Understanding the Heart of the Matter

Coronary Artery Disease (CAD) and Testing

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Outline

- Coronary artery disease (CAD)

  – Risk factors and pathophysiology

- Assessment of flow limiting (stenotic) disease

  – Exercise Tolerance Test (ETT)

  – Stress imaging (echocardiography or nuclear)

  – Pharmacologic stress with imaging (echocardiography or nuclear)

- Atherosclerotic burden in the coronary arteries

  – Calcium score

- Visualization of the coronary arteries

  – Coronary CT angiography (CCTA)

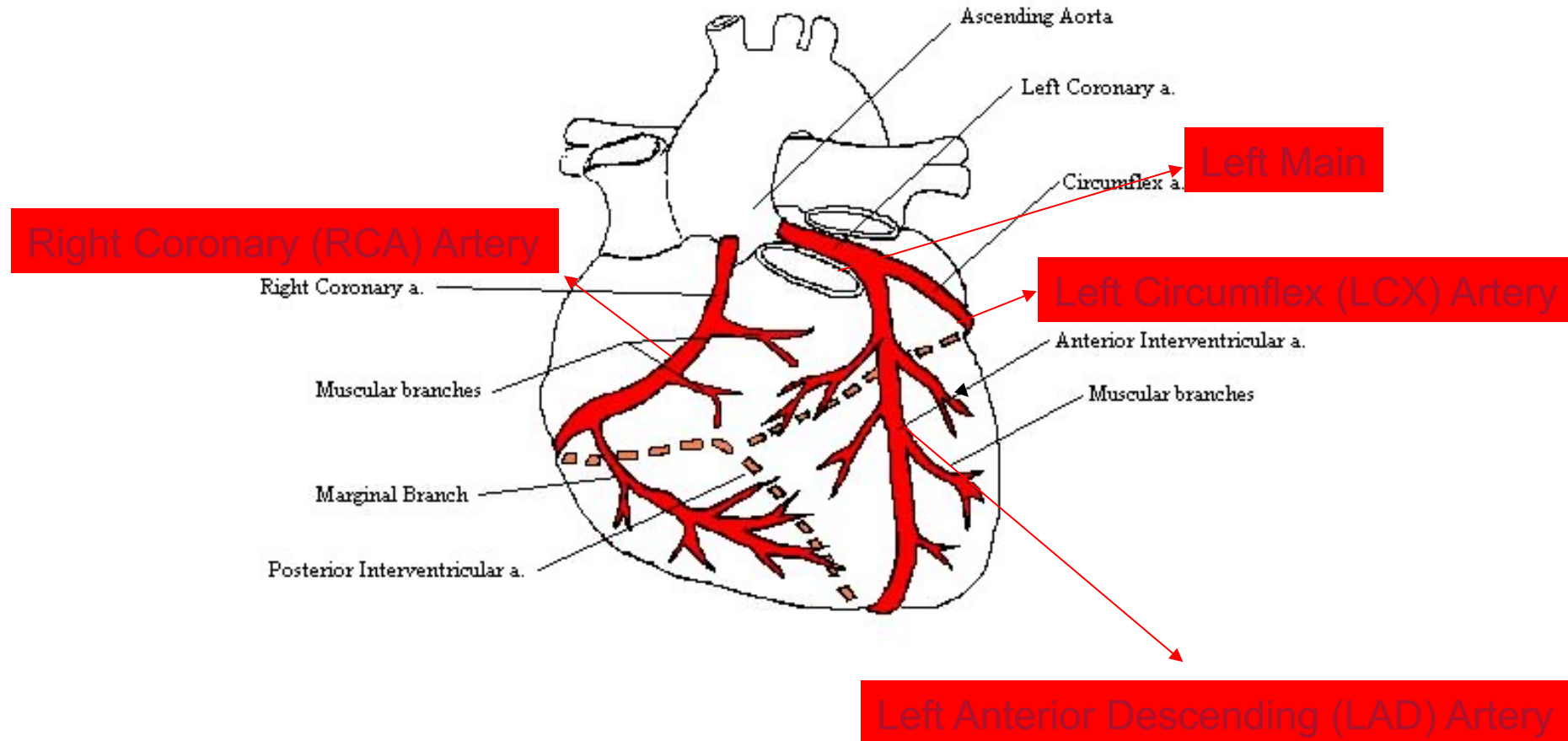 – Cardiac catherization with angiography

Coronary Arteries - Anatomy

IMAGE SOURCE PAGE: *http://faculty.etsu.edu/forsman/coronaryarteriescomplete.htm - altered for educational purposes only*

Coronary Artery Risk Factors

- Modifiable Risk Factors

 - American Heart Association – Life's Simple 7

    - Manage blood pressure (risk factor – HTN)

    - Control cholesterol (risk factor – dyslipidemia)

    - Reduce blood sugar (risk factor – hyperglycemia and DM)

    - Get active (risk factor- sedentary lifestyle)

    - Eat better (risk factor – high trans fat, high red meat, low fiber, low fruits and vegs)

    - Lose weight (risk factor – obesity)

    - Stop smoking (risk factor – smoking)

- Nonmodifiable Risk Factors

    - Age

    - Sex at birth

    - Family history (parent/sibling- F<65, M<55)

Pathophysiology - Atherosclerosis

- Plaque formation

- "Response to injury" theory

  - Endothelial dysfunction

  - Vascular inflammation

  - Cholesterol and lipid build up

  - Vascular remodeling

  - Calcium deposition

High blood pressure
Smoking
Elevated blood sugar
Elevated LDL

Smoking
Elevated blood sugar
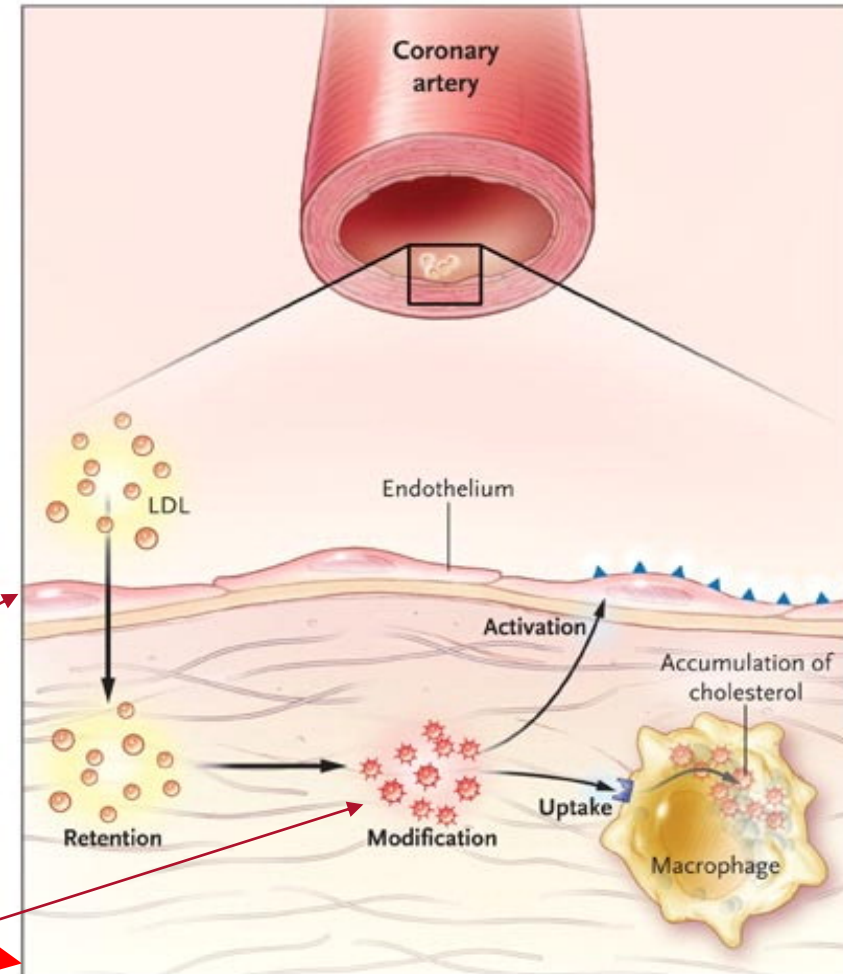
Hansson GK. N Engl J Med 2005;352:1685-1695

Activating Effect of LDL Infiltration on Inflammation in the Artery. In patients with hypercholesterolemia, excess LDL infiltrates the artery and is retained in the intima, particularly at sites of hemodynamic strain. Oxidative and enzymatic modifications lead to the release of inflammatory lipids that induce endothelial cells to express leukocyte adhesion molecules. The modified LDL particles are taken up by scavenger receptors of macrophages, which evolve into foam cells.

Symptomatic CAD

- Gradual progression of a stable plaque

  - A stable plaque that grows and eventually occludes the artery and blocks blood flow to the heart muscle
  - Symptoms initially usually occur with exertion and gradually progress until they occur with minimal activity or at rest
  - Typically represents a >70% stenosis of the lumen of the artery

- "Vulnerable" plaque rupture

  - Acute rupture of an unstable plaque (large lipid core, inflammation, thin fibrous cap – prone to rupture)
  - Typically, an unstable plaque represents a 40-50% or less stenosis of the lumen of the artery
  - Usually asymptomatic until a sudden event occurs that causes the plaque to rupture and results in sudden occlusion of blood vessel and possible heart attack or death – usually no prior warning symptoms

Acute Coronary Syndrome

- Acute plaque rupture or erosion

- Other causes of ACS in the absence of atherosclerotic plaque rupture
  - Coronary artery dissection
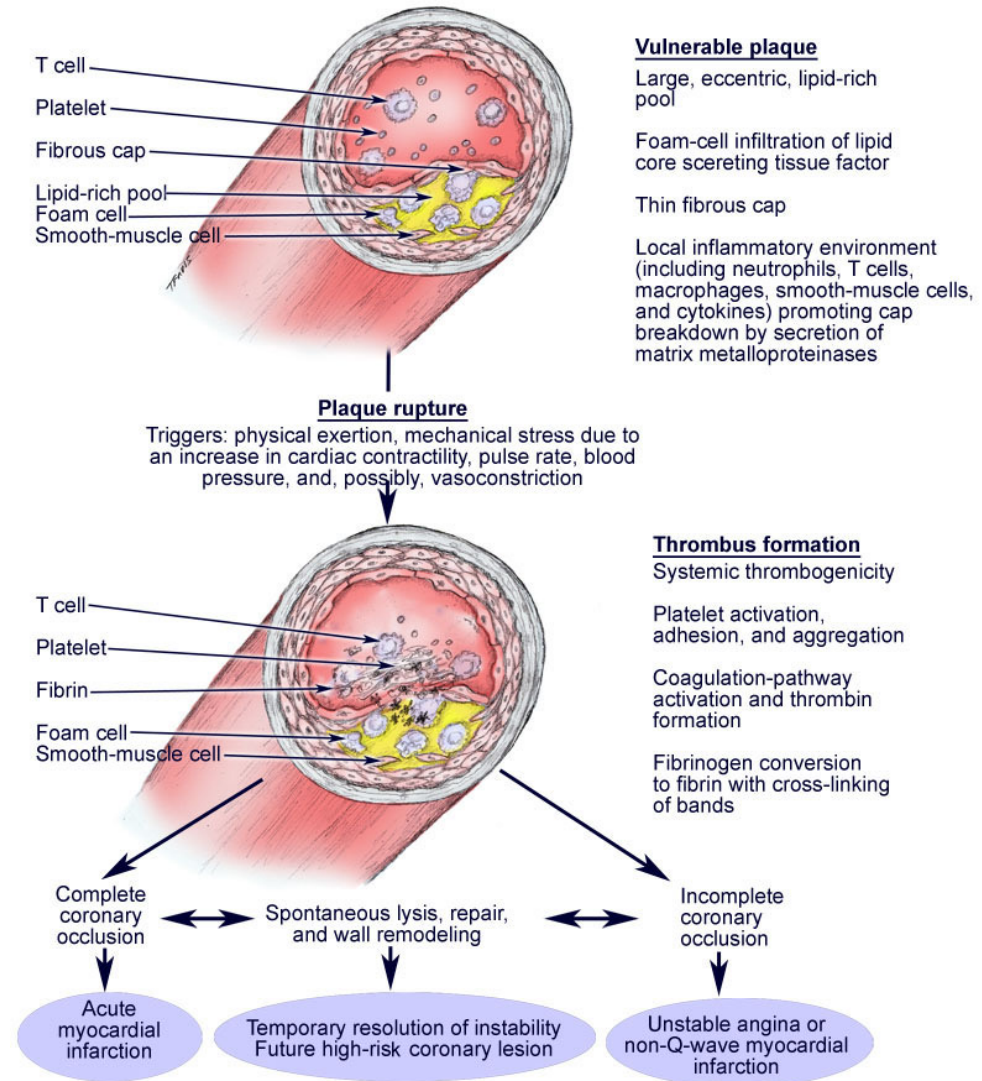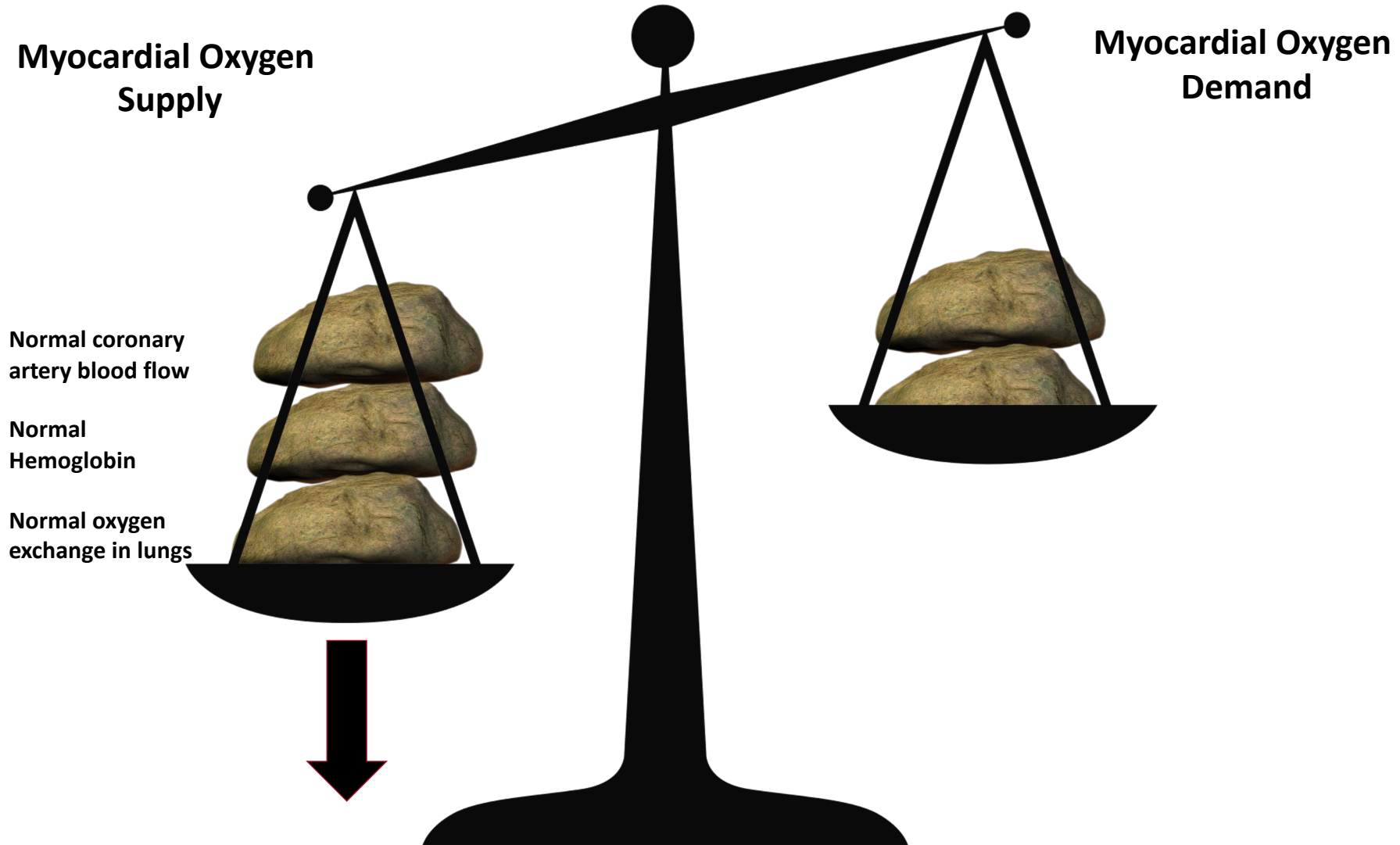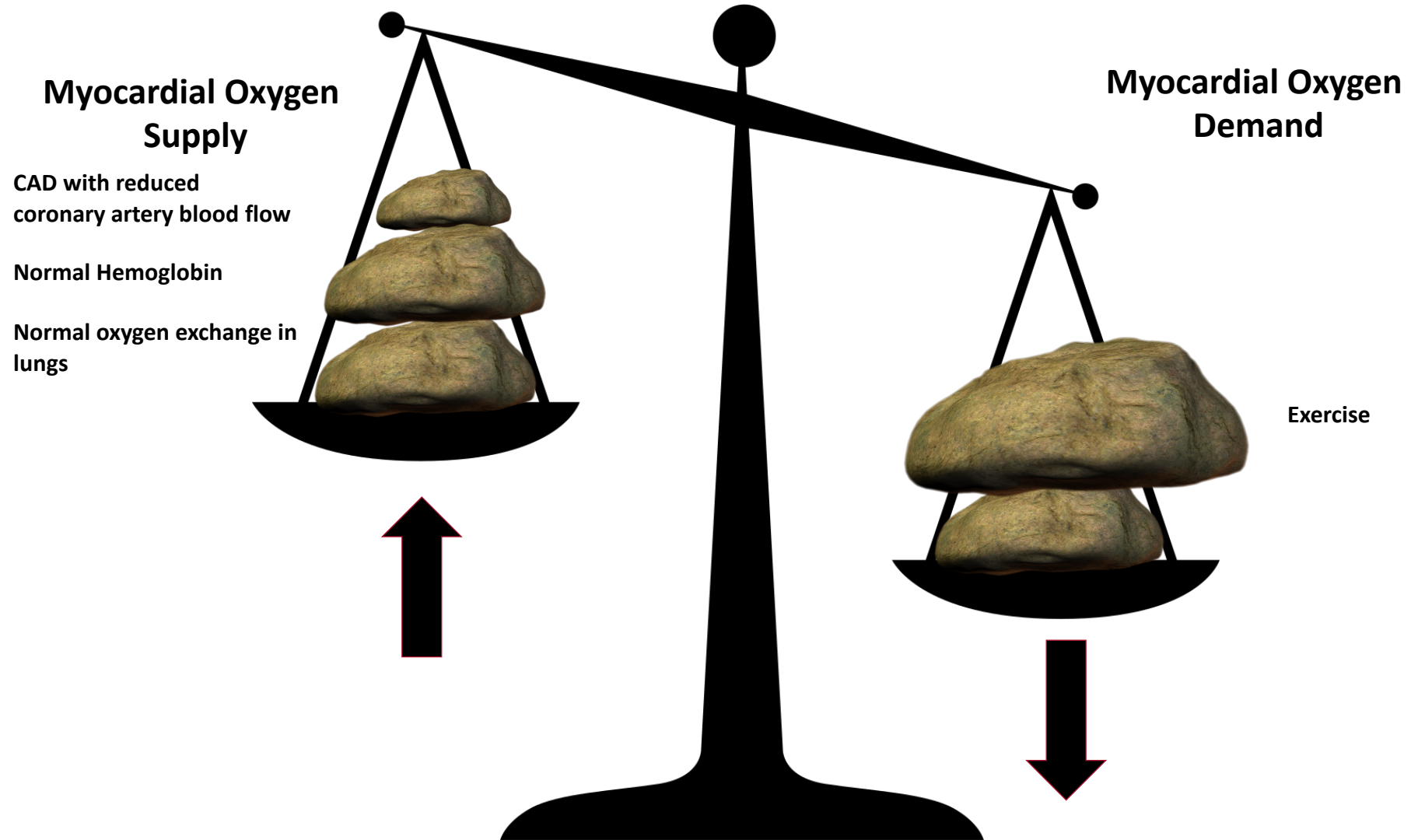 - Coronary artery spasm
  - Coronary microvascular dysfunction

IMAGE SOURCE PAGE: *http://www.medicalresearchs.com/2011/03/15/coronary-artery-atherosclerosis*

Myocardial Oxygen – Supply vs Demand

Myocardial Oxygen Supply

Myocardial Oxygen Demand

Normal coronary artery blood flow

Normal Hemoglobin

Normal oxygen exchange in lungs

Ischemia

Myocardial Oxygen Supply

CAD with reduced coronary artery blood flow

Normal Hemoglobin

Normal oxygen exchange in lungs

Myocardial Oxygen Demand

Exercise

Stress Testing – So Many Options!

- Type of stress test often determined by the following:

  – EKG normal vs abnormal

  – Person able to exercise y/n

- If EKG normal and able to exercise

  – Exercise Tolerance Test (ETT)

- If EKG is abnormal but able to exercise

  – Exercise test with imaging (exercise nuclear or stress echo)

- If person is unable to exercise – Pharmacologic stress test

  – Vasodilators – adenosine, dipyridamole, regadenoson

  – Inotropic/chronotropic medication – dobutamine

  – Contraindications to either pharmacologic option must be considered

- Other considerations - echo windows, structural disease, center preference, etc.…

Exercise Treadmill Testing (ETT)

- Can the someone exercise?

  – Arthritis, pulmonary disease, claudication

  – At least 85%MPHR – to achieve a valid evaluation for ischemia

- Can the EKG be used as a valid tool to monitor for ischemic changes?

  – Not if LBBB, significant ST-T changes at baseline, ventricular pacing

- Types of exercise

  – Treadmill

  – Bicycle – weight bearing issues

- Protocols – most common

  – Bruce – extensively validated incorporates 3 min successive stages with faster speed and steeper grade

  – Modified Bruce – adds two low workload stages to the beginning of a standard Bruce

Exercise – Functional Capacity

- Functional capacity can be assessed using metabolic equivalents (METs)

- 1 MET – metabolic equivalent – 3.5ml O2 uptake/kg/min – which represents the resting oxygen uptake in a sitting position

- Walk up a flight of steps or a hill or walk on level ground at 3-4 mph (4 METs)

- Heavy work around the house, scrubbing floors, moving heavy furniture or climb two flights of stairs (4-10METs)

- Sports

  – Cycling 10 mph (7 METs)

  – Running 12min/mi (8.7 METs)

    □ 8 min/mi– 12.5 METs)

  – Boxing (in ring 13.3 METs)

Treadmill exercise testing protocols

| Protocol name	Stage	Speed (mph)	Grade (%)	Total time (min)	METS*
Modified Bruce¶	0	1.7	0	3	2.3
	1/2	1.7	5	6	3.4
Bruce	1	1.7	10	3	4.5
	2	2.5	12	6	7
	3	3.4	14	9	10
	4	4.2	16	12	13
	5	5	18	15	15
	6	5.5	20	18	18
	7	5.5	22	21	20
Naughton (modified)	1	2	0	2	2
	2	2	3.5	4	3
	3	2	7	6	4
	4	2	10.5	8	5
	5	2	14	10	6
	6	2	17.5	12	7
	7	2.6	14	14	8
	8	3	14	16	9
	9	3.4	14	18	10
	10	3.7	14	20	11
Naughton	1	1	0	3	2
	2	1.5	0	6	2.5
	3	2	3.5	9	3
	4	2	7	12	4
	5	2	10.5	15	5
	6	2	14	18	6
	7	2	17.5	21	7
	8	3	12.5	24	8
	9	3	15	27	9
	10	3	17.5	30	10
	11	3	20	33	11

mph: miles per hour.

* Metabolic equivalents – 1 MET = 3.5 mL O_2/kg/min.

¶ Stages 1 through 7 of the Modified Bruce protocol are identical to stages 1 through 7 of the standard Bruce protocol.

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Underwriting an ETT

- Assess functional capacity with minutes and METs

- Look at hemodynamic response to exercise

  – Hypertensive response –review blood pressure control

  – If systolic blood pressure drops during exercise –CONCERNING!

    ▫ Multivessel disease, underlying heart failure, fixed cardiac output (severe AS or HCM)

  – Heart rate – did applicant reach at least 85% of their maximum predicted heart rate (MPHR) If not, why? (Beta blocker? Stopped due to symptoms?)

    ▫ Heart rate recovery - HR at peak exercise should fall about 12 beats within the first minute of recovery

- Did exercise reproduce or lead to symptoms

- EKG changes – during stress and early recovery

  – Considered abnormal (i.e., "positive" for ischemia) when there is ≥1 mm horizontal or down sloping ST segment depression in one or more leads

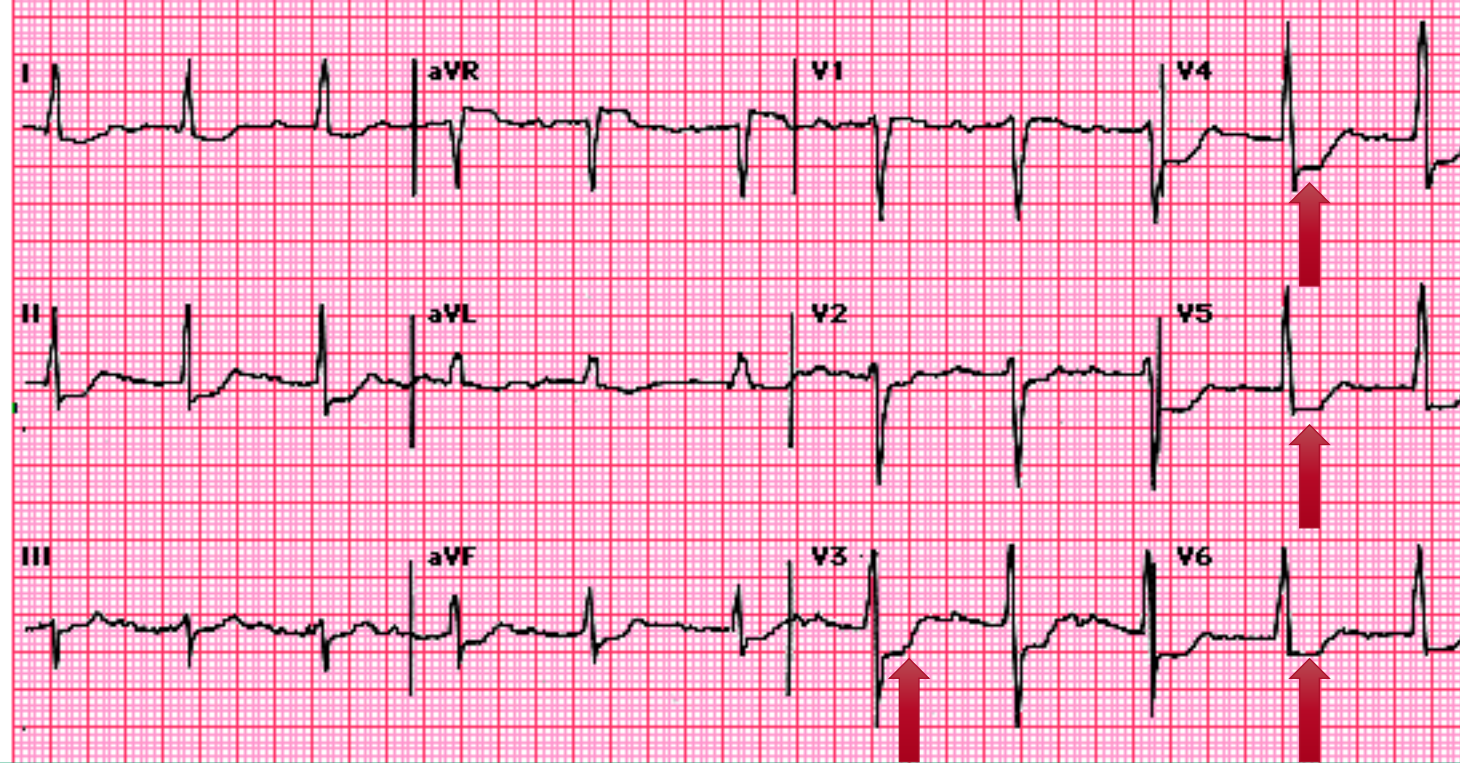 – Ventricular ectopy or arrhythmias

Normal ECG
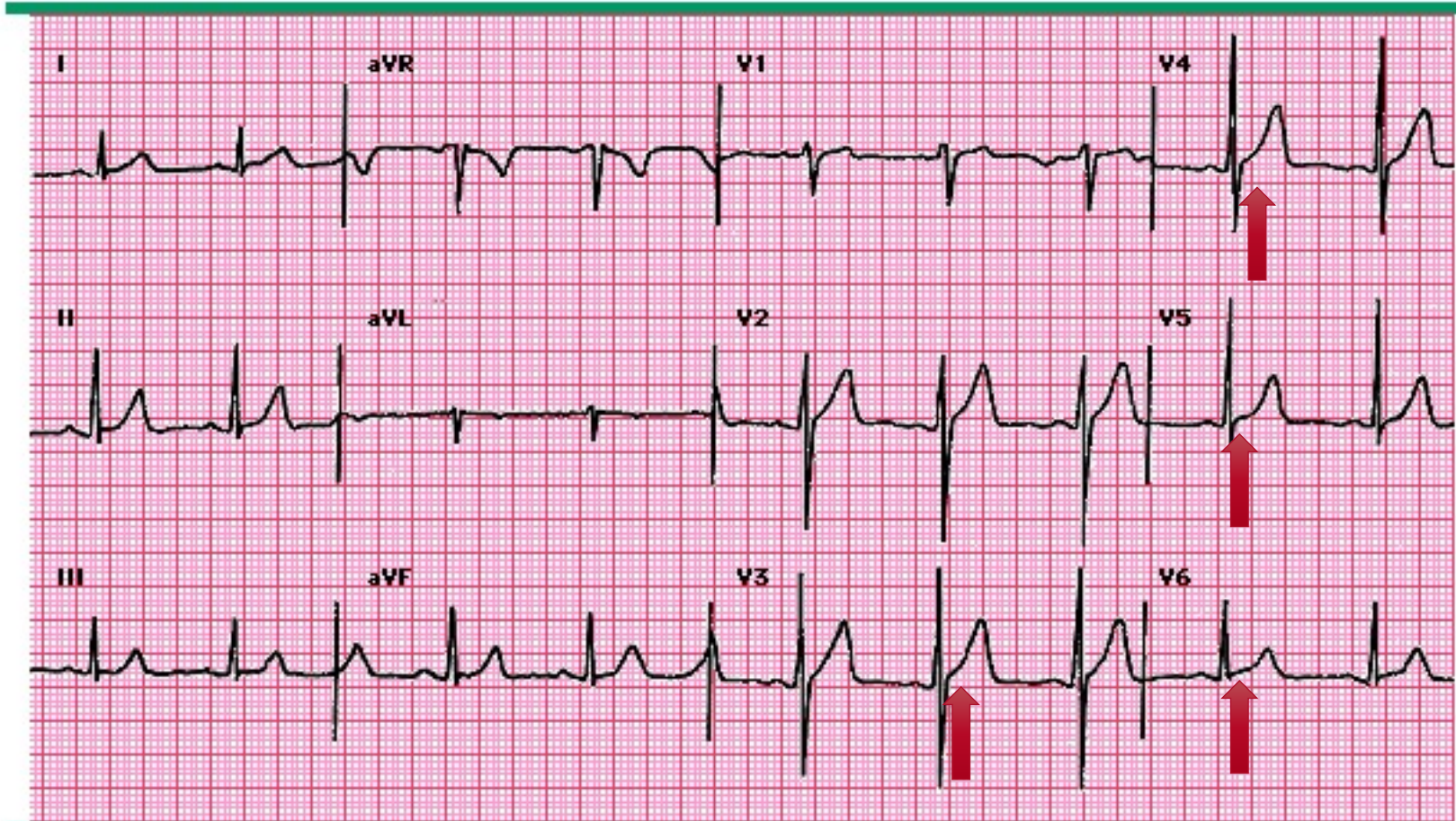
Normal electrocardiogram showing normal sinus rhythm at a rate of 75 beats/minute, a PR interval of 0.14 seconds, a QRS interval of 0.10 seconds, and a QRS axis of approximately 75°.

Courtesy of Ary Goldberger, MD.

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ECG diffuse subendocardial ischemia

Diffuse subendocardial ischemia manifested by prominent ST depressions in leads I, II, aVL, aVF, and V2 to V6, with ST elevation in aVR. A prolonged PR interval (0.28 sec) is also present. The findings also raise the possiblitity of severe multivessel or left main coronary artery disease.
*Courtesy of Ary Goldberger, MD.*

Stress Echocardiography

- EKG protocol - gain all the ETT information PLUS –

- Baseline echo – *Extent of baseline description varies

  – LV function with wall motion and EF

  – LV function, LV size, LV wall thickness, aortic root diameter, pericardium, gross valvular structure and function, estimate of PASP

  – A detailed resting echo

- Stress echo

  – Assessment of global and regional LV systolic function (side by side comparison with rest imaging)

  – With stress LV becomes hypercontractile, cavity size is smaller and EF increases – ALL NORMAL responses to exercise

Stress Echocardiography

- LV regional wall motion analysis

- Typically 16 or 17 segment model

- Each segment is graded
  - Normal
  - Hyperdynamic
  - Hypokinetic
  - Akinetic
  - Dyskinetic
  - Aneurysmal

- At rest and with stress

- Global LV systolic function and cavity size

Left ventricular segmentation

① Four chamber
② Two chamber
③ Long axis
④ Base
⑤ Mid
⑥ Apex
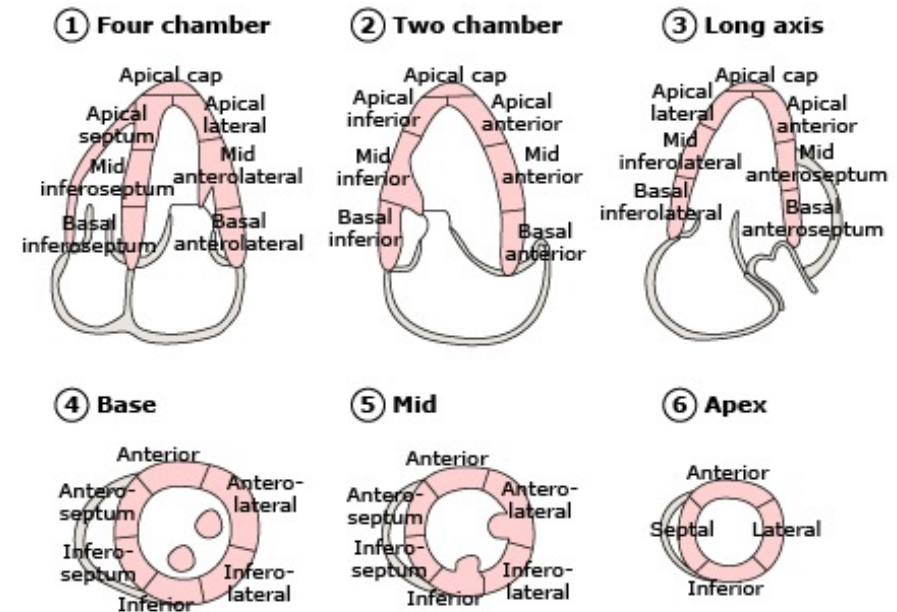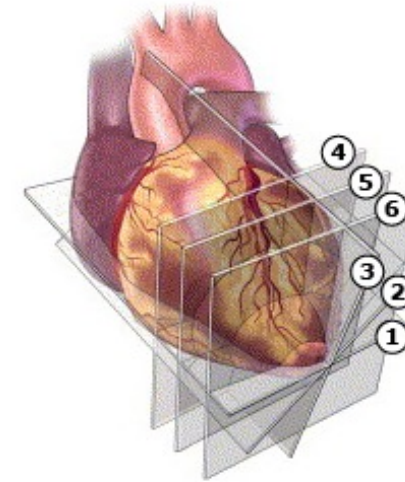
Wall Motion on Echocardiography

- Hypokinesis (HK)

  – Segment is moving but not contracting as vigorously as expected

- Akinesis (AK)

  – No motion in that segment or area. You can see often apical AK following a large anterior MI

- Dyskinesis

  – Abnormal movement (i.e. instead of contracting in systole segment bulges out)

Stress Echocardiography

Echo Finding	At Rest	At Stress	Abnormality
Normal wall motion	Normal	Normal or hyperdynamic	None
**Hypokinesis, Dyskinesis or Akinesis	Not present	Present	Ischemia
	Present	Present	Scar from prior MI Cardiomyopathy
** Underlying LBBB or prior cardiac surgery may cause dyskinesis at rest and stress however the echo report will typically indicate dyskinesis consistent with known conduction system abnormality or prior surgery			

Nuclear Stress Testing

- EKG protocol - gain all of the ETT information PLUS –

- Evaluation of cardiac perfusion and function at rest and during stress, wall motion and ejection fraction

- Radioactive tracer given IV and a special camera system (single-photon emission computed tomography- SPECT or positron emission tomography- PET) is used to detect the gamma photons

- Images of the heart are obtained – either during both exercise and rest or exercise only (and if normal, skip rest images)

- Provides information on presence of ischemia, myocardial infarction/scar, global and regional LV systolic function

Normal single-photon emission computed tomography (SPECT) radionuclide myocardial perfusion imaging (MPI) study
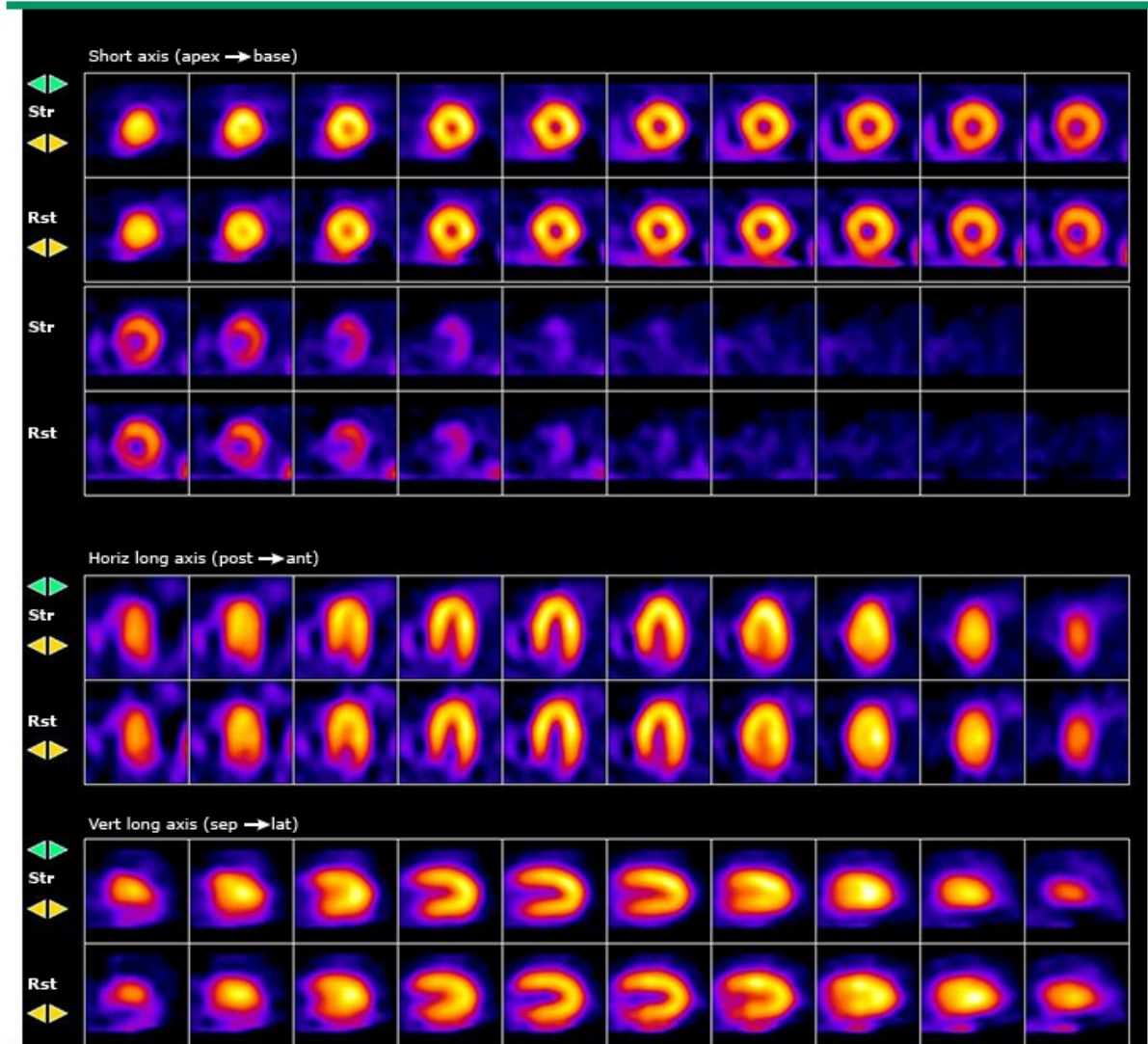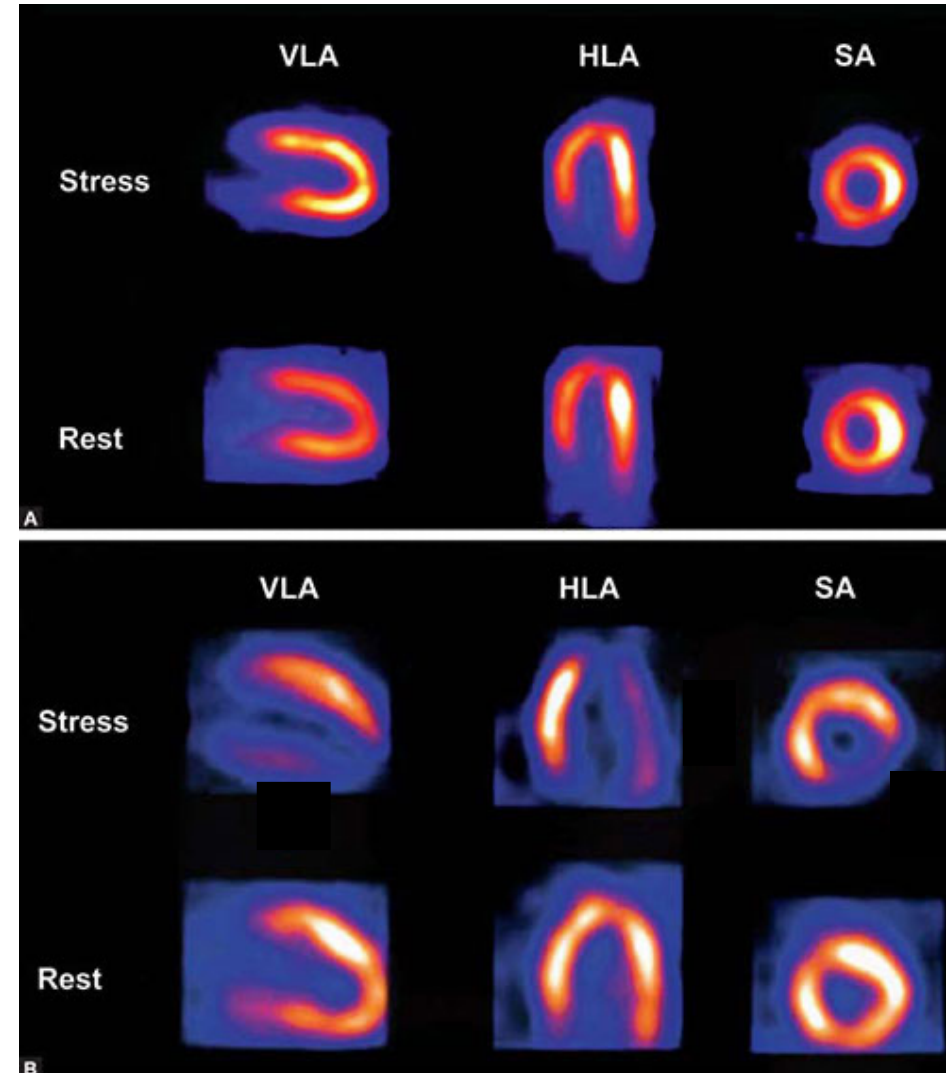

Single-photon emission computed tomography (SPECT) radionuclide myocardial perfusion imaging (rMPI) showing normal perfusion both at rest and following stress.

Courtesy of James Udelson, MD.

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Stress Nuclear Imaging

- Stress and Rest images are compared

- Normal Study

- What about this study

- What's the concern?

Question #1

- Stress and Rest images are compared

- Normal Study

- What is the abnormality noted on nuclear imaging?

- A) No abnormality, the stress test is normal

- B) Stress test is abnormal and positive for ischemia

- C) Stress test is abnormal and positive for infarct
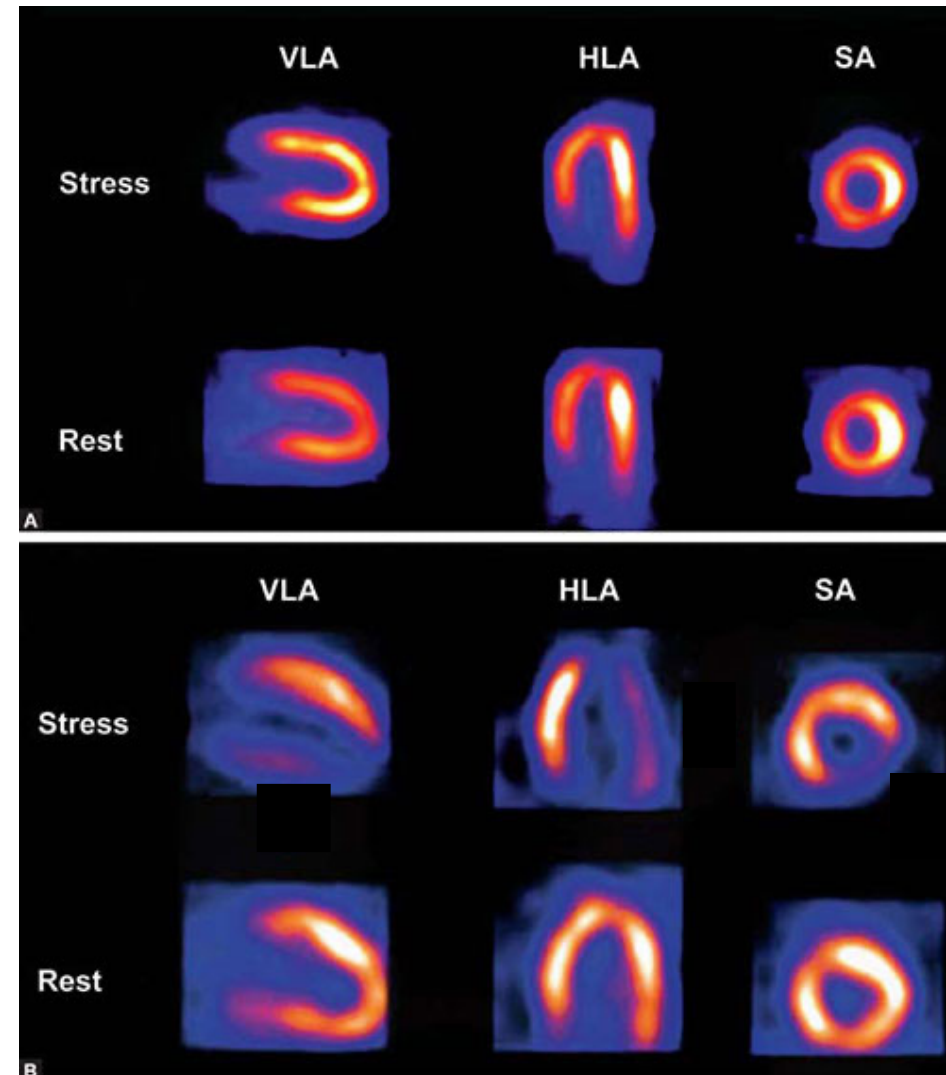
- D) Not sure

Question #1

- What is the abnormality noted on nuclear imaging?

- A) No abnormality, the stress test is normal
- B) Stress test is abnormal and positive for ischemia
- C) Stress test is abnormal and positive for infarct
- D) Not sure

For broker-dealer use only. Not for use with the public.

Reversible Perfusion Defects - Ischemia

- Stress and Rest images are compared

- Normal study reference

- Perfusion defects during stress only (reversible)
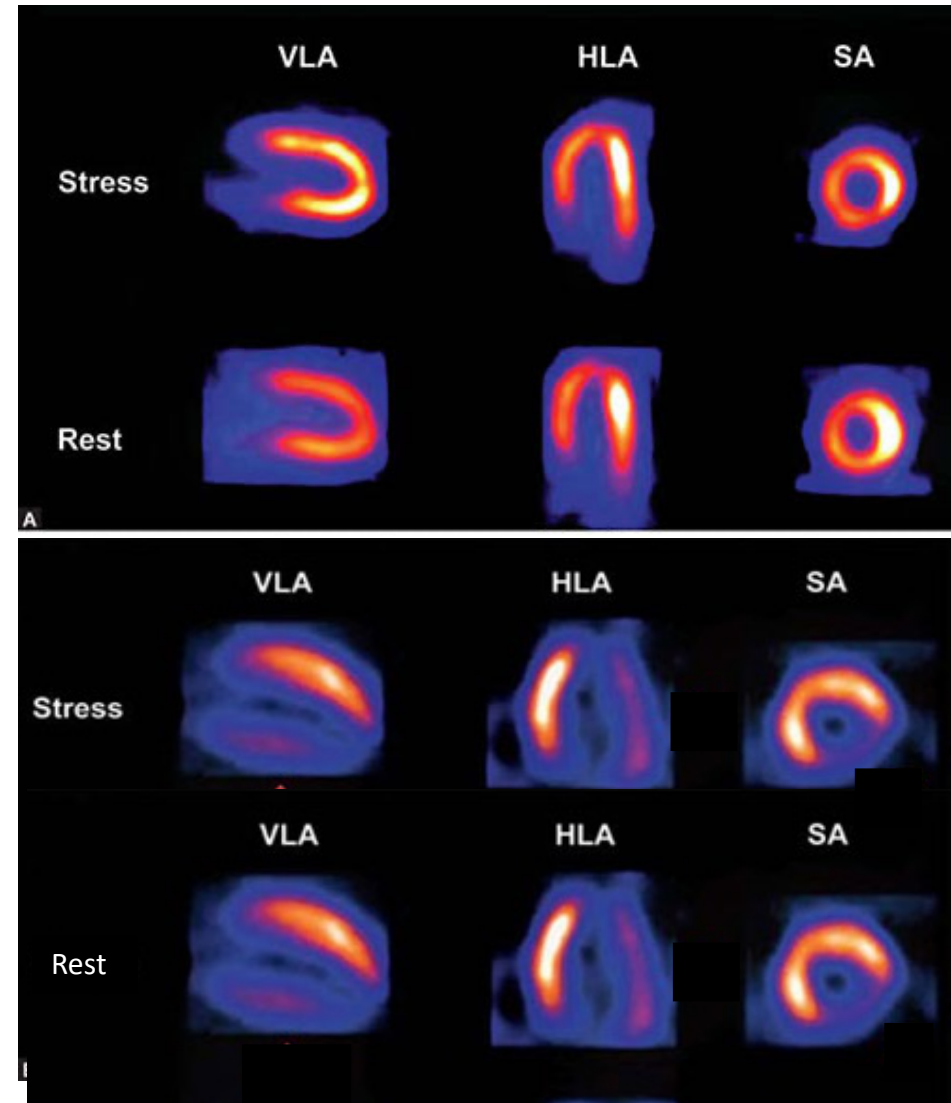 - Ischemia
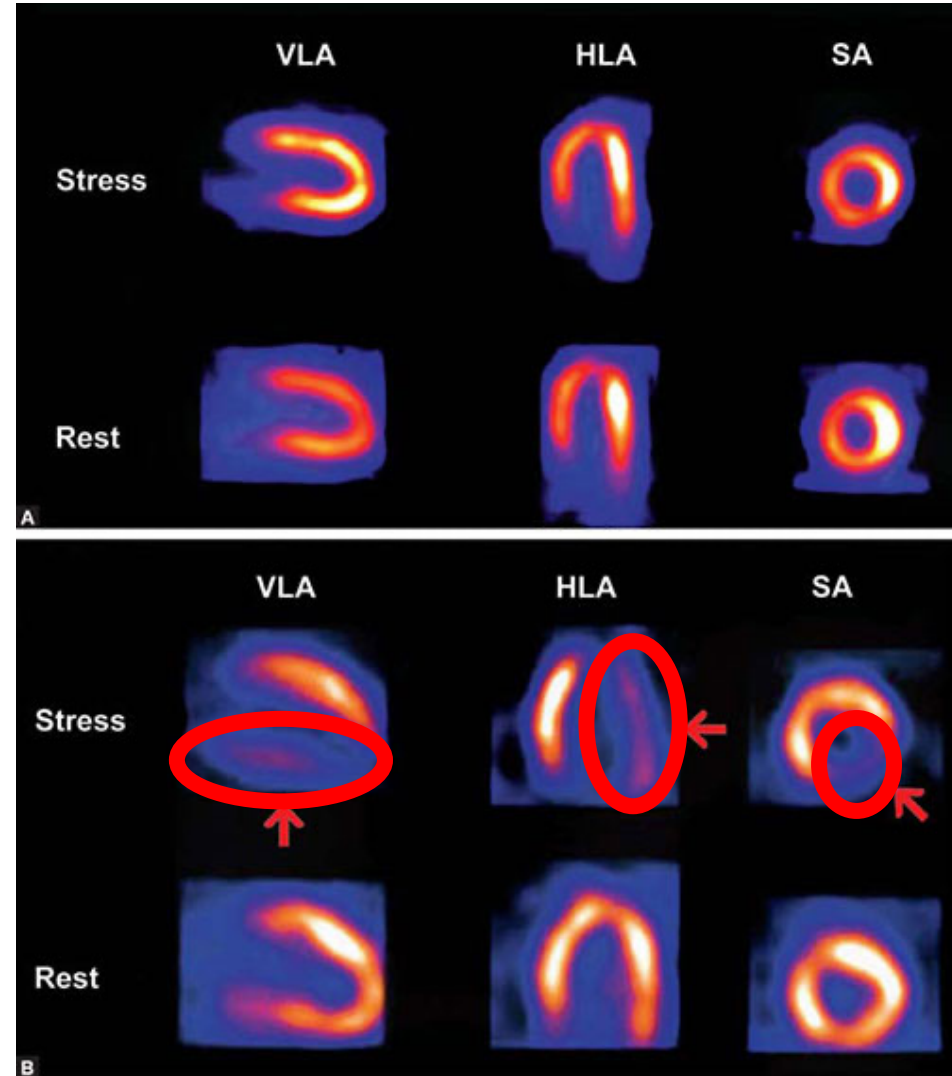
Question #2

- What would ischemia look like if the applicant had a stress echo?

- A) Normal wall motion at rest and stress
- B) Abnormal wall motion at rest, normal wall motion at stress
- C) Abnormal wall motion at rest and at stress
- D) Normal wall motion at rest, abnormal wall motion at stress
- E) Not sure

Question #2

- What would ischemia look like if the applicant had a stress echo?

- A) Normal wall motion at rest and stress

- B) Abnormal wall motion at rest, normal wall motion at stress

- C) Abnormal wall motion at rest and at stress

- D) Normal wall motion at rest, abnormal wall motion at stress

- E) Not sure
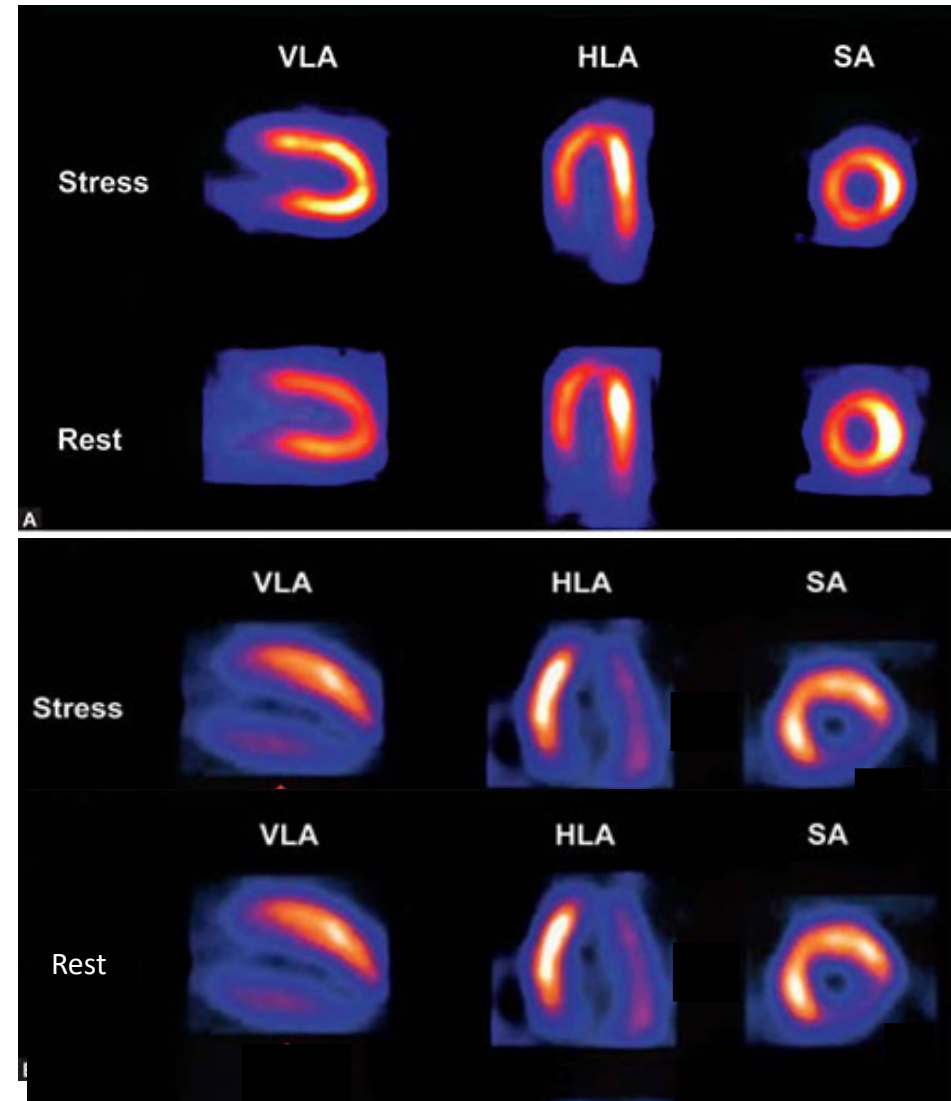
Stress Nuclear Imaging

- Normal Study

- What is the abnormality noted on nuclear imaging?

Question #3

- Normal Study

- What is the abnormality noted on nuclear imaging?

  - A) No abnormality, the stress test is normal

  - B) Stress test is abnormal and positive for ischemia

  - C) Stress test is abnormal and positive for infarct
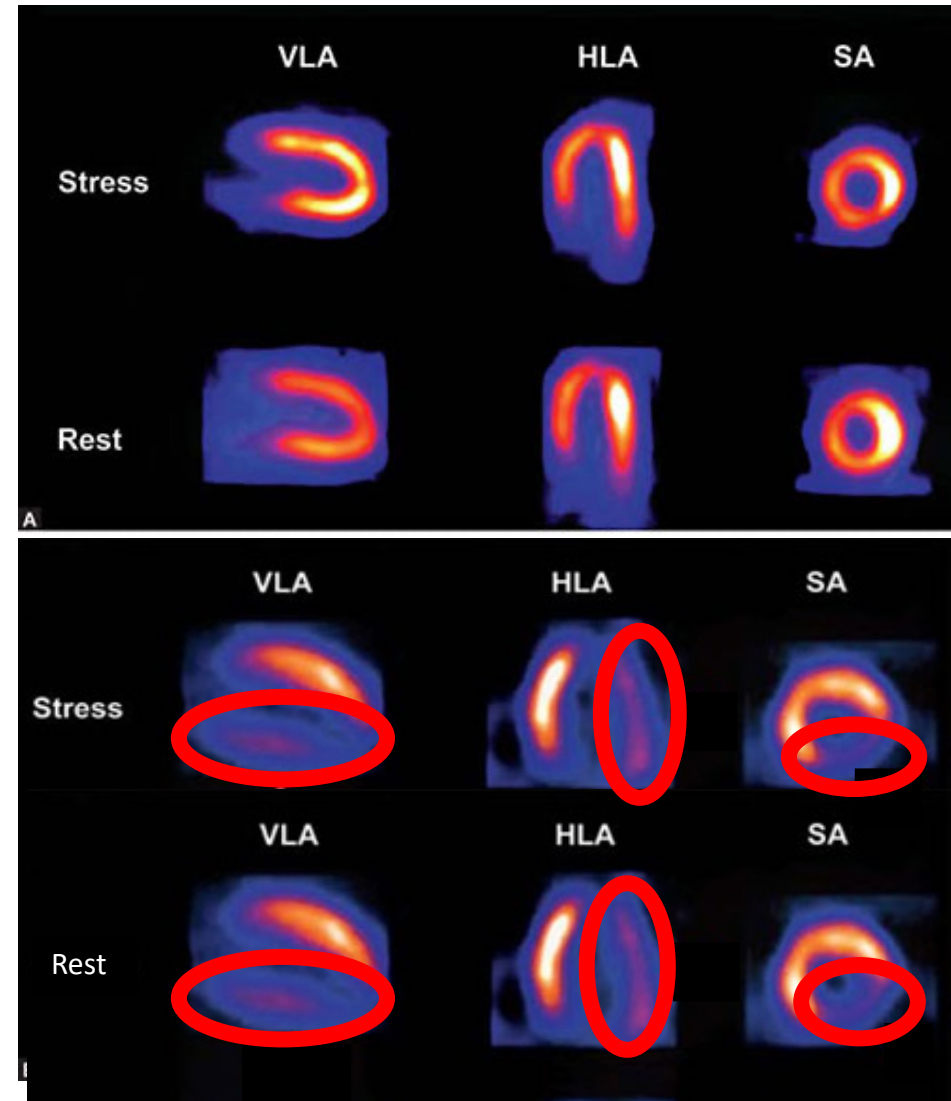
  - D) Not sure

Question #3

- What is the abnormality noted on nuclear imaging?

- A) No abnormality, the stress test is normal

- B) Stress test is abnormal and positive for ischemia

- C) Stress test is abnormal and positive for infarct

- D) Not sure

Fixed Perfusion Defects

- Normal Study Reference

- Perfusion defects during both rest and stress (fixed)
  - Infarction

Question #4

- What would an MI look like if the applicant had a stress echo?

- A) Normal wall motion at rest and stress
- B) Abnormal wall motion at rest, normal wall motion at stress
- C) Abnormal wall motion at rest and at stress
- D) Normal wall motion at rest, abnormal wall motion at stress
- E) Not sure

Question #4

- What would an MI look like if the applicant had a stress echo?

- A) Normal wall motion at rest and stress

- B) Abnormal wall motion at rest, normal wall motion at stress

- C) Abnormal wall motion at rest and at stress

- D) Normal wall motion at rest, abnormal wall motion at stress

- E) Not sure

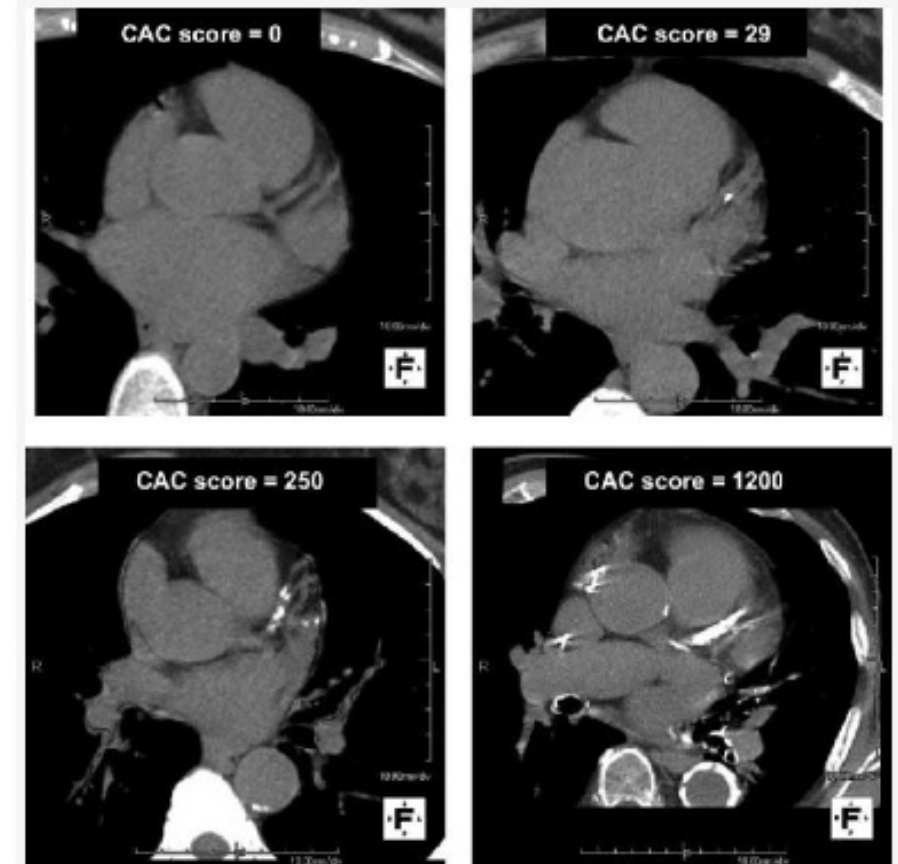# Nuclear Imaging – Gated Images

- Gated imaging allows for assessment of wall thickening at end diastole and end systole

- Provides additional information regarding wall motion

- Can help with attenuation artifact

  – Photon attenuation occurs as photon beams experience a loss of energy while going through tissue – since the heart is surrounded by tissue of varying densities (lung, bone, breast) imaging can result in non-uniform myocardial activity

  – Repositioning (ex: prone position) a person can help to sort this out as well as the gated wall motion analysis

- A fixed defect with normal systolic thickening and wall motion

  – Likely attenuation

- A fixed defect with reduced systolic thickening and hypokinesis

  – Likely an old scar from a myocardial infarction

Pharmacology Stress Imaging

- Lacks the functional information provided by the ETT

- Does not mimic physiology as well as exercise

- Provides similar imaging information regarding ischemia, infarction and wall motion

- Pharmacologic protocols
  - Vasodilators (ex: adenosine, dipyridamole, regadenoson)
    - Increases coronary blood flow
    - Brings out relative flow differences
  - Inotrope/chronotrope (ex: dobutamine)
    - Raises myocardial oxygen demand to a similar level as with exercise

Coronary Artery Calcium (CAC) Score

- Measure of overall coronary atherosclerosis burden

- In asymptomatic people it measures the extent of subclinical atherosclerosis

- The presence and extent of CAC can predict the presence of coronary artery stenoses but in general, it is a better marker of the extent of atherosclerosis than the severity of stenosis

Non-contrast CT scans showing different scores from a calcium score test.

https://my.clevelandclinic.org/health/diagnostics/16824-calcium-score-screening-heart-scan

Question #5

- If you have a calcium score and a coronary CT angiography which study would you consider the better assessment of coronary artery disease?

- A) Calcium score

- B) Coronary CT angiography

- C) Whichever carried a higher rating

- D) Whichever carried a lower rating

- E) Not sure

Question #5

- If you have a calcium score and a coronary CT angiography which study would you consider the better assessment of coronary artery disease?

- A) Calcium score

- B) Coronary CT angiography

- C) Whichever carried a higher rating

- D) Whichever carried a lower rating

- E) Not sure

CT Angiography

- Among noninvasive testing – high diagnostic accuracy for detecting luminal narrowing of $\geq$50% in epicardial coronary arteries

- CAD-RADs score
  - 0 – 0% stenosis
  - 1 – 1-24% stenosis
  - 2 – 25-49% stenosis
  - 3 – 50-69% stenosis
  - 4A – 70-99% stenosis
  - 4B - > 50% LM stenosis or >70% 3v ds
  - 5 – 100% stenosis
  - N – Nondiagnostic

- LV function

Coronary computed tomography angiographic findings and recommended management
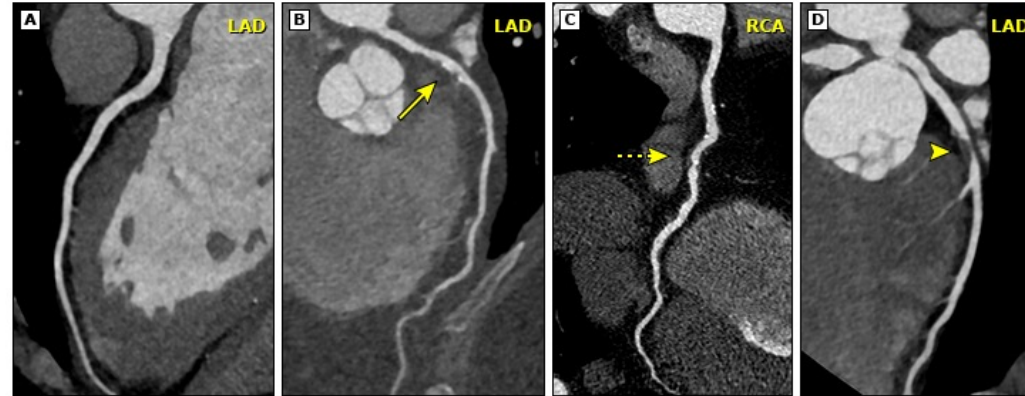
(A) **No coronary atherosclerosis.** Excellent prognosis. Management: Reassurance. Symptoms non-atherosclerotic in nature.

(B) **Non-obstructive (<50% stenosis; unlikely flow limiting) coronary artery disease (arrow).** Symptoms likely not atherosclerotic in nature. Management: Preventive pharmacotherapy, risk factor modification and lifestyle changes. Patient risk is higher if multiple segments and/or high-risk plaque features (refer to UpToDate text).

(C) **Moderate stenosis (50 to 69% stenosis; dashed arrow).** Symptoms possibly atherosclerotic in nature. Medical management if non-proximal location. Consider CT-FFR if proximal location or considering revascularization for symptom benefit. Aggressive cardiovascular risk factor modification.

(D) **Obstructive (likely flow-limiting) coronary artery disease.** Management: Symptom-guided anti-ischemia therapies, including revascularization, per guidelines. Preventive pharmacotherapies.
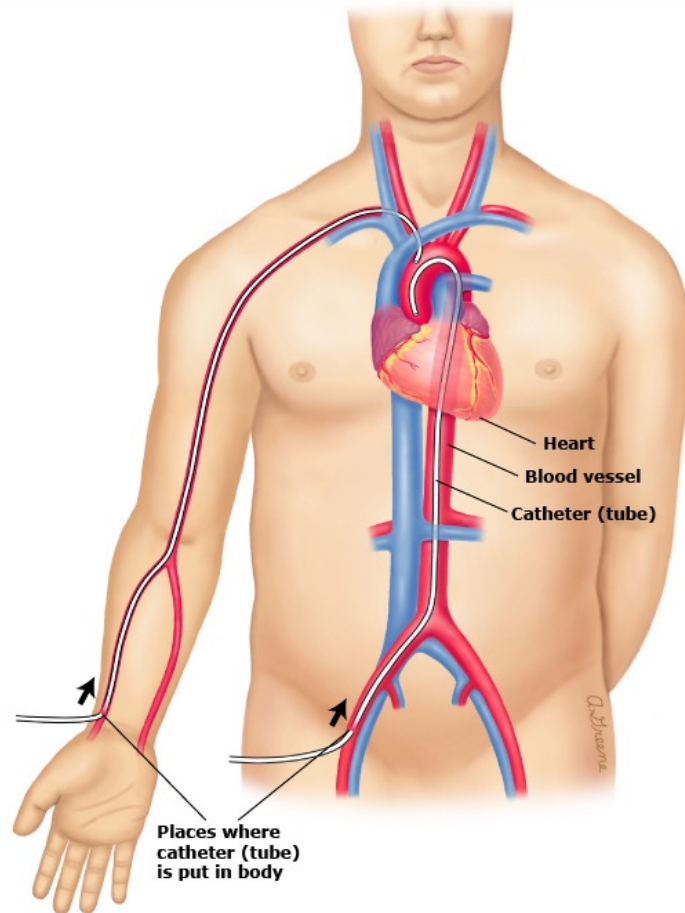
CT-FFR: computed tomography derived fractional flow reserve; LAD: left anterior descending coronary artery; RCA: right coronary artery.
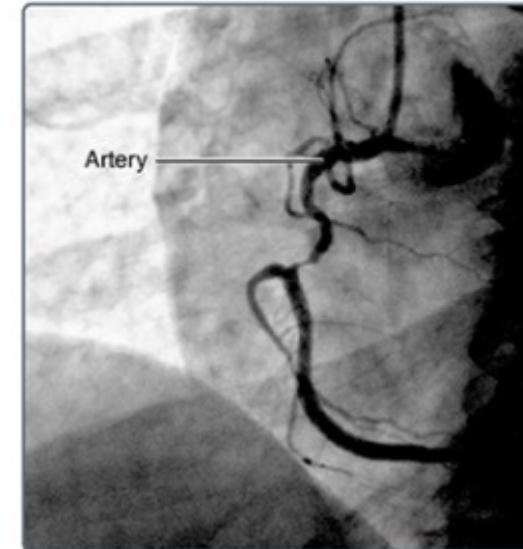
Courtesy of Todd Villines, MD.

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Cardiac Catherization

Cardiac catheterization

Heart
Blood vessel
Catheter (tube)

Places where catheter (tube) is put in body

For a cardiac catheterization, your doctor will make a very small cut in the top, inner part of your leg, or just above your hand. He or she will put a thin plastic tube, called a "catheter," in a blood vessel which is just below the cut. Then he or she will move the tube through your blood vessels to your heart. When the tube is in place, your doctor can do different tests. Most people have a test called "coronary angiography." For this test, your doctor will inject a dye that creates pictures to show if your heart arteries are clogged.

Angiogram

Artery

Source:https://www.hopkinsmedicine.org/health/treatment-tests-and-therapies/cardiac-catheterization

UpToDate® **Not for use with the public.**

Summary

- Coronary artery disease is due to atherosclerotic plaque formation

- Key to progression is risk factor control

- ETT

  – Provides functional capacity as well as assessment of ischemia in setting of a normal resting EKG and an applicant who can exercise

- Stress echo

  – Wall motion abnormality(ies) during stress only – ischemia

  – Wall motion abnormality(ies) present at stress and rest – infarct

- Nuclear stress

  – Reversible perfusion defects – occur at stress only – ischemia

  – Fixed perfusion defects – occur at rest and stress – infarct

- Calcium score – indirect measure overall burden of atherosclerosis

- Coronary CTA is a noninvasive approach to angiography and can be assessed in a similar manner as a cardiac catherization angiogram

- Cardiac catherization is the gold standard assessment for CAD

Thank you

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