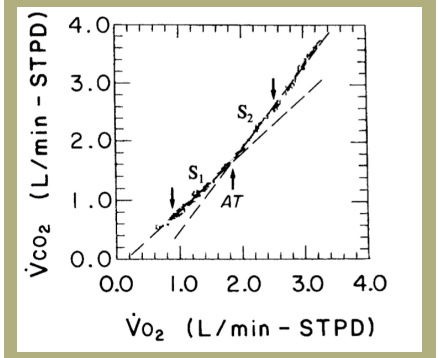

Καρδιοαναπνευστική Δοκιμασία Άσκησης

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Εργοσπιρομετρία

=

Καρδιοαναπνευστική
Δοκιμασία (Μέγιστης) Άσκησης

=

Cardiopulmonary
Exercise Testing
(CPET)

Περίγραμμα παρουσίασης

- Η φυσιολογία της άσκησης επιγραμματικά
- Τι είναι, τι μελετά και σε ποιες ερωτήσεις απαντά η εργοσπιρομετρία?
- Κλινικές εφαρμογές της εργοσπιρομετρίας .
- Μεθοδολογία της εργοσπιρομέτρίας.
- Ερμηνεία εργοσπιρομετρίας
- Παραδείγματα εργοσπιρομετρίας

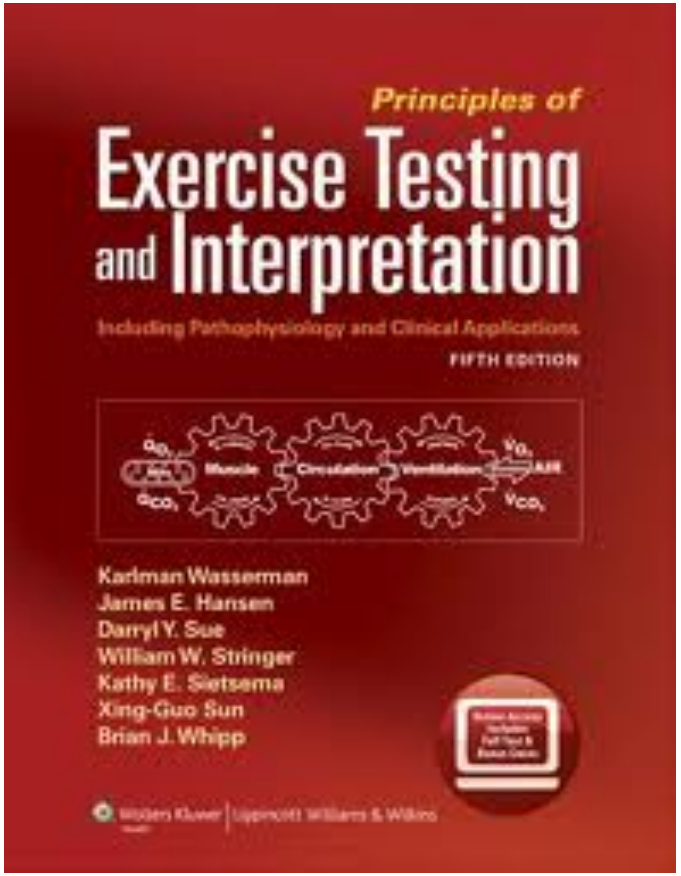
Βιβλιογραφία

American Thoracic Society/
American College of Chest Physicians

ATS/ACCP Statement on Cardiopulmonary Exercise Testing

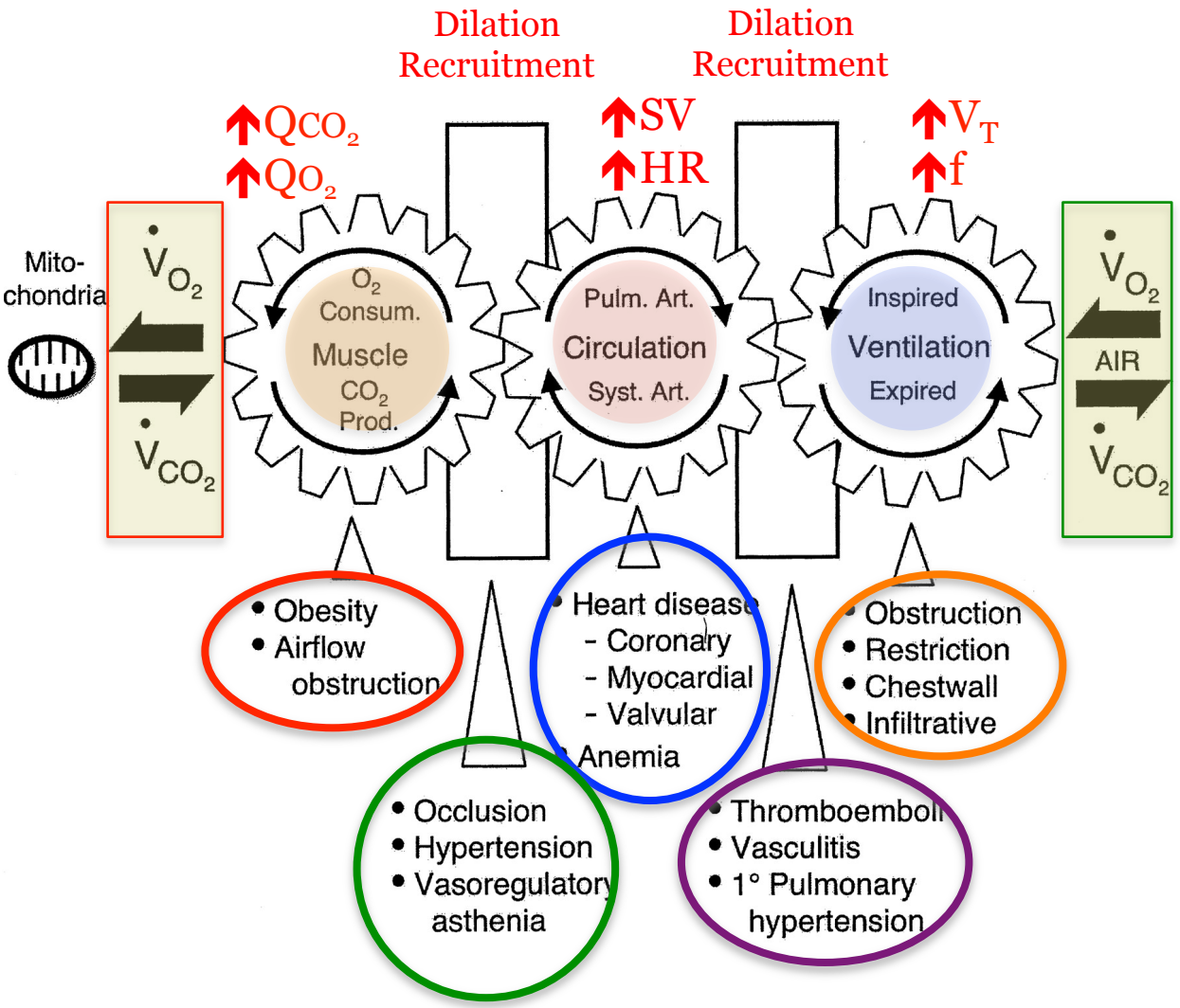
This Joint Statement of the American Thoracic Society (ATS) and the American College of Chest Physicians (ACCP) was adopted by the ATS Board of Directors, March 1, 2002 and by the ACCP Health Science Policy Committee, November 1, 2001

Karlman Wasserman



Η Φυσιολογία της Άσκησης

Η Φυσιολογία της Άσκησης

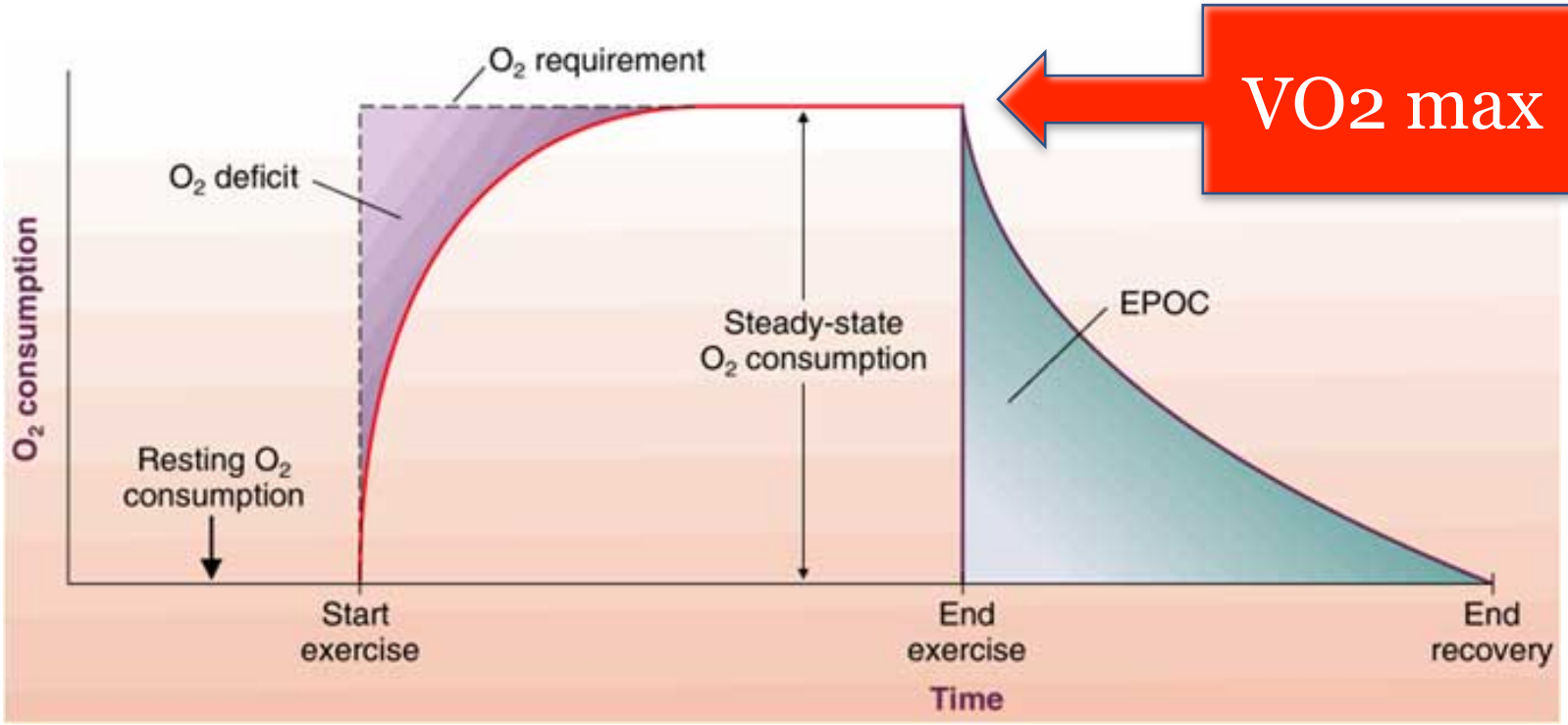


Στόμα/μύτη

Oxygen Uptake (VO2)

The amount of O2 in liters that the body consumes per minute

Represents the internal metabolic work and is directly proportional to the external work rate (in watts) applied through the cycle ergometer or treadmill.



$$\dot{V}O_2 = SV \times HR \times (1.34) \times Hgb \times (S_aO_2 - S_{\bar{v}}O_2)$$

Maximal O2 uptake (VO2 max)

$$\dot{V}O_2 = SV \times HR \times (1.34) \times Hgb \times (S_aO_2 - S_{\bar{v}}O_2)$$

- VO2max is the maximal volume of O2 that can be consumed during maximal aerobic exercise.
- VO2max is considered the best index of the maximum aerobic capacity of the large muscle groups(maximum exercise capacity) and the gold standard for cardiorespiratory fitness.
- In clinical testing situations, a clear plateau may not be achieved before symptom limitation of exercise. Consequently, VO2peak is often used as an estimate for VO2max.
- The main determinants of the predicted Vo2max are genetic factors and quantity of exercising muscle. VO2max is also dependent on age, sex, and body size, and it can be affected by training.
- Vo2 can increase from a resting value of about 3.5 ml/min/Kg (about 250 ml/minute in an average individual) to values about 15 times the resting value (30–50 ml/min/Kg). Athletes may attain values over 20 times their resting values (up to 80 ml/min/Kg).

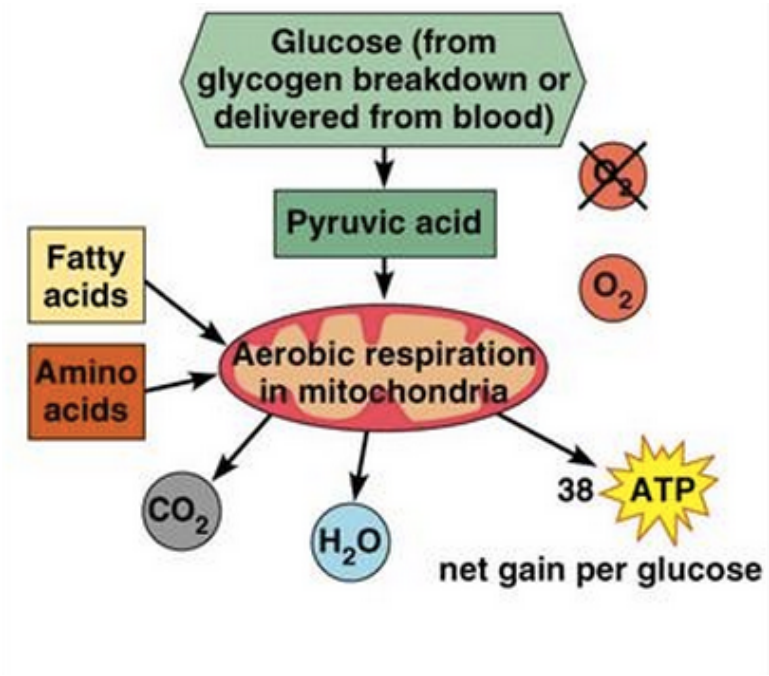
Η φυσιολογία της άσκησης

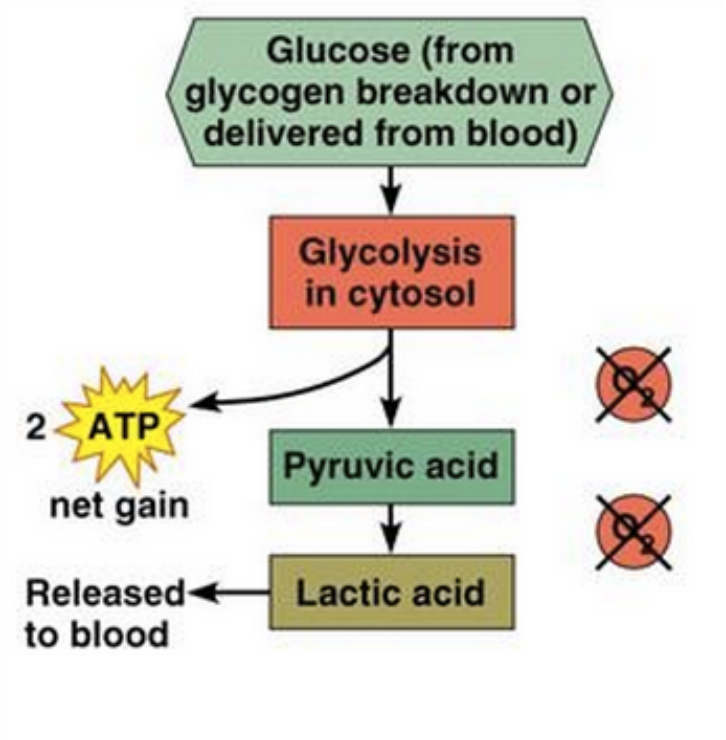
Aerobic Metabolism

Energy source: Glucose, Pyruvic Acid, Free Fatty Acids.
Oxygen Use: Required
Products: 38 ATP per Glucose, CO2, H2O
Duration of energy provision: Hours

Anaerobic Metabolism

Energy source: Glucose
Oxygen Use: None
Products: 2 ATP per Glucose, Lactic acid
Duration of energy provision: 30-60 sec





Η φυσιολογία της άσκησης

Αναερόβιο κατώφλι

- Anaerobic threshold (AT)
- Lactate threshold
- Lactic acid threshold
- Gas exchange threshold
- Ventilatory threshold

- AT is considered an estimator of the onset of metabolic acidosis caused predominantly by the increased rate of rise of arterial lactate during exercise.
- AT demarcates the upper limit of a range of exercise intensities that can be accomplished almost entirely aerobically.
- AT is determined predominately by the CV system.
- Whereas work rates below the AT can be sustained essentially indefinitely, a progressive increase in work rate above AT is associated with a progressive decrease in exercise tolerance.
- AT is helpful as an indicator of level of fitness, for exercise prescription, and to monitor the effect of physical training.
- AT determination is age, modality & protocol specific.

Respiratory Exchange Ratio (RER)

- The amount of CO_2 the body produces for each liter (mole) of O_2 it consumes as measured by the exhale air at the mouth: the ratio of VCO_2/VO_2
- Conventionally, RER > 1.15 is considered to define maximal effort.
- Under steady state conditions, the RER equals the Respiratory Quotient, whose value is determined by the fuels used for metabolic processes.
- *Note:* RER greater than 1.0 could also be caused by CO_2 derived from lactic acid or by hyperventilation.

TABLE 4.1 Percentage of Fat and Carbohydrate Metabolized as Determined by a Nonprotein Respiratory Exchange Ratio (R)

R	% Fat	% Carbohydrate
0.70	100	0
0.75	83	17
0.80	67	33
0.85	50	50
0.90	33	67
0.95	17	83
1.00	0	100

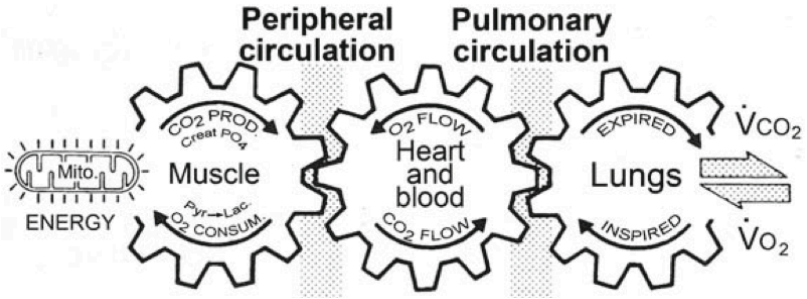
- RER should not exceed 1.3 at peak exercise. If so, it indicates a gas-exchange abnormality.

Εργοσπιρομετρία

Καρδιοαναπνευστική Δοκιμασία Άσκησης

Cardiopulmonary Exercise Testing (CPET)

Εργοσπιρομετρία: Τι μελετά?



- Δυνατότητα ταυτόχρονης μελέτης της απόδοσης των τριών κύριων συστημάτων που ευοδώνουν την άσκηση:

Καρδιοαγγειακό – Αναπνευστικό – Μυικό

μέσα από καταγραφή βιολογικών και υποκειμενικών παραγόντων κατά τη σωματικής διάρκεια άσκησης ελεγχόμενου και αυξανόμενου βαθμού δυσκολίας.

Εργοσπιρομετρία:
Βασικές ερωτήσεις που απαντά.

1. Είναι η ικανότητα για (αερόβια) άσκηση μειωμένη;
2. Περιορίζεται η ικανότητα άσκησης από αναπνευστικούς παράγοντες (μηχανική αναπνοής/ανταλλαγή αερίων);
3. Περιορίζεται η ικανότητα άσκησης από την μειωμένη παροχή οξυγόνου στην περιφέρεια;
4. Περιορίζεται η ικανότητα άσκησης στο επίπεδο μεταβολισμού των μυών;
5. Η ικανότητα άσκησης είναι μειωμένη λόγω κακής φυσικής κατάστασης (deconditioning) ή μειωμένης προσπάθειας;
6. Υπάρχει πρόωρη γαλακτική οξέωση?

Εργοσπιρομετρία: Ενδείξεις 1/2

Evaluation of exercise tolerance
- Determination of functional impairment or capacity (peak $\dot{V}O_2$)
- 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

Εργοσπιρομετρία: Ενδείξεις 2/2

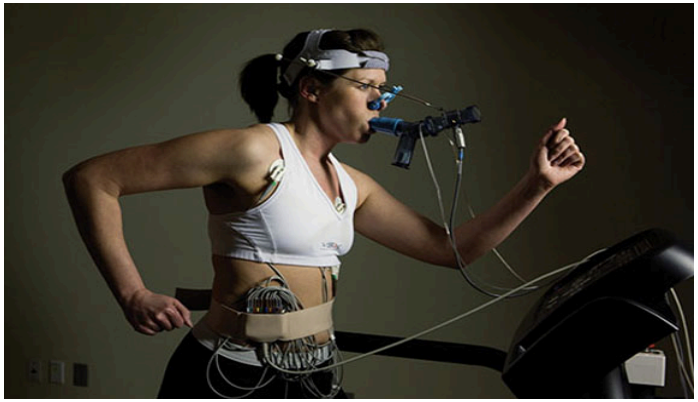
Specific clinical applications

- Preoperative evaluation
  - Lung resectional surgery
  - Elderly patients undergoing major abdominal surgery
  - Lung volume resectional surgery for emphysema (currently investigational)
- Exercise evaluation and prescription for pulmonary rehabilitation
- Evaluation for impairment–disability
- Evaluation for lung, heart–lung transplantation

Εργοσπιρομετρία: Αντενδείξεις

Απόλυτες	Σχετικές
Acute myocardial infarction (3–5 days)	Left main coronary stenosis or its equivalent
Unstable angina	Moderate stenotic valvular heart disease
Uncontrolled arrhythmias causing symptoms or hemodynamic compromise	Severe untreated arterial hypertension at rest (> 200 mm Hg systolic, > 120 mm Hg diastolic)
Syncope	Tachyarrhythmias or bradyarrhythmias
Active endocarditis	High-degree atrioventricular block
Acute myocarditis or pericarditis	Hypertrophic cardiomyopathy
Symptomatic severe aortic stenosis	Significant pulmonary hypertension
Uncontrolled heart failure	Advanced or complicated pregnancy
Acute pulmonary embolus or pulmonary infarction	Electrolyte abnormalities
Thrombosis of lower extremities	Orthopedic impairment that compromises exercise performance
Suspected dissecting aneurysm	
Uncontrolled asthma	
Pulmonary edema	
Room air desaturation at rest ⩽ 85%*	
Respiratory failure	
Acute noncardiopulmonary disorder that may affect exercise performance or be aggravated by exercise (i.e. infection, renal failure, thyrotoxicosis)	
Mental impairment leading to inability to cooperate	

Εργοσπιρομετρία: Μεθοδολογία:
Κυλιόμενος Τάπητας ή Κυκλοεργόμετρο



Εργοσπιρομετρία:
Μεθοδολογία

TABLE 2. EXERCISE EQUIPMENT: CYCLE ERGOMETRY VERSUS TREADMILL

	Cycle	Treadmill
$\dot{V}O_2$max	lower	higher
Work rate measurement	yes	no
Blood gas collection	easier	more difficult
Noise and artifacts	less	more
Safety	safer	less safe?
Weight bearing in obese	less	more
Degree of leg muscle training	less	more
More appropriate for:	patients	active normal subjects

Definition of abbreviation: $\dot{V}O_2$ max = maximal oxygen uptake.

Εργοσπιρομετρία:
Μετρήσεις παραμέτρων

Κυλιόμενος Τάπητας ή Κυκλοεργόμετρο

1. Έργο άσκησης σε Watt

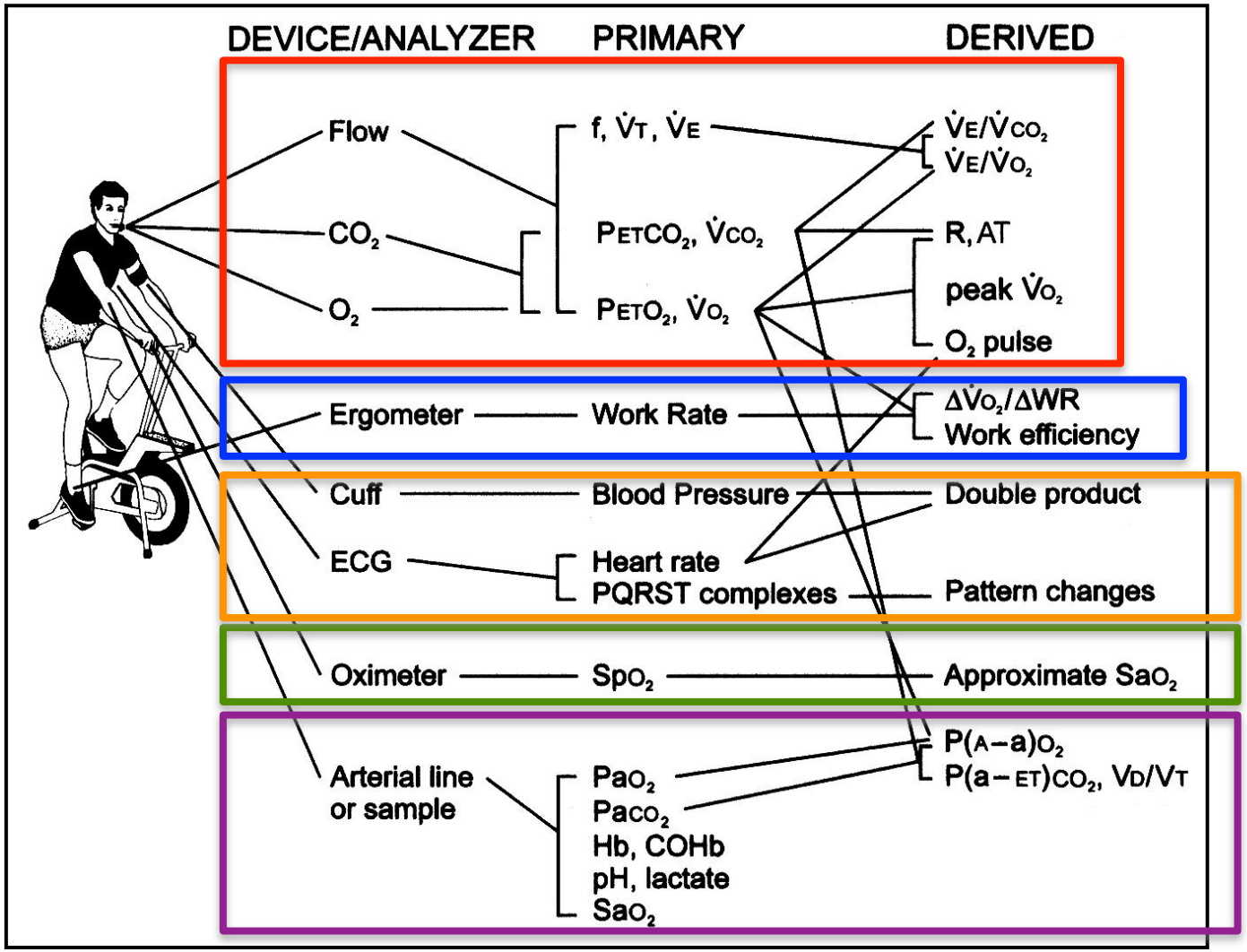
Αναπνευστικό Monitoring

1. Αναλυτής αερίων
   - εκπνεόμενο και εισπνεόμενο O_2 και CO_2.
2. Οξύμετρο
   - SpO_2
3. Αρτηριακή γραμμή
   - SaO_2, PaO_2, $PaCO_2$, pH, HCO_3^-, $P(A–a)O_2$,Hb, γαλακτικό.
4. Κλίμακα Borg
   - δύσπνοια
5. Σπιρόμετρο
   - V_E, V_T, fr, καμπύλη ροής-όγκου, εισπνευστική χωρητικότητα, δυναμική υπερδιάταση.

Καρδιαγγειακό Monitoring

1. ΗΚΓ
2. Αρτηριακή πίεση
3. Καρδιακή συχνότητα

Εργοσπιρομετρία:
Μεθοδολογία



Εργοσπιρομετρία:
Μεθοδολογία

Clinical Status Evaluation

Clinical diagnosis and reason(s) for CPET
Health questionnaire (cardiopulmonary); physical activity profile
Medical and occupational history and physical examination
PFTs, CXR, ECG, and other appropriate laboratory tests
Determination of indications and contraindications for CPET

↓

Pretest Procedures

Abstain from smoking for at least 8 h before the test
Refrain from exercise on the day of the test
Medications as instructed
Consent form

↓

Conduct of CPET

Laboratory procedures
  Quality control
  Equipment calibration
Protocol Selection
  Incremental versus constant work rate; invasive versus noninvasive
Patient preparation
  Familiarization
  12-lead ECG, pulse oximetry, blood pressure
  Arterial line (if warranted)
Cardiopulmonary exercise testing

↓

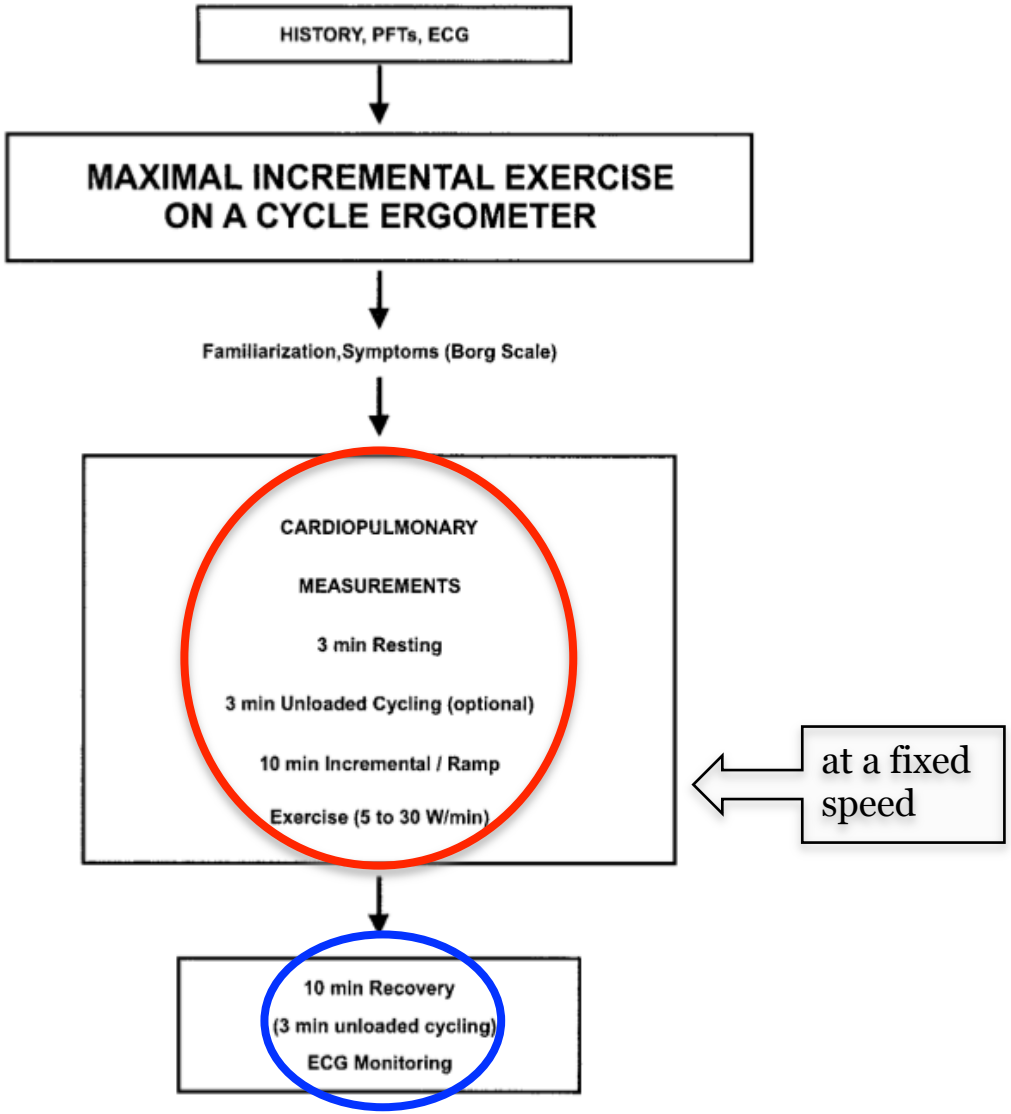
Interpretation of CPET Results

Data processing
Quality and consistency of results
Comparison of results with appropriate reference values
Integrative approach to interpretation of CPET results
Preparation of CPET report

Εργοσπιρομετρία:
Μεθοδολογία

1. Maximal incremental cycle ergometry protocols
   - 5 to 25 W/min. increments
     - Incremental (progressive)
     - Ramp (continuous)
   - Duration: 8-12 min
2. Maximal incremental treadmill protocols.
   - Manipulation of speed and/or elevation, eg., constant speed at 3.3 mph and increasing elevation by 1% per min.
     - Incremental (progressive)
     - Ramp (continuous)
3. Constant work rate protocol.
   - The same work rate (approximating the subject's usual daily activities) e.g., up to 3.0 mph on a treadmill, or up to 50 W on a cycle ergometer
   - Duration: 5-30 mins.

Maximal symptom-limited cardiopulmonary incremental cycle ergometry protocol



Εργοσπιρομετρία:

Κριτήρια μέγιστης προσπάθειας

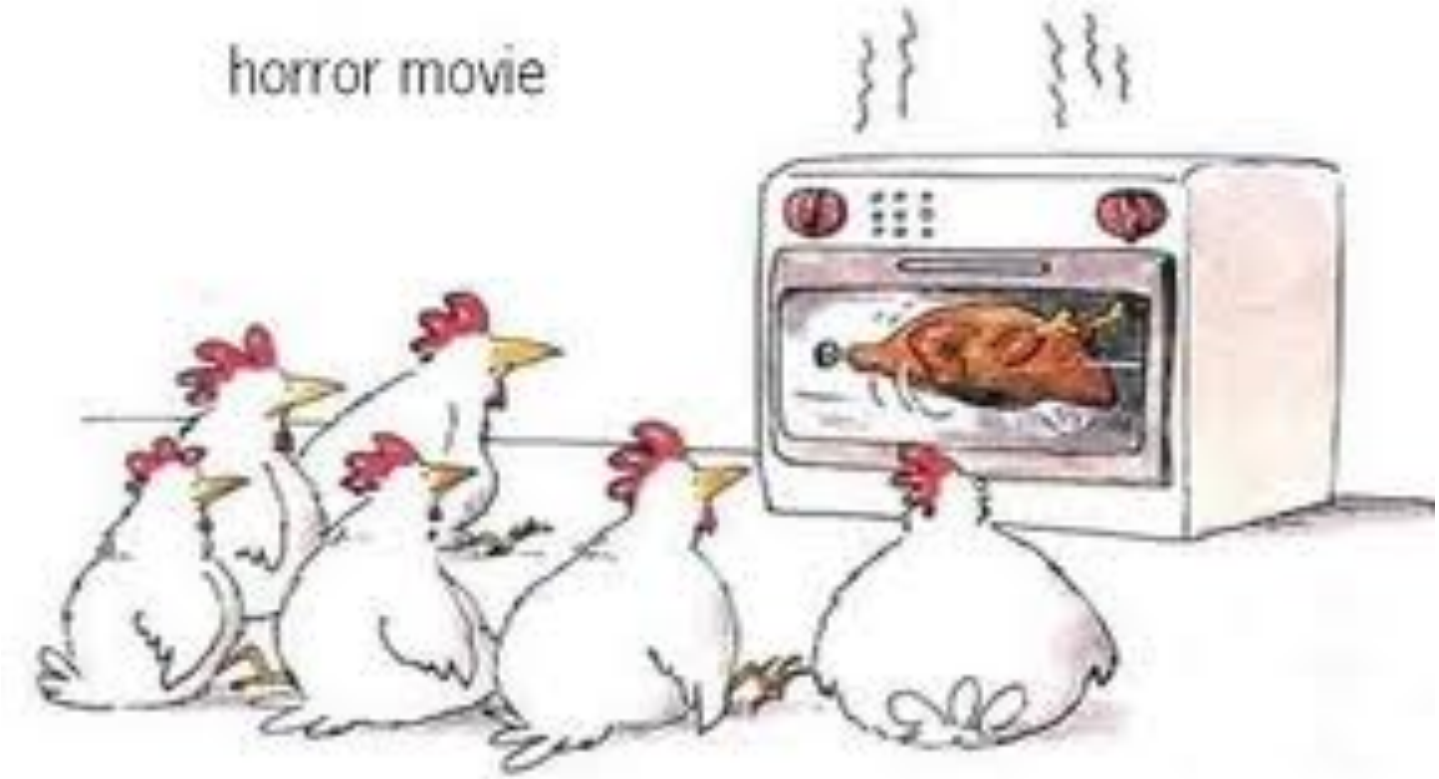
1. The patient achieves predicted peak oxygen uptake and/or a plateau is observed.
2. Predicted maximal work rate is achieved.
3. Predicted maximal heart rate is achieved (HR_{max}= 220 - age).
4. There is evidence of ventilatory limitation, that is, peak exercise ventilation approaches or exceeds maximal ventilatory capacity.
5. Although no one RER value defines maximal effort, values greater than 1.15 are more likely to be associated with near maximal or maximal effort.
6. Patient exhaustion/Borg Scale rating of 9–10 on a 0-to-10 scale.

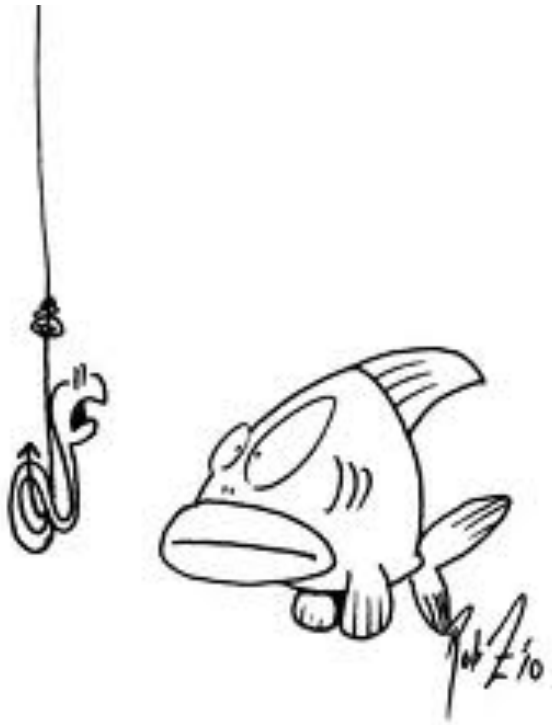
Η κλίμακα Borg

0–10 Borg Rating of Perceived Exertion Scale	
0	Rest
1	Really easy
2	Easy
3	Moderate
4	Sort of hard
5	Hard
6	
7	Really hard
8	
9	Really, really, hard
10	Maximal: just like my hardest race

Εργοσπιρομετρία:
Ενδείξεις Άμεσου Τερματισμού

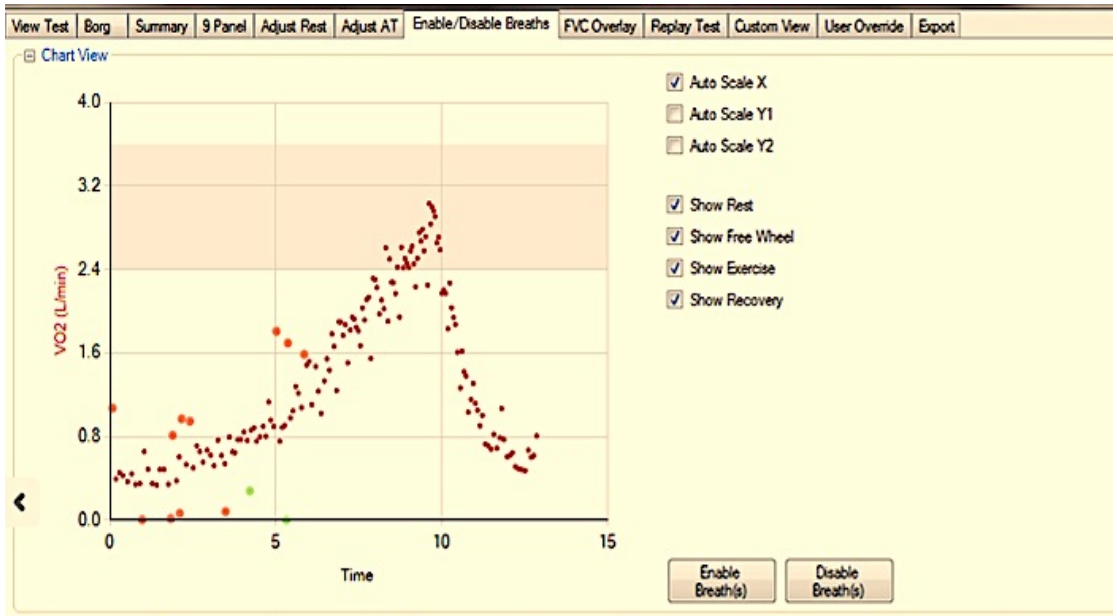
Chest pain suggestive of ischemia
Ischemic ECG changes
Complex ectopy
Second or third degree heart block
Fall in systolic pressure > 20 mm Hg from the highest value during the test
Hypertension (> 250 mm Hg systolic; > 120 mm Hg diastolic)
Severe desaturation: Sp_{O_2} ⩽ 80% when accompanied by symptoms and signs of severe hypoxemia
Sudden pallor
Loss of coordination
Mental confusion
Dizziness or faintness
Signs of respiratory failure


horror movie



"Turn back! It's a trap!"

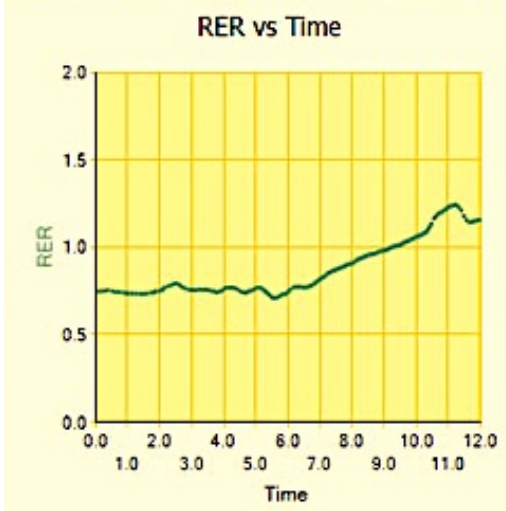
Εργοσπιρομετρία: Τα δεδομένα



Time	VO2	VCO2	RER	Ve	Vt	ETO2	ETCO2	HR
0:03	1.08	0.79	0.73	27.6	1.593	14.72	5.06	62
0:10	0.40	0.30	0.76	10.8	1.145	14.93	5.00	61
0:16	0.46	0.34	0.75	11.6	1.278	14.63	5.21	60
0:22	0.43	0.32	0.75	10.9	1.068	14.72	5.14	60
0:31	0.37	0.28	0.75	9.0	1.313	14.54	5.20	60
0:38	0.44	0.33	0.75	10.7	1.302	14.44	5.24	59
0:45	0.34	0.25	0.74	8.8	1.004	14.63	5.13	58
0:53	0.35	0.26	0.74	8.6	1.147	14.38	5.22	58
0:57	0.01	0.00	0.47	0.5	0.034	18.88	1.47	57
1:01	0.66	0.48	0.73	15.3	0.956	14.35	5.22	59
1:08	0.49	0.36	0.74	11.7	1.368	14.59	5.16	60

Εργοσπιρομετρία: Τα δεδομένα

View Test | Borg | Summary | 9 Panel | Adjust Rest | Adjust AT | Enable/Disable Breaths | FVC Overlay | Replay Test | Custom View | User Override | Export



Computer Interpretation

Moderate obesity may contribute to decreased exercise capacity. Aerobic capacity is normal. Anaerobic (ventilatory) threshold suggests normal cardiovascular conditioning. The 41 bpm reduction in heart rate at 2 minutes post-exercise indicates normal heart rate recovery. Normal breathing reserve indicates chest bellows capacity is not limiting. No significant oxygen desaturation is noted during exercise.

Spirometry

Parameter	Units	Predicted	Measured	% Predicted
FVC	(L)	5.55	7.76	140
FEV1	(L)	4.25	5.07	119
MVV	(L)	148.8	196.2	132

Resting Data

HR (bpm)	60	SpO2	99.0	Sys BP	122	Dia BP	93

Peak Cardiovascular Responses

Parameter	Units	Predicted	Measured	% Predicted
VO2 / kg	(ml/kg/min)	33.6	29.7	88
VO2	(L/min)	3.00	2.98	99
VCO2	(L/min)	---	3.08	---
Work	(Watts)	250	202	81
Anaerobic Threshold	(L/min)	> 0.924%	2.03	---
AT (% Pred Max VO2)	(L/min)	> 1%		---
Heart Rate	(bpm)	163	114	70
O2 Pulse	(ml/beat)	21.0	26.0	124
Systolic BP (Max)	(ml/beat)	120 - 210		---
Diastolic BP (Max)	(ml/beat)	70 - 100		---
Heart Rate Reserve	(bpm)	< 15	50	---
Heart Rate Recovery	(bpm)	> 24	41	---

Peak Ventilatory Responses

Parameter	Units	Predicted	Measured	% Predicted
VE (Max)	(L/min BTPS)	104.2	92.1	88
Tidal Volume	(L)	---	3.969	---
Respiratory Rate	(Breaths/min)	< 50	23	---
Breathing Reserve	(%)	20 - 40	110	---

Gas Exchange Responses

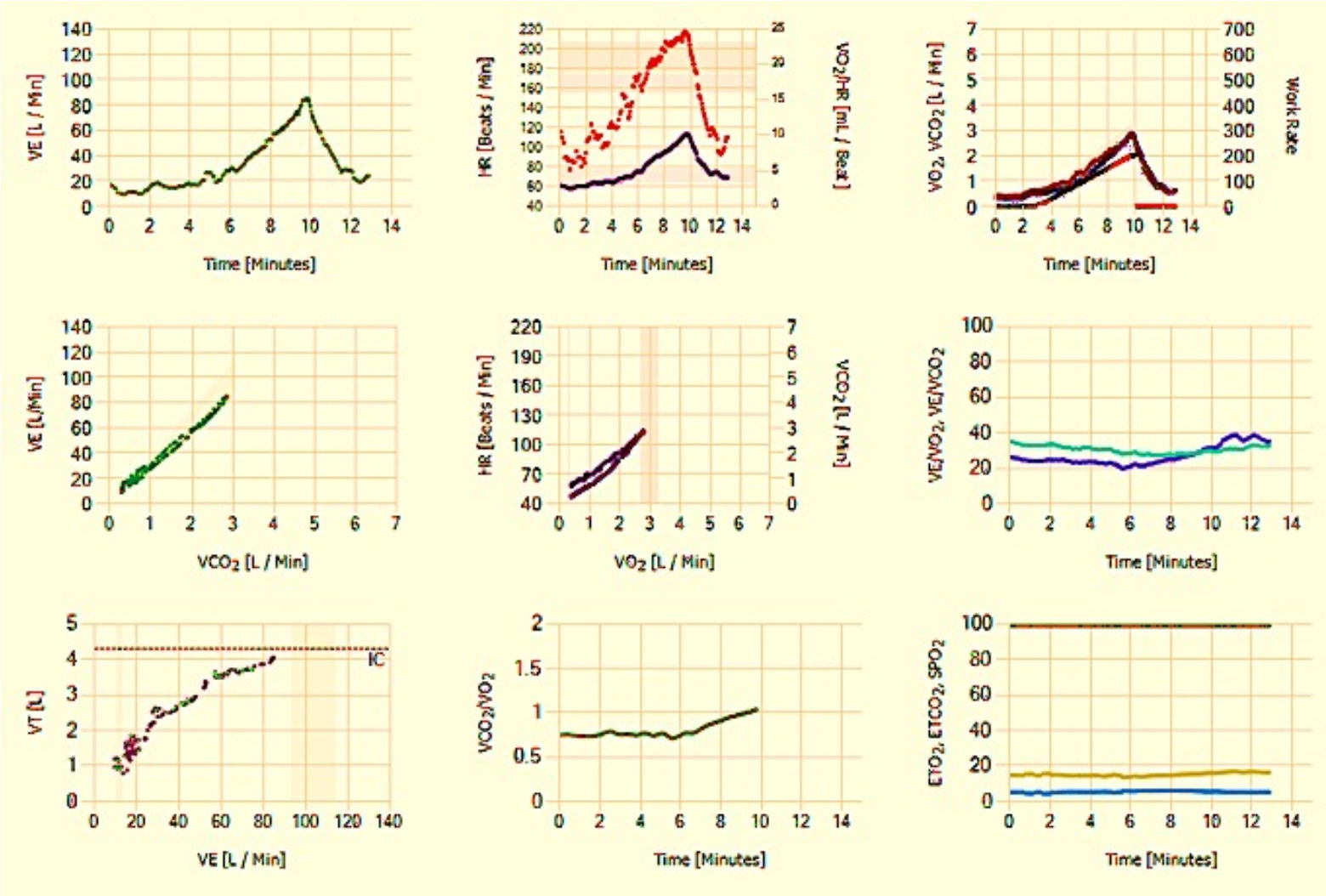
Εργοσπιρομετρία:

Συσχετίσεις μεταξύ παραγόντων

TABLE 11. SUGGESTED GRAPHIC INTERRELATIONSHIPS OF KEY CARDIOPULMONARY VARIABLES DURING EXERCISE

Ordinate (*y axis*)	Abscissa (*x axis*)
$\dot{V}O_2$	Work rate
$\dot{V}E$	$\dot{V}CO_2$ or $\dot{V}O_2$
V_T and f_R	$\dot{V}O_2$
HR and O_2 pulse	$\dot{V}O_2$
$\dot{V}CO_2$	$\dot{V}O_2$
$\dot{V}E/\dot{V}O_2$ and $\dot{V}E/\dot{V}CO_2$	$\dot{V}O_2$
$P_{ET_{O_2}}$ and $P_{ET_{CO_2}}$	$\dot{V}O_2$
Pa_{O_2}, $P(A–a)O_2$, and Sa_{O_2}	$\dot{V}O_2$
Pa_{CO_2} and V_D/V_T	$\dot{V}O_2$
$[La^-]$ or HCO_3^-	$\dot{V}O_2$

Συσχετίσεις μεταξύ παραγόντων: Οι 9 καμπύλες του Wasserman



Η Εργοσπιρομετρία ΔΕΝ είναι Καρδιολογική Δοκιμασία Κόπωσης, είναι πολλά περισσότερα..

Δοκιμασία Καρδιοαναπνευστικής Άσκησης

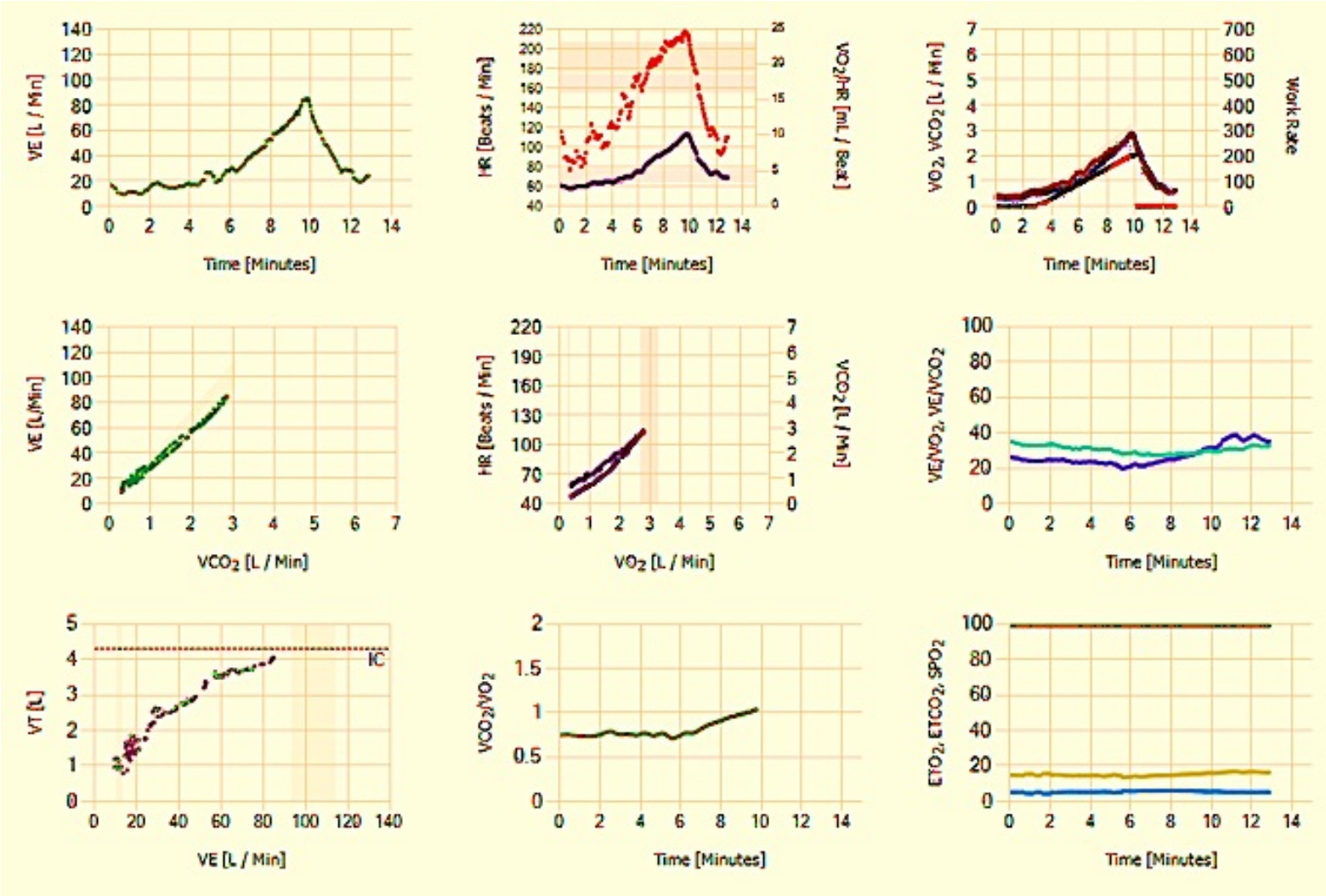
- Μελετά την Αναπνευστική, Καρδιαγγειακή και Μυική απάντηση στην άσκηση.
- Καταγραφή πολλαπλών βιοφυσιολογικών παραγόντων.
- Απαντά σε πληθώρα ερωτημάτων σχετικά με την ικανότητα για άσκηση.

Καρδιολογική Δοκιμασία Κόπωσης

- Μελετά την Καρδιαγγειακή απάντηση στην άσκηση
- Καταγραφή αρτηριακής πίεσης, καρδιακής συνχότητας, ΗΚΓ
- Διαγνωστικό μέσο για στεφανιαία νόσο, αρρυθμίες και άλλες παθήσεις του καρδιαγγειακού.
- ΔΕΝ μελετά την ικανότητα μέγιστης άσκησης

Εργοσπιρομετρία: Ερμηνεία

Εργοσπιρομετρία:
Ερμηνεία



Εργοσπιρομετρία:
Ερμηνεία

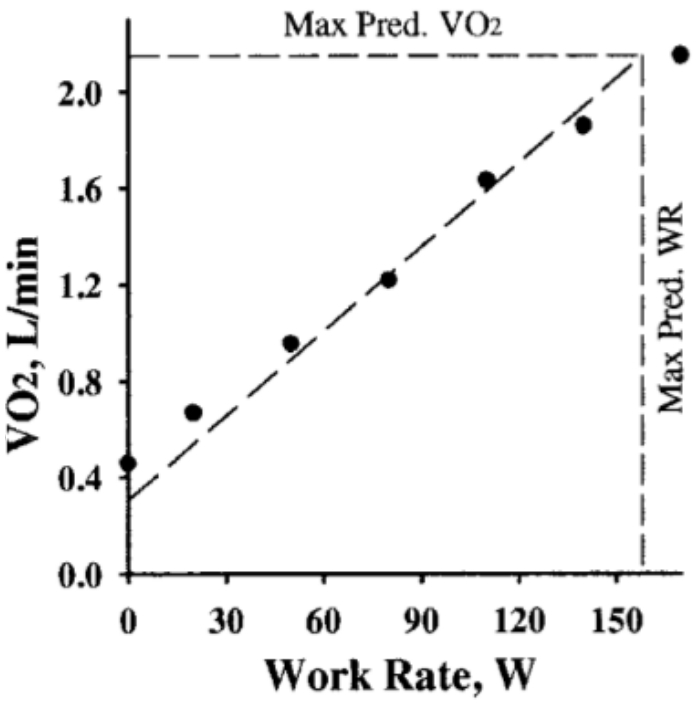
TABLE 16. INTEGRATIVE APPROACH TO THE INTERPRETATION OF CARDIOPULMONARY EXERCISE TESTING RESULTS

1. Determine reason(s) for CPET
2. Review pertinent clinical and laboratory information (clinical status)
3. Note overall quality of test, assessment of subject effort, and reasons for exercise cessation
4. Identify key variables: initially $\dot{V}O_2$, and then HR, $\dot{V}E$, Sa_{O_2}, and other measurements subsequently
5. Use tabular and graphic presentation of the data
6. Pay attention to trending phenomena: submaximal through maximal responses
7. Compare exercise responses with appropriate reference values
8. Evaluate exercise limitation: physiologic versus nonphysiologic
9. Establish patterns of exercise responses
10. Consider what conditions/clinical entities may be associated with these patterns
11. Correlate CPET results with clinical status
12. Generate CPET report

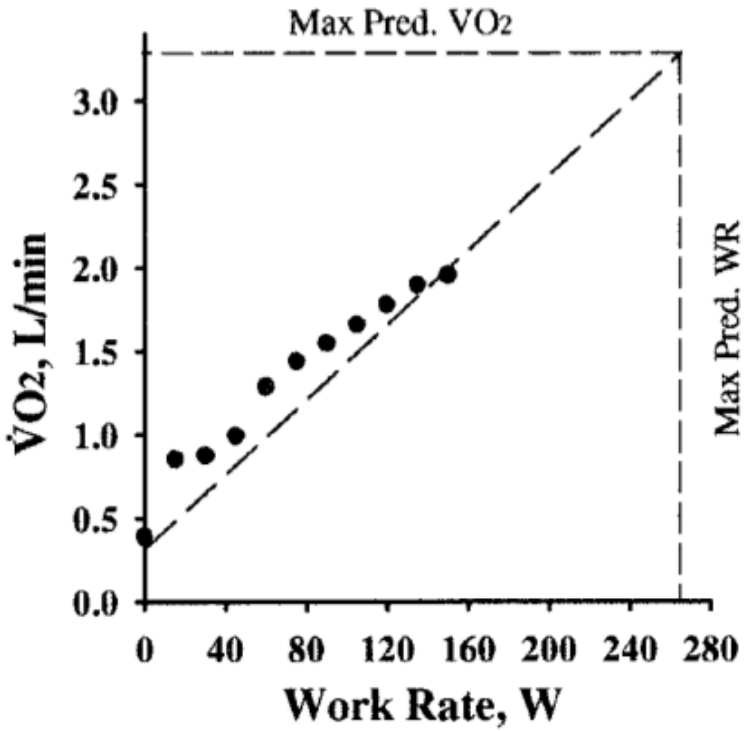
VO2–Work Rate Relationship

The slope Vo2/WR reflects the efficiency of the metabolic conversion of chemical potential energy to mechanical work and the mechanical efficiency of the musculoskeletal system. Normally it is about 8.5–11 ml/min/watt and is independent of sex, age, or height.

Normal



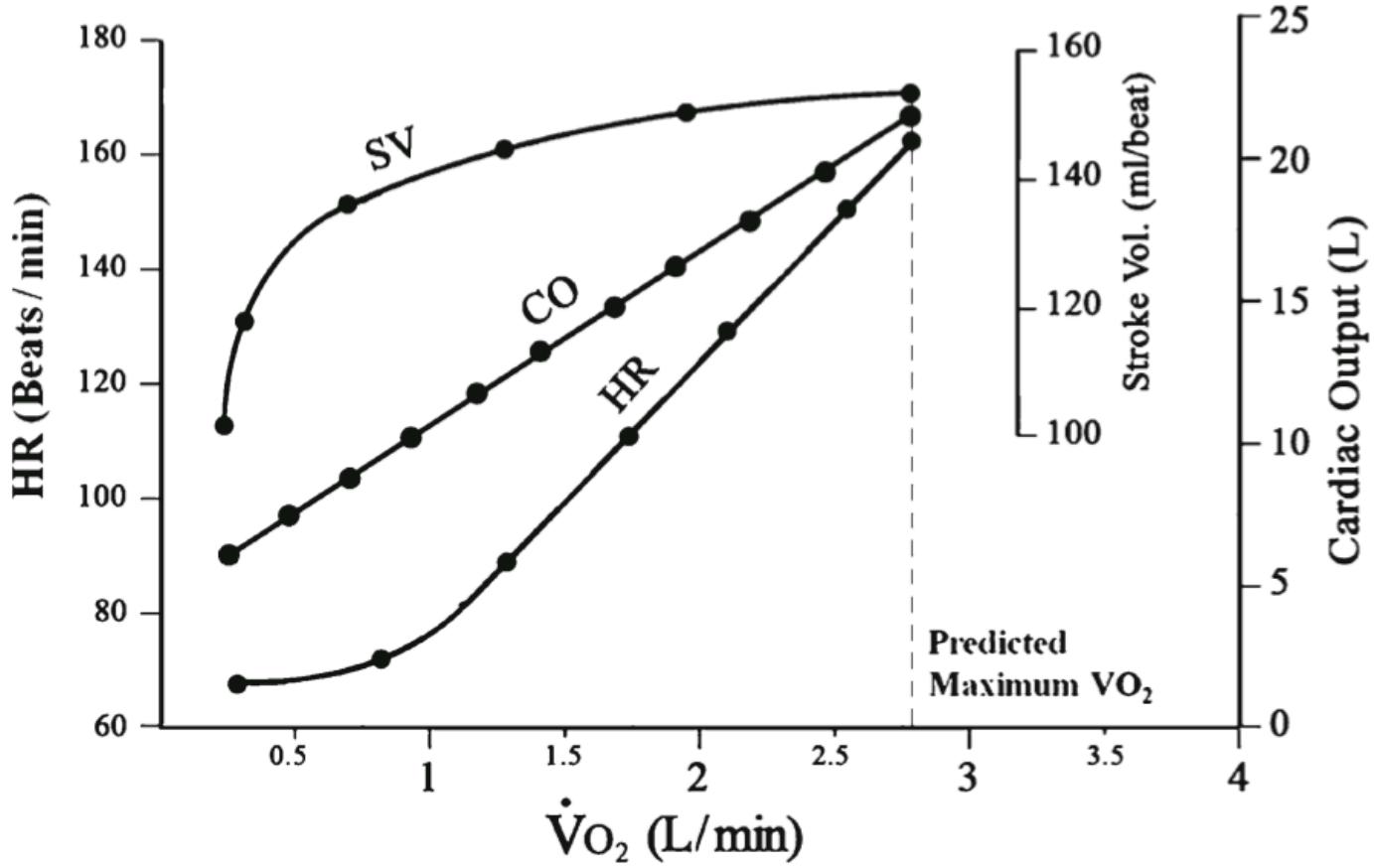
Pulmonary Vascular Disease



Εργοσπιρομετρία:
Το Καρδιαγγειακό Σύστημα

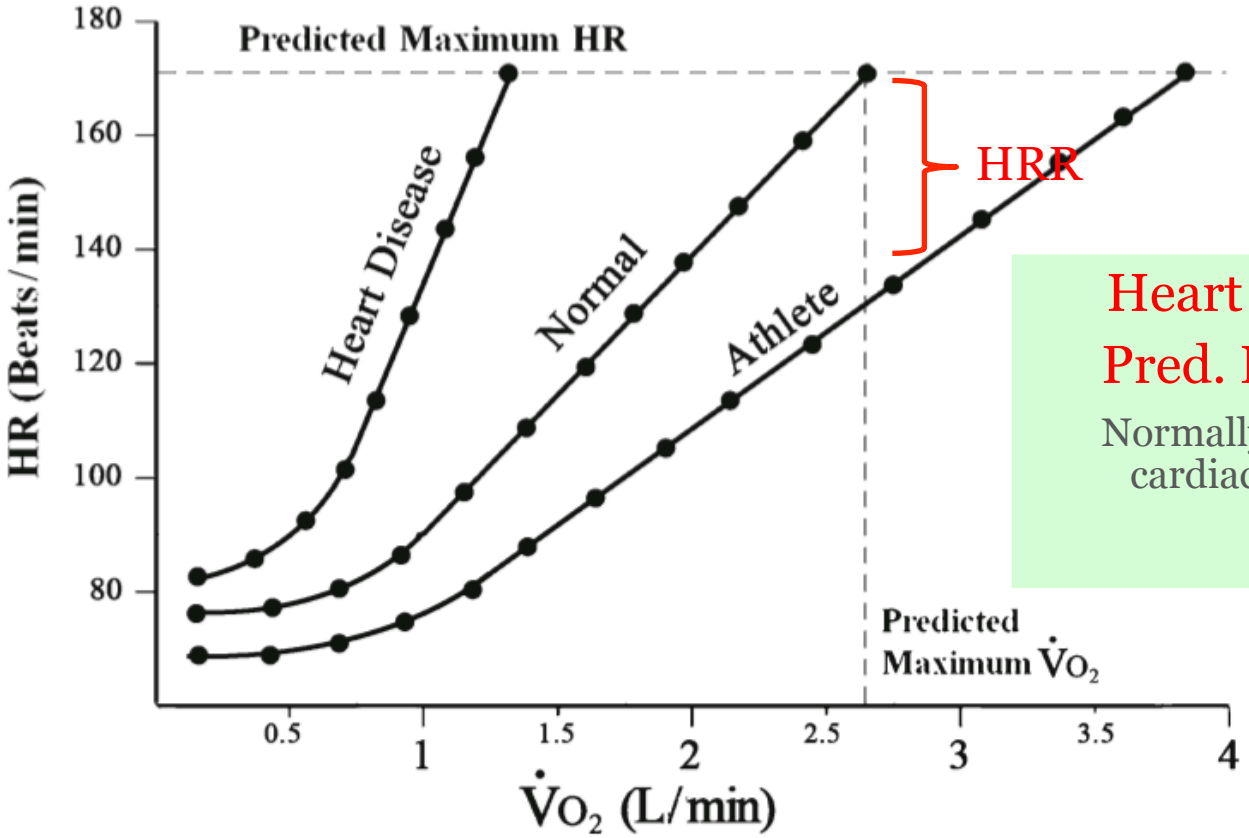
Heart Rate *versus* VO2:

The Normal Response; Aerobic Exercise



Heart Rate *versus* VO2

Normally we are exercise-limited by our heart, that is, we stop exercising when we achieve our maximum HR. Achievement of age-predicted values for maximal HR during exercise is often used as a reflection of maximal or near maximal effort and presumably signals the achievement of VO2max. [Predicted HRmax=220–age].



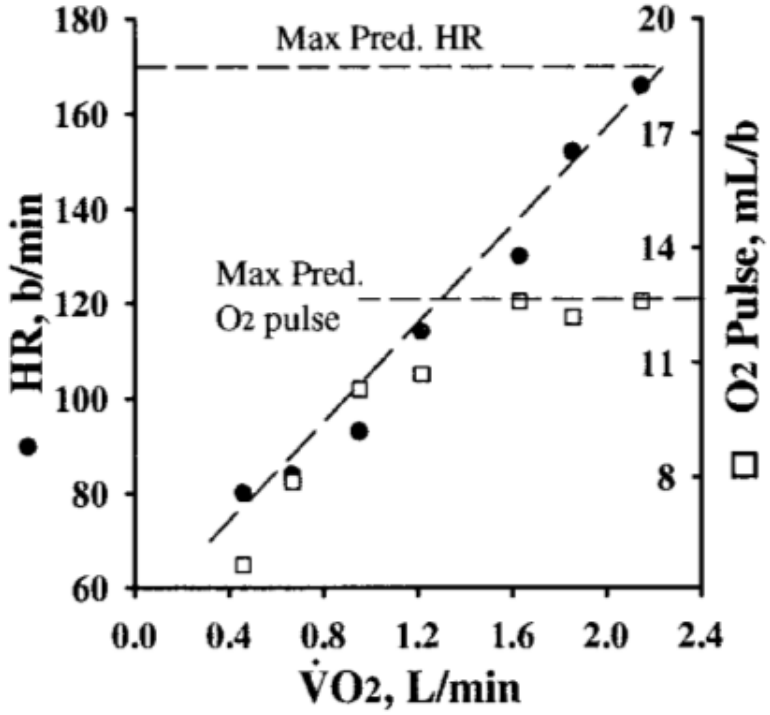
Heart Rate Reserve (HRR) = Pred. HR max–max. ach. HR

Normally < 15 beats/min; decreased in cardiac disease; increased in lung & muscle disease.

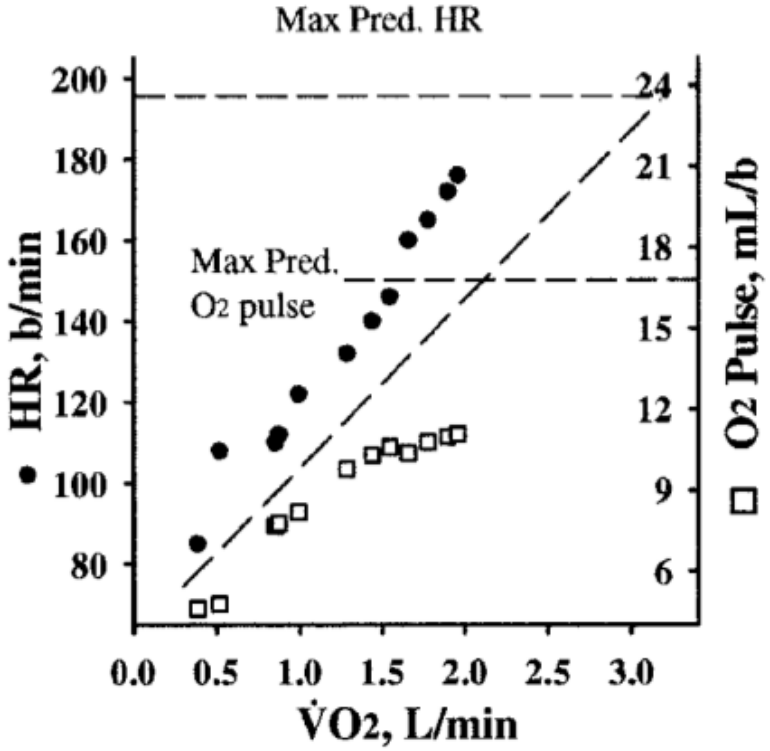
Heart Rate & O2 pulse *versus* VO2

The ratio of VO2 to HR is termed the "oxygen pulse" and reflects the amount of O2 extracted by the skeletal muscle per heart beat and SV. It is considered a noninvasive surrogate marker of SV. [Vo2/HR = SV x 1.34 x Hgb x C(a–v)O2].

Normal

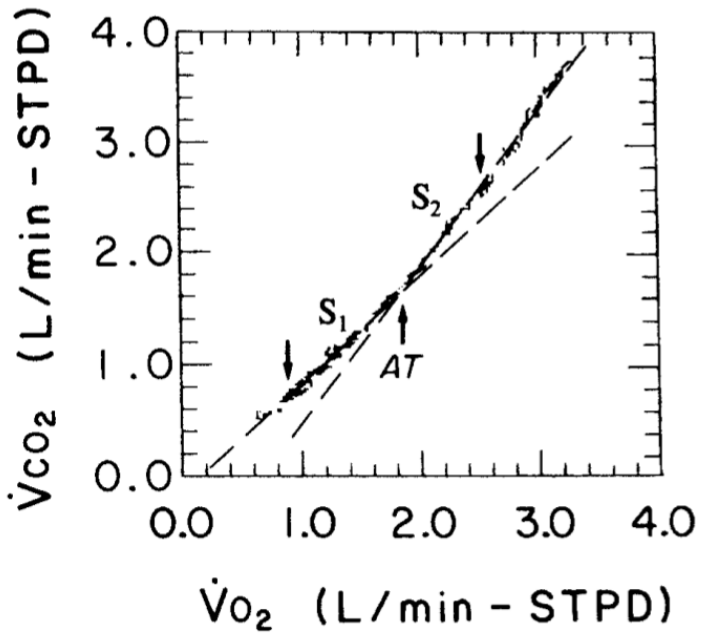


Pulmonary Vascular Disease



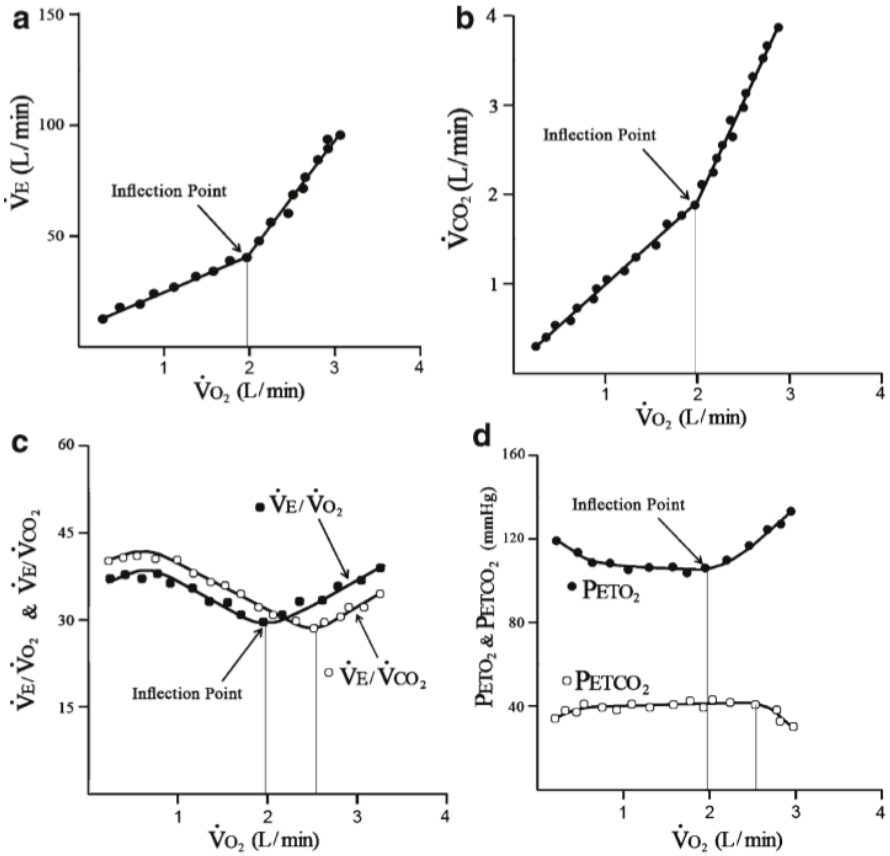
CO_2 production versus VO_2

The V-Slope method for identification of AT.



- In normal sedentary individuals, the AT occurs at ~ 50–60% VO2max pred. (range 35 to 80%).

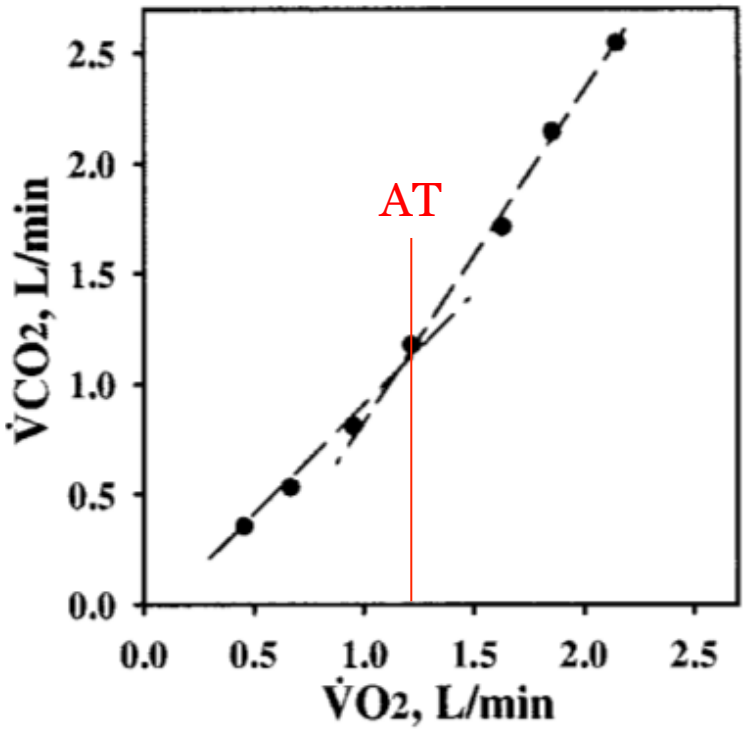
Αναερόβιο Κατώφλι



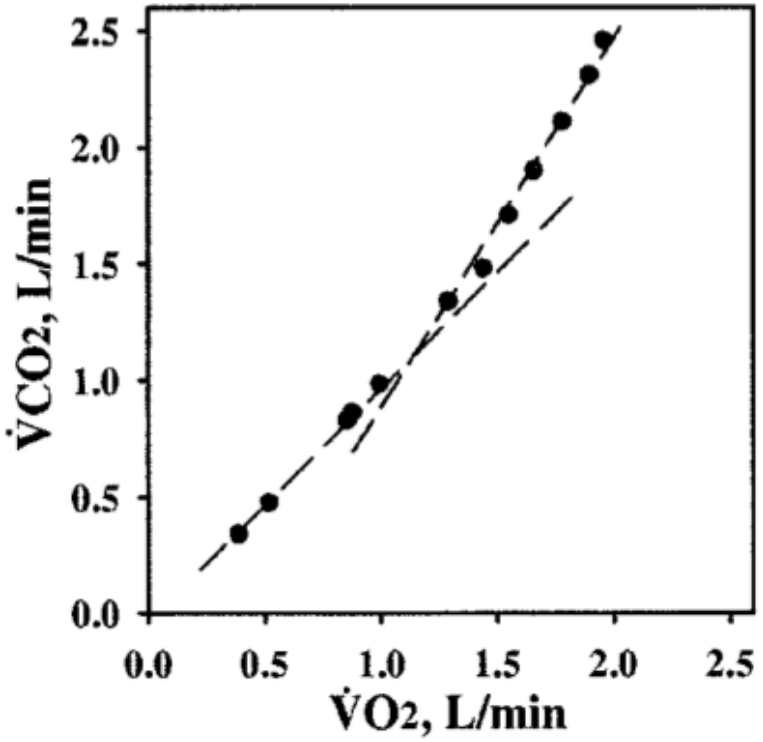
CO_2 production *versus* VO_2

The V-Slope method for identification of AT.
AT is determined predominately by the CV system.

Normal



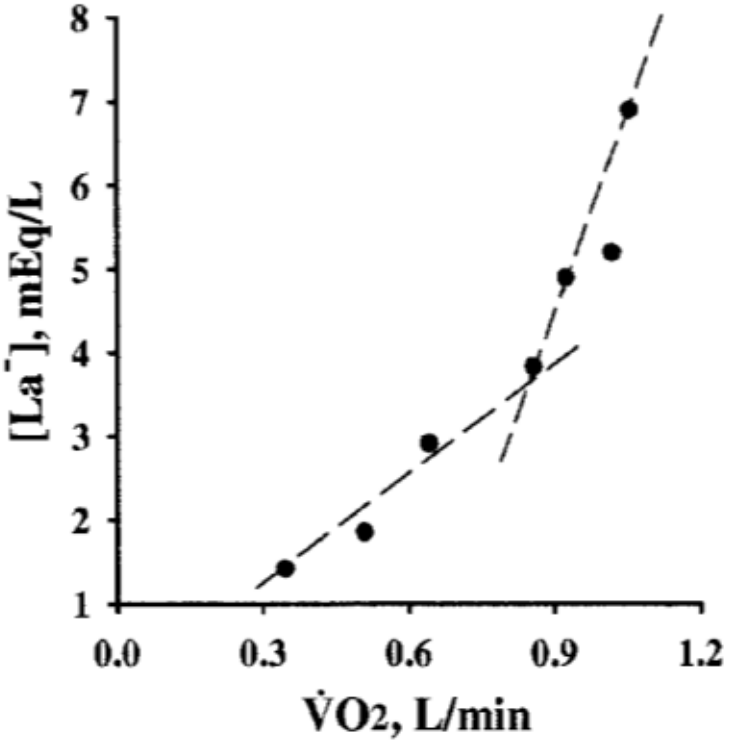
Pulmonary Vascular Disease



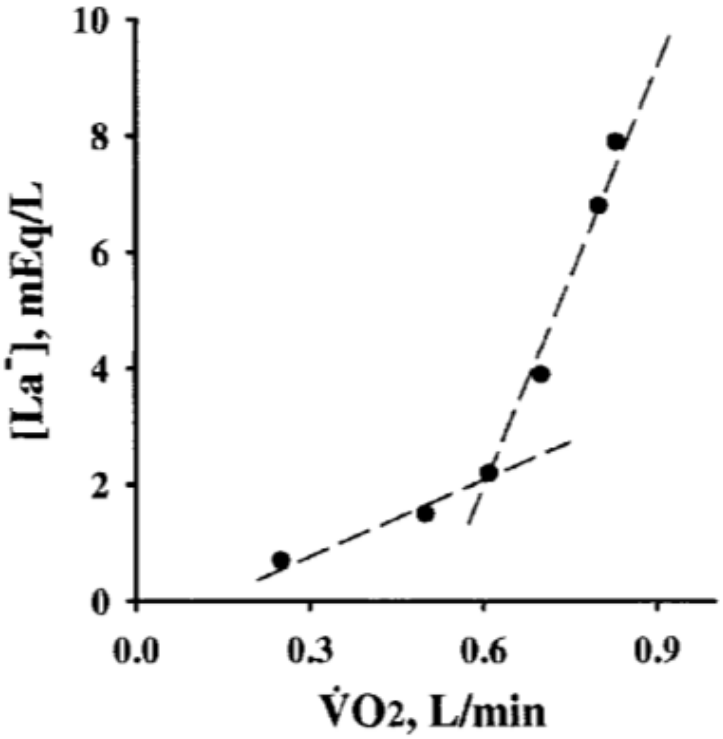
Arterial Lactate *versus* VO2

Invasive determination of AT

COPD



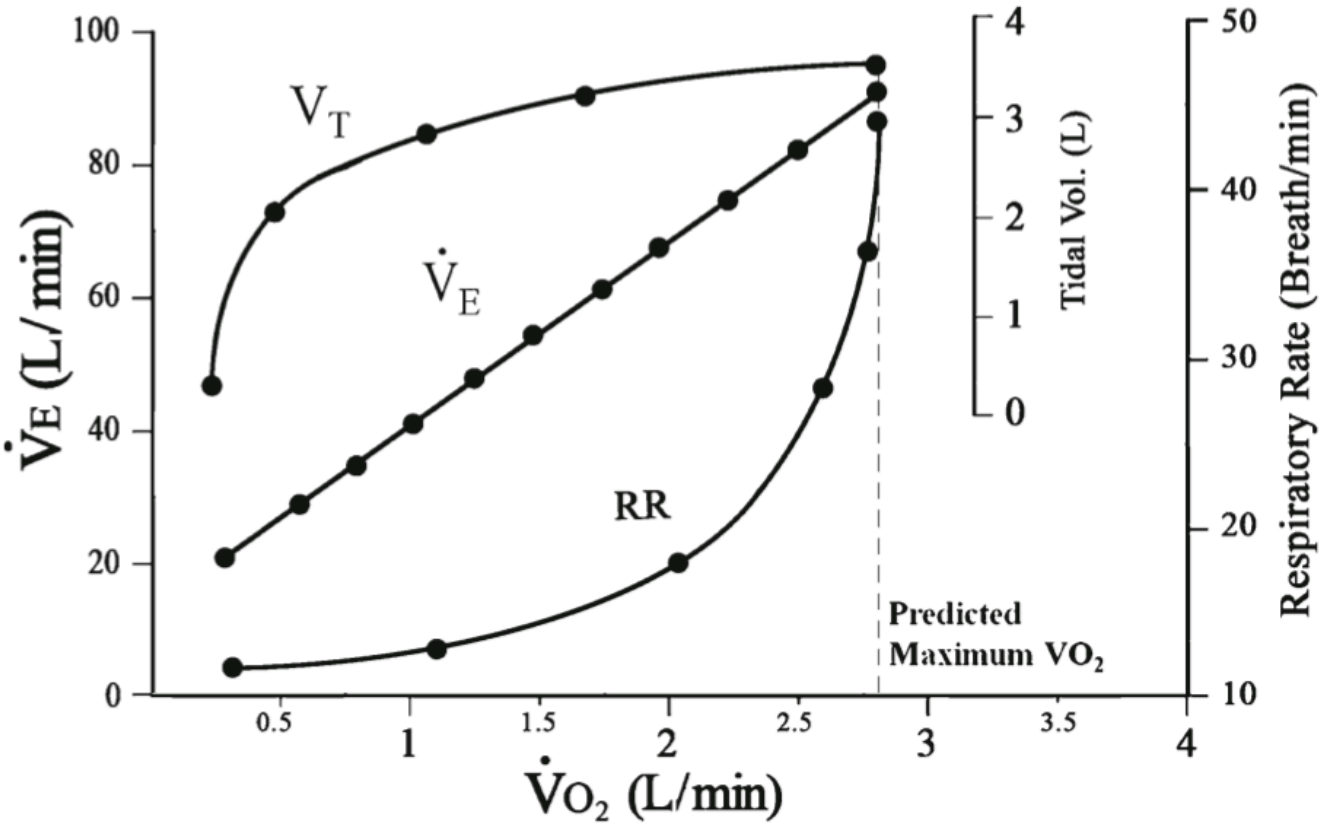
Heart Failure



Εργοσπιρομετρία: Το Αναπνευστικό Σύστημα

Minute ventilation *versus* VO2:

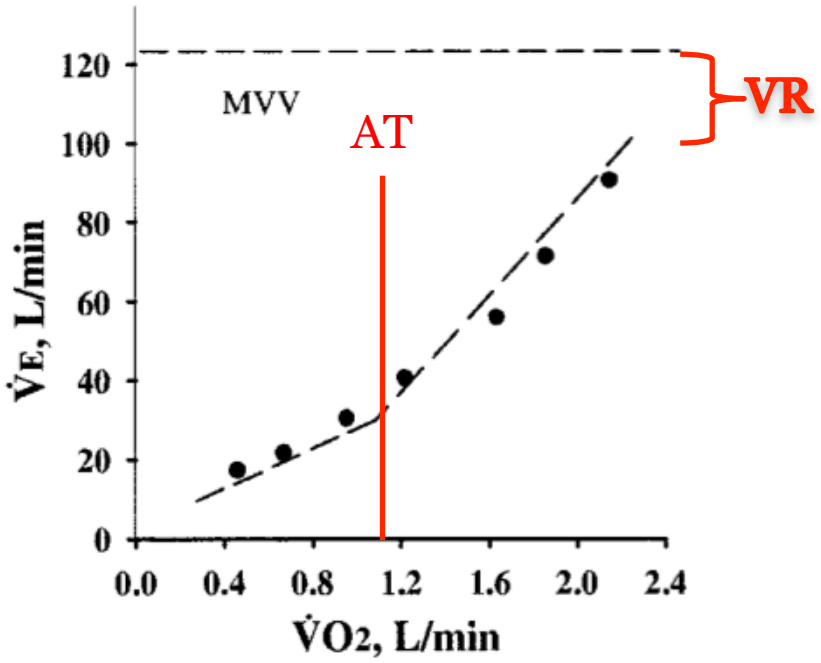
The Normal Response; Aerobic Exercise.



Minute Ventilation *versus* VO2:

The Normal Response; Aerobic Exercise.

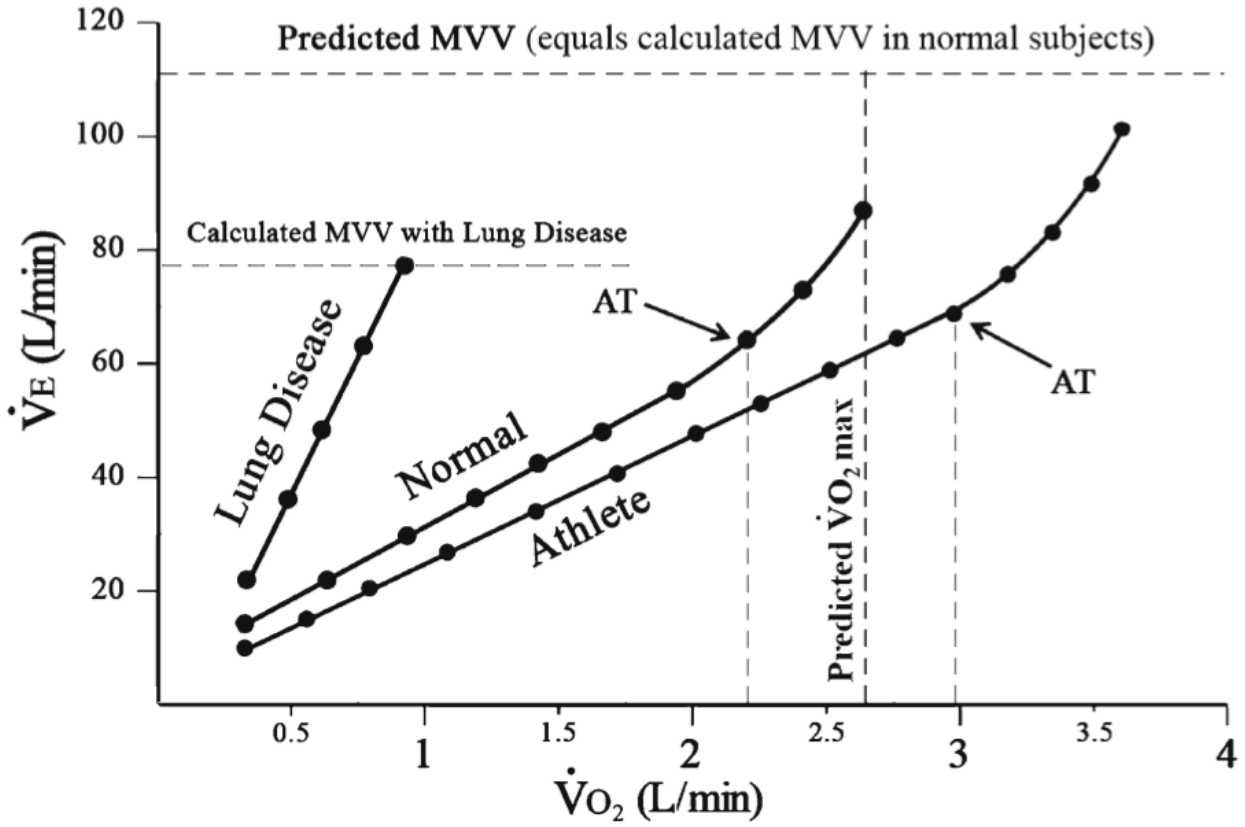
Ventilatory reserve= Predicted – measured VE max
= MVV – VE max = [FEV1 × 40] - VE max



- Unlike HR, the maximum RR (50/min) is not reached normally at peak exercise allowing for some reserve in VE (~30–40% of the predicted VEmax).
- If VE max is achieved during exercise, then the patient is generally exercise-limited by ventilatory parameters, and stops exercise because of dyspnea.
- Normally >11 L

Minute Ventilation *versus* VO2:

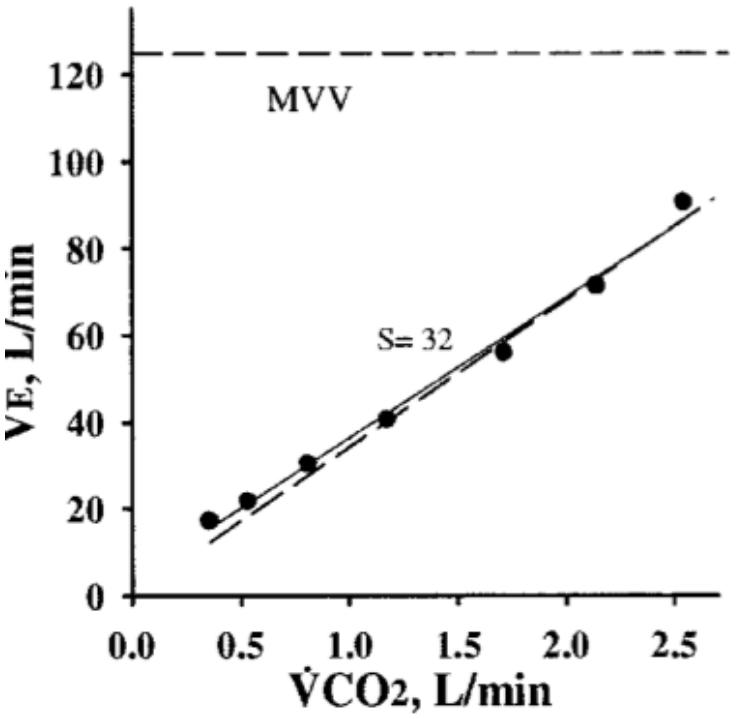
The Normal Response.



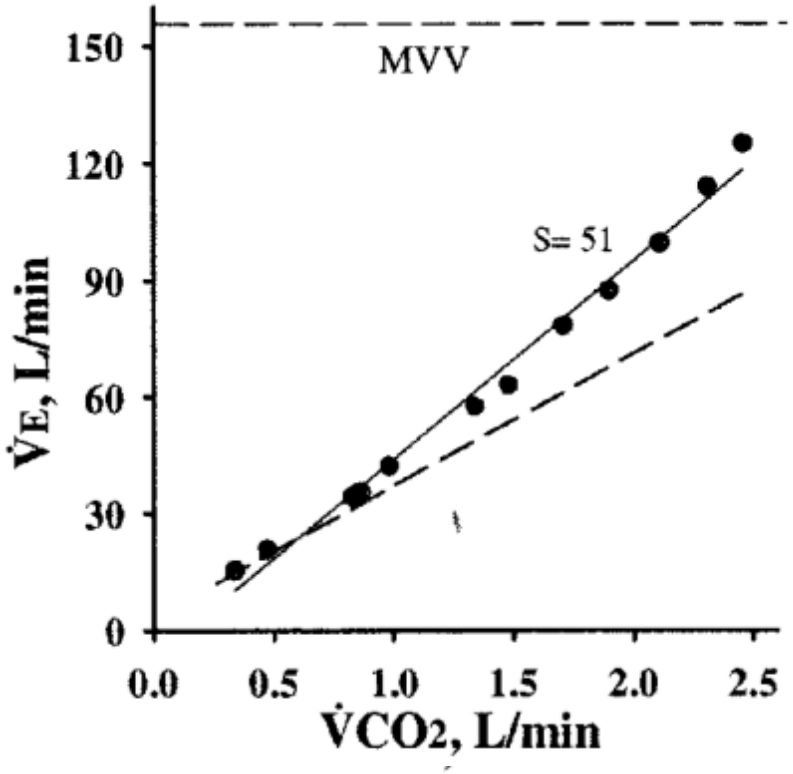
Minute ventilation *versus* VCO_2

Ventilatory reserve= Predicted – measured VE max

Normal

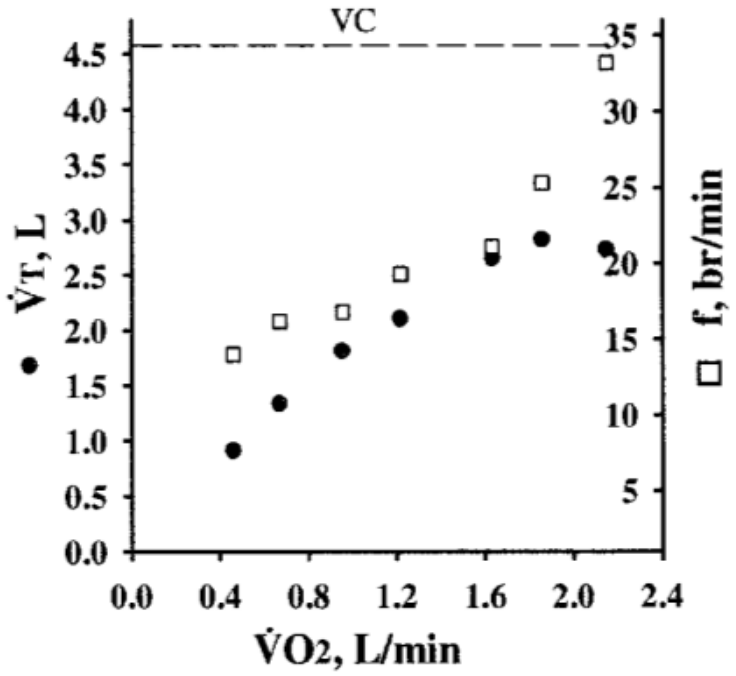


Pulmonary Vascular Disease

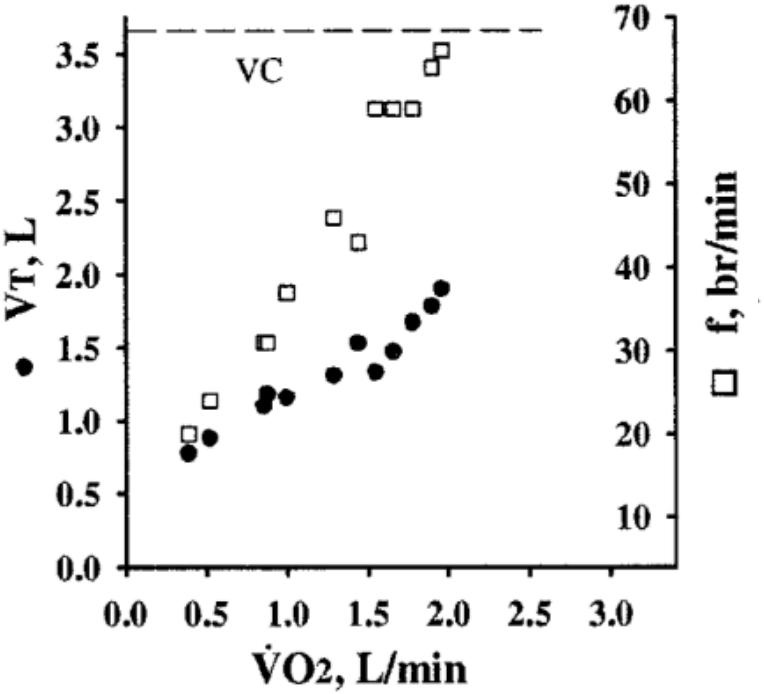


Tidal Volume & Respiratory Frequency *versus* VO2

Normal



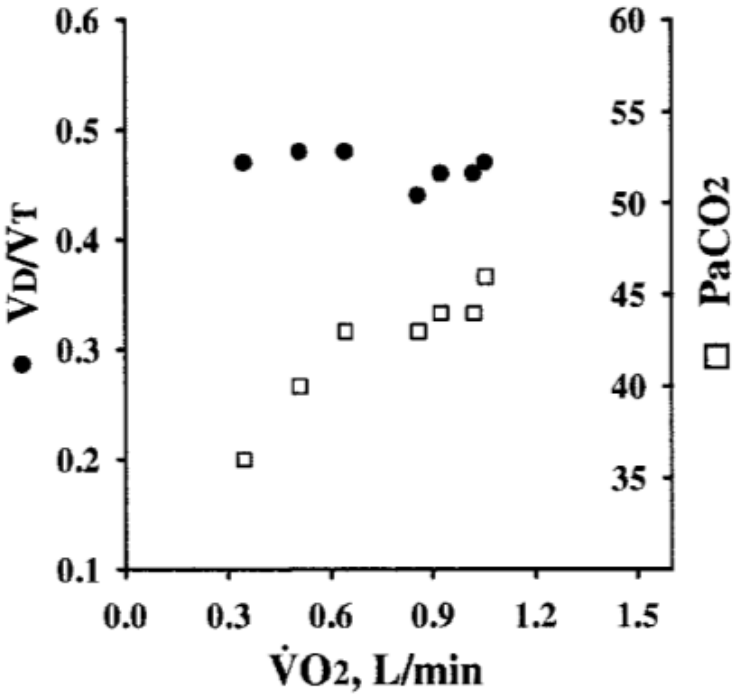
Pulmonary Vascular Disease



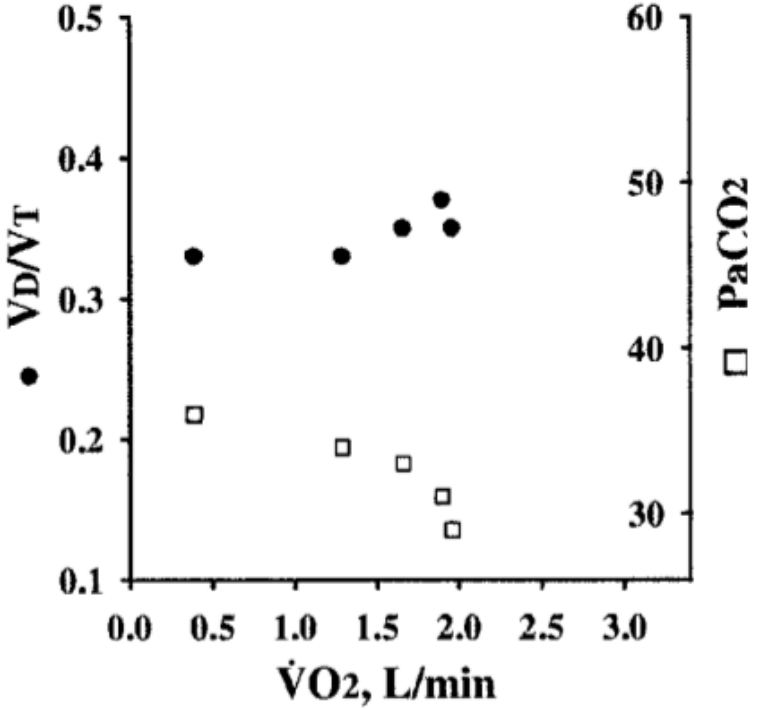
V_D/V_T ratio & PaCO2 *versus* VO2

The dead space ventilation (in absolute terms) increases with exercise; however, the dead space–tidal volume ratio (Vd/Vt) falls. There is a tendency for V_D/V_T to increase slightly near peak exercise as fr increases and in some cases V_T falls. V_D/V_T =(PaCO2 - PeCO2)/PaCO2 or, V_D/V_T =(P_{ET}CO2 - PeCO2)/P_{ET}CO2 (noninvasive).

COPD

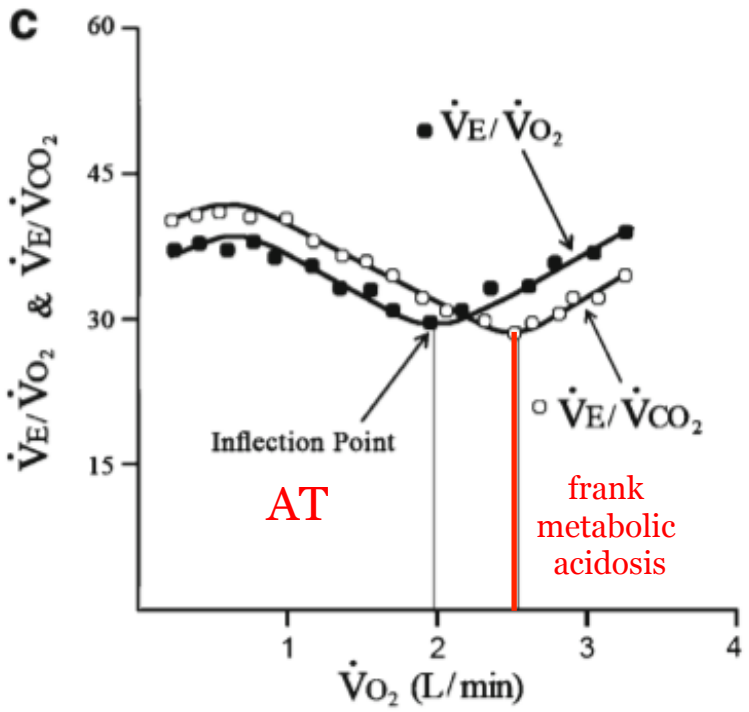


Pulmonary Vascular Disease

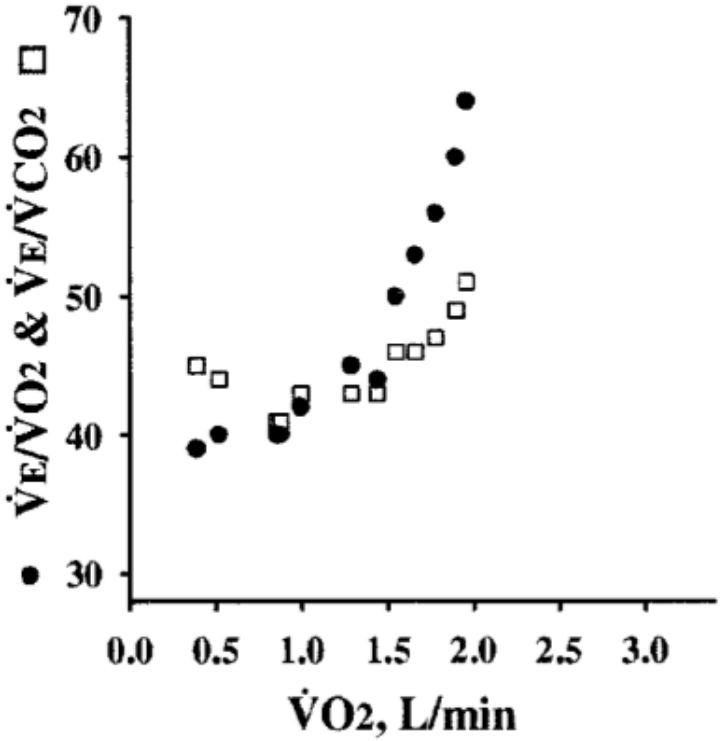


Ventilatory equivalent for O2 (VE/VO2)* & Ventilatory equivalent for CO2 (VE/VCO2)** *versus* VO2.

Normal



Pulmonary Vascular Disease

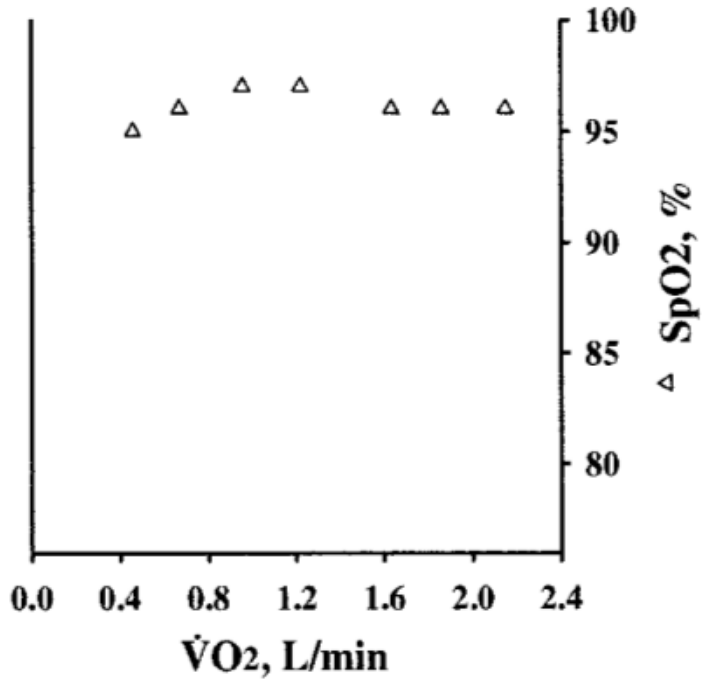


*the amount of VE at a given level of VO2 (WR)
** the amount of VE at a given level of VCO2

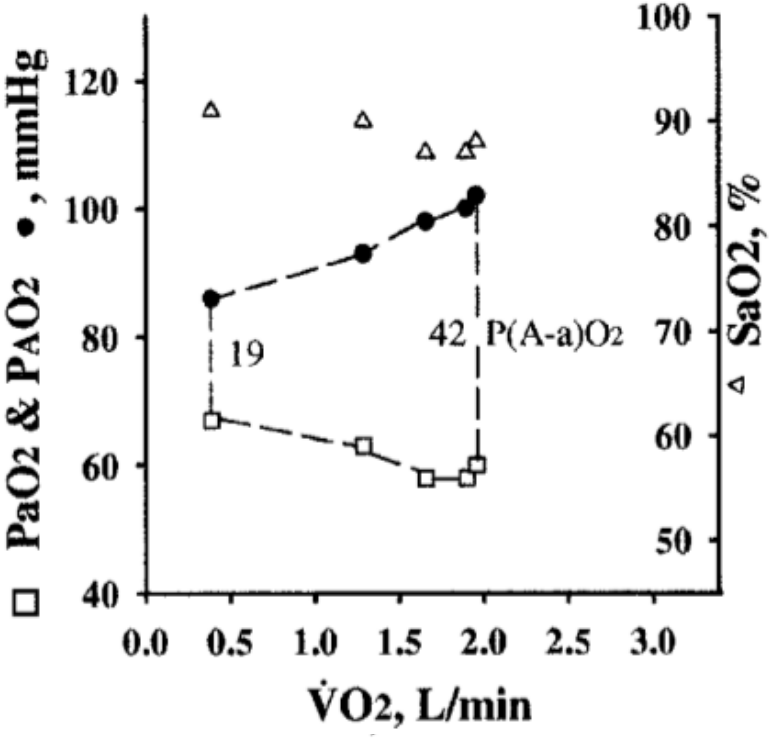
PaO2, PAO2 & SpO2 *versus* VO2

*Pa*CO2 normally remain stable until AT is reached, then it starts to decrease due to the increased VE. In some ventilatory disorders, however, *P*aCO2 can increase due to a relative hypoventilation.

Normal



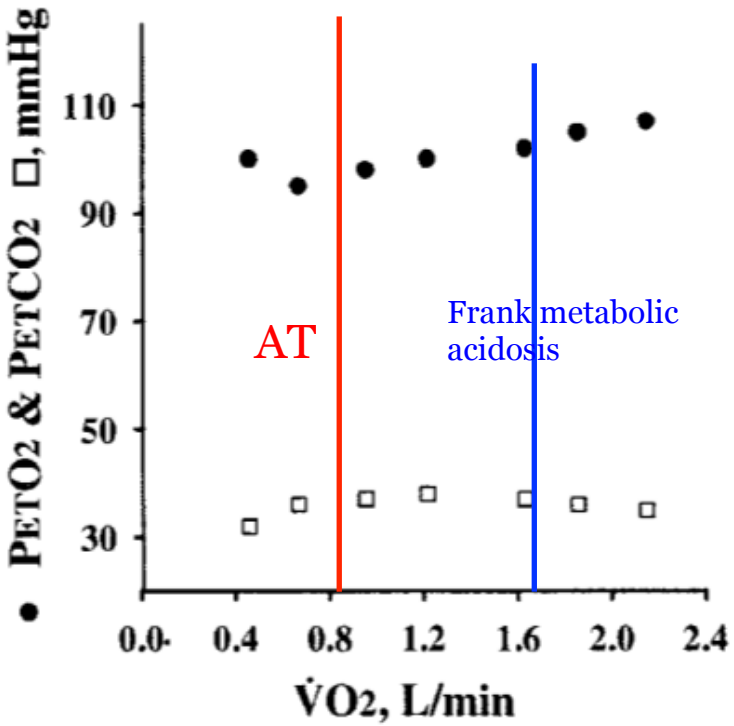
Pulmonary Vascular Disease



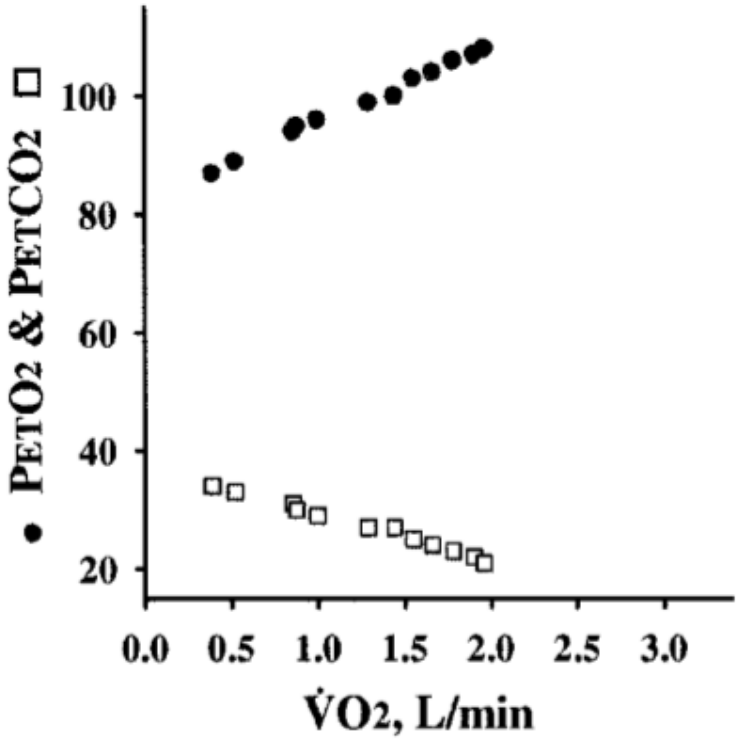
At rest, P(A–a)O2 is normally <10 mmHg and increases with exercise to >20 mmHg, as PAO2 normally increases with exercise and PaO2 remains normal. However, any increase in P(A–a)O2 of >35 mmHg with exercise is considered abnormal and indicates a gas-exchange abnormality.

End-tidal pressure for O2 ($P_{ET}O_2$) & End-tidal pressure for CO2 ($P_{ET}CO_2$) *versus* VO2

Normal



Pulmonary Vascular Disease

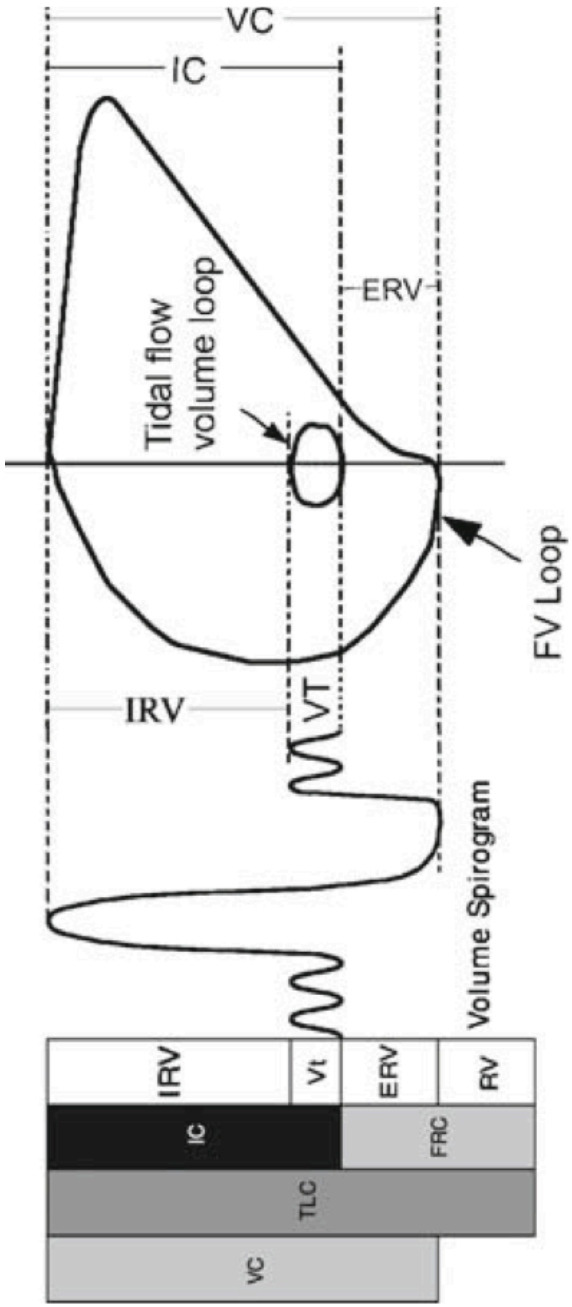


Εργοσπιρομετρία:

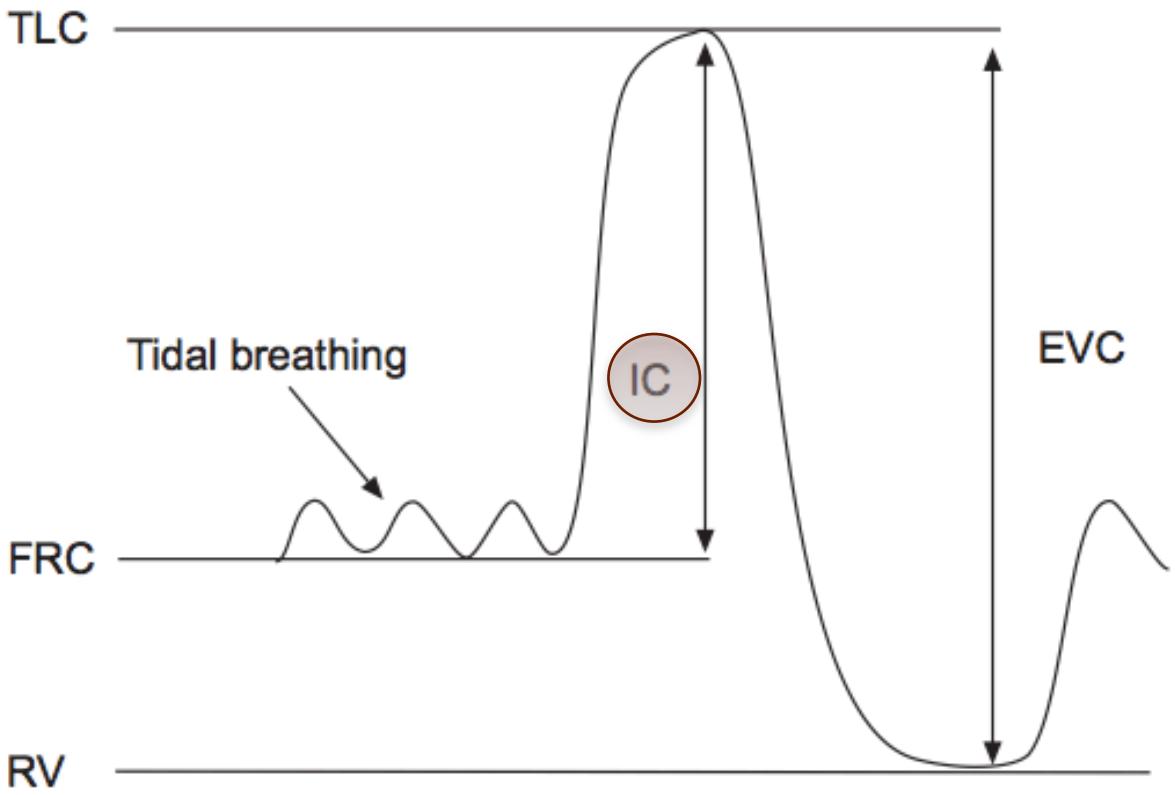
Φυσιολογικές τιμές

$\dot{V}O_2$max or $\dot{V}O_2$peak	> 84% predicted
Anaerobic threshold	> 40% $\dot{V}O_2$max predicted; wide range of normal (40–80%)
Heart rate (HR)	HRmax > 90% age predicted
Heart rate reserve (HRR)	HRR < 15 beats/min
Blood pressure	< 220/90
O_2 pulse ($\dot{V}O_2$/HR)	> 80%
Ventilatory reserve (VR)	MVV − $\dot{V}E$max: > 11 L or $\dot{V}E$max/MVV × 100: < 85%. Wide normal range: 72 ± 15%
Respiratory frequency (f_R)	< 60 breaths/min
$\dot{V}E/\dot{V}CO_2$ (at AT)	< 34
V_D/V_T	< 0.28; < 0.30 for age > 40 years
Pa_{O_2}	> 80 mm Hg
$P(A–a)O_2$	< 35 mm Hg

Εργοσπιρομετρία:
Μέτρηση Πνευμονικών Όγκων



Εργοσπιρομετρία:
Μέτρηση Εισπνευστικής Χωρητικότητας (IC)



Η φυσιολογική καμπύλη ροής-όγκου σε νεαρό και ηλικιωμένο άτομο

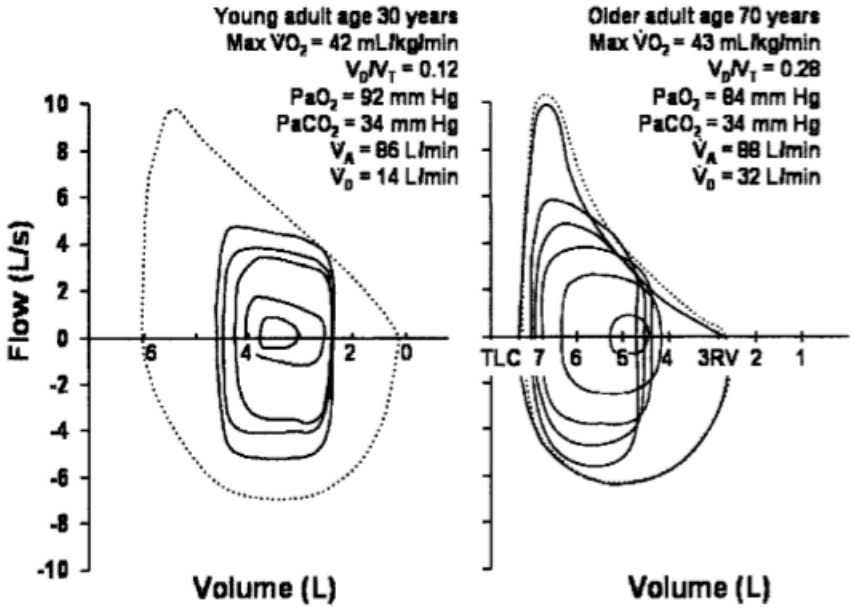
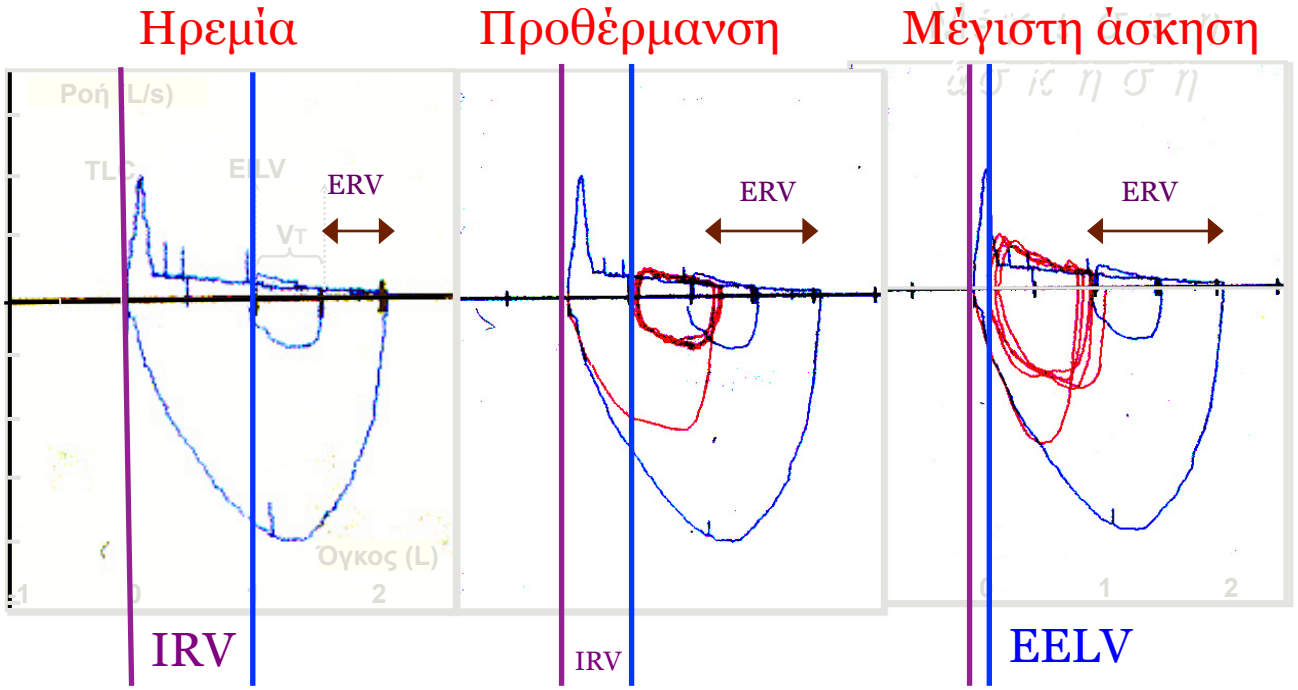


Figure 6. Flow–volume responses to exercise in younger (*left*) and older (*right*) adults. Subjects were matched for similar peak $\dot{V}O_2$ values. Key differences in the ventilatory response to exercise: *Young adult*: (*1*) drop in FRC, (*2*) encroachment equally on IRV and ERV, (*3*) little or no expiratory flow limitation, (*4*) available inspiratory flow reserve, and (*5*) significant volume reserve. *Older adult*: (*1*) drop in FRC followed by an increase with flow limitation, (*2*) encroachment mostly on IRV, (*3*) significant expiratory flow limitation, (*4*) minimal inspiratory flow reserve, (*5*) little reserve to increase either flow or volume at peak exercise. It should be noted that the young adults had average levels of fitness, whereas the older adults studied were much fitter than predicted for age ($\dot{V}O_2$max approximately twice the age-predicted value)

Εργοσπιρομετρία:
Δυναμική Πνευμονική Υπερδιάταση



Η καμπύλη ροής-όγκου στη ΧΑΠ

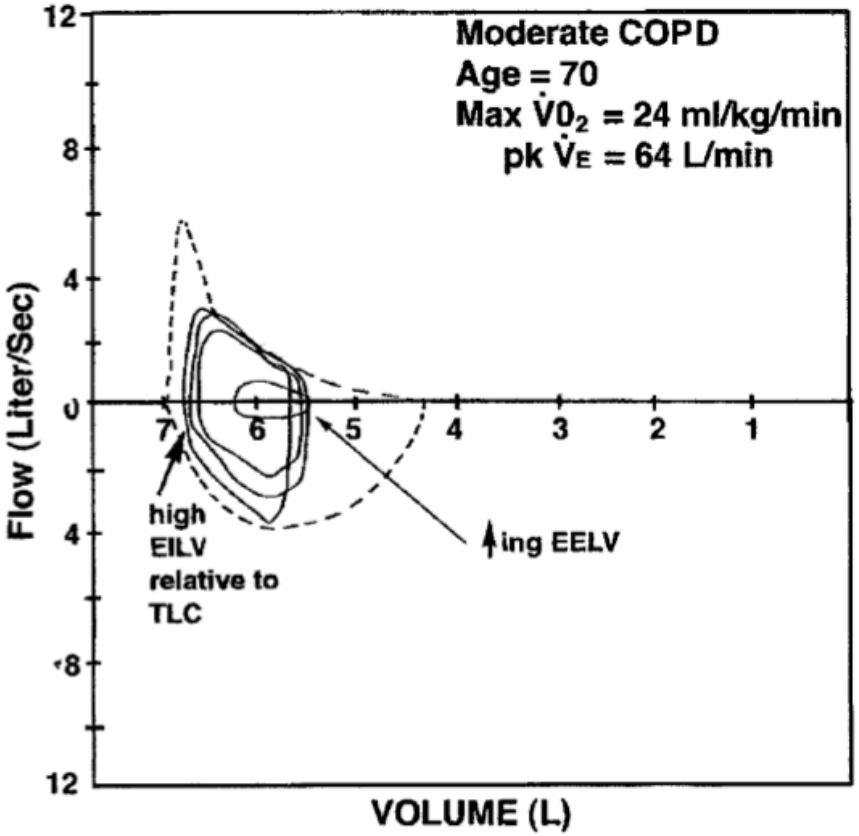
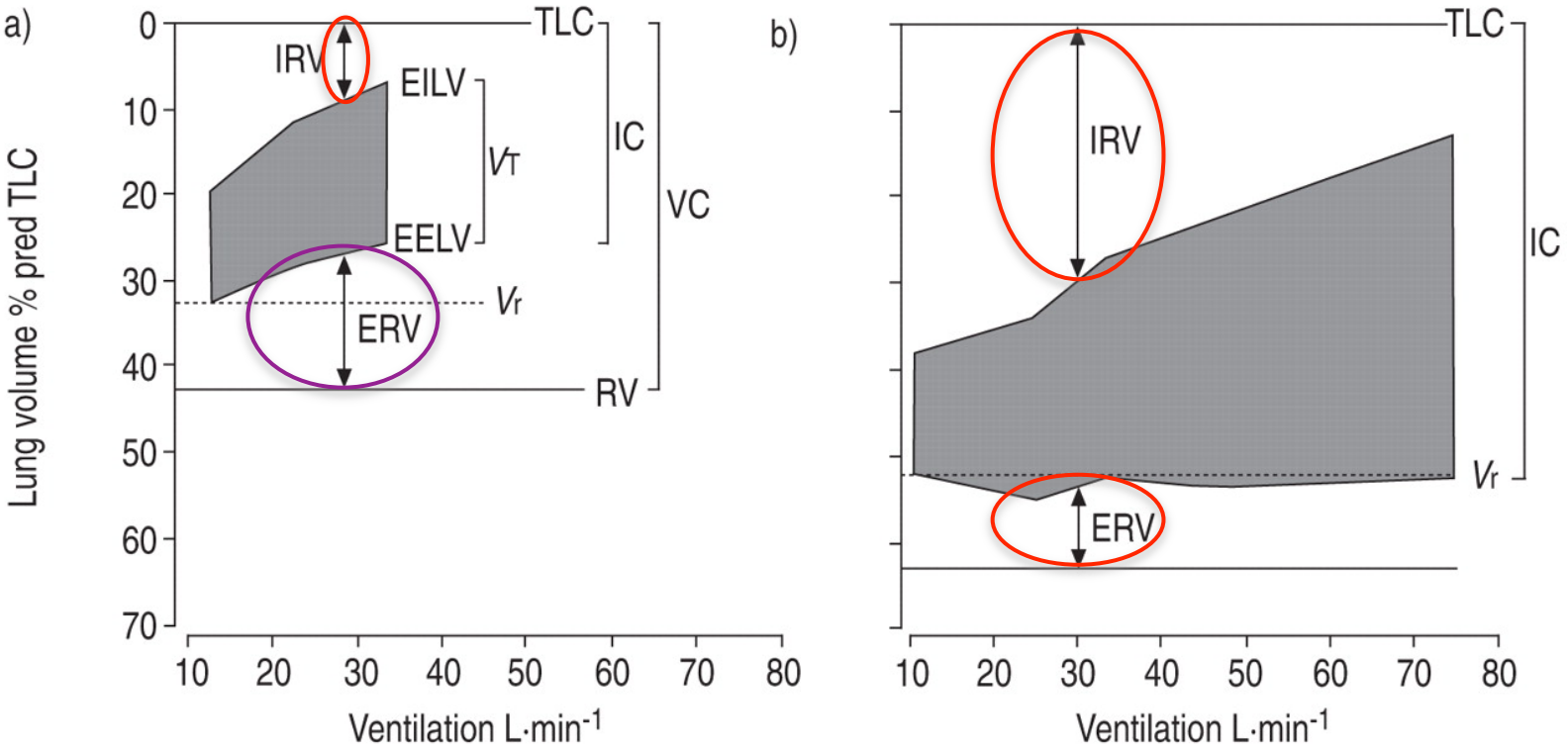


Figure 7. Patient with history of moderate COPD (forced expiratory flow at 50% of VC = 35% of value predicted for age): EELV increases from the onset of exercise and expiratory flow limitation is present over more than 80% of the V_T by peak exercise. Inspiratory flows approach those available over the higher lung volumes. Little room exists to increase ventilation (288). *EELV* = End-expiratory lung volume; *EILV* = end-inspiratory lung volume; *TLC* = total lung capacity.

Πνευμονική Υπερδιάταση

COPD

Normal



Η καμπύλη ροής-όγκου στην χρόνια Καρδιακή Ανεπάρκεια

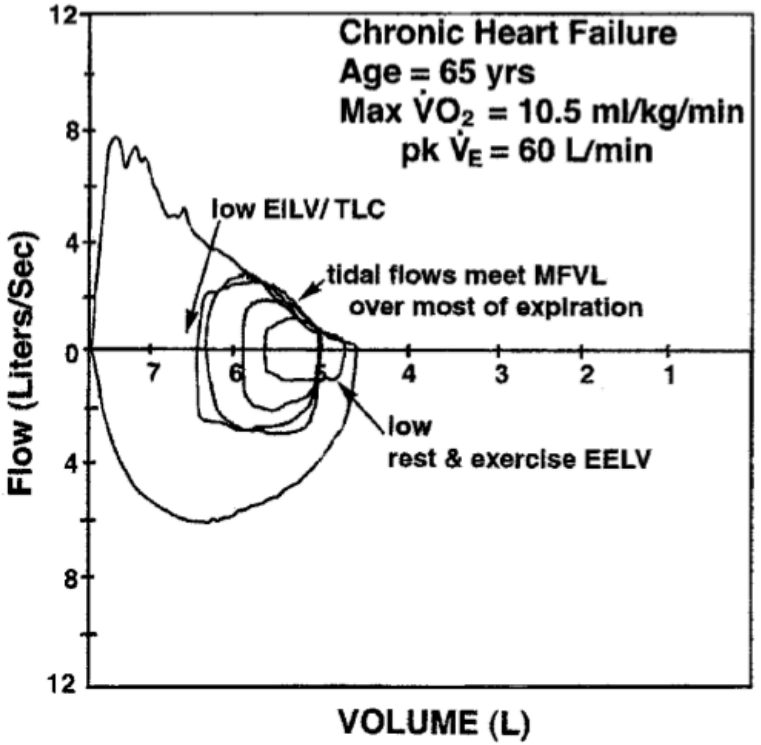


Figure 8. Example of a patient with stable congestive heart failure (New York Heart Association Class III). Shown are rest, mild, moderate, and peak exercise tidal flow–volume loops plotted within the maximal flow–volume loop. EELV is reduced at rest and remains near RV throughout exercise despite significant expiratory flow limitation and apparent room to increase EELV to avoid the flow limitation (288). *EELV* = end-expiratory lung volume; *EILV* = end-inspiratory lung volume; *MFVL* = maximal flow–volume loop; *TLC* = total lung capacity.

Η καμπύλη ροής-όγκου στην Διάμεση Πνευμονοπάθεια

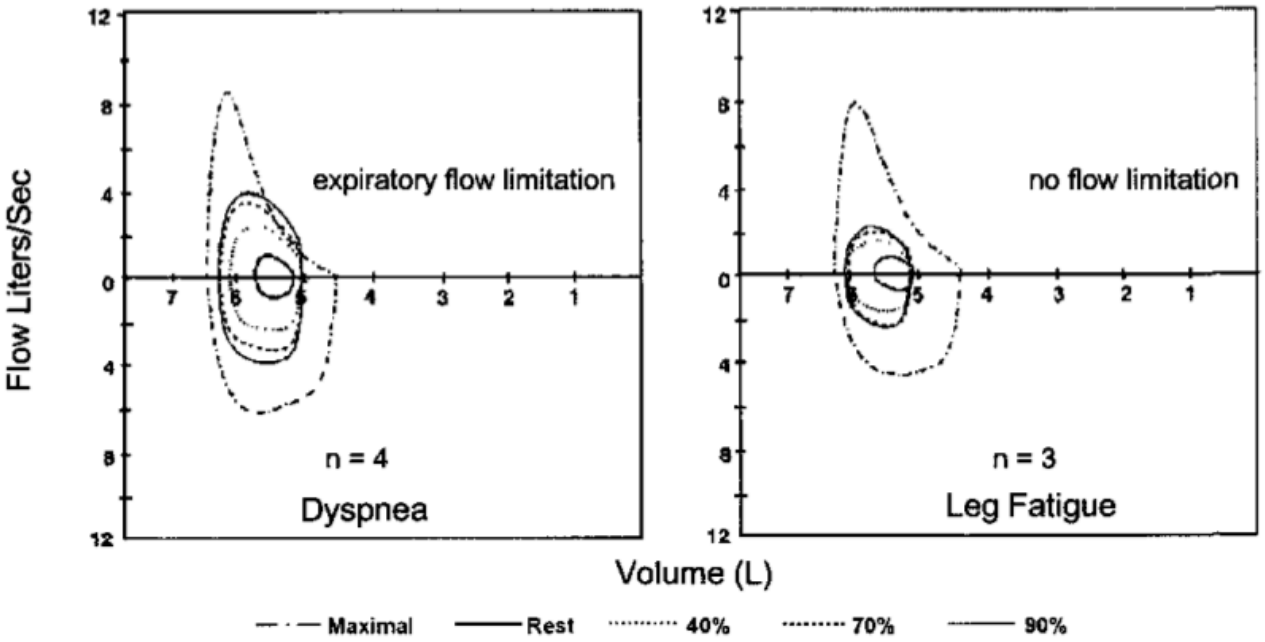


Figure 9. Maximal and extFVL in patients with ILD. *Left*: Patients who stopped secondary to dyspnea. *Right*: Patients who stopped due to leg fatigue. Minimal change was observed in EELV in either group, with the group complaining of dyspnea demonstrated significant expiratory flow limitation (modified from Marciniuk and coworkers [378]). *EELV* = end-expiratory lung volume; *ExtFVL* = exercise tidal flow–volume loop; *ILD* = interstitial lung disease.

Εργοσπιρομετρία

TABLE 18. USUAL CARDIOPULMONARY EXERCISE RESPONSE PATTERNS

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

Definition of abbreviations: AT = Anaerobic threshold; COPD = chronic obstructive pulmonary disease; HR = heart rate; ILD = interstitial lung disease; MVV = maximal voluntary ventilation; $P(A–a)O_2$ = alveolar–arterial difference for oxygen pressure; VD/VT = ratio of physiologic dead space to tidal volume; $\dot{V}E$ = minute ventilation; $\dot{V}CO_2$ = carbon dioxide output; $\dot{V}O_2$max = maximal oxygen uptake; $\dot{V}O_2$peak = peak oxygen uptake.

Adapted by permission from References 3, 49, and 72.

* *Decreased*, *normal*, and *increased* are with respect to the normal response.

Normal Exercise Limitation

- In a normal individual, ventilation does not appear to be the limiting factor, because at maximal exercise there is significant ventilatory reserve with $PaCO_2$ decreasing, indicating that the bellows are capable of removing CO_2 efficiently
- Pulmonary gas exchange does not appear to limit exercise, because blood SpO_2 and content are kept near baseline values despite some widening of the $P(A–a)O_2$.
- The metabolic and contractile properties of the skeletal muscles are not the limiting factors. There is good evidence that the muscles are capable of utilizing whatever O_2 is supplied to them (i.e., good metabolic reserve)
- Maximal exercise appears limited by O_2 delivery (=cardiac output & arterial O_2 content); there is a linear relationship between O_2 delivery and VO_2. As arterial O_2 content is normally maintained even at peak exercise, cardiac output is likely the limiting link.

Exercise Limitation in Cardiopulmonary Patients

- Exercise limitation in patients with reduced VO2max is often multifactorial and as such not limited by any single component of the O2 transport/ utilization process but rather by their collective quantitative interaction(s).
- In contrast to normal subjects, in whom physiologic limitation to O2 transport may be evident, patients are often symptom limited and may stop exercise before reaching limits of metabolic or gas transport capacity.

Exercise Limitation in Cardiopulmonary Patients

Cardiovascular Limitation Functional disturbances of the heart and/or the pulmonary and systemic circulation, and/ or the blood (e.g anemia, carboxyHb).	Reduced O2 delivery to the exercising muscle (HR, systolic & diastolic cardiac dysfunction, imapaired peripheral circulation), abnormal pulmonary vascular responses, skeletal muscle dysfunction, deconditioning.
Respiratory Limitation *V*entilatory (mechanical) & gas exchange factors.	Decreased ventilatory capacity (mostly due to mechanical factors), abnormal gas exchange (hypoxemia and increased V_D), respiratory and peripheral muscle dysfunction, deconditioning, cardiovascular abnormalities (cor pulmonale, hemodynamic consequences of dynamic hyperinflation.
Peripheral Limitation Neuromuscular, microvascular, and metabolically related abnormalities that could impact tissue O2 conductance, O2 utilization, and mechanisms of contraction.	Abnormalities in skeletal muscle oxidative capacity, O2 utilization, muscle metabolism

Μέγιστη Δοκιμασία Άσκησης: Χαρακτηριστικά ασθενούς

	Measured	%Predicted
Age (yr)	62	-
Height (cm)	173	-
Weight (kg)	78	-
FEV_1 (L)	0.75	23
FVC (L)	1.67	38
FEV_1/FVC (%)	45	-
IC (L)	1.22	42
TLC (L)	8.30	121
MVV (L/min)	30	24
TL_{CO} (ml/mmHg/min)	18.5	60
PaO_2 (mmHg)	78.0	-
$PaCO_2$ (mmHg)	47.0	-
pH	7.35	-

Μέγιστη Δοκιμασία Άσκησης:
Τυπικό παράδειγμα ασθενούς

Time min	Work rate watts	VO_2 L/min	VCO_2 L/min	R	HR min $^{-1}$	VO_2/ HR ml/beat	VE L/min	f min^{-1}
Rest		0.24	0.22	0.92	110	2.2	9.8	20
Rest		0.18	0.16	0.89	112	1.6	8.4	20
Rest		0.22	0.20	0.91	108	2.0	9.1	19
Unloaded		040	0.35	0.88	121	3.3	14.2	23
Unloaded		0.34	0.30	0.88	119	2.9	13.1	25
Unloaded		0.44	0.39	0.89	117	3.8	15.3	24
1.0	10	0.42	0.38	0.90	121	3.5	14.8	25
2.0	20	0.48	0.42	0.88	124	3.9	16.3	25
3.0	30	0.64	0.56	0.88	128	5.0	18.6	22
4.0	40	0.72	0.64	0.89	130	5.5	21.1	24
5.0	50	0.77	0.72	0.94	136	5.7	23.9	28
6.0	60	0.86	0.81	0.94	135	6.4	25.6	28
7.0	70	0.94	0.91	0.97	138	6.8	29.0	32
8.0	**80**	**0.96**	**1.02**	**1.20**	**124**	**6.9**	**32.1**	**37**

Μέγιστη Δοκιμασία Άσκησης:
Τυπικό παράδειγμα ασθενούς

Time min	Workrate watts	pH	Po_2, mmHg			Pco_2, mmHg			V_D/V_T
			ET	a	(A – a)	ET	a	(a –ET)	
Rest			102			42			
Rest			103			41			
Rest		7.35	102	78	21	42	47	6	0.42
Unloaded			96			45			
Unloaded			98			44			
Unloaded		7.35	99	71	25	43	49	6	0.42
1.0	10		99			43			
2.0	20	7.35	97	68	27	44	49	6	0.42
3.0	30	7.35	94			46			
4.0	40	7.35	94	61	36	47	48	1	0.36
5.0	50		96			46			
6.0	60	7.35	96	57	42	48	49	1	0.35
7.0	70		95			48			
8.0	80	**7.32**	**101**	**53**	**51**	**48**	**53**	**5**	**0.38**

Μέγιστη Δοκιμασίας Άσκησης:
Προ και Μετά Οξυγόνου

	21% O_2	Predicted	100% O_2 isotime	100%O_{2peak}
Endurance time (min)	8	-	8	12
WR_{peak} (Watt)	80	48	80	120
VO_{2peak} (L/min)	0.96	45		
HR_{peak} (beats/min)	140	88	144	165
O_2pulse (ml/beat)	6.9	51	16	16
$\Delta VO_2/\Delta WR$ (ml/Watt)	8.3	10.3		
AT (L/min)	not reached	-		
$V_{E_{peak}}$ (L/min)	32.1	55	28.9	40.1
V_E/MVV (%)	107	-	99	
fb (breaths/min)	37	-	37	37
$\Delta IC_{\text{ from rest}}$ (L)	-0.600	-	-0.450	-0.620
V_D/V_T	0.38	-	0.42	0.37

Ευχαριστώ


I exercised once, but found I was allergic to it. My skin flushed and my heart raced. I got sweaty and short of breath. Very dangerous.
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