



STANDARD & CARDIOPULMONARY EXERCISE TESTING

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Standard Stress Exercise Testing



Treadmill or **pedal ergometer** are commonly used to increase the heart rate, increasing the work of the heart muscle, and often revealing of underlying disease. Alternatively, **pharmacological agents** – e.g. dobutamine or adenosine) may be used to increase heart rate. **Echocardiography** and **nuclear** studies may also be combined.



University of Iowa treadmill Stress Testing

<https://youtu.be/aVtOfhANKCY?feature=shared>

Echocardiography for Regional Wall Motion Assessment (LV Function) & Ejection Fraction

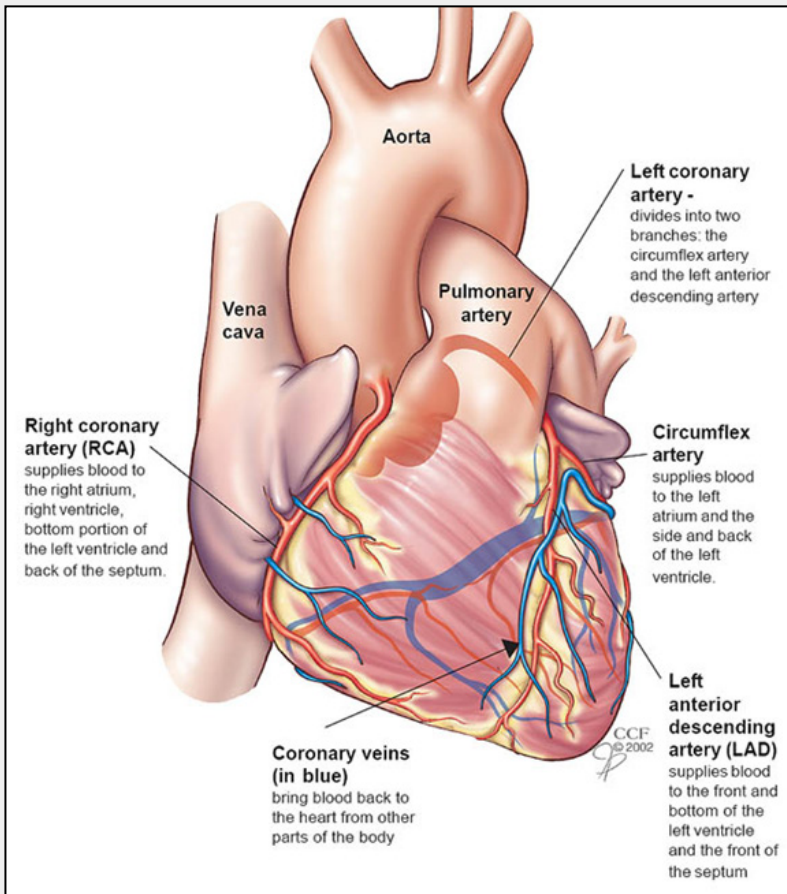


Image Courtesy of the Cleveland Clinic

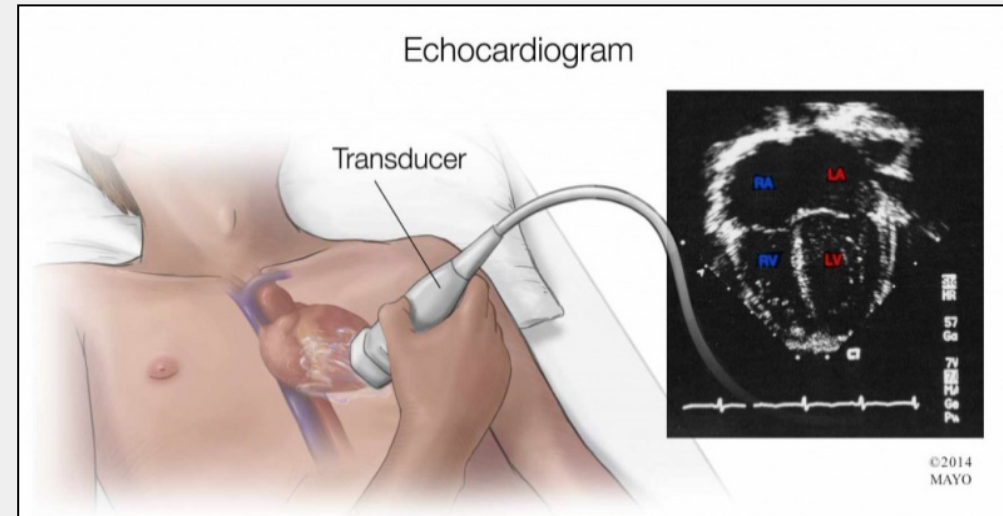


Image courtesy of the Mayo Clinic

Looking for normal vs. hypokinetic, hyperkinetic akinetic, dyskinetic and aneurysmal (bulging during diastole and systole) changes, suggesting CAD.

Addition of Post-Stress Echocardiography...



Image courtesy of Asian Heart & Vascular Center



University of Minnesota Stress Echocardiography

2D echocardiography may be performed by exercise or pharmacologic stresses.

Value

- Assessment of extent and severity of CAD.
- Detection of myocardial ischemia.
- Transient worsening of regional function is the hallmark of *inducible ischemia*.
- Stress echocardiography provides similar diagnostic and prognostic accuracy as radionuclide stress perfusion or magnetic resonance imaging, at a substantially lower cost.

Who Can Be Stress Exercise Tested?

- Those with low to intermediate pretest probability of CAD – the Diamond & Forrester Scale.
- Known CAD with *change* in clinical status.
- Those with low to *intermediate risk stable* angina pectoris (chest pain), free of active ischemia (insufficient tissue oxygenation) or heart failure (heart is unable to pump enough blood*), for 12-24 hr after presentation.
- Those requiring *risk stratification* prior to discharge or surgery.

*Shortness of breath & leg swelling

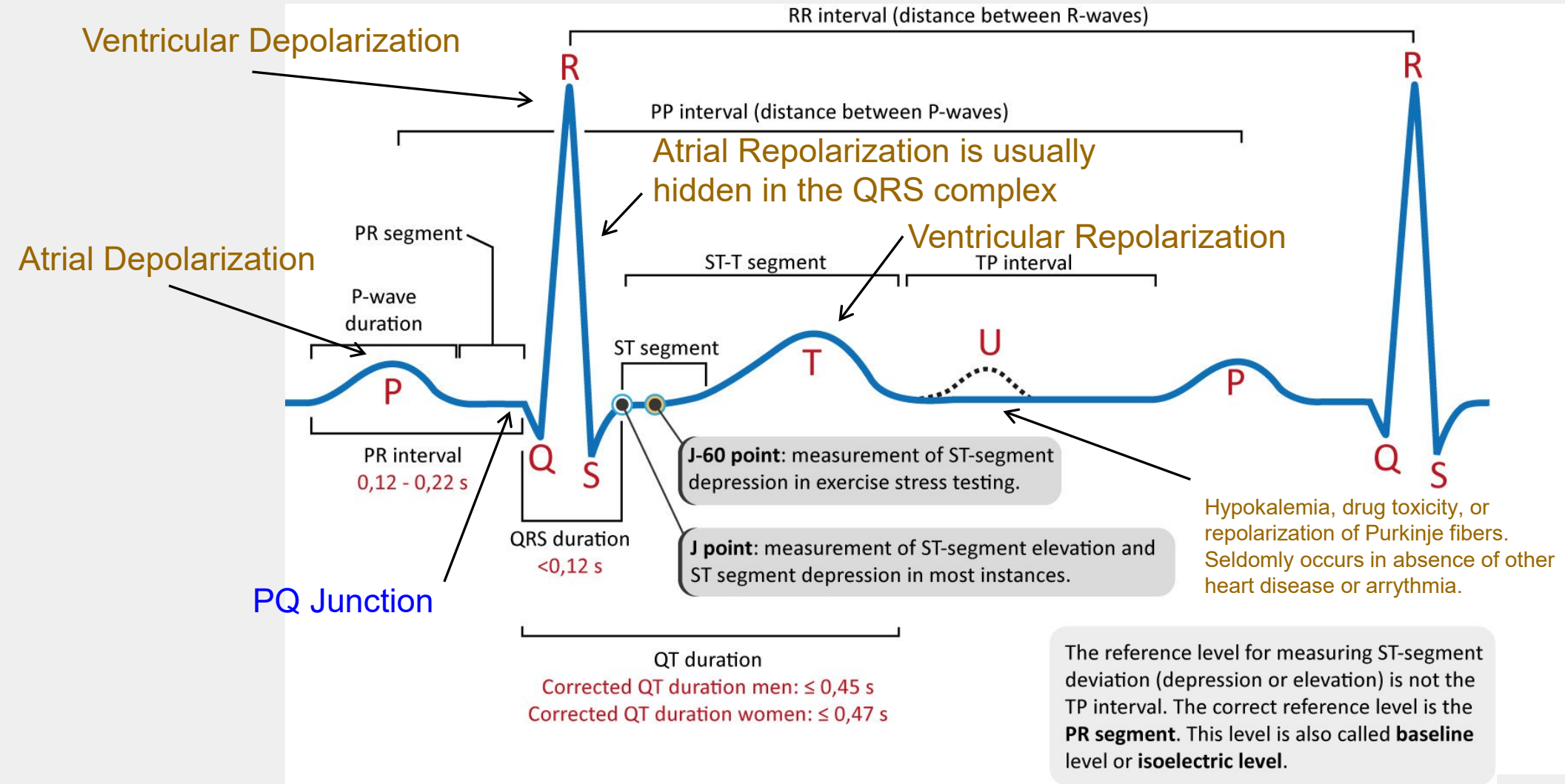
Vaidya GN. Application of exercise ECG stress test in the current high cost modern-era healthcare system. *Indian heart journal*. 2017;69(4):551-555.

Pretest Probability...

Table 1. Diamond and Forrester Score for Pretest Probability of Coronary Artery Disease

Age (years)	Sex	Typical/ definite angina pectoris	Atypical/ probable angina pectoris	Nonanginal chest pain
≤ 39	Male	Intermediate	Intermediate	Low
	Female	Intermediate	Very low	Very low
40 to 49	Male	High	Intermediate	Intermediate
	Female	Intermediate	Low	Very low
50 to 59	Male	High	Intermediate	Intermediate
	Female	Intermediate	Intermediate	Low
≥ 60	Male	High	Intermediate	Intermediate
	Female	High	Intermediate	Intermediate

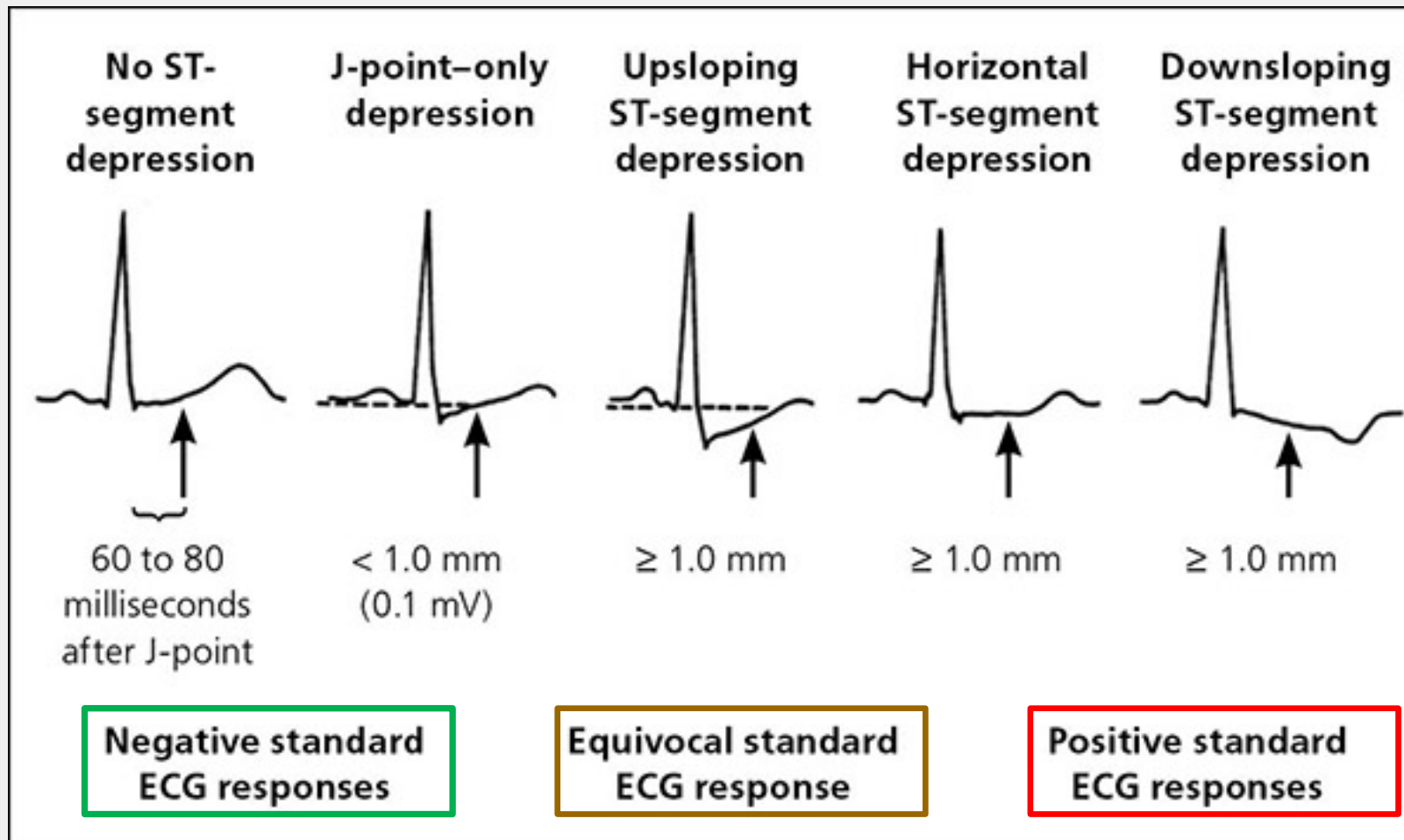
Electrocardiogram Components (Nomenclature)



Interpretation

- ST segment deviations:
 - Normally the action potential duration is longer in the endocardium than the epicardium, and repolarization proceeds from the endocardium → epicardium.
 - The endocardium is more susceptible to ischemia, and with ischemia the *action potential shortens*, and electrical gradients change causing ST depression.
 - Abnormal: *1mm or more of J point depression measured from the PQ junction, with a relatively flat ST-segment at 60ms after the J point (ST60), in three consecutive beats with a stable baseline.* (With heart rate greater than 130/min – if lower use ST80)

ST Segment Abnormality...



Fletcher GF, Ades PA, Kligfield P, et al. Exercise standards for testing and training: a scientific statement from the American Heart Association. *Circulation*. 2013;128(8):885.

- The sooner ST-segment depression develops and the longer it lasts during recover suggests more severe CAD.
- Some patients with CAD (10%) develop abnormal ECG changes only during recovery.
- Other Findings
 - Inability to increase systolic BP during exercise suggests LV dysfunction or ischemia. (Stop the test if there is a fall in BP by more than 10 mm Hg).
 - Associated symptoms – angina, heart rate and workload at time of changes.
 - Ventricular tachycardia, onset of *LBBB* (if chronic, ST changes during exercise are not diagnostic), transient intraventricular conduction delay (*LBBB*, *RBBB* or hemiblocks).

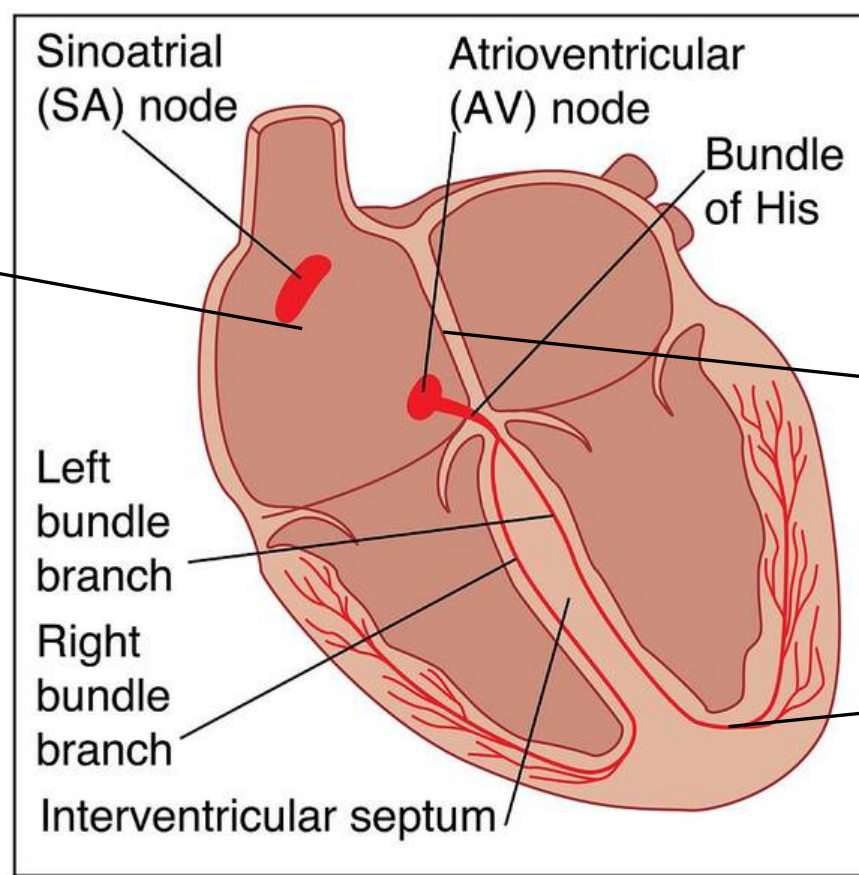
Review of the Cardiac Conduction System

Heart's Natural Pacemaker

Intranodal Pathways

Ant., middle and post. internodal tracts.

Right and left conduction pathways are made up of fascicles - specialized heart muscle cells. There are left anterior & left posterior divisions of the LBB.



Delays the electrical impulse

Nerve fibers carrying the impulse to the Purkinje fibers.

Bachmann bundle

Large muscle bundle conducting impulse from right to left atrium.

Purkinje fibers

Travel down & wrap around the ventricles.

Duke Treadmill Score...

$$\text{Duke Treadmill Score} = \text{Exercise Duration (min)} - 5 \left(\frac{\text{ST Deviation (mm)}}{\text{ST Deviation (mm)}} \right) - 4 \left(\frac{\text{Angina Index}}{\text{Angina Index}} \right)$$

Angina Index

0 – none, 1 – typical angina, 2 – angina causing test cessation

Score	Risk Group	Stenosis $\geq 75\%$	Multivessel Disease	1-Year Mortality
≥ 5	Low	40.1%	23.7%	0.25%
-10 to 4	Intermediate	67.3%	55.0%	1.25%
≤ -11	High	99.6%	93.7%	5.25%

Bourque JM, Beller GA. Value of Exercise ECG for Risk Stratification in Suspected or Known CAD in the Era of Advanced Imaging Technologies. *JACC Cardiovasc Imaging*. 2015;8(11):1309-1321.

Cardiopulmonary Exercise Testing*

*Abbreviated CPET or CPX



Metabolic cart (gas exchange), treadmill and electrocardiogram monitor.



Vyntus® CPX Metabolic Cart and pedal ergometer, showing mask with gas sensors.



Cardiopulmonary Stress Testing at John Hunter Hospital

<https://youtu.be/U5tY3vPHuMc?feature=shared>

Indications for CPET...

- Evaluation of dyspnea of unclear etiology after routine cardiopulmonary testing.
- Determination of functional impairment in exercise intolerance.
- Heart failure.
- Evaluation for exercise-induced bronchospasm, and response to therapy.
- Preoperative evaluation prior to lung and/or heart surgery.
- Muscle-metabolic disorders.
- Athlete monitoring.

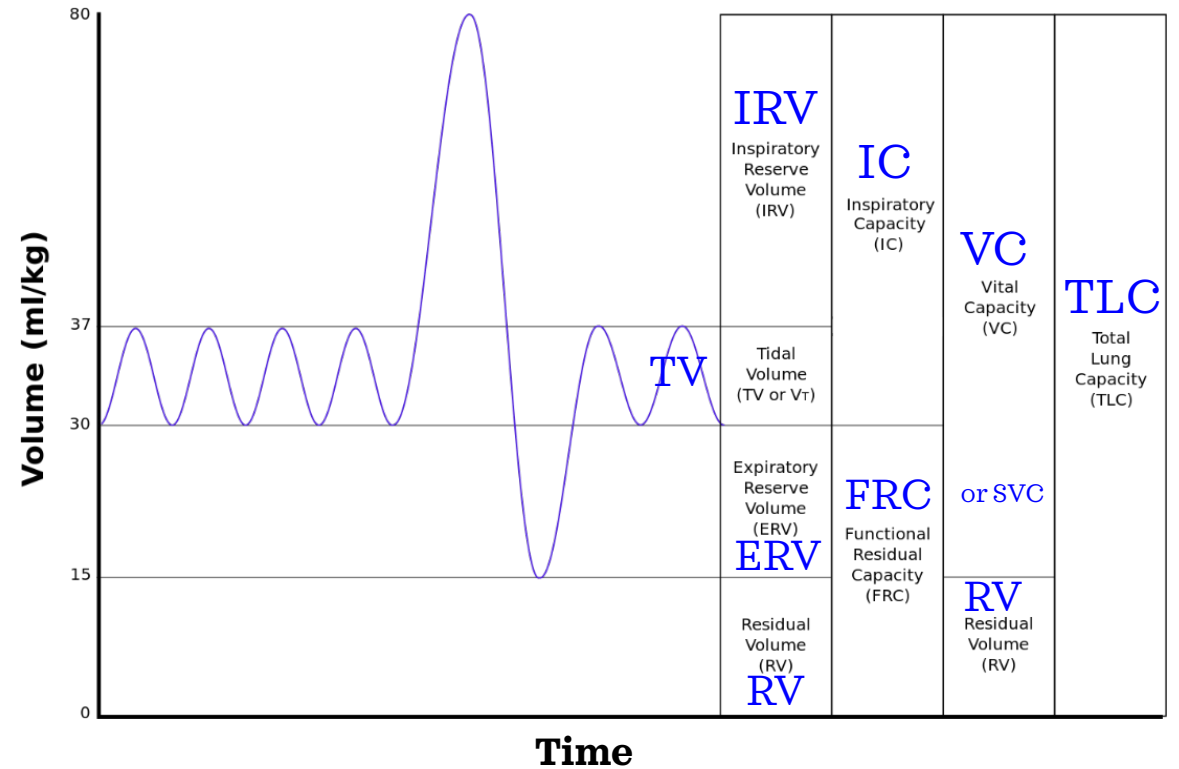
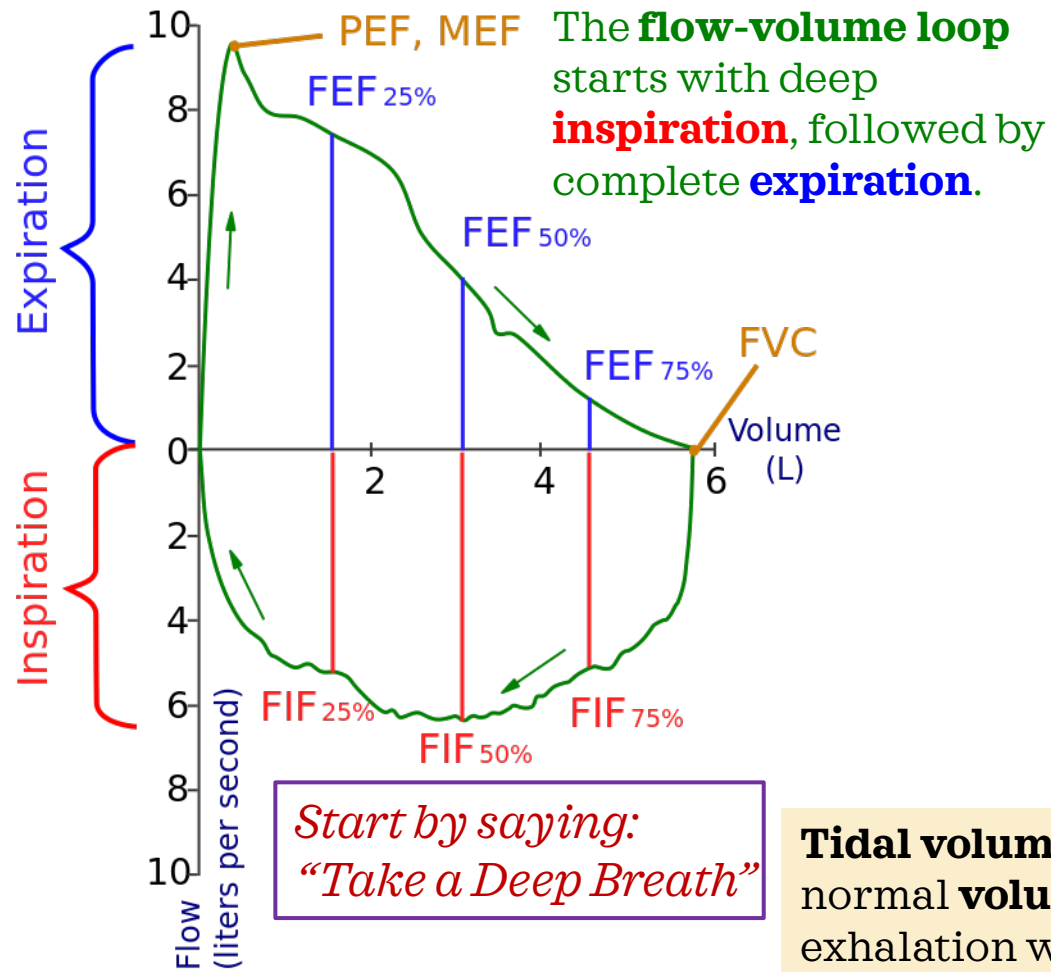
Special Parameters...

- MET (metabolic equivalent): The ratio of the work metabolic rate to the resting metabolic rate. One MET is defined as 1 kcal/kg/hour and is roughly equivalent to the energy cost of sitting quietly.
- MMV (maximum voluntary ventilation): a measure of the *maximum amount of air* that can be inhaled and exhaled within one minute.
- RER (respiratory exchange ratio): The respiratory exchange ratio is the ratio between the amount of carbon dioxide produced in metabolism and oxygen used. The ratio is determined by *comparing exhaled gases to room air*.

- **VE (minute ventilation):** the *volume* of gas inhaled (inhaled minute volume) or exhaled (exhaled minute volume) from a person's lungs per minute.
- **VE/VO₂ and VE/VCO₂:** These are the *Ventilatory Equivalents* for O₂ and CO₂. They describes the ratio of ventilation (minute volume) to oxygen intake, or to carbon dioxide output.
 - A measure of instantaneous ventilatory and gas exchange efficiency.
 - Tells how many liters does the patient have to breath in order to uptake 1 liter of oxygen or to produce 1 liter of carbon dioxide?

- **AT (Anaerobic Threshold) or V_T (Ventilatory Threshold):** refers to the point during exercise at which ventilation starts to increase at a faster rate than VO_2 (volume of oxygen). Two thresholds;
 - **V_{T1}**
 - It is a marker of intensity that can be observed in a person's breathing at a point where lactate begins to accumulate in the blood.
 - As the intensity of the exercise begins to increase, V_{T1} can be identified at the point where the breathing rate begins to increase.
 - **V_{T2}**
 - At V_{T2} , lactate has quickly accumulated in the blood and the person needs to breathe heavily.
 - At this rapid rate of breathing, the exerciser can no longer speak.

Spirometry...



Tidal volume (symbol V_T , T_V) is the lung **volume** representing the normal **volume** of air displaced between normal inhalation and exhalation when extra effort is not applied. In a healthy, young human adult, **tidal volume** is approximately 500 mL per inspiration or 7 mL/kg of body mass.

Pulmonary Function Report

Forced vital capacity
Forced expt. volume @ 1 sec.

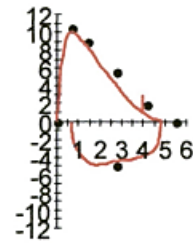
Forced expiratory flow @ 25%

Forced inspiratory vital capacity
Forced inspiratory flow max.

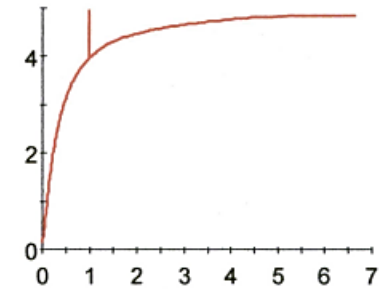
Slow vital capacity (TLC=IC+ERV)
Inspiratory capacity
Expiratory reserve capacity

Name: Test, Patient	ID: 0123456789	BMI: 36.5	Date: 12/04/2015
Tech:	Height: 185.00	Age: 50	Room:
Doctor:	Weight: 125.00	Sex: Male	Race: <Unspecified

	Pre-Bronch			LLN	Post-Bronch		
	Actual	Pred	%Pred		Actual	%Pred	
---- SPIROMETRY ----							
FVC (L)	4.85	5.53	87	4.52			
FEV1 (L)	3.99	4.27	93	3.41			
FEV1/FVC (%)	82	78	105	68			
FEF 25% (L/sec)	8.92	8.89	100	6.30			
FEF 75% (L/sec)	1.59	1.90	83	0.73			
FEF 25-75% (L/sec)	4.00	3.71	107	1.98			
FEF Max (L/sec)	9.92	10.44	95	7.93			
FIVC (L)	4.18						
FIF Max (L/sec)	4.91						
SVC (L)	5.08	5.53	91	4.52			
IC (L)	2.76	3.64	75				
ERV (L)	2.32	1.89	122				



• Pred — Pre



Peak $\dot{V}O_2$

- Global marker of fitness. It represents the combination of ventricular systolic and diastolic function (cardiac output), vascular function (O_2 delivery), and peripheral skeletal muscle metabolic capacity (O_2 utilization).
- According to the Fick principle, $\dot{V}O_2$ is determined by
 - Heart rate, stroke volume, the concentration of hemoglobin and its capacity to transport oxygen.
 - Difference between arterial oxygen saturation (reflecting lung problems and other right-to-left shunts), and
 - Mixed venous oxygen saturation (reflecting peripheral blood flow distribution and oxygen extraction in the muscle).

Wagner J, Agostoni P, Arena R, et al. The Role of Gas Exchange Variables in Cardiopulmonary Exercise Testing for Risk Stratification and Management of Heart Failure with Reduced Ejection Fraction. *Am Heart J*. 2018;202:116-126.

Ventilatory Threshold & Peak VO_2 , VCO_2 ...

Ventilatory threshold

Point at which anaerobic metabolism increases
 VO_2 at ventilatory threshold typically is 40%–60% of peak VO_2
A low value is consistent with deconditioning or disease; a high value is consistent with athletic training

Anaerobic exercise

Short, fast, high-intensity exercises that don't make your body use oxygen like it does for cardio (or aerobic) activities. Instead, anaerobic activities break down glucose that's already in your muscles for a form of energy.

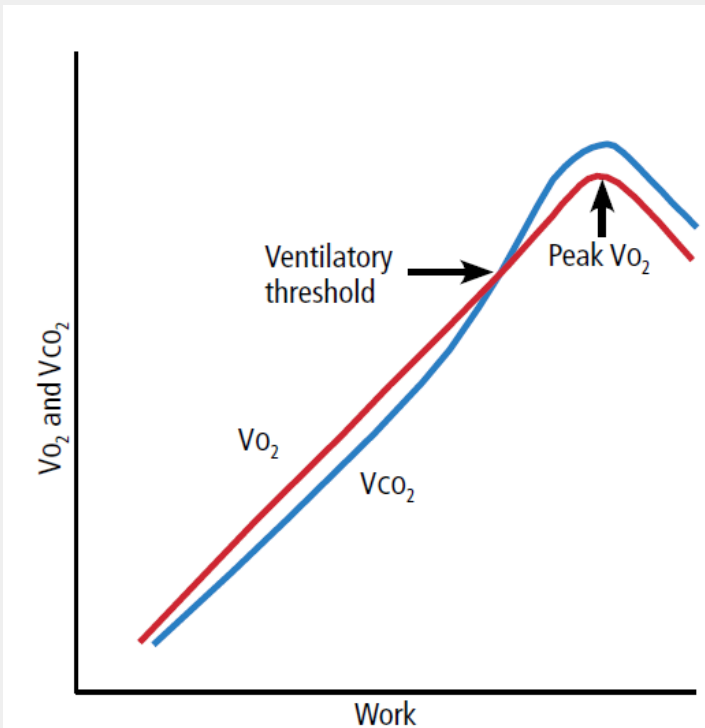


FIGURE 1. Diagram of response to work. Impairment from any cause will lower the peak VO_2 and ventilatory threshold.

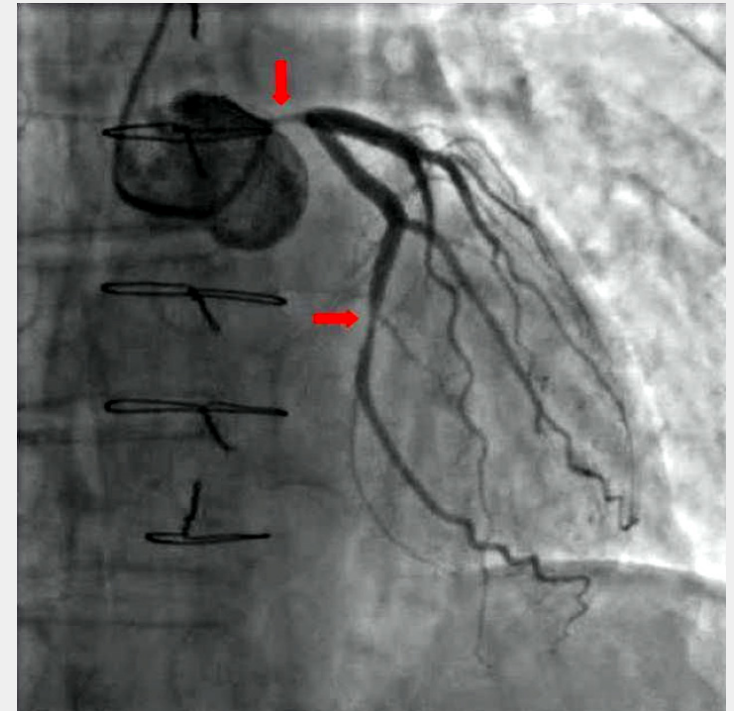
Peak VO_2

Highest oxygen uptake obtained (aerobic capacity)
Values vary widely with age, sex, activity level, weight, and disease (< 20 mL/kg/min in elderly; > 90 in elite athletes)
Nonspecific but starting point for interpretation and stratification
Peak $VO_2 \geq 85\%$ of predicted is generally favorable; ≤ 14 mL/kg/min carries a poor prognosis in heart failure (≤ 10 if on beta-blockers)

Imaging Techniques

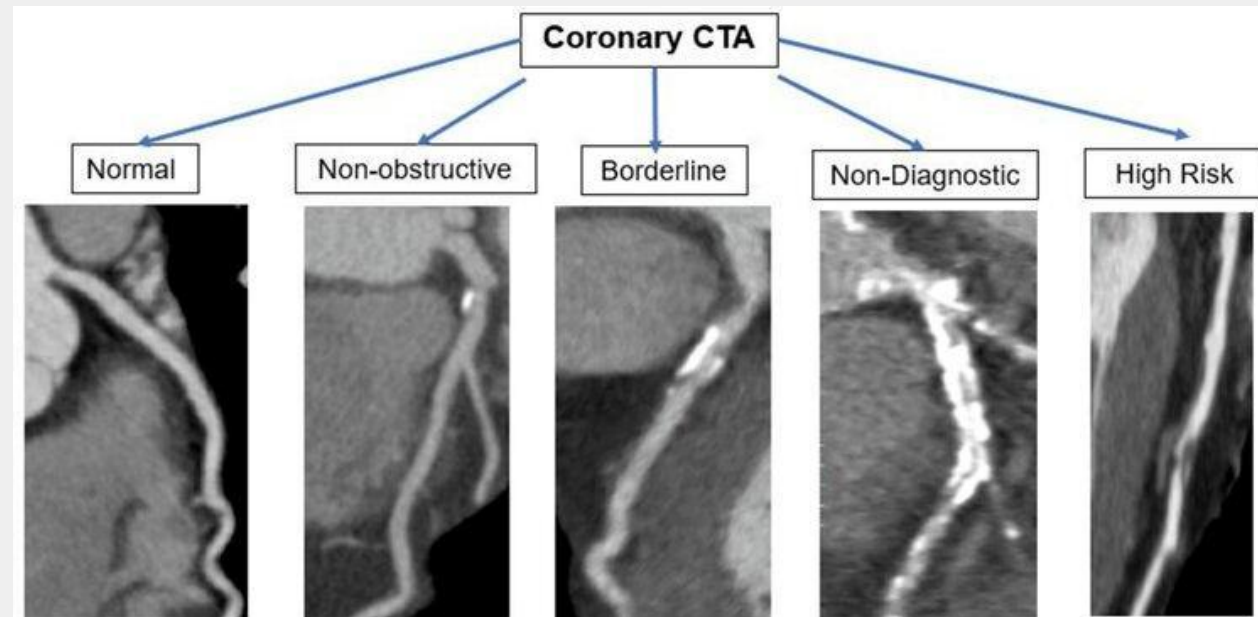
Coronary Catheterization...

- Minimally invasive procedure. Injection of radiocontrast agent.
- Indications include MI, abnormal stress test, unexplained CHF, persistent chest pain, Prinzmetal angina (vasospasm).
- Diagnosis of occlusion, stenosis, thrombosis, muscle performance & pressure measurements.



Coronary CTA...

- **Coronary Computed Tomography Angiography.**
 - 3D images are created by injecting iodine contrast medium, then looking for narrowing with a CT scan.
 - Positive predictive value of cardiac CTA is approximately 82% and the negative predictive value is around 93%.

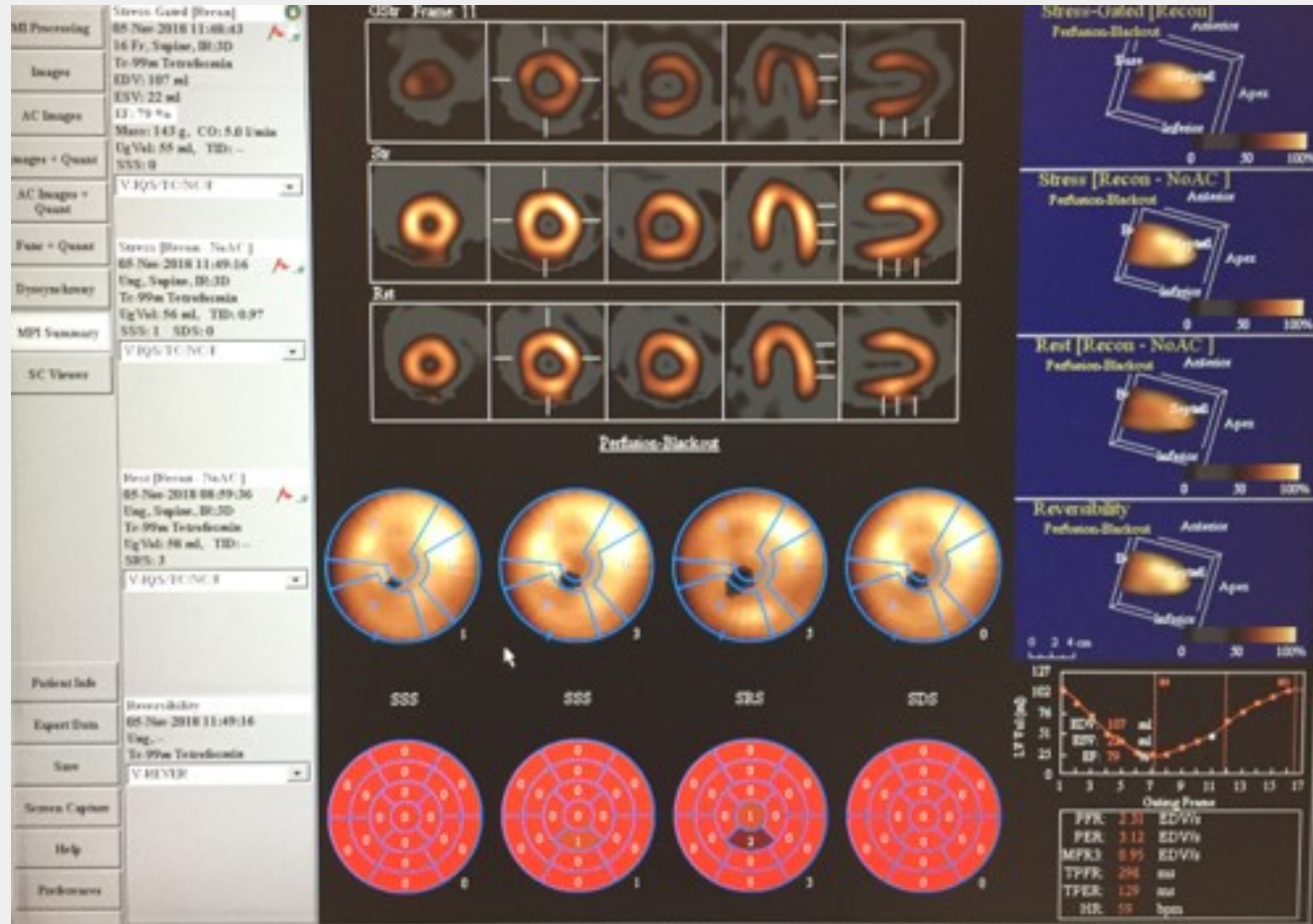


Cardioperfusion Imaging - SPECT-CT...

- Single photon emission tomography (SPECT) - CT
 - 3D nuclear scans are obtained by rotating the *gamma ray* camera around the patient (360 degrees).
 - Data is “fused” with CT data allowing for digital compensation of interfering bone and tissue.
 - Lexiscan is a prescription medication used in a cardiac nuclear stress test (myocardial perfusion imaging), increasing blood flow in the coronary arteries
 - The patient has a SPECT-CT before and after administration of Lexiscan.



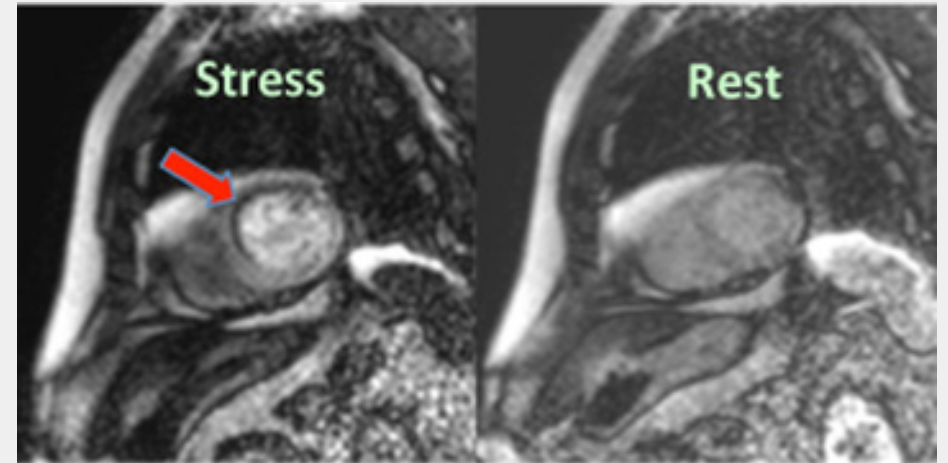
Interpreting the Perfusion Slices...



No video on this pdf version.

Cardiac Magnetic Resonance Imaging...

- Used for more advanced or complex heart disease. IV vasodilator* and Gadolinium contrast are used.
- Patients maybe referred after undergoing transthoracic echocardiography.
- Diagnose:
 - Coronary art. narrowing.
 - Inflammation of the myocardium.
 - Aortic disease (tear, aneurysm, narrowing).
 - Pericarditis (disease of the pericardium).
 - Cardiomyopathy, valve disorders and congenital disease.



Inducible ischemia (dark area, arrow) in the anteroseptal cardiac wall noted on perfusion study during stress but not at rest.

*Vasodilator (adenosine or regadenoson) or positive inotrope (dobutamine).

Key Points

- Exercise testing can tell us much about conditioning, underlying coronary artery disease, and risk for future events.
- Cardiopulmonary stress exercise testing can tell us more about dyspnea, functional impairment, heart failure, response to therapy for bronchospasm, pre-surgical assessment, muscle-metabolic disorders, and athletic conditioning.
- Imaging techniques can tell us more about extent of CAD, inflammation of the myocardium, aortic disease (tear, aneurysm, narrowing), pericardial disease, cardiomyopathy, valve disorders and congenital disease.