Cardiorespiratory Control Mechanisms

Dr Charlotte Manisty

Outline

- Cardiopulmonary exercise testing
- Sleep apnoea - a cardiovascular perspective

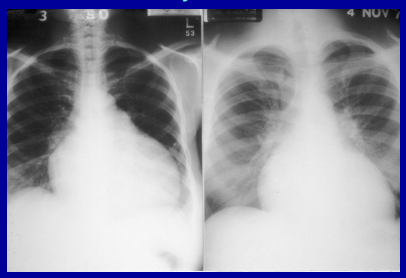
Clinical scenario

2 patients
55 year old males
30 pack year smoking
Known previous MI with impaired LV
Few scattered bibasal creps

⇒Both are short of breath on exertion
⇒How would you proceed to investigate them to ascertain the severity of their heart failure and symptoms?

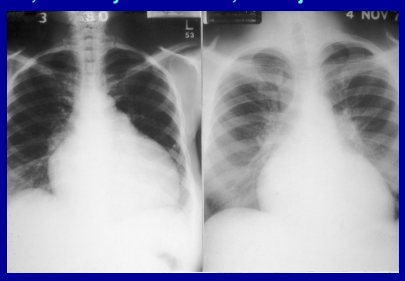
ASSESSING THE SEVERITY OF CHRONIC CARDIAC FAILURE

By CXR



ASSESSING THE SEVERITY OF CHRONIC CARDIAC FAILURE

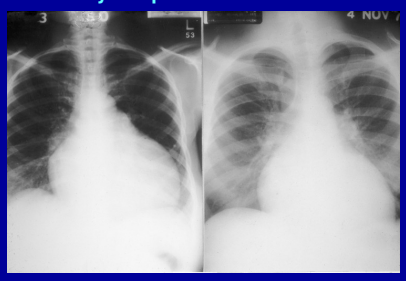
By CXR, Hemodynamic Data, and Ejection Fraction



	Resting	Resting
CI (L/min/M²)	1.80	1.85
PCW (mmHg)	28	27
EF (%)	24	26

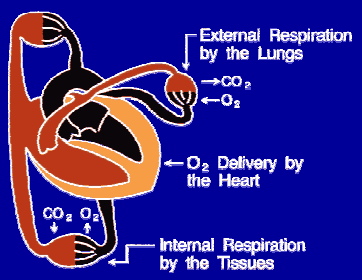
ASSESSING THE SEVERITY OF CHRONIC CARDIAC FAILURE

By Response to Exercise



	Resting	Exercise	Resting	Exercise
CI (L/min/M²)	1.80	3.43	1.85	6.00
PCW (mmHg)	28	42	27	40
EF (%)	24	--	26	--
Exerc. capac. (sec)	--	492	--	924

THE GAS TRANSPORT SYSTEM



Normal Cardiopulmonary Response to Exercise

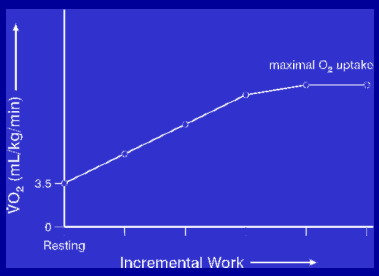
	Rest	Exercise	Increase
VO2, L/min	0.250	3.0-4.5	12-18 x
HR, bpm	70	180	2.5-3 x
SV, ml	70	105-140	1.5-2 x
CO, L/min	5	20-25	4-5 x
Ve, L/min	8	180	20-25 x

What is Cardiopulmonary Exercise Testing (CPET)?

- Measurement of rate of oxygen uptake (VO2), rate of CO2 production (VCO2), minute ventilation and other ventilatory parameters while monitoring 12-lead ECG, BP and O2 saturation during **maximal "symptom-limited" exercise**
- Oxygen uptake is the best indicator of aerobic capacity

OXYGEN UPTAKE AND INCREMENTAL MUSCULAR WORK

Maximal O_2 Uptake

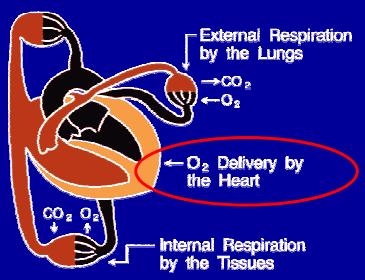


Determinants of Peak VO2: the Fick Equation

VO2 = HR x SV x (CaO2 – CvO2)

- Sinus node dysfunction
- Drugs
- Cardiomyopathies
- Valvular heart dz
- Conditioning
- Genetic factors
- PaO2
- Hemoglobin
- SaO2
- Skeletal muscle dysfunction
- Capillary density

THE GAS TRANSPORT SYSTEM



CLASSIFYING FITNESS

Maximal Oxygen Uptake (VO_2 -- ml/kg)

	MEN					WOMEN				
AGE	LOW	FAIR	AVG.	GOOD	HIGH	LOW	FAIR	AVG.	GOOD	HIGH
20-29	< 25	25-33	34-42	43-52	> 52	< 24	24-30	31-37	38-48	> 48
30-39	< 23	23-30	31-38	39-48	> 48	< 20	20-27	28-33	34-44	> 44
40-49	< 20	20-26	27-35	36-44	> 44	< 17	17-23	24-30	31-41	> 41
50-59	< 18	18-24	25-33	34-42	> 42	< 15	15-20	21-27	28-37	> 37
60-69	< 16	16-22	23-30	31-40	> 40	< 13	13-17	18-23	24-34	> 34

TABLE 1. INDICATIONS FOR CARDIOPULMONARY EXERCISE TESTING

Evaluation of exercise tolerance
- Determination of functional impairment or capacity (peak VO_2)
- Determination of exercise-limiting factors and pathophysiologic mechanisms

Evaluation of undiagnosed exercise intolerance
- Assessing contribution of cardiac and pulmonary etiology in coexisting disease
- Symptoms disproportionate to resting pulmonary and cardiac tests
- Unexplained dyspnea when initial cardiopulmonary testing is nondiagnostic

Evaluation of patients with cardiovascular disease
- Functional evaluation and prognosis in patients with heart failure
- Selection for cardiac transplantation
- Exercise prescription and monitoring response to exercise training for cardiac rehabilitation (special circumstances; i.e., pacemakers)

Evaluation of patients with respiratory disease
- Functional impairment assessment (see specific clinical applications)
- Chronic obstructive pulmonary disease
  - Establishing exercise limitation(s) and assessing other potential contributing factors, especially occult heart disease (ischemia)
  - Determination of magnitude of hypoxemia and for O_2 prescription
  - When objective determination of therapeutic intervention is necessary and not adequately addressed by standard pulmonary function testing
- Interstitial lung diseases
  - Detection of early (occult) gas exchange abnormalities
  - Overall assessment/monitoring of pulmonary gas exchange
  - Determination of magnitude of hypoxemia and for O_2 prescription
  - Determination of potential exercise-limiting factors
  - Documentation of therapeutic response to potentially toxic therapy
- Pulmonary vascular disease (careful risk–benefit analysis required)
- Cystic fibrosis
- Exercise-induced bronchospasm

Mechanisms of Exercise Limitation

- "Reserve": difference between predicted maximal values and measured values for a given variable
- **Heart rate reserve (HRR)** = predicted maximal HR - measured maximal HR
  - Normal: <15 bpm
- **Ventilatory reserve (VR)** = MVV – $V_E$max, or $V_E$max/MVV
  - Normal: >11L, or <75-85%

Heart Rate

- **Predicted HRmax = 220-age**
- Abnormal HR response may reflect disease of either the left or right heart
  - Affected by other factors, including **drugs**, anxiety, anemia
  - Resting HR: high -- suggests anxiety or disease, low -- suggests good conditioning or conduction problems

ECG

- CPET is also a stress test; done using a 12-lead ECG
- Observe for conduction problems, arrhythmias, ischaemia.
- Occasional PVCs and nonspecific ST-T changes not uncommon and usually of little clinical significance

Blood Pressure

- Normal resting BP usually < 140/90
- At maximum exercise, SBP can increase to about 200 and diastolic to within 10 of resting (i.e., pulse pressure normally increases)
- Higher values suggest hypertension or CV disease
- Sometimes difficult to measure with exercise due to motion artifact

Ventilatory Response to Exercise

- Normal resting V_E: 5-10 L/min
  - higher suggests anxiety, low suggests either equipment problems or is of no significance
  - increases with exercise up to 25x
  - up to AT this increase is linear with VO2
- MVV = ventilatory capacity = predicted maximum V_E = FEV1x 40
- Ventilatory reserve = (ventilatory capacity – V_{Emax})
- Patients with respiratory disease typically have reduced MVV and increased ventilatory demand, resulting in reduced ventilatory reserve (<15%).
- V_E v V_{CO2} or V_E v V_{O2} used to assess ventilatory response to metabolic needs

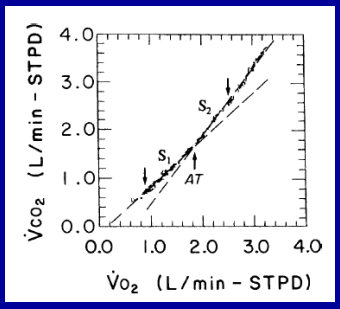
O2 Pulse

- **O2 pulse** = VO2/HR
  - ml O2 consumed per beat
  - taken to reflect stroke volume
    - assuming PaO2 and C(a-v)O2 respond normally
  - **O2 pulse < 80% predicted is abnormal**
    - cardiovascular disease
    - anemia (low O2 content), arterial hypoxemia, metabolic myopathies, deconditioning (affect a-v O2 difference)

Anaerobic Threshold

- Direct measurement requires measuring lactate levels in blood
  - requires frequent blood sampling; impractical
- Noninvasive assessment using gas exchange parameters
  - buffering of lactate by bicarbonate produces disproportionate increase in VCO2
  - **"V-slope method"**

Anaerobic Threshold: V-Slope Method



Am J Respir Crit Care Med · Vol 167. pp 211–277, 2003

Approach to Interpretation of CPET

- Is the exercise capacity normal?
  - peak VO2, max work rate
- Is the cardiovascular response normal?
  - HR vs VO2, O2 pulse, anaerobic threshold, VO2 vs work rate
- Is the ventilatory response normal?
  - V_E/MVV, max RR, PaCO2
- Is gas exchange normal?
  - V_E/VCO2, PaO2, P(A-a)O2, SpO2

Measurement	Heart Failure	COPD	Obesity	Deconditioned
$\dot{V}O_2$max or $\dot{V}O_2$peak	Decreased	Decreased	Decreased for actual, normal for ideal weight	Decreased
Anaerobic threshold	Decreased	Normal/decreased/ indeterminate	Normal	Normal or decreased
Peak HR	Variable, usually normal in mild	Decreased, normal in mild	Normal/slightly decreased	Normal/slightly decreased
O_2 pulse	Decreased	Normal or decreased	Normal	Decreased
$(V_E/MVV) \times 100$	Normal or decreased	Increased	Normal or increased	Normal
$V_E/\dot{V}CO_2$ (at AT)	Increased	Increased	Normal	Normal
V_D/V_T	Increased	Increased	Normal	Normal
Pa_{O_2}	Normal	Variable	Normal/may increase	Normal
$P(A-a)O_2$	Usually normal	Variable, usually increased	May decrease	Normal

TABLE 19. RESULTS OF MAXIMAL CARDIOPULMONARY EXERCISE TESTING FOR A HEALTHY PERSON

62-year-old male; white; height, 175 cm; weight, 84 kg; ideal weight, 78 kg
Clinical Dx: Exertional dyspnea
Medications: None
Reason for testing: Shortness of breath on exertion

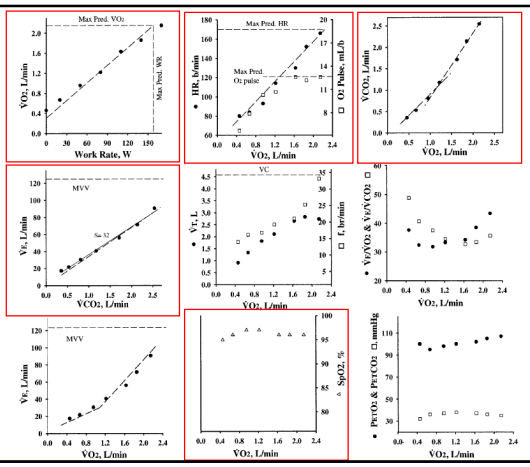
Resting Pulmonary Function Tests

Variable	Actual	% Pred	Variable	Actual	% Pred
FVC, L	4.50	99	TLC, L	6.52	103
FEV_1, L	3.10	88	RV, L	2.54	109
FEV_1/FVC, %	69		D_{LCO}, ml/min per mm Hg	26.3	91
MVV, L/min	124				

Cardiopulmonary Exercise Test

Protocol: Maximal, symptom limited, incremental cycle ergometry, 30 W/min
P_B, 722 mm Hg; P_{IO_2}, 142 mm Hg

Variable	Peak	% Pred	Variable	Rest	Peak
Work rate, W	170	109	Sa_{O_2}, %		
$\dot{V}O_2$, L/min	2.1	98	Sp_{O_2}, %	95	96
$\dot{V}O_2$, ml/kg per min	25.6	91	Pa_{O_2}, mm Hg		
AT, L/min	1.05	N (> 0.86)	Pa_{CO_2}, mm Hg		
$\Delta\dot{V}O_2/\Delta$WR, ml/min/W	10.3	N (> 8.6)	pH		
HR, beats/min	166	98	HCO_3^-, mEq/L		
O_2 pulse, ml/beat	12.6	100	$P(A-a)O_2$, mm Hg		
BP, mm Hg	176/90		V_D/V_T		
$\dot{V}_E$, L/min	90.7	73	Lactate, mEq/L		
f_R, breaths/min	33	N			
$V_E/\dot{V}CO_2$, at AT	34	N			



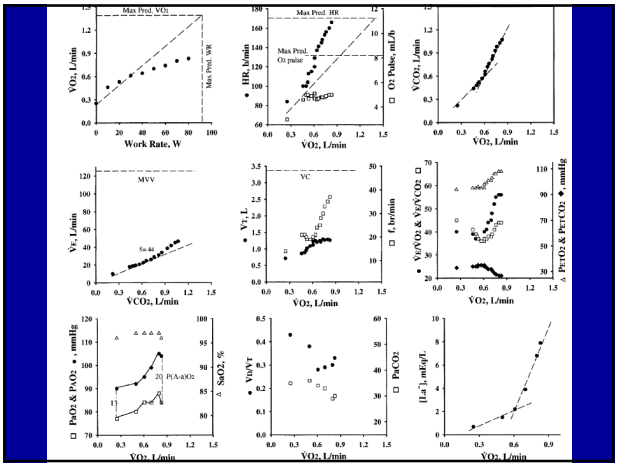
Resting Pulmonary Function Tests

Variable	Actual	% Pred	Variable	Actual	% Pred
FVC, L	3.44	96	TLC, L	5.08	100
FEV_1, L	2.39	85	RV, L	1.61	102
FEV_1/FVC, %	70		D_{LCO}, ml/min per mm Hg	10.5	46
MVV, L/min	129	128			

Cardiopulmonary Exercise Test

Protocol: Maximal, symptom limited, incremental cycle ergometry, 20 W/min
P_B, 656 mm Hg; P_{IO_2}, 128 mm Hg

Variable	Peak	% Pred	Variable	Rest	Peak
Work rate, W	80	88	Sa_{O_2}, %	96	95
$\dot{V}O_2$, L/min	0.83	60	Sp_{O_2}, %	95	85
$\dot{V}O_2$, ml/kg per min	15.8	60	Pa_{O_2}, mm Hg	77	84
AT, L/min	0.60	L (> 0.76)	Pa_{CO_2}, mm Hg	35	30
$\Delta\dot{V}O_2/\Delta$WR, ml/min/W	5.1	L (> 8.6)	pH	7.451	7.346
HR, beats/min	166	94	HCO_3^-, mEq/L	24	17
O_2 pulse, ml/beat	5.0	64	$P(A-a)O_2$, mm Hg	13	20
BP, mm Hg	174/87		V_D/V_T	0.43	0.33
$\dot{V}_E$, L/min	47	36	Lactate, mEq/L	0.7	7.9
f_R, breaths/min	37	N			
$V_E/\dot{V}CO_2$, at AT	37	H			
RER	1.28		**Stop:** Dyspnea, 3/10; leg fatigue, 4–5/10		



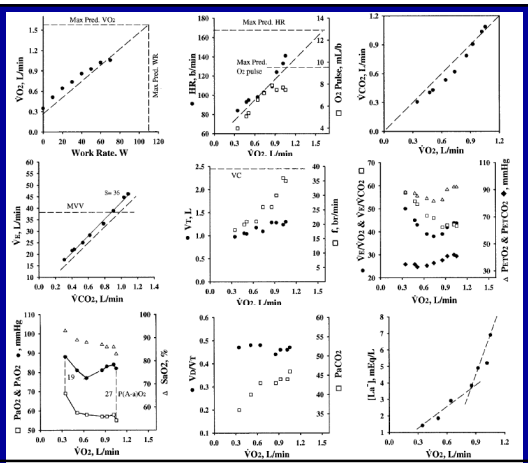
Resting Pulmonary Function Tests

Variable	Actual	% Pred	Variable	Actual	% Pred
FVC, L	2.44	55	TLC, L	9.45	139
FEV_1, L	0.88	25	RV, L	7.01	303
FEV_1/FVC, %	36		D_{LCO}, ml/min per mm Hg	16.5	51
MVV, L/min	38				

Cardiopulmonary Exercise Test

Protocol: Maximal, symptom limited, incremental cycle ergometry, 10 W/min
P_B, 656 mm Hg, P_{IO_2}, 128 mm Hg

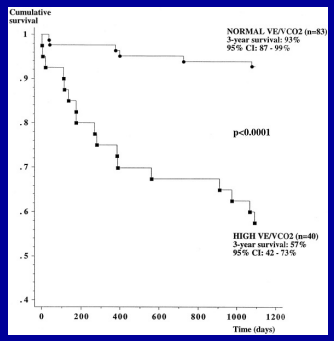
Variable	Peak	% Pred	Variable	Rest	Peak
Work rate, W	70	65	Sa_{O_2}, %	92	83
$\dot{V}O_2$, L/min	1.06	66	Sp_{O_2}, %	90	85
$\dot{V}O_2$, ml/kg per min	17.4	66	Pa_{O_2}, mm Hg	65	55
AT, L/min	0.75	N (> 0.64)	Pa_{CO_2}, mm Hg	38	46
$\Delta\dot{V}O_2/\Delta$WR, ml/min/W	9.3	N (> 8.6)	pH	7.413	7.279
HR, beats/min	141	84	HCO_3^-, mEq/L	24	21
O_2 pulse, ml/beat	7.5	79	$P(A-a)O_2$, mm Hg	20	27
BP, mm Hg	166/72		V_D/V_T	0.45	0.42
$\dot{V}_E$, L/min	46	121	Lactate, mEq/L	1.4	6.9
f_R, breaths/min	36	N			
$V_E/\dot{V}CO_2$, at AT	44	H			
RER	1.03		**Stop:** Dyspnea, 10/10		



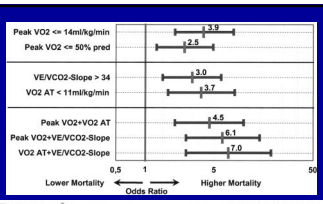
Functional Classification of Patients with Congestive Heart Failure†

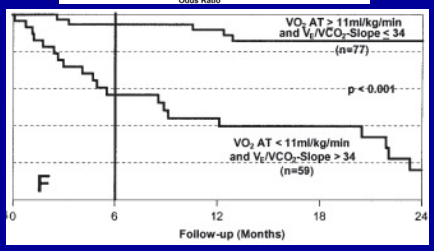
Class	Severity	VO2max, mL/kg/min	Anaerobic threshold, mL/kg/min	Maximal cardiac index, L/min/m2
A	None to mild	>20	>14	>8
B	Mild to moderate	16-20	11-14	6-8
C	Moderate to severe	10-15	8-11	4-6
D	Severe	6-9	5-8	2-4
E	Very severe	<6	3-4	<2

†Data from Weber, KT, Janicki, JS. CardioPulmonary Exercise Testing. Physiologic Principles and Clinical Applications. WB Saunders, Philadelphia, 1986.



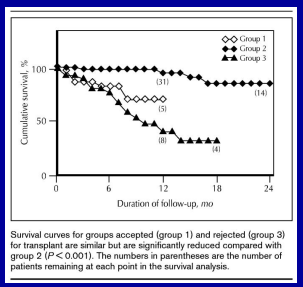
Ponikowski P et al. Circulation 2001;103:967-972





Circulation. 2002;106:3079-3084

Cardiac Transplant Evaluation



Survival curves for groups accepted (group 1) and rejected (group 3) for transplant are similar but are significantly reduced compared with group 2 ($P < 0.001$). The numbers in parentheses are the number of patients remaining at each point in the survival analysis.

Group 1: Peak VO2 < 14 ml/kg/min, transplanted

Group 2: Peak VO2 > 14 ml/kg/min, transplant deferred

Group 3: Peak VO2 < 14 ml/kg/min, not transplant candidates

Mancini et al, Circulation 1991; 83:778