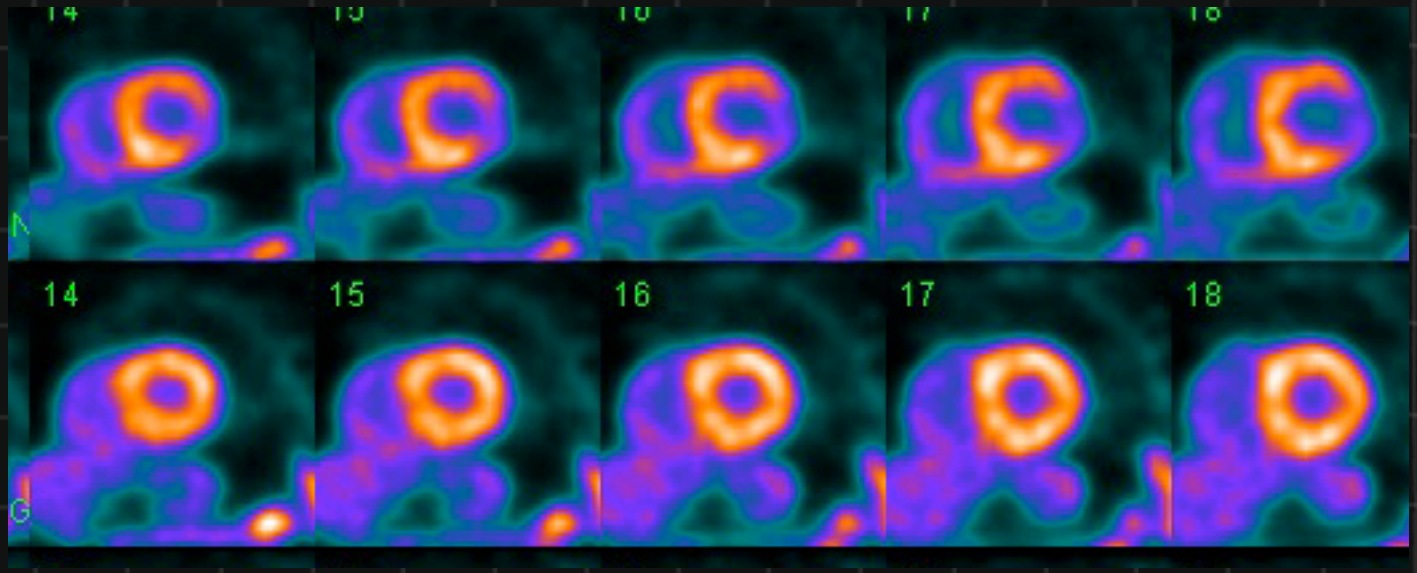
Radionuclide Ventriculography



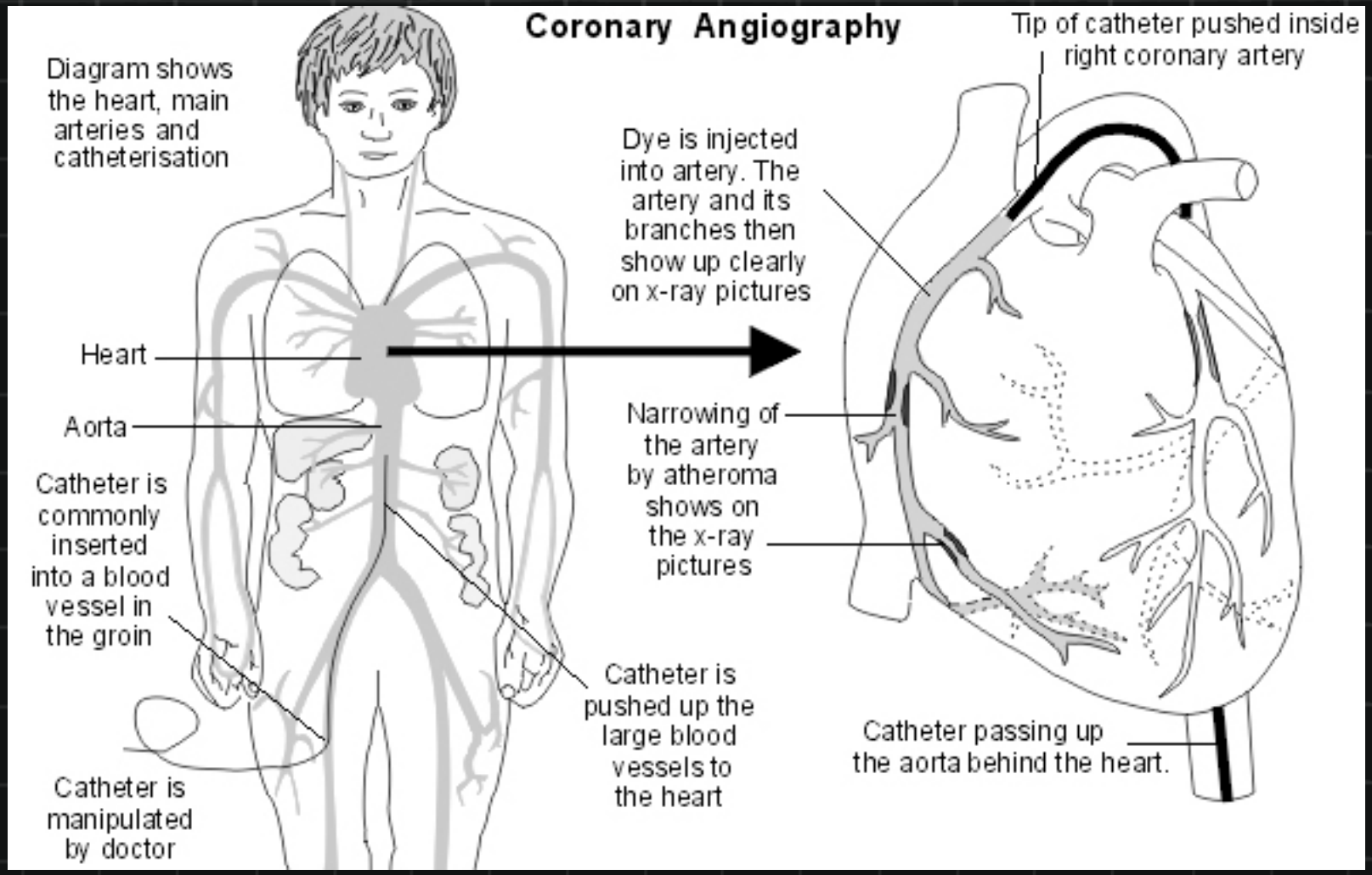
SPECT MPI


Short axis
Horizontal long axis
Vertical long axis
Gated perfusion images
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
Total perfusion deficit
Perfusion
Defect blackout map
LAD
LCX
RCA
506.0
0.0
100.0%
0.0%
145.0
50.0%

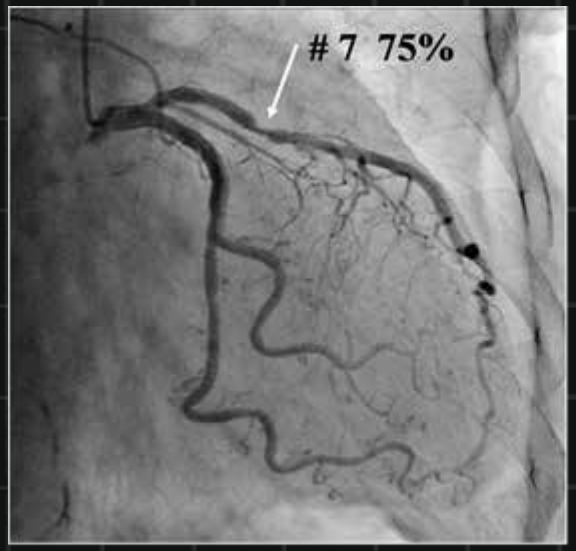
PET MPI



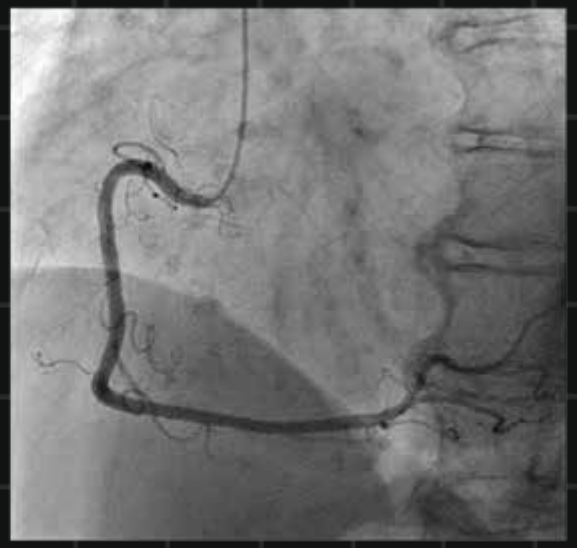
Angiocardiography



Angiocardiography



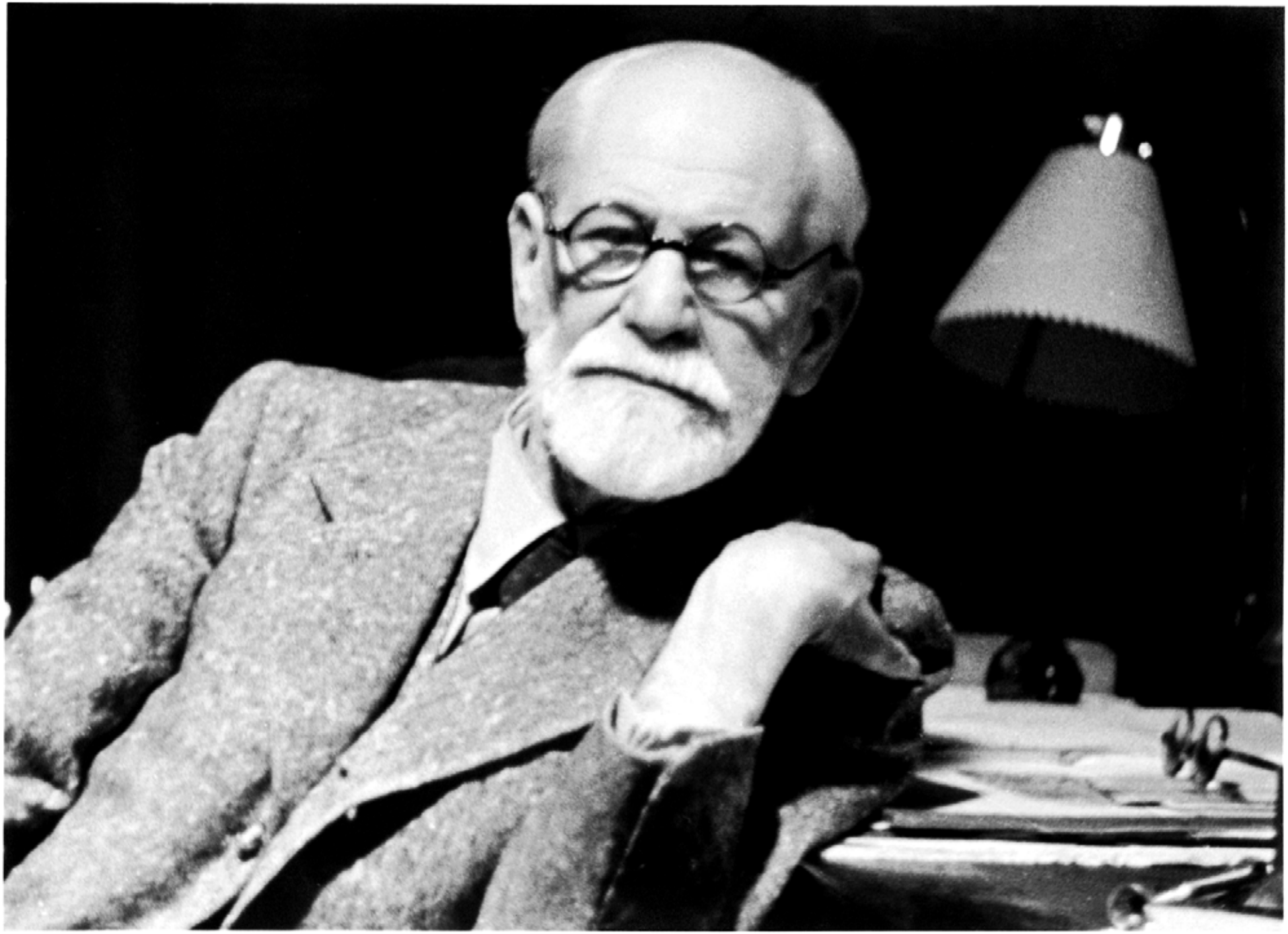
LCA



RCA

Cardiac Imaging Myths

- Coronary angiography since 1959 – “the dye doesn’t lie”
- MRI/CT/Echo – “your one-stop shop for cardiovascular imaging”

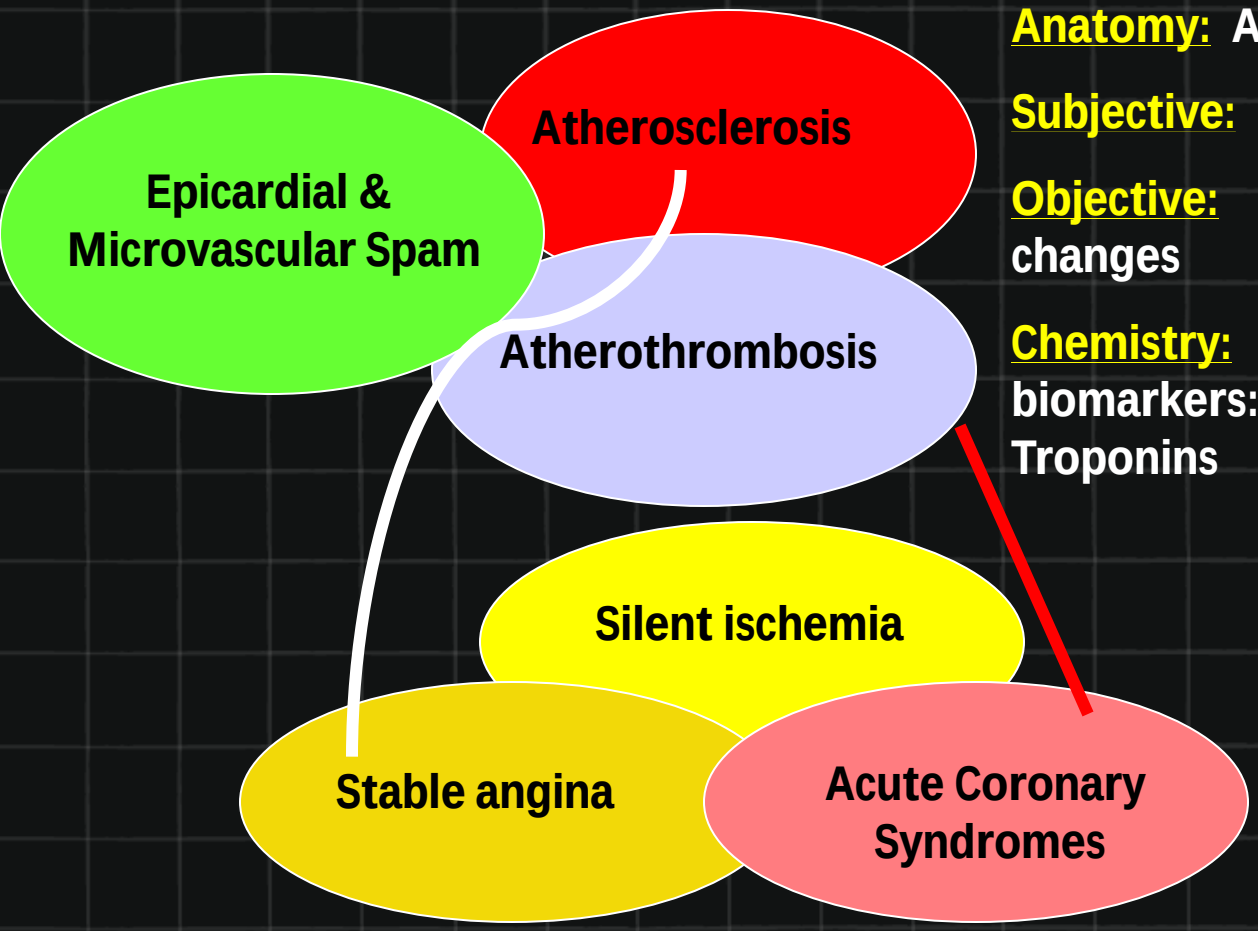


Imaging of Known or Suspected CAD

- CVD – leading cause of death worldwide
- 2010 – 379,559 U.S. deaths
- New, non-fatal MIs – 620,000 per year
- Recurrent MIs – 295,000
- New silent MIs – 150,000

Ischemic Heart Disease - Overview

Pathophysiology



Clinical Presentations

Parameters

Anatomy: Atheroma / Atherothrombosis

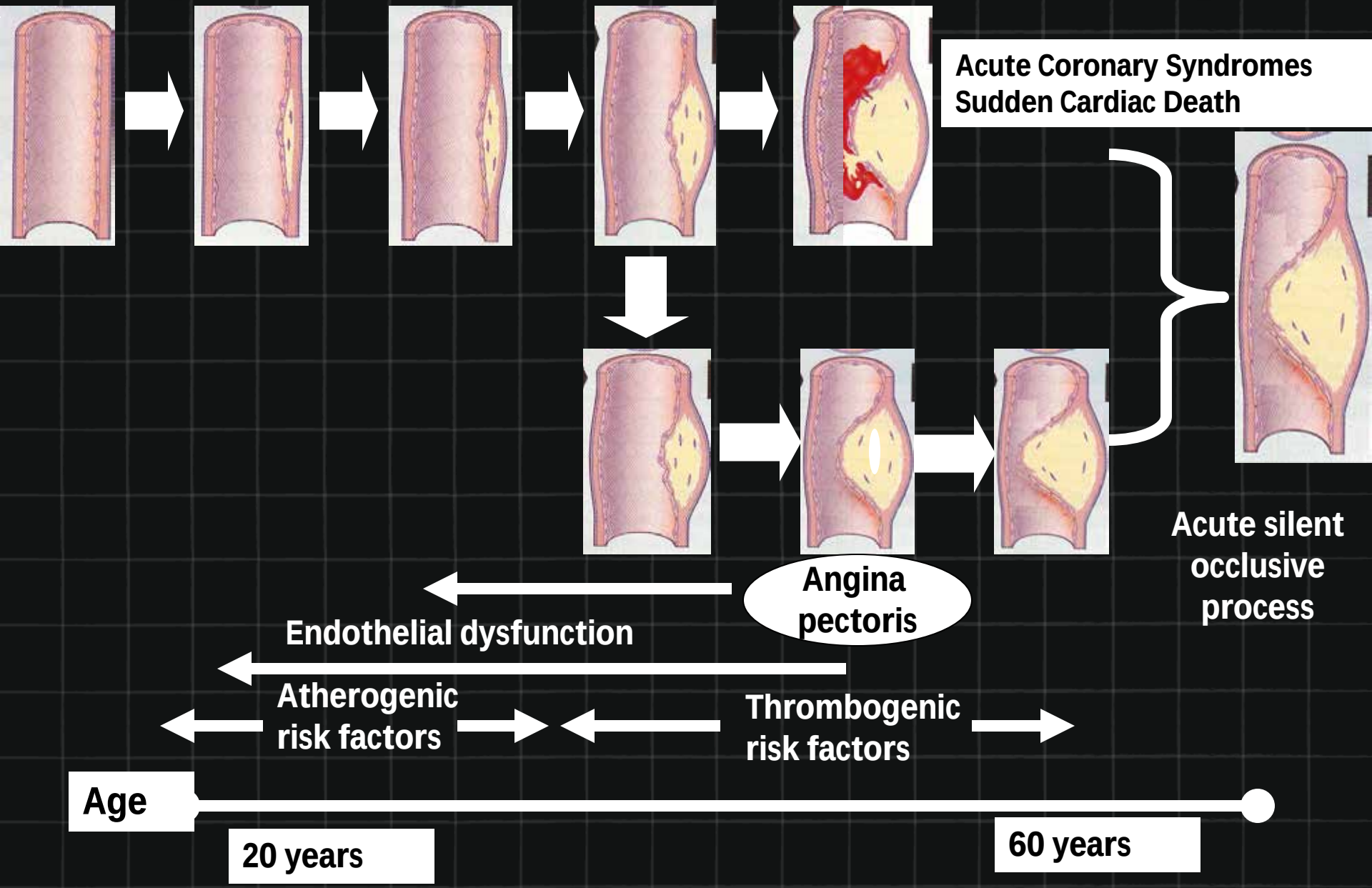
Subjective: Angina

Objective: EKG T wave ST seg changes

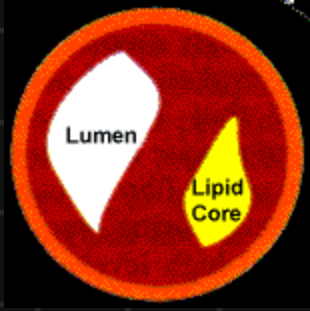
Chemistry: Cardiac serum biomarkers: CPK, CK-MB, Troponins

Prevalence & severity of stenosis

Progression of coronary plaque over time Clinical Findings



CAD - Clinical Spectrum



- Chronic ischemic heart disease

Ischemia precipitated by increased myocardial oxygen demand in the setting of a fixed, not vulnerable atherosclerotic lesion. It is called *Stable Angina* when the clinical characteristics (Angina attacks) do not change in frequency, duration, precipitating causes, or easy with the angina is relieved, for at least 60 days.

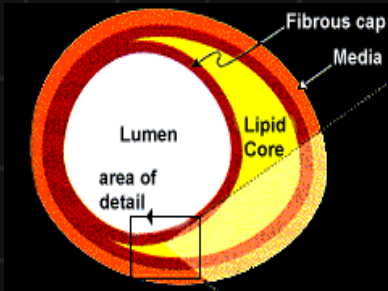
-Silent Ischemia, -Mixed Angina -Syndome X -Stunning & Hibernating.

- Acute Coronary Syndromes (ACS)

Ischemia or infarction are caused from a primary reduction in coronary flow, precipitated by plaque disruption and subsequent thrombus formation:

Unstable Angina, NSTEMI, STEMI

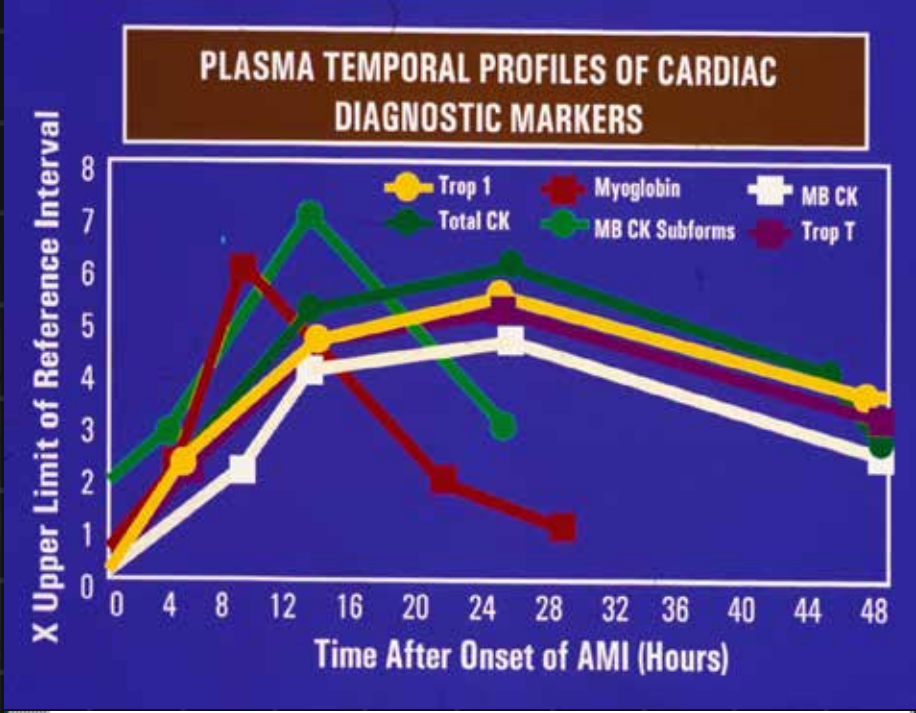
Prinzmetal Angina

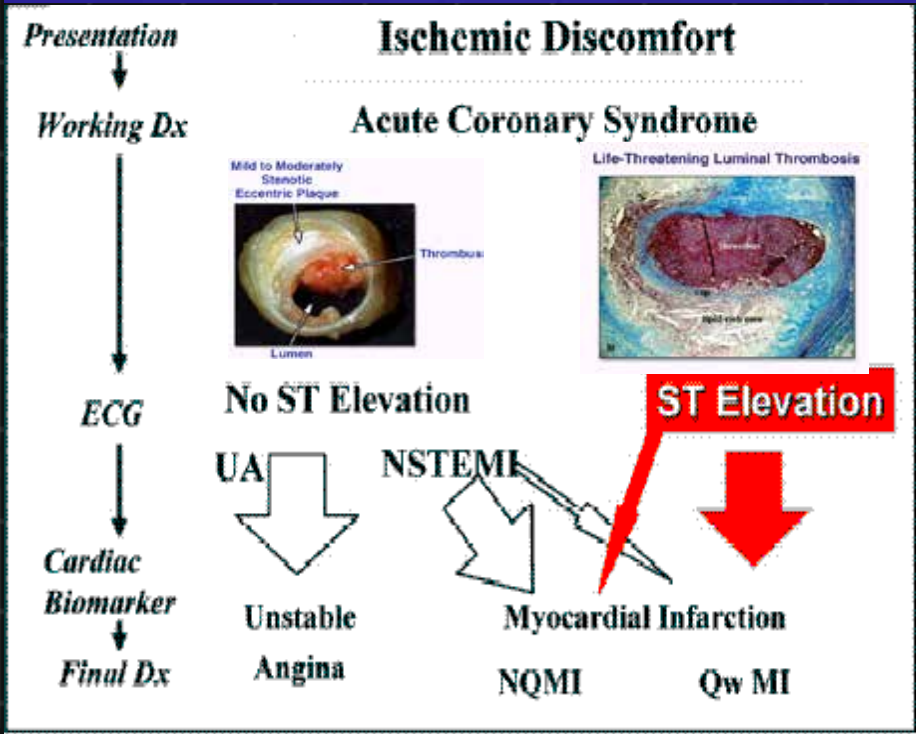


Acute MI

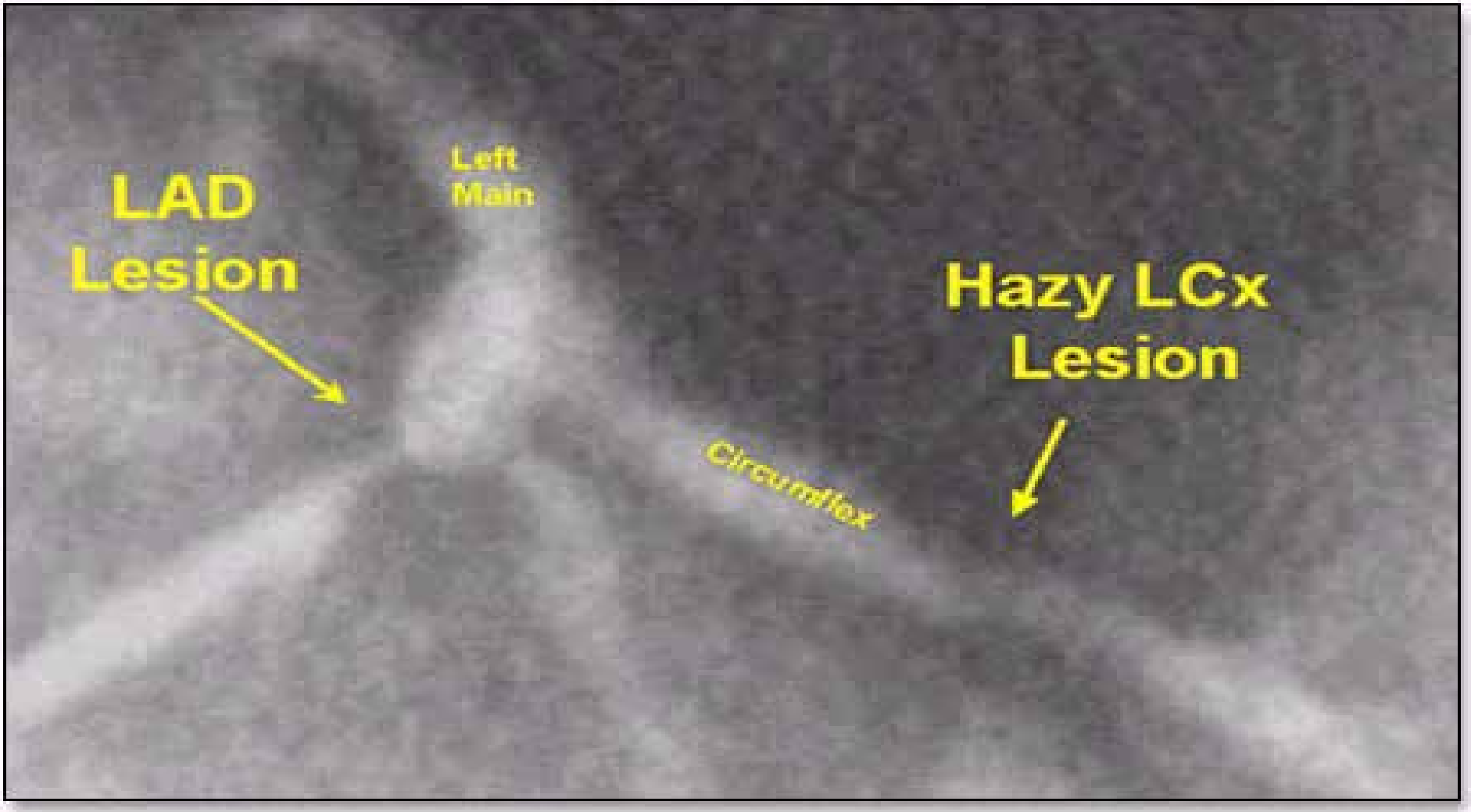
Typical rise and gradual fall (troponin) or more rapid rise and fall of CK-MB, markers of myocardial necrosis, with at least one of the following:

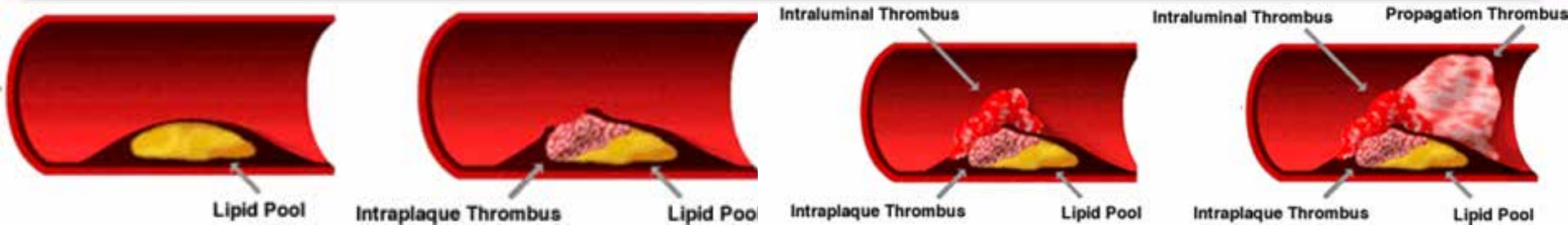
- Ischemic symptoms
- EKG changes indicative of ischemia (ST-seg elevation or depression)





Acute Coronary Syndromes Coronary

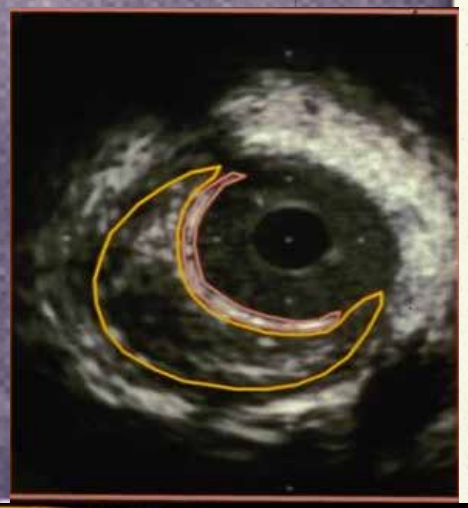


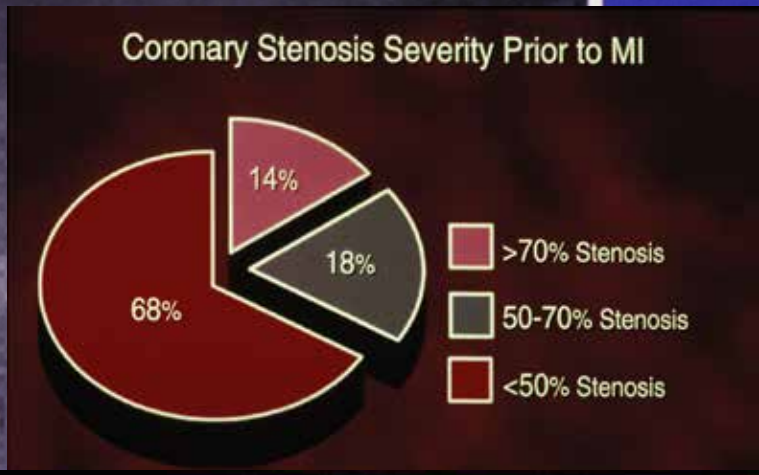


-RCA, 1yr. Before of the acute MI (B)

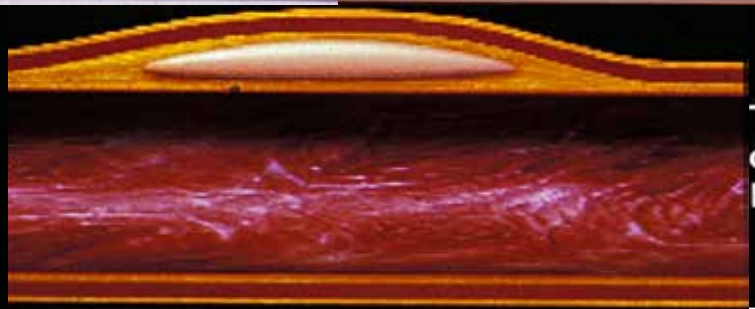
A

B

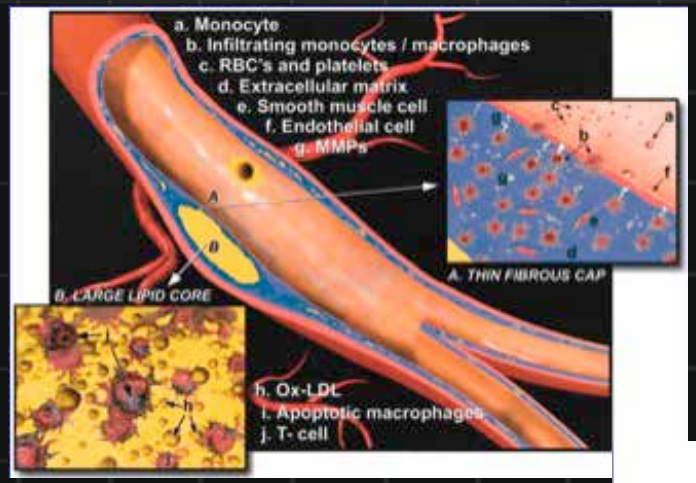


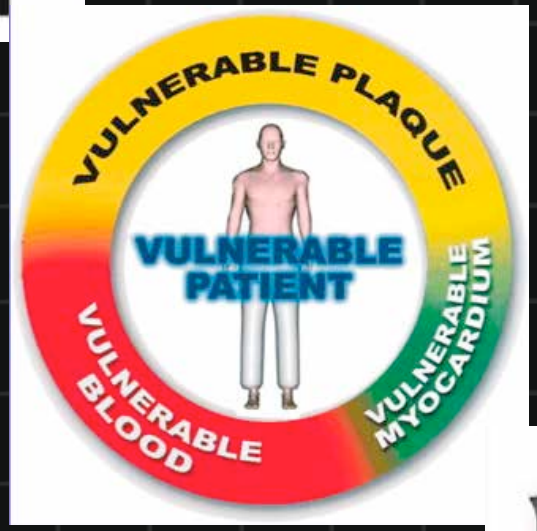


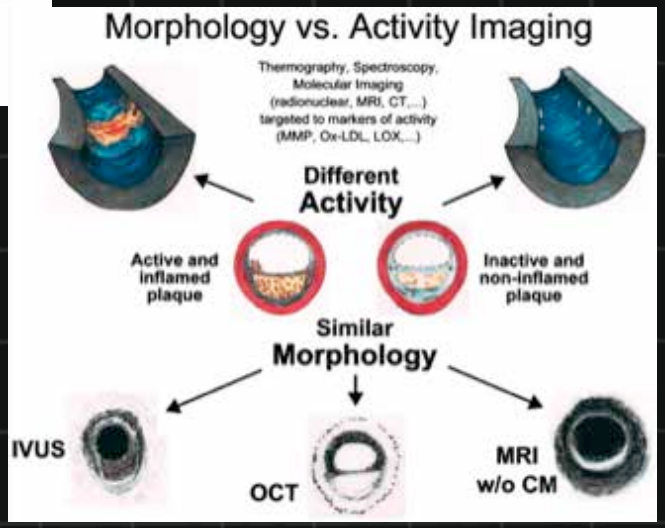
Arterial Remodeling Supported by IVUS



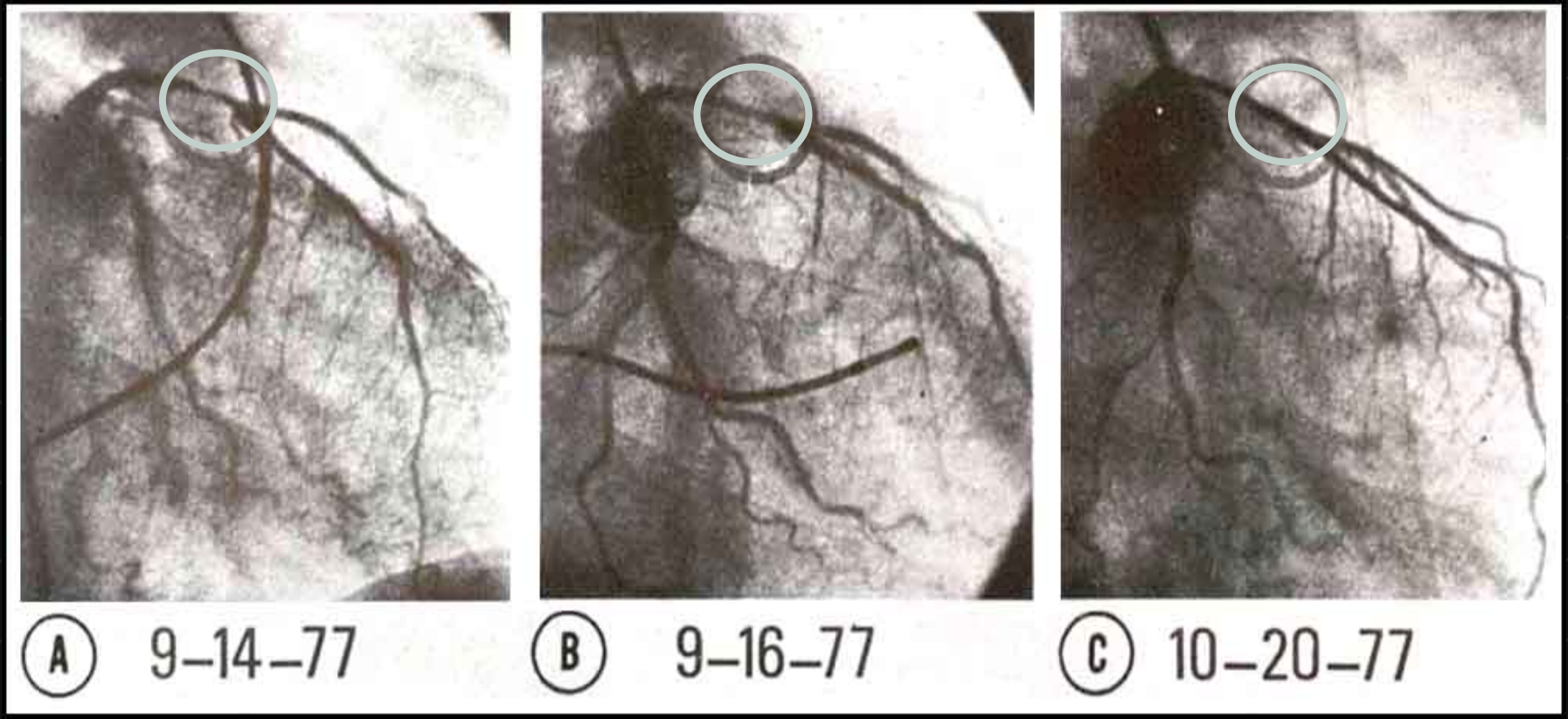
Traditional Model of Plaque Progression


a. Monocyte
b. Infiltrating monocytes / macrophages
c. RBC's and platelets
d. Extracellular matrix
e. Smooth muscle cell
f. Endothelial cell
g. MMPs
A. THIN FIBROUS CAP
B. LARGE LIPID CORE
h. Ox-LDL
i. Apoptotic macrophages
j. T- cell


VULNERABLE PLAQUE
VULNERABLE PATIENT
VULNERABLE MYOCARDIUM
VULNERABLE BLOOD


Morphology vs. Activity Imaging
Thermography, Spectroscopy, Molecular Imaging (radionuclear, MRI, CT,...) targeted to markers of activity (MMP, Ox-LDL, LOX,...)
Different Activity
Active and inflamed plaque
Inactive and non-inflamed plaque
Similar Morphology
IVUS
OCT
MRI w/o CM

The First Coronary Angioplasty for Stable CAD; 1977



First coronary angioplasty lesion (circles) two days before (A), immediately after (B), and one month after (C) balloon dilation

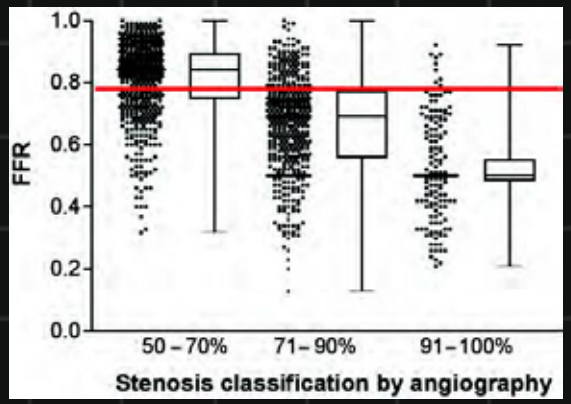
Conventional Wisdom

Treatment Assumptions in CAD Management:

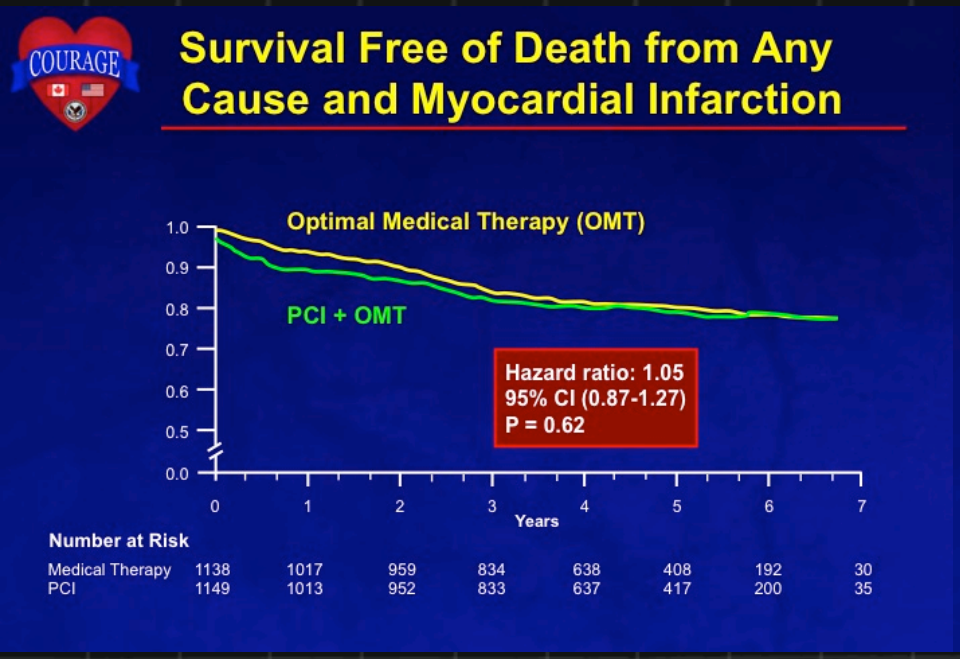
- Patients with symptomatic CAD and chronic angina who have significant coronary stenoses "need" revascularization
- Revascularization is required to improve prognosis
- PCI is less invasive than CABG surgery (i.e., is safer) and, therefore, should be selected

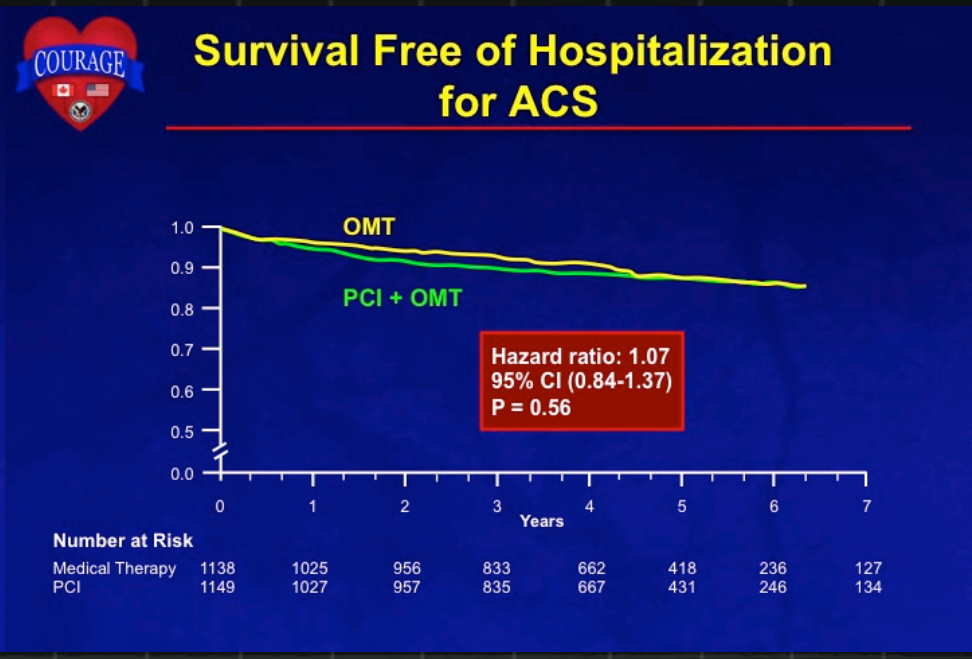
Clinical Outcomes Utilizing Revascularization and Aggressive Guideline-Drive Drug Evaluation

Background: > 1 million PCI procedures/year
Majority – patients with stable CAD
Does PCI reduce mortality, MI, or hospitalization for ACS

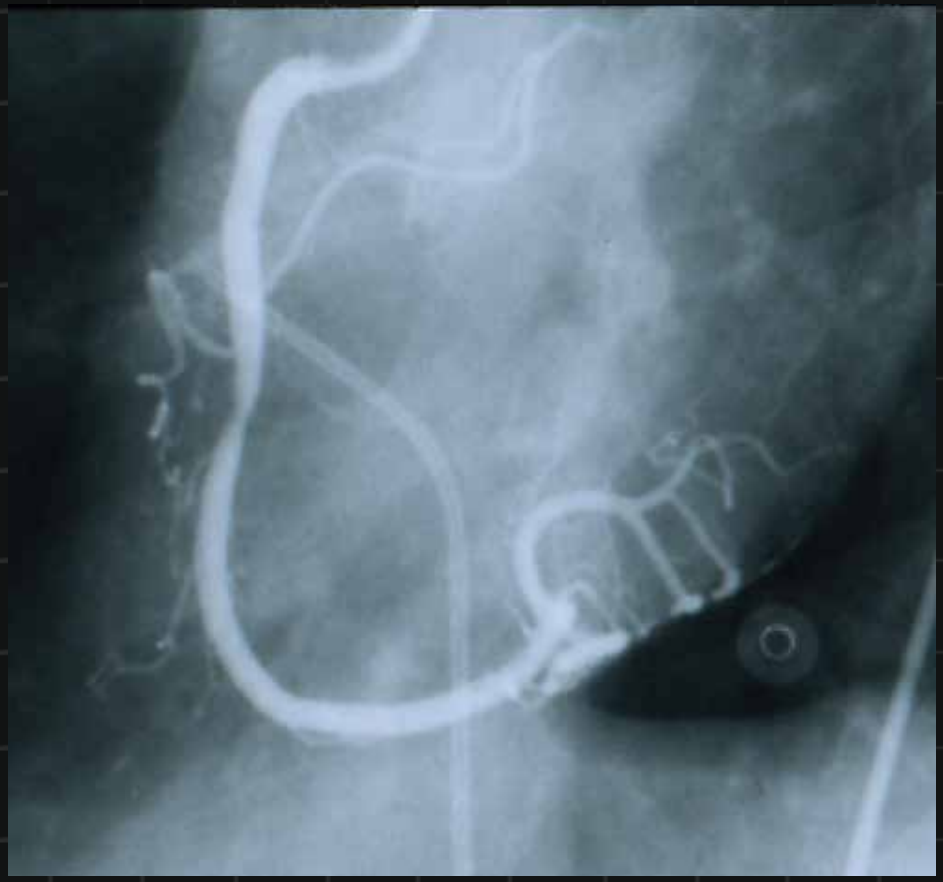


COURAGE Results





As an initial management strategy in patients with stable CAD, PCI did NOT reduce mortality, MI, or other major cardiovascular events (MACE) when added to optimal medical therapy. It did result in better angina relief during most of the follow-up but this difference was negligible at 5 years



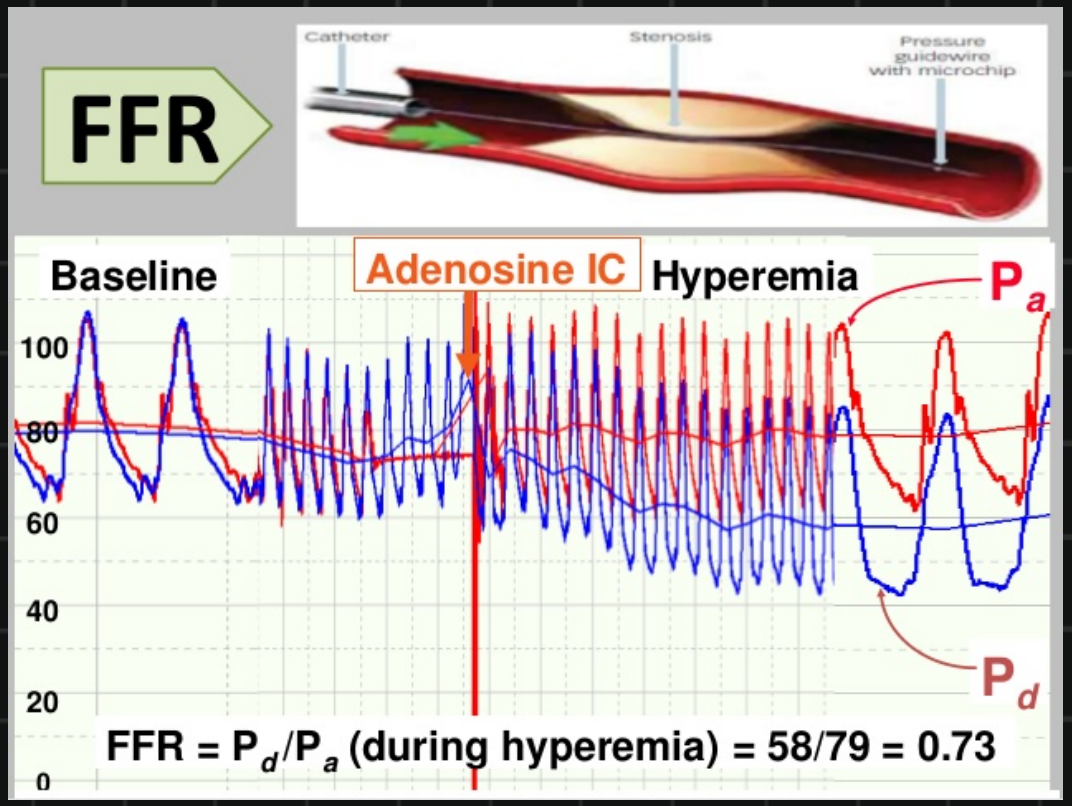
- female, 58-y-old
- underwent PCI of severe LCX lesion a minute before
- 50 % stenosis in mid RCA

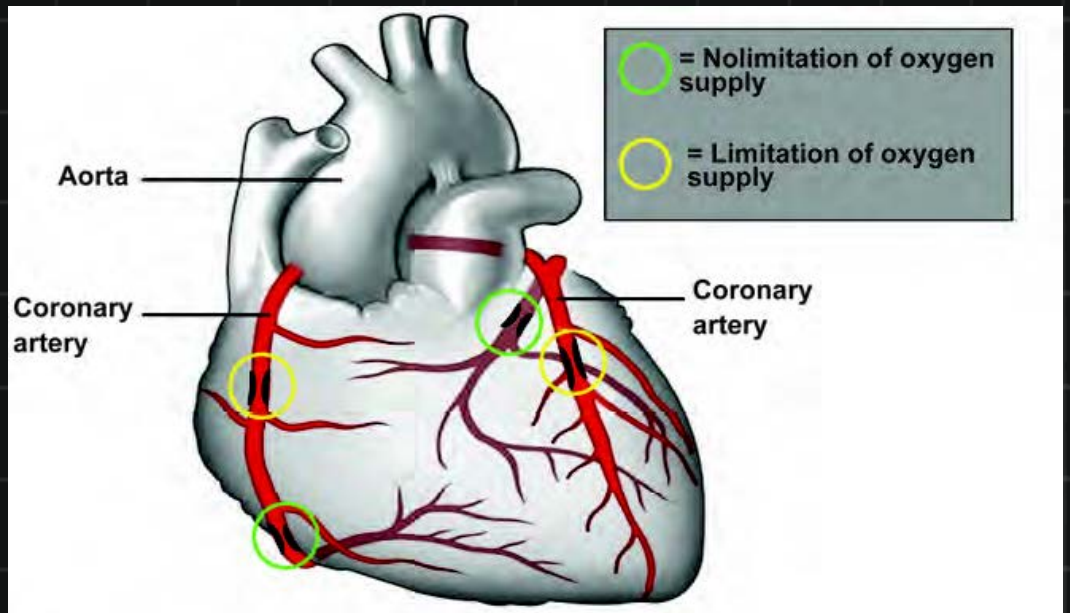
Should this lesion be stented ??

DEFER and FAME

DEFER – compare Deferral vs. PCI of Non-ischemia producing stenoses

FAME – FFR vs. angiography for guiding PCI in patients with MVCAD



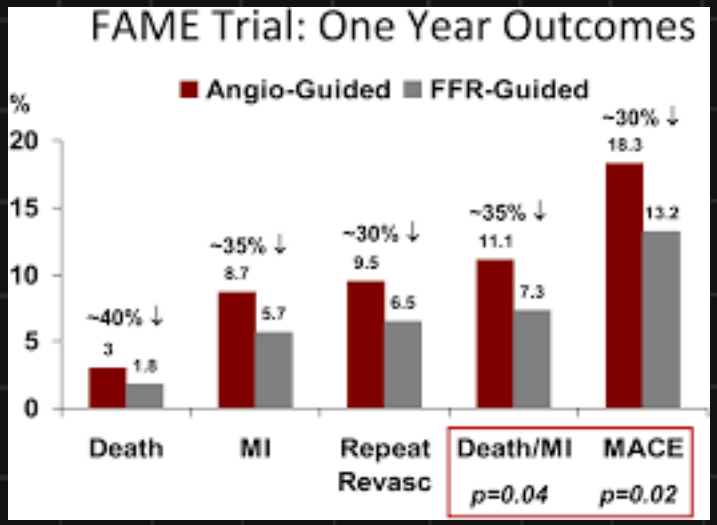


Ischaemic lesion → intrinsic risk 5% per year
Non-ischaemic lesion → intrinsic risk 1% per year
Stented stenosis → intrinsic risk 3% per year

Stenting strategies

"Stent 'm all" → Intrinsic risk 12% → 12%
"Stent only the ischaemic ones" → Intrinsic risk 12 → 8 %

Both strategies eliminate ischaemia → similar functional class



Women and Ischemic Heart Disease

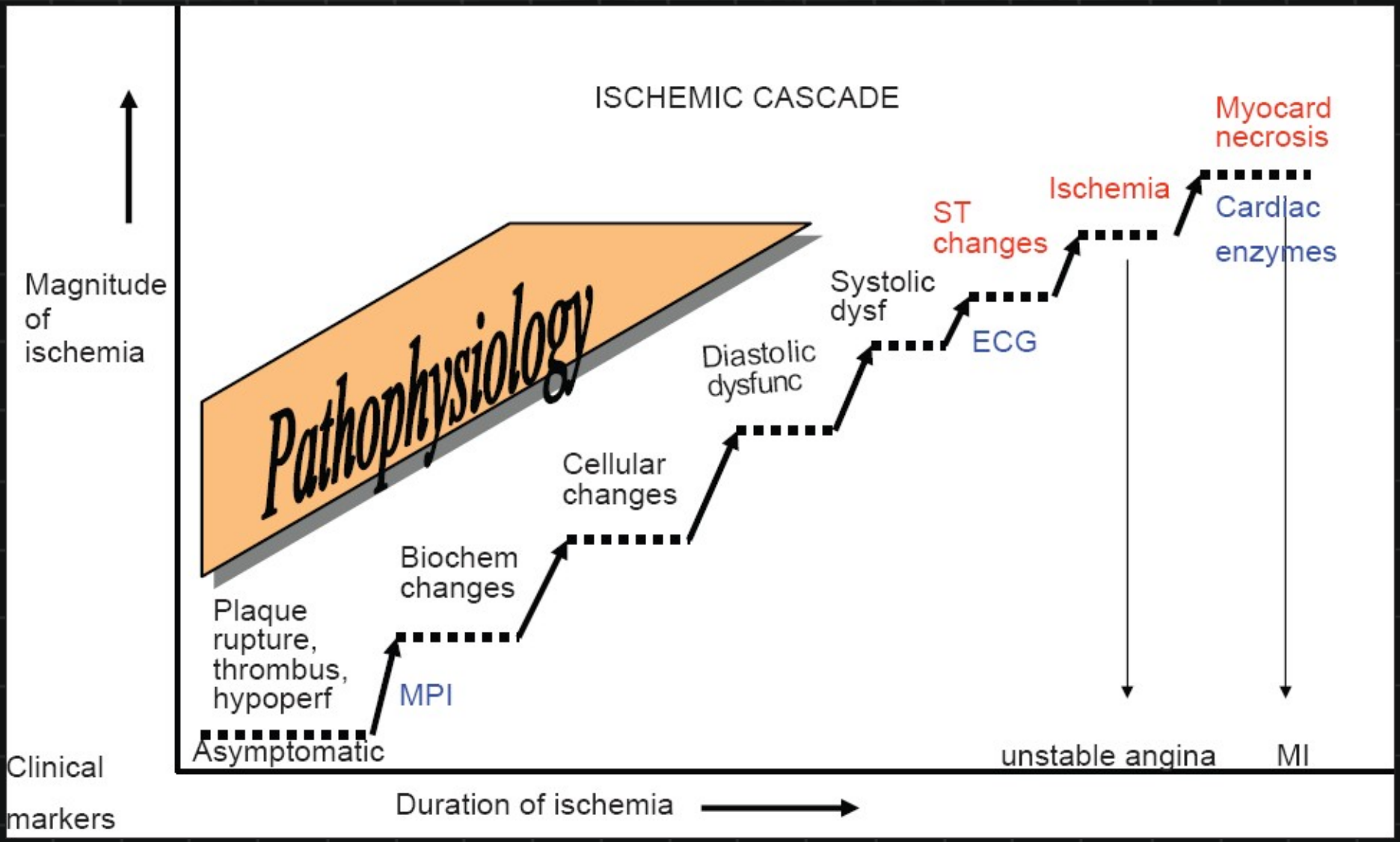
- Paradoxical segment differences – less anatomic disease and relatively preserved LV systolic function but > rates of ischemia and mortality
- More women die from IHD and a greater proportion die suddenly before they reach the hospital
- > 80% of midlife women have 1 or more cardiovascular risk factors
- > 1/3 midlife women are obese with 7% > 40 kg/m^2

Women and Ischemic Heart Disease

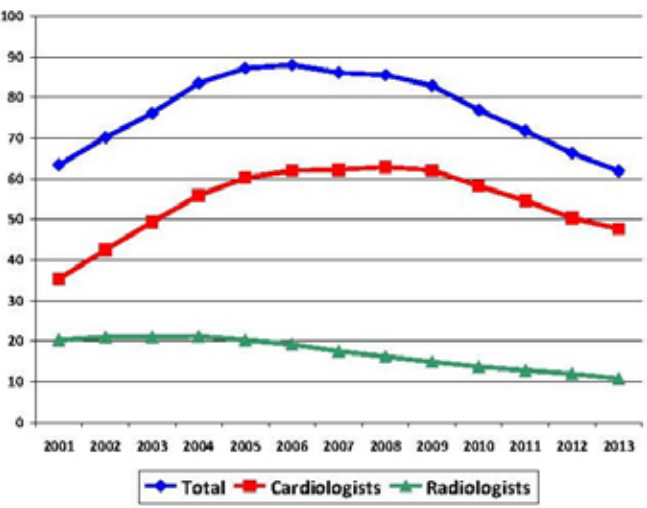
- Hypertriglyceridemia – more potent risk factor
- Diabetic women > rates of IHD mortality compared to men and a 3.3 x risk compared to non-diabetic women
- Traditional risk factors and most risk scores underestimate IHD risk in women
- Women have higher levels of CRP
- Women report more symptoms despite lower rates of obstructive CAD

Women and Ischemic Heart Disease

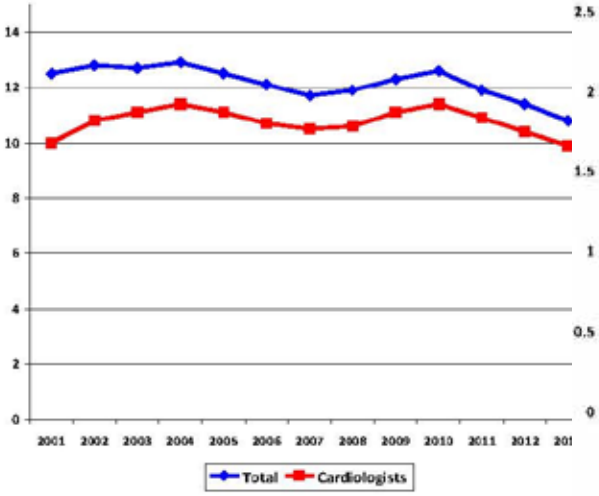
- > 50% of symptomatic women without “obstructive” CAD continue to have signs/symptoms of ischemia and undergo repeat hospitalizations and LHC
- Women with non-specific chest pain/discomfort have a 2 x risk for nonfatal MI
- Exercise ECG has an even lower sensitivity and specificity for obstructive CAD
- MPI effectively risk stratifies women


ISCHEMIC CASCADE
Magnitude of ischemia
Pathophysiology
Plaque rupture, thrombus, hypoperf
Biochem changes
Cellular changes
Diastolic dysfunc
Systolic dysf
ST changes
Ischemia
Myocard necrosis
Asymptomatic
MPI
ECG
Cardiac enzymes
unstable angina
MI
Clinical markers
Duration of ischemia

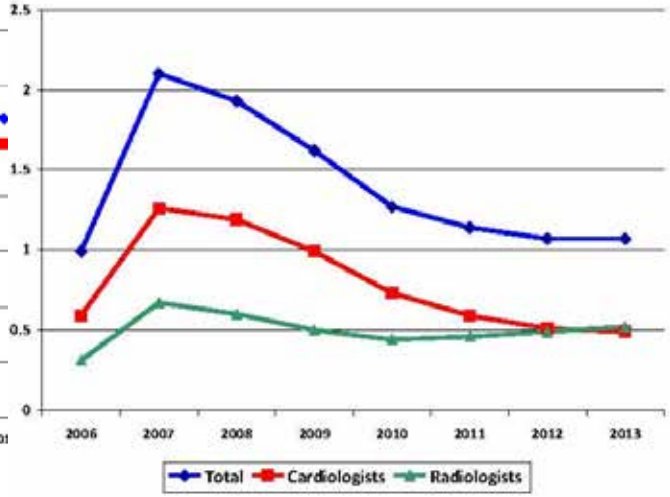
So – How do we evaluate ischemia?



MPI



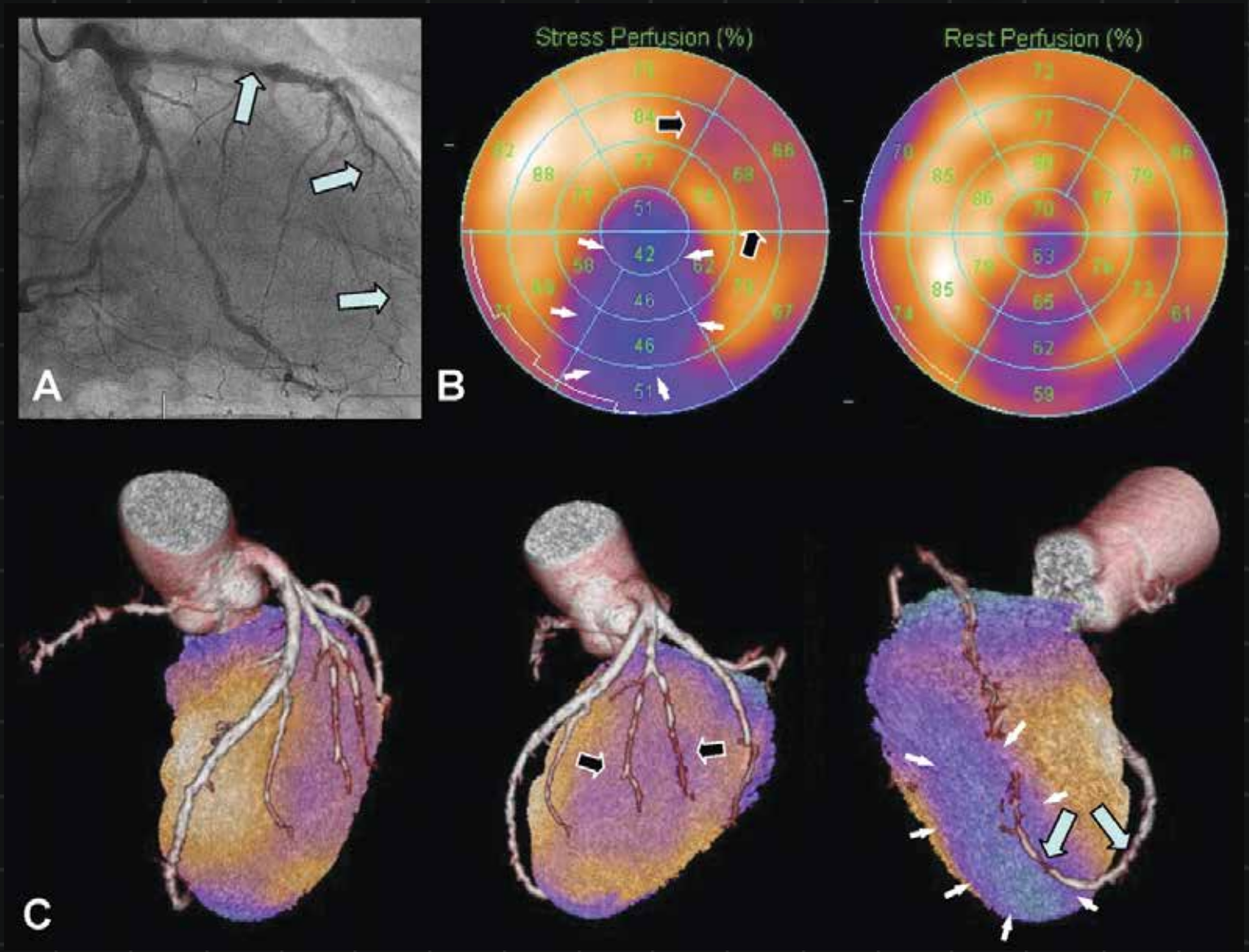
Stress Echo



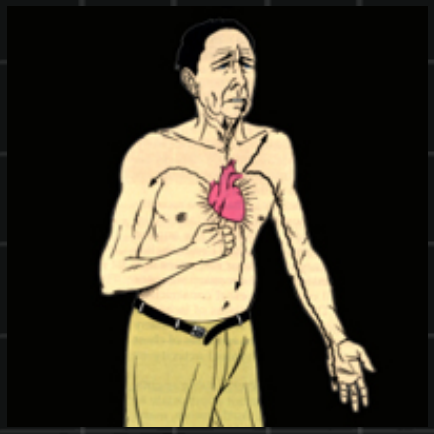
CCTA

Levin, Parker, Halpern, and Rao – Recent Trends in Imaging for Suspected CAD: What is the Best Approach

Hybrid Imaging

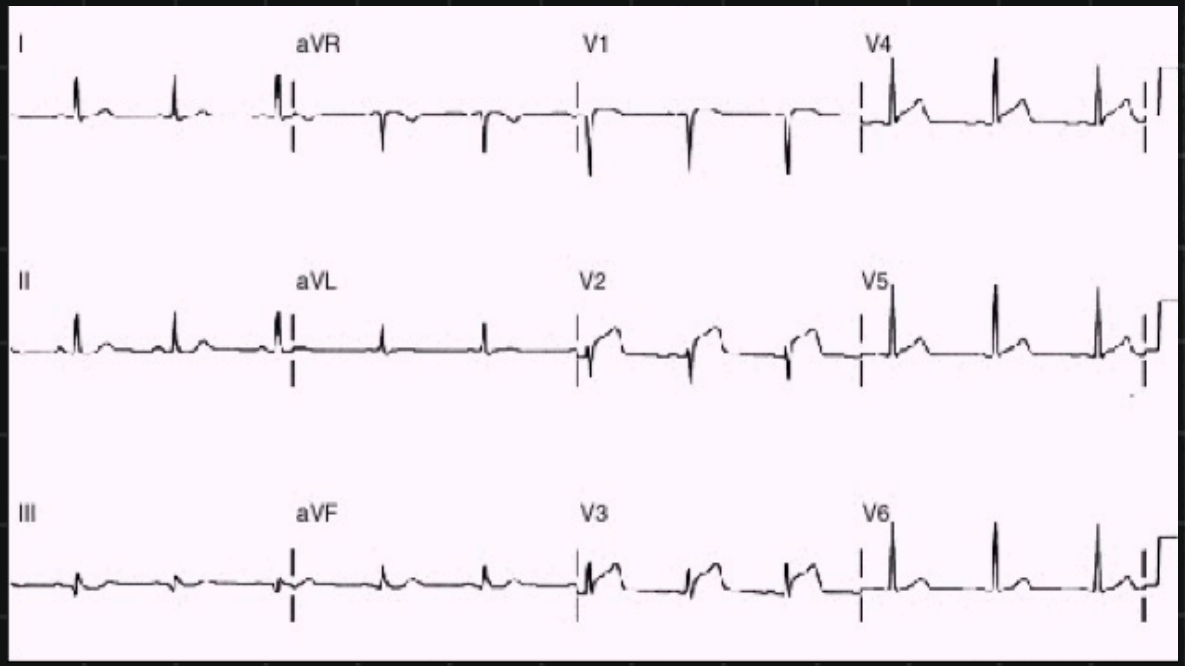


Who do you treat?



The Changing Landscape of Cardiovascular Imaging

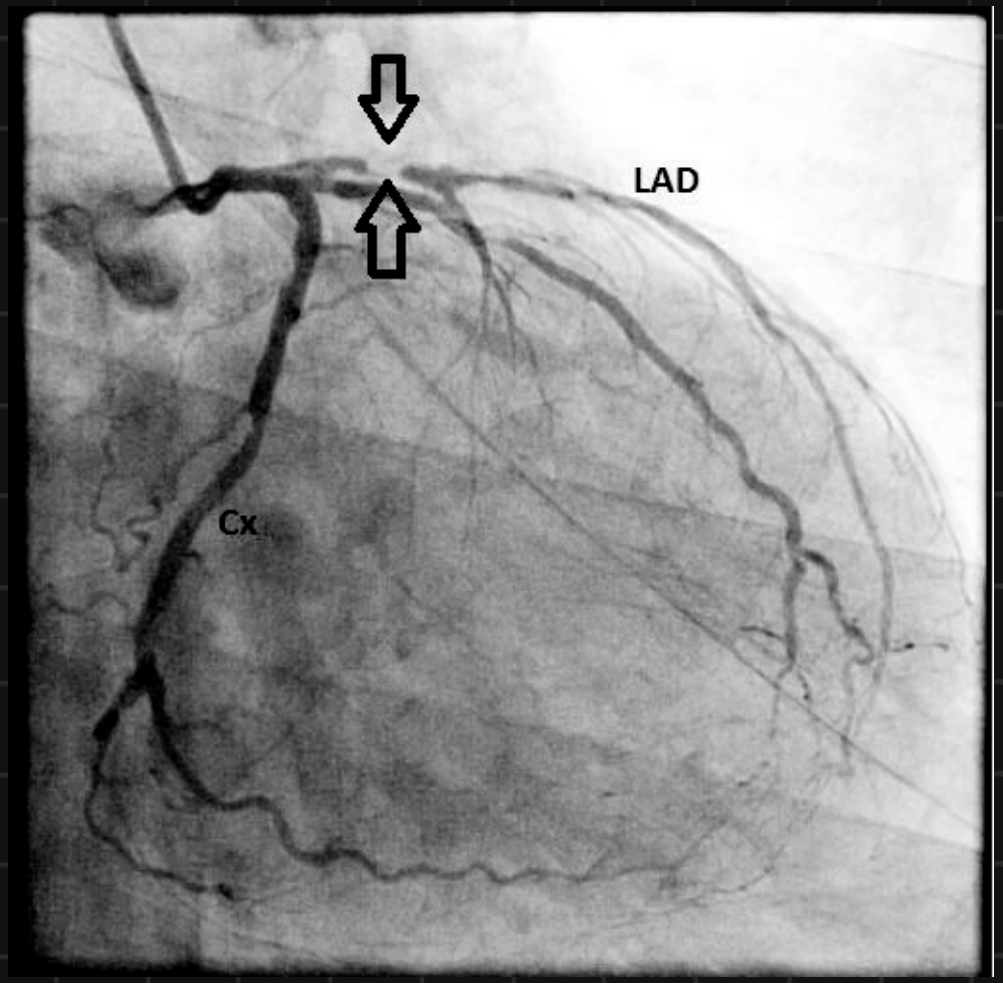
Samuel E. Lewis, M.D., M.S.E.E., F.A.C.C., DABNM



A 59M with no reported history of CAD but with significant cardiovascular risk factors presents to the ER with 30 minutes of sustained 9/10 chest pain/discomfort radiating to his L arm with associated nausea and diaphoresis. His EKG is shown above.

The most appropriate imaging procedure is:

A) Echocardiography to define LV systolic function
B) MPI to define the perfusion pattern and LV systolic function
C) Cardiac MRI with first pass contrast and delayed imaging
D) CCTA
E) Emergent LHC with selective angiography and revascularization



The high-grade proximal LAD stenosis (probable culprit lesion) is primarily stented (DES)

A 72F with no documented CAD (no previous non-invasive evaluations) is studied because of atypical chest pain/discomfort. She has a history of hypertension and dyslipidemia (appropriately managed). Her cardiologist believes that "the dye doesn't lie" and obtains this RCA angiogram. The left system was normal. She has normal LV systolic function.

The best approach to manage this patient is:

A) Immediate revascularization (PCI) with follow-up surveillance angiography
B) No further investigation is warranted – the patient can be managed medically
C) IVUS to assess plaque characteristics
D) Quantitative angiography to estimate the severity of the stenosis
E) Evaluation of the hemodynamic significance of this lesion

Myocardial Ischemia

The mismatch between myocardial oxygen supply and demand has serious clinical consequences. The earliest manifestation is:

A) Segmental myocardial dysfunction – wall motion abnormality
B) Relative hypoperfusion of the involved region
C) EKG changes
D) Chest pain
E) Alteration of myocardial metabolism with a shift in substrate utilization from FFA to glucose

Women and CAD

Which of the following statement best characterizes our current knowledge about CAD in women?

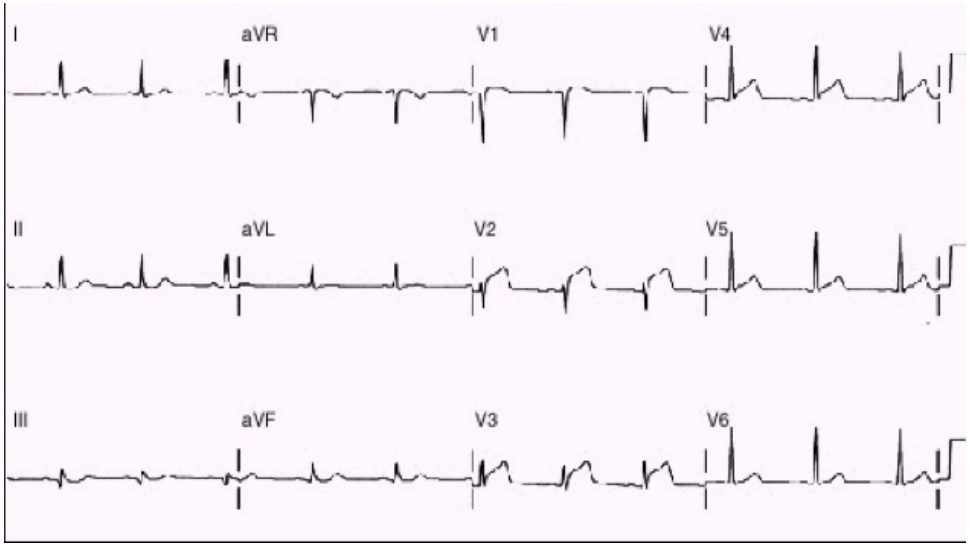
A) Women typically report more angina despite similar rates of obstructive CAD
B) The Framingham Risk Score (FRS) accurately reflects the risk of individual women
C) Women with obstructive CAD at angiography have only slightly greater odds of in-hospital mortality as compared to those with non-obstructive CAD
D) Up to 30% of women with chest pain/discomfort and "normal" angiograms but with endothelial dysfunction developed significant obstructive CAD during a 10-year follow-up
E) Women receive similar medical treatment after MI compared to men

Estimating the Severity of Coronary Atherosclerosis

Which of the following statements is most appropriate regarding the severity of individual coronary lesions?

A) The amount of calcium correlates well with lesion severity
B) Lesions graded at > 70% luminal diameter narrowing are always hemodynamically significant
C) Revascularization of lesions > 70% luminal diameter narrowing results in fewer cardiac deaths, fewer repeat revascularizations, and fewer major adverse cardiac events (MACE)
D) Lesion severity as assessed by visual analysis or by quantitative angiography has a linear relationship with measurements of hemodynamic significant by invasive or by non-invasive techniques
E) Revascularization of hemodynamically significant lesions ONLY does improve survival, rate of revascularization (risk/cost), and rates of MACE

The Changing Landscape of Cardiovascular Imaging, Samuel Lewis, MD



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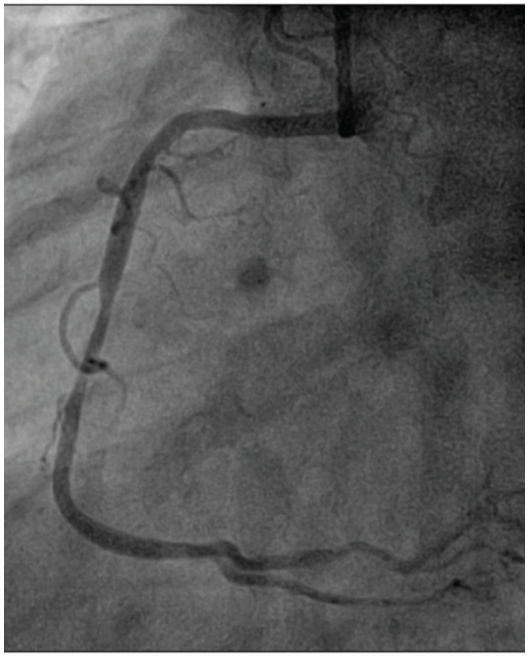
C. Cardiac MRI with first pass contrast and delayed imaging
D. CCTA
E. Emergent LHC with selective angiography and revascularization **(KEY)**

The correct answer is E.

References: Rybicki FJ, Udelson, JE, Peacock, WF, Goldhaber, SZ, Isselbacher EM, Kazerooni E, Kontos MC, Litt H, and Woodard PK: 2015 ACR/ACC/AHA/AATS/ACEP/ASNC/NASCI; SAEM/SCCT/SCMR/SCPC/SNMMI/STR/STS Appropriate Utilization of Cardiovascular Imaging in Emergency Department Patients With Chest Pain; JACC (2105)

2. A 72F with no documented CAD (no previous non-invasive evaluations) is studied because of atypical chest pain/discomfort. She has a history of hypertension and dyslipidemia (appropriately managed). Her cardiologist believes that “the dye doesn’t lie” and obtains this RCA angiogram. The left system was normal. She has normal LV systolic function.



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C. No further investigation is warranted – the patient can be managed medically
D. IVUS to assess plaque characteristics
E. Quantitative angiography to estimate the severity of the stenosis **(KEY)**
F. Evaluation of the hemodynamic significance of this lesion

The correct answer is E.
References: Bech G J W, De Bruyne B, Pijls N H J, de Muinck E D, Hoorntje J C A, Escaned J, Stella P R, Boersma E, Bartunek J, Koolen J J, and Wijns W: Fractional Flow Reserve to Determine the Appropriateness of Angioplasty in Moderate Coronary Stenosis – A Randomized Trial; Circulation 2001: 103: 2928-2934

3. The mismatch between myocardial oxygen supply and demand has serious clinical consequences. The earliest manifestation is:

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B. Relative hypoperfusion of the involved region **(KEY)**
C. EKG changes
D. Chest pain
E. Alteration of myocardial metabolism with a shift in substrate utilization from FFA to glucose

The correct answer is B.
Reference: Pakkal M, Raj V, and McCann GP: Non-invasive imaging in coronary artery disease including anatomical and functional evaluation of ischaemia and viability assessment; Bri J Rad, 84 (2011), S280-S295

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E. Women receive similar medical treatment after MI compared to men

The correct answer is D.
References: Shaw LJ, Bugieardini R, and Merz C N B: Women and Ischemic Heart Disease – Evolving Knowledge; J Am Coll Cardiol 2009;54:1561–75) © 2009 by the American College of Cardiology Foundation
Bairey Merz CN, Shaw LJ, Reis SE. Ischemic heart disease in women: insights from the NHLBI-sponsored Women’s Ischemia Syndrome Evaluation (WISE) Study. Part II: Gender differences in presentation, diagnosis, and outcome with regard to sex-based pathophysiology of atherosclerosis, macro- and micro-vascular CAD. J Am Coll Cardiol 2006; 47 Suppl:21s–9s.

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The correct answer is E.
References: Tonino P A L, De Bruyne B, Pijls N H J, Siebert U, Ikeno F, van t Veer M, Klauss V, Manoharan G Engstrom T, Oldroyd KG, Ver Lee P N, MacCarthy PA, and Fearon W F for the FAME SGtudy Investigators: Fractional Flow Reserve versus Angiography for Guiding Percutaneous Coronary Intervention; N Engl J Med 2009: 360: 213-224
Pijls N H J, van Schaardenburgh P, Manoharan G, Boersma E, Bech J-W, van’t Veer M, Bar F, Hoorntje J, Koolen, Wijns W, and de Bruyne B: Percutaneous Coronary Intervention of Functionally Nonsignificant Stenosis – 5-Year Follow-Up of the DEFER study: J Am Coll Cardiol 2007; 49(21) 2105-2111