


STANDARD & CARDIOPULMONARY EXERCISE TESTING

Prof. Steven Saliterman, MD, FACP
<https://saliterman.umn.edu/physiology>

Standard Stress Exercise Testing



Treadmill exercise (or pedal ergometer); use of pharmacological agents - e.g. dobutamine or adenosine) may be used to increase heart rate.


	Stress		
	EKG	Echo	Nuclear (Technetium or Thallium)
Test	Treadmill EKG	Treadmill Echo	Treadmill Nuclear
Chemical (Dobutamine, Persantine, Adenosine)		Chemical Echo	Chemical Nuclear*

*Most Common

Dobutamine and adenosine are contraindicated in severe conduction abnormalities and bronchospasm.

Bricker, E. Compass, 5 Types of Cardiac Stress Tests—They are Not All the Same. <https://www.compassrph.com>

Increased heart rate means increased work of the cardiac muscle, and may reveal underlying CAD.



University of Iowa treadmill Stress Testing
<https://youtu.be/iVtOfmANKCY?feature=shared>

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 *radionucleotide stress perfusion or magnetic resonance imaging*, at a substantially lower cost.

Sicari R, Cortigiani L. The clinical use of stress echocardiography in ischemic heart disease. *Cardiovascular ultrasound*. 2017;15(1):7.

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

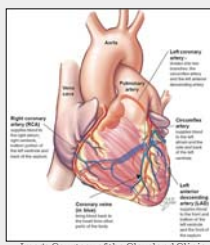


Image Courtesy of the Cleveland Clinic

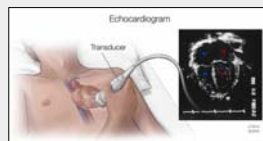


Image courtesy of the Mayo Clinic

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

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, free of active ischemia or heart failure for 12-24 hr after presentation.
- Those requiring *risk stratification* prior to discharge or surgery.

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

Bailey, MJ et al. *J Am Coll Cardiol*, 2014; 63(4):388

Electrocardiogram Components

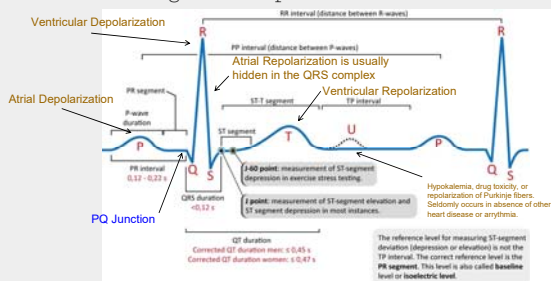


Image courtesy of DrSwenson@Dr_Swenson

Interpretation

- ST segment deviations:
 - Normally the action potential duration is longer in the endocardium than the epicardium, and repolarization proceeds from the endocardium to the 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)

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.

ST Segment Abnormality...

No ST-segment depression	J-point-only depression	Upsloping ST-segment depression	Horizontal ST-segment depression	Downsloping ST-segment depression
60 to 80 milliseconds after J-point	< 1.0 mm (0.1 mV)	≥ 1.0 mm	≥ 1.0 mm	≥ 1.0 mm
Negative standard ECG responses	Equivocal standard ECG response	Positive standard ECG responses	Positive standard ECG responses	Positive standard ECG responses

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).

Garner, KK et al. Exercise stress testing: indications and common questions. *Am Fam Physician*. 2017 Sept 1, 96(5):293-200A

Duke Treadmill Score...

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

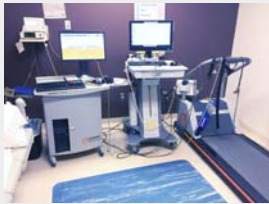
Angina Index
 0 – none, 1 – typical angina, 2 – angina causing test cessation

Score	Risk Group	Stenosis ≥ 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.



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



Cardiopulmonary Stress Testing at John Hunter Hospital

<https://youtu.be/USkY3vPHuMc?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.

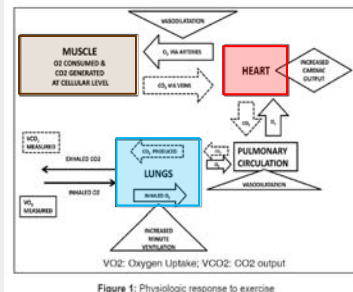


Figure 1: Physiologic response to exercise

Datta D, Normandin E, ZuWallack R. Cardiopulmonary exercise testing in the assessment of exertional dyspnea. *Ann Thorac Med.* 2015;10(2):77-86.

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*.

- o **VE (minute ventilation):** the *volume* of gas inhaled (inhaled minute volume) or exhaled (exhaled minute volume) from a person's lungs per minute.
- o **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.
 - o A measure of instantaneous ventilatory and gas exchange efficiency.
 - o 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?

- o **AT (Anaerobic Threshold) or VT (Ventilatory Threshold):** refers to the point during exercise at which ventilation starts to increase at a faster rate than VO₂ (volume of oxygen). Two thresholds;
 - o **VT1**
 - o 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.
 - o As the intensity of the exercise begins to increase, VT1 can be identified at the point where the breathing rate begins to increase.
 - o **VT2**
 - o At VT2, lactate has quickly accumulated in the blood and the person needs to breathe heavily.
 - o At this rapid rate of breathing, the exerciser can no longer speak.

Spirometry...

The flow-volume loop starts with deep inspiration, followed by complete expiration.

Start by saying: "Take a Deep Breath"

Tidal volume (symbol VT, TV) 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.

Jmarchin, Wikipedia

Pulmonary Function Report

Name: Test Patient ID: 0123456789 HMI: J63 Date: 12/04/2013
 Tech: Height: 185.00 Age: 50 Room:
 Doctor: Weight: 125.00 Sex: Male Race: Unspecified

	Pre-Brach			LLN	Post-Brach	
	Actual	Pred	%Pred		Actual	%Pred
SPYROMETRY						
Forced vital capacity	FVC (L)	4.85	5.53	87	4.32	
Forced expt. volume @ 1 sec.	FEV1 (L)	3.99	4.27	93	3.41	
Forced expiratory flow @ 25%	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	
Forced inspiratory vital capacity	FEF 25-75% (L/Sec)	4.00	3.71	107	1.98	
	FEF Max (L/Sec)	9.82	10.44	95	7.93	
	FIVC (L)	4.18				
Forced inspiratory flow max.	FIF Max (L/Sec)	4.91				
Slow vital capacity (TLC-IC-ERV)	SVC (L)	5.08	5.53	91	4.52	
Inspiratory capacity	IC (L)	2.76	3.64	75		
Expiratory reserve capacity	ERV (L)	2.32	1.89	122		

University of Minnesota ECG Lab Printout

Peak VO₂

- Global marker of fitness. It represents the combination of ventricular systolic and diastolic function (cardiac output), vascular function (O₂ delivery), and peripheral skeletal muscle metabolic capacity (O₂ utilization).
- According to the Fick principle, VO₂ 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.

Peak VO₂ VCO₂ & Ventilatory Threshold...

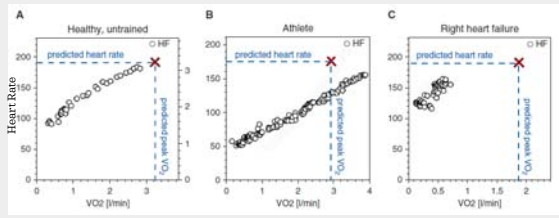
Peak VO₂
 Highest oxygen uptake obtained (aerobic capacity)
 Values vary widely with age, sex, activity level, weight, and disease (< 20 mL/kg/min in elderly; > 90 in elite athletes)
 Nonspecific but starting point for interpretation and stratification
 Peak VO₂ ≥ 85% of predicted is generally favorable;
 ≤ 14 mL/kg/min carries a poor prognosis in heart failure (≤ 10 if on beta-blockers)

Ventilatory threshold
 Point at which anaerobic metabolism increases
 VO₂ at ventilatory threshold typically is 40%–60% of peak VO₂
 A low value is consistent with deconditioning or disease; a high value is consistent with athletic training

FIGURE 1. Diagram of response to work. Impairment from any cause will lower the peak VO₂ and ventilatory threshold.

Leclerc K. Cardiopulmonary exercise testing: A contemporary and versatile clinical tool. *Cleve Clin J Med.* 2017;84(2):161-168.

Vo₂ vs Heart Rate; Level of Conditioning & Heart Failure...



Note that Maximal Predicted HR = (220-Age) x 85%

Dumitrescu D, Rosenkranz S. Graphical Data Display for Clinical Cardiopulmonary Exercise Testing. *Annals of the American Thoracic Society*. 2017;14(Supplement_1):S12-S21.

VE/VCO₂ (minute ventilation/CO₂ output) ...

VE/VCO₂ slope

Ventilatory volume/carbon dioxide output; reflects ventilatory efficiency

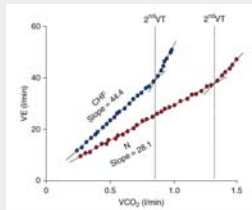
Normal 25–30

May be slightly elevated in isolation in otherwise healthy elderly patients

Elevated value reflects ventilatory inefficiency or ventilation-perfusion mismatch

Values ≥ 34 indicate clinically significant cardiopulmonary disease (heart failure, pulmonary hypertension, chronic obstructive pulmonary disease)

Higher values = worse prognosis



Leclerc K. Cardiopulmonary exercise testing: A contemporary and versatile clinical tool. *Cleve Clin J Med*. 2017;84(2):161-168.
 Mezzani A. Cardiopulmonary Exercise Testing: Basics of Methodology and Measurements. *Annals of the American Thoracic Society*. 2017;14(Supplement_1):S3-S11.

Scoring for Heart Failure...

Cardiopulmonary exercise testing scoring system for patients with heart failure

Variable	Value	Points
Ventilation/carbon dioxide (VE/VCO ₂) slope	≥ 34	7
Heart rate recovery*	≤ 6 bpm	5 [†]
Oxygen uptake efficiency slope	≤ 1.4	2
Peak Vo ₂	≤ 14 mL/kg/min	2

Score > 15 points: annual mortality rate 12.2%; relative risk > 9 for transplant, left ventricular assist device, or cardiac death.

Score < 5 points: annual mortality rate 1.2%.

*Maximum heart rate minus heart rate at 1 minute in recovery.


[†] 2 points if on a beta-blocker.

Leclerc K. Cardiopulmonary exercise testing: A contemporary and versatile clinical tool. *Cleve Clin J Med*. 2017;84(2):161-168.

Imaging Techniques

Coronary Catheterization...

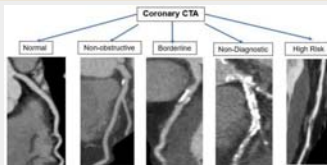
- Minimally invasive procedure. Injection of radiocontrast agent.
- Indications include MI, abnormal stress test, unexplained CHF, persistent chest pain, Prinzmetal angina (vasospasm).
- Diagnosis of occlusion, stenosis, thrombosis, muscle performance & pressure measurements.



Images: https://en.wikipedia.org/wiki/Coronary_catheterization

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%.



<https://www.cardiavision.com/contents/services/how-we-help>

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.



University of Minnesota Single Photon Emission Tomography (SPECT) - CT

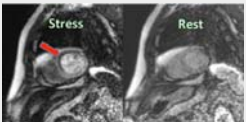
Interpreting the Perfusion Slices...



Salterman, S.

Cardiac Magnetic Resonance Imaging...

- Used for more advanced or complex heart disease. IV vasodilator* and Gadolinium contrast are used.
- Patients may be 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).

<https://mriquestions.com/whyhow-stress-test.html>

Summary

- Traditional Exercise Testing:
 - Treadmill & ECG.
 - Treadmill & Echocardiography.
 - Pharmacological stressing.
 - Treadmill or chemical nuclear (SPECT-CT).
- Echocardiography
- Stress ECG interpretation:
- Cardiopulmonary Stress Exercise Testing
 - Metabolic cart plus bicycle or treadmill stress.
 - Most useful CPET variables.
- Imaging Techniques:
 - Coronary catheterization.
 - Coronary CTA.
 - SPECT-CT/Lexiscan/Nuclear Scan and PET.
 - Magnetic resonance imaging.
