Cardiopulmonary Exercise Testing

DM Seminar

25 Feb2005

CPET

- Introduction
- Indications
- Technical aspects
- Physiologic basis
- Exercise limitation
- Interpretation of CPET
- Future directions

Introduction

- Initially was tool of research physiologists
- Has become tool to help the clinicians in evaluating undiagnosed exercise intolerance or exercise related symptoms
- When questions remain after clinical examination and basic clinical data including CXR,PFT and resting ECG

Introduction

- Provides *global assessment* of integrative exercise response involving pulmonary, cardiovascular,hematopoietic,neuropsychological and skeletal muscle systems
- Resting cardio-pulmonary function tests cannot predict the exercise performance and functional capacity

Field tests

- 6 min walk test and shuttle test easy to perform , related to activities of daily living
- lack of reference values
- absence of physiological measures
- healthy subjects fairly good correlation with VO_2 max is observed
- Pitfalls: occult IHD, combined diseases

Weisman et al Clin Chest Med ,2001

When to do

- Evaluate exercise capacity
- Undiagnosed exercise intolerance
- Cardiovascular diseases
- Respiratory diseases/symptoms (EIA)
- Preoperative evaluation
- Pulmonary rehabilitation
- Impairment/disability assessment

Exercise Intolerance

- Assessment of exercise capacity
- Pathophysiologic basis of exercise limitation
- Contribution of cardiac /respiratory disease
- Symptoms disproportionate to routine tests

Cardio Resp diseases

Cardiovascular
Functional classific
Exercise Rx
Heart Tx selection

COPD/ILD/PVD
Functional assess
Gas exchange
After intervention
Oxygen Rx

ATS /ACCP Statement, 2003

Preoperative evaluation

- Lung resection: VO2 peak less than 50-60% associated with increased morbidity and mortality after lung resection

  Morice RC et al Chest 1996
- Elderly undergoing major Abdominal surgery
- LVRS for Emphysema

  ATS/ACCP statement 2003

Other uses

- Disability assessment: occupational/co-morbid diseases
- Exercise prescription :pulmonary and cardiac rehabilitation
- Evaluation of LVRS : NETT trial used max work rate achieved as primary outcome measure
- Evaluation for lung & heart transplantation

Absolute Contraindications

- Rate of death during testing 2-5/lakh tests
  - AMI(3-5 days) or unstable angina
  - Uncontrolled arrhythmia with hemodyn compromise
  - Syncope
  - Respiratory or Heart failure
  - Active endocarditis or myocarditis
  - Severe AS
  - Pulmonary embolism or Lower limb DVT
  - Uncontrolled asthma

ATS /ACCP Statement, 2003

Relative contraindications

- Left main coronary stenosis
- Moderate Stenotic valvular heart disease
- Severe untreated HTN (>200/120)
- Tachy or bradyarrhythmia /AV block
- Hypertrophic Cardiomyopathy
- Significant Pulmonary Hypertension
- Advanced pregnancy
- Orthopedic disease

ATS /ACCP Statement 2003

Types of equipment

- Cycle Ergometers
  - Computer controlled programme
  - Work rate easily quantified
  - Most preferred mode of exercise
- Motor driven Treadmill
  - Difficult to quantify work
  - Predicting VO_2 becomes difficult
- Arm Crank Ergometers
  - Neurologic / orthopedic disability lower limbs
  - Peak VO2 achieved ~ 70% of leg exercises

Exercise equipment

	Cycle	Treadmill
$\dot{V}O_2max$	lower	higher (5-10%)
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

Cheaper Expensive

Other equipment

- Airflow Volume transducers
  - Pneumotachograph
  - mass flow sensor
- Gas analyzers
  - mass spectrometer(gold standard,costly)
  - oxygen cell (Zirconium oxide)
  - CO2 sensor (Infra red light)

Gas exchange equipment

- Breath by breath analyzer
  - most popular method
  - Online analysis by sensor
  - Values averaged every 30-60 sec (↓ noise)
- Mixing chamber
- Douglas Bag

Other data recorded

- Electrocardiography
- Noninvasive blood pressure
- Pulse oximetry
- Arterial blood gas (if indicated)
- Invasive arterial BP

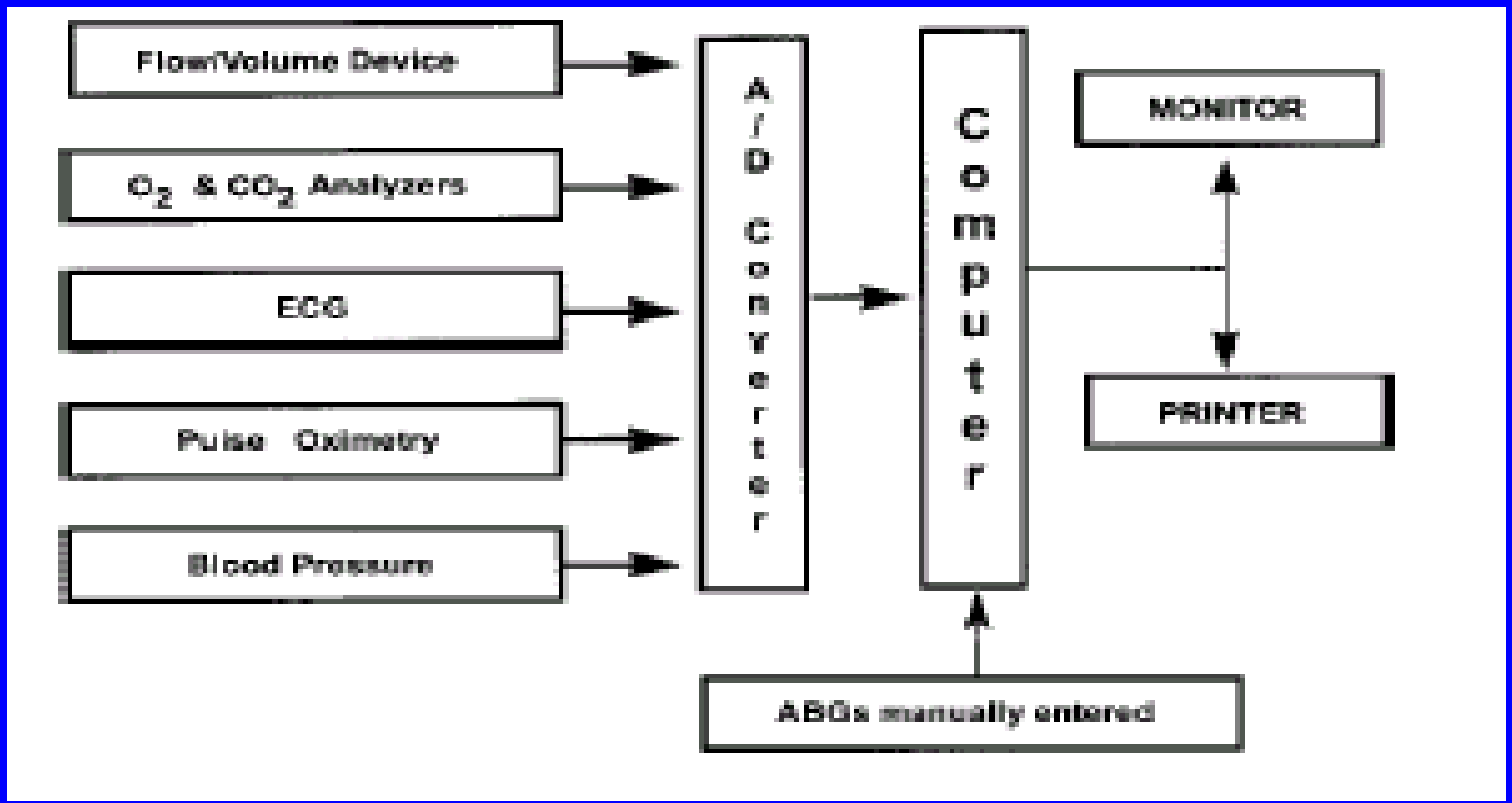
Arterial blood gas

- Invasive anaerobic threshold (AT)- Lactate
- COPD/ILD/PVD(Significant desaturation)
- Accuracy of oximetry reduced SpO2 < 88%
- Oxygen prescription
- SpO2 unreliable in following
  - Dark skin color
  - Weak pulses in cardiac diseases

Quality control

- Supervision by cardiologist/Pulmonologist (trained in exercise physiology& testing)
- Calibrate flow transducers
- Calibrate breath by breath systems
- Calibrate CO_2 and O_2 analyzers
- Noninvasive BP
- Healthy member " test" to validate the measured VO_2, V_E and VCO_2 with database values

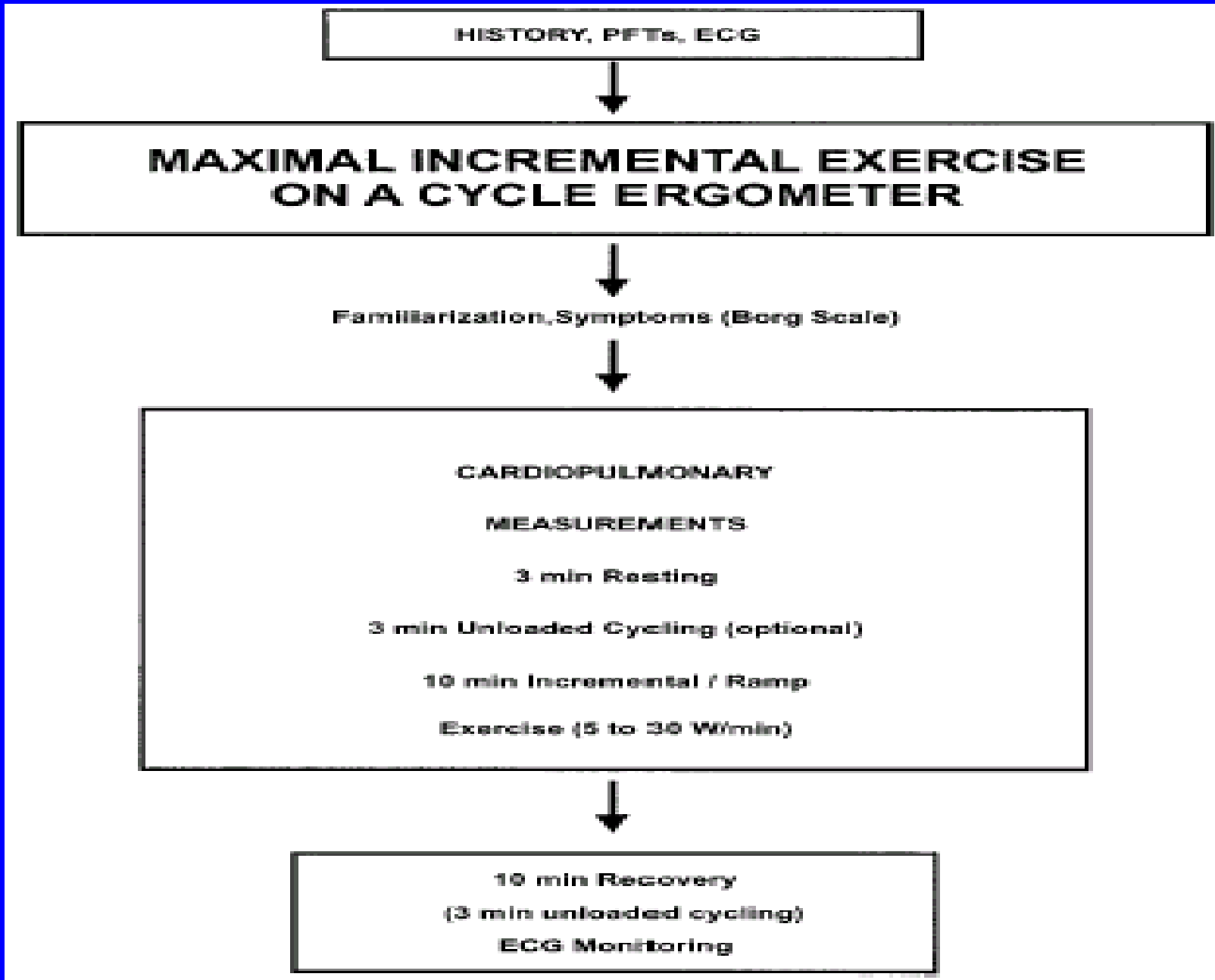
Schematic representation



Incremental Treadmill protocol

- Bruce protocol (suited for healthy,or mild diseases as high WR which increases)
- Modified Naughton protocol(low initial WR gradual build up suitable for patients)
- Balke protocol(constant speed , slope increased 1% every minute)
- Modified Balke protocol(slope increased by constant amount every min)

Incremental protocol



Constant work rate protocol

- Done at 50-70% of maximal work rate
- 5-10 min achieves 70-90% VO_2 max IET
- For assessing response to interventions- LVRS, LTOT , pulm rehabilitation
- Analysis of Exercise FV Loops and dynamic hyperinflation ,gas exchange kinetics

Stop exercise

- Ischemic chest pain
- Ischemic ECG changes
- Complex ectopy
- Second or third degree heart block
- Fall in systolic pressure > 20 mm Hg
- Hypertension (250 /120 mm Hg)
- Symptomatic desaturation: SpO2 <80%
- Signs of respiratory failure

Parameters measured

Measurements	Non Invasive	Invasive (ABGs)
External work	WR	
Metabolic gas exchange	$\dot{V}O_2$, $\dot{V}CO_2$, RER, AT	Lactate
Cardiovascular	HR, ECG, BP, O_2 pulse	
Ventilatory	$\dot{V}E$, V_T, f_R	
Pulmonary gas exchange	Sp_{O_2}, $\dot{V}E/\dot{V}CO_2$, $\dot{V}E/\dot{V}O_2$, $P_{ET}O_2$, $P_{ET}CO_2$	Pa_{O_2}, Sa_{O_2}, $P(A-a)O_2$, V_D/V_T
Acid-base		pH, Pa_{CO_2}, standard HCO_3^-
Symptoms	Dyspnea, fatigue, chest pain	

Oxygen Uptake (VO_2)

Factors affectingVO2

- Oxygen carrying capacity(Hb%, SaO2)
- Cardiac function(Cardiac output)
- Distribution of blood to tissues
- Extraction by tissues(capillary density, mitochondria density& function , perfusion and diffusion)

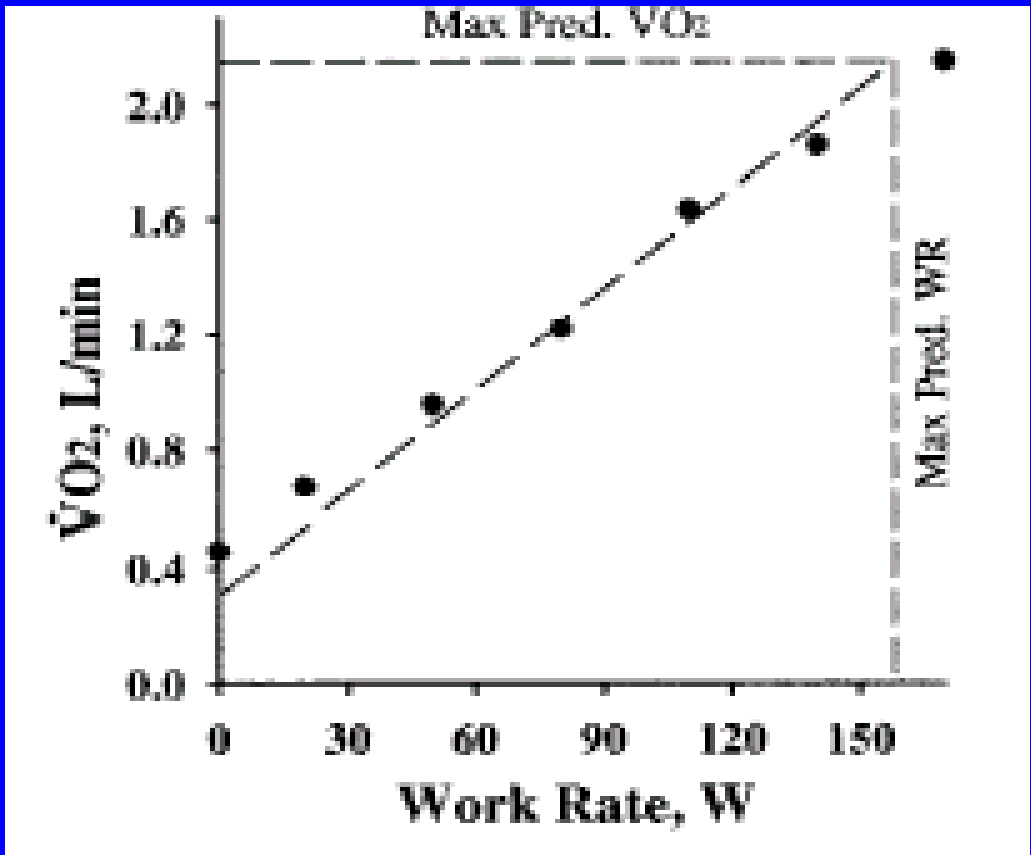
VO_2 max

- Maximum VO_2 plateau achieved during maximal incremental exercise
- Best index of aerobic capacity & cardiorespiratory fitness
- Peak VO_2 if clear plateau not achieved due to symptom limitation of exercise
- Predicted VO_2 max calculated (N >84% predicted)

  Male: W x (50.75-0.372xA)

  female: W+43 x (22.78-0.17xA)

VO2 –WR relation



Linear relation normal

Reduction of slope indicates-Inadequate O2 transport / utilization

Disease of heart ,lung or circulation
Musculoskeletal disease
Poor effort

Oxygen uptake

- Resting VO2: 3.5 ml/kg/min(250 ml/min)
- VO2 max: 30-50ml/kg/min(15 times basal)
- Trained athletes: 80ml/kg/min
- Decrease in VO2 max is general indicator of reduced exercise capacity
- Cause of exercise limitation determined by pattern of response & other variables

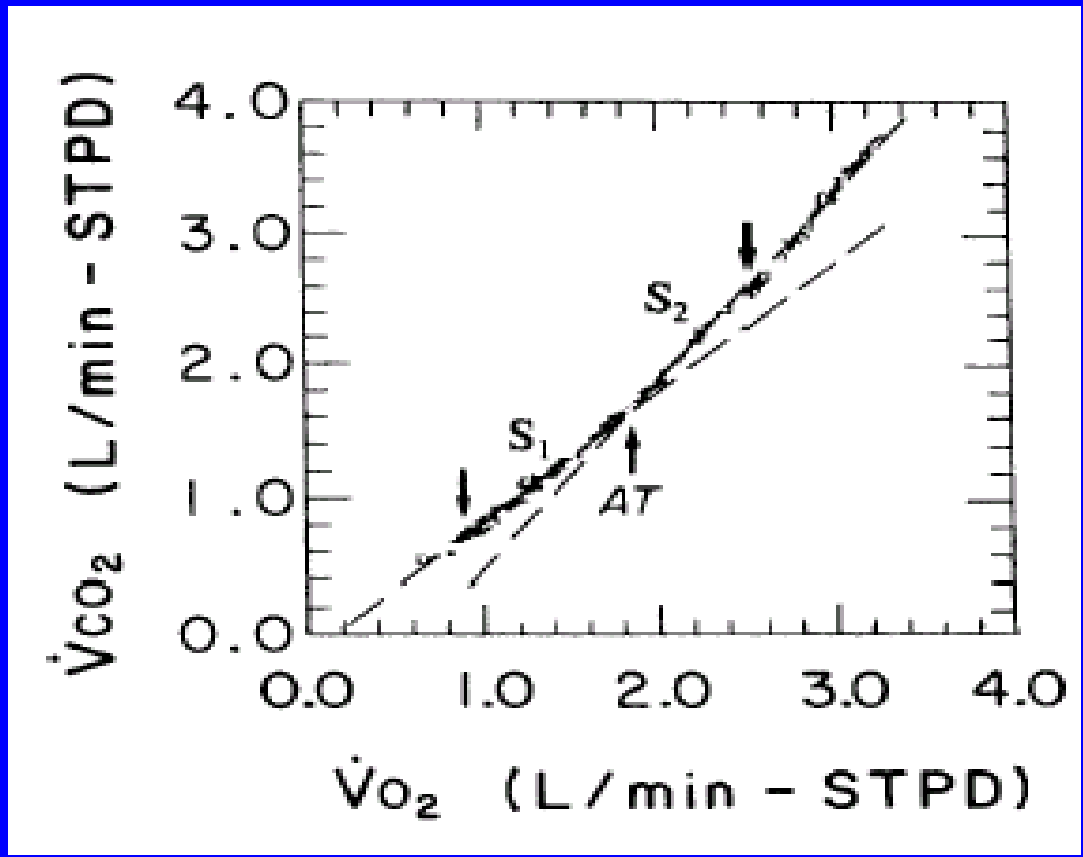
Oxygen pulse

- Ratio of oxygen uptake to HR (N >80%)
- Amount of oxygen extracted per heart beat
- Reflects the product of stroke volume & oxygen extraction
- Indicates cardiac dysfunction(assuming O2 extraction is normal)
- Low O_2 pulse :
  - Cardiovascular disease
  - Deconditioning/poor effort
  - Early exercise limitation(respir disease)

CO_2 Output (VCO_2)

- CO_2 output during exercise depends on cardiac output, CO_2carrying capacity and tissue exchange
- VCO_2 increases nearly linear with VO_2 at lower work rates, after the AT the VCO_2 increases steeply as lactate is buffered by bicarbonate at higher work loads.

Anaerobic Threshold - V slope method



Anaerobic threshold

- Occurs at 50- 60% of VO_2 max predicted in normal (wide range of normal 35-80%)
- Indicates the upper limit of exercise that can be performed aerobically
- AT below 40% predicted VO_2 max indicate cardio-pulmonary disease or limitation of O_2 supply to tissues or mitochondrial dysfunction in muscle

Anaerobic threshold

Noninvasive

- V slope method
- Modified V slope method
- Ventilatory equivalent method

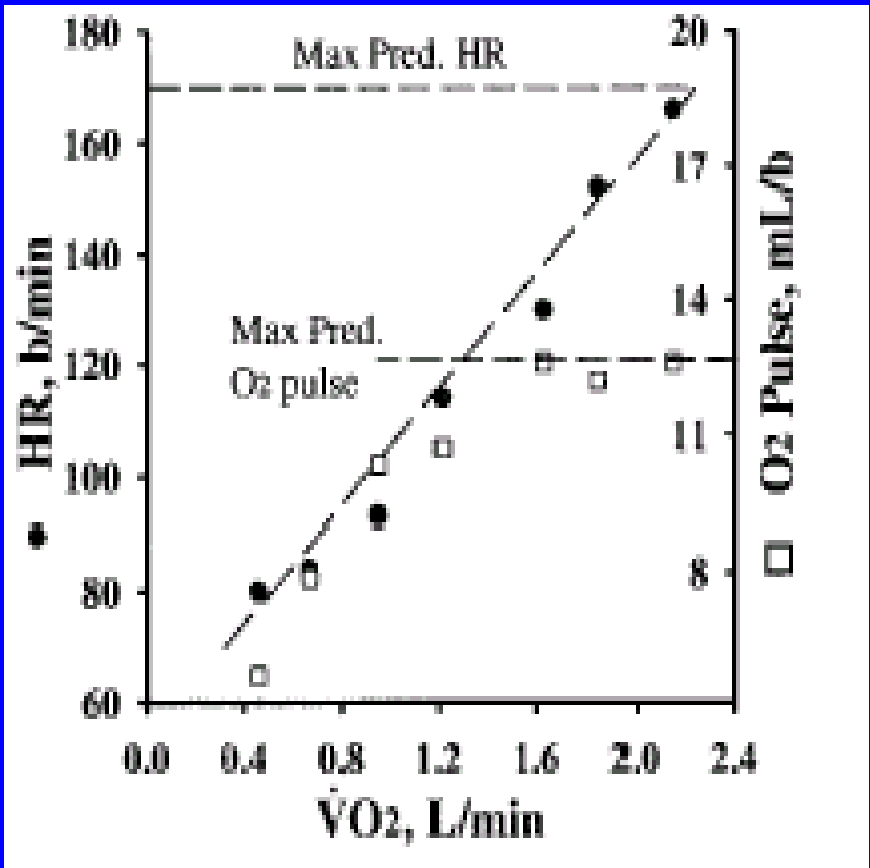
Invasive (Arterial)

- lactate
- Bicarbonate

Cardiac parameters

- Cardiac output(CO) increases linearly with VO_2 and does not vary with training
- Initial increase CO by increase HR and SV at low work , later exclusively by HR increase at high work loads
- Heart rate reserve: difference of max HR achieved and max predicted HR
- Normal < 15bpm

HR-VO2 relation



Linear relation

Age predicted maximal HR used to signal maximal effort

Pred max HR= 220 - age or 210 - Age X 0.65

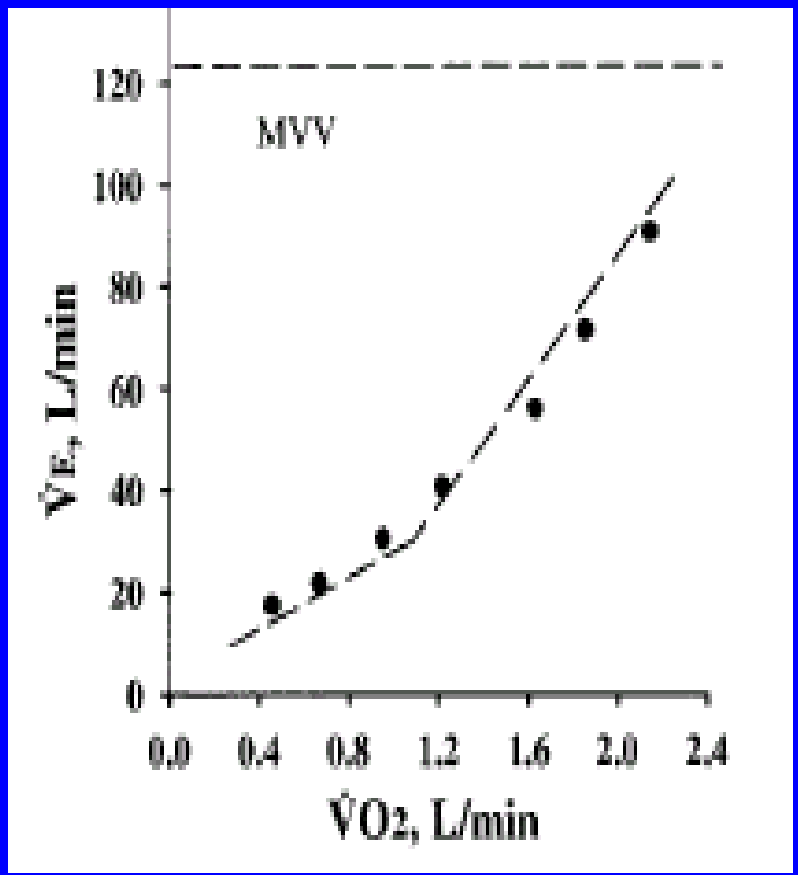
Ventilation parameters

- Minute ventilation (V_E) increases with exercise : increase V_T at mod work(up to 50-60 % of VC) and later by increase Fr at high work loads
- Normal subjects Fr increases by 1-3 fold
- Athletes Fr increases by 5-7 folds

Ventilatory reserve

- Difference or ratio between max minute ventilation during exercise(V_E max) and the maximal voluntary ventilation(MVV)
- Normal reserve > 15% of MVV (range 72+/-15%)
- MVV calculated as FEV_1 x 40 (approximates the measured value)
- Pulmonary diseases have reduced reserve
- Cardiac diseases have normal reserve

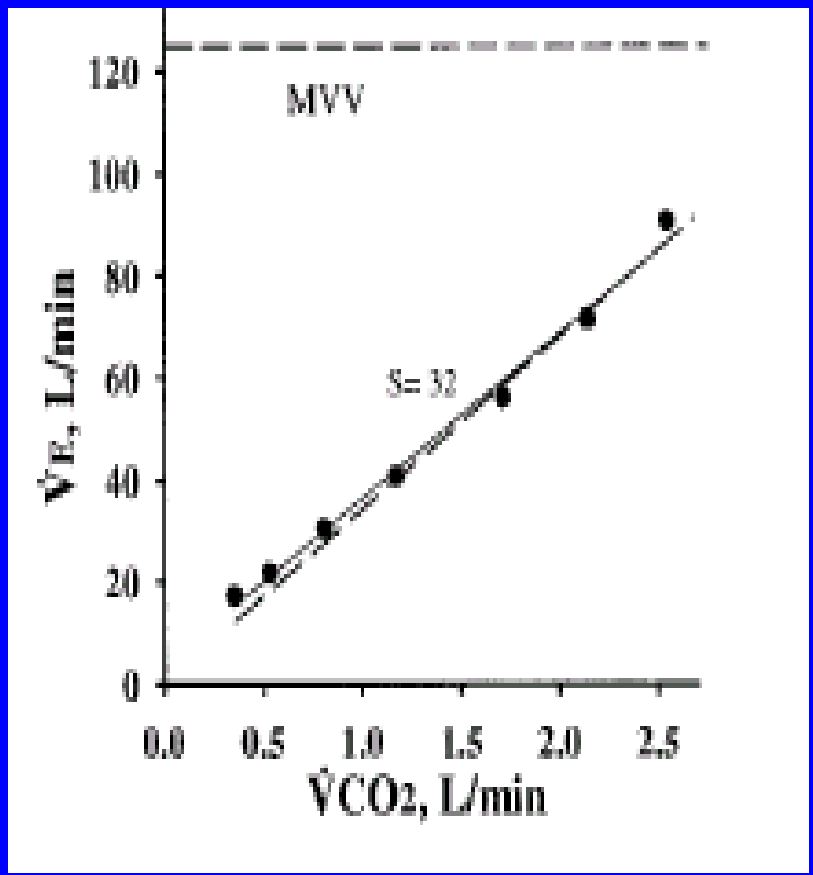
VE and VO2



Relation complex

Usually nonlinear

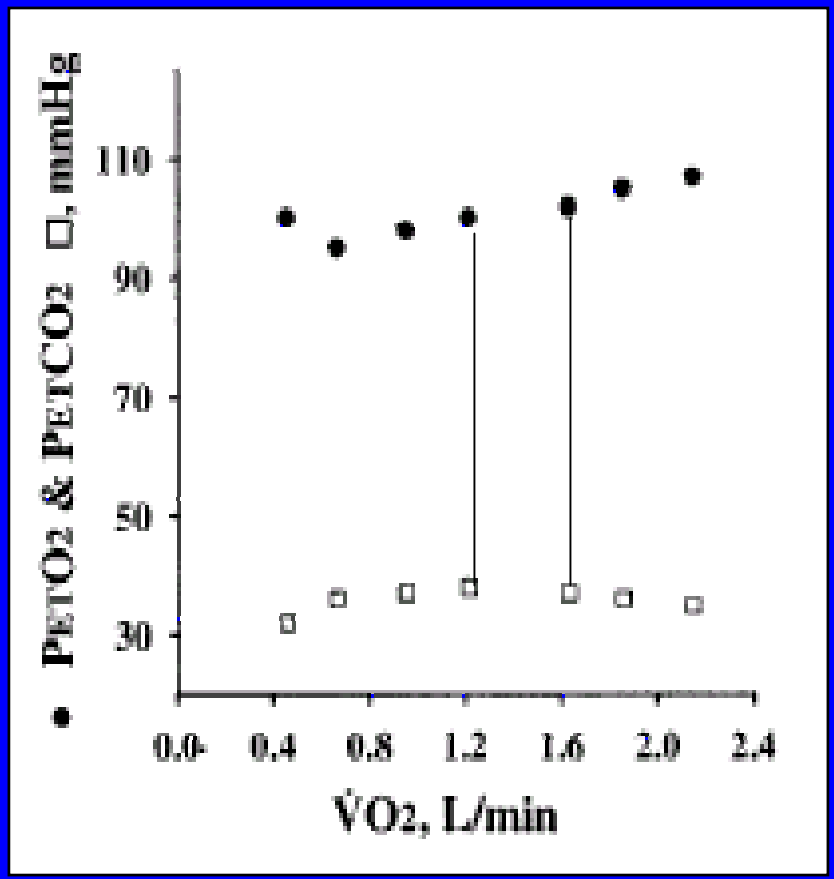
VE and VCO2



Healthy subjects linear relation (23 -25 L VE required to remove one litre CO2)

Psychogenic /Anxiety disorders assoc with increased VE/VCO2 hypocapnia with respir alkalosis

End tidal O2 and CO2



Isocapnic buffering

buffering of the lactate (after AT) increased production of the CO2 and ventilation increases proportionately so the alveolar & arterial CO2 do not change.
With further,accumulation of lactate -VE increases and CO2 falls

Normal parameters

Variables	Criteria of Normality
$\dot{V}O_2$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 (fR)	< 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

Summary: Response patterns

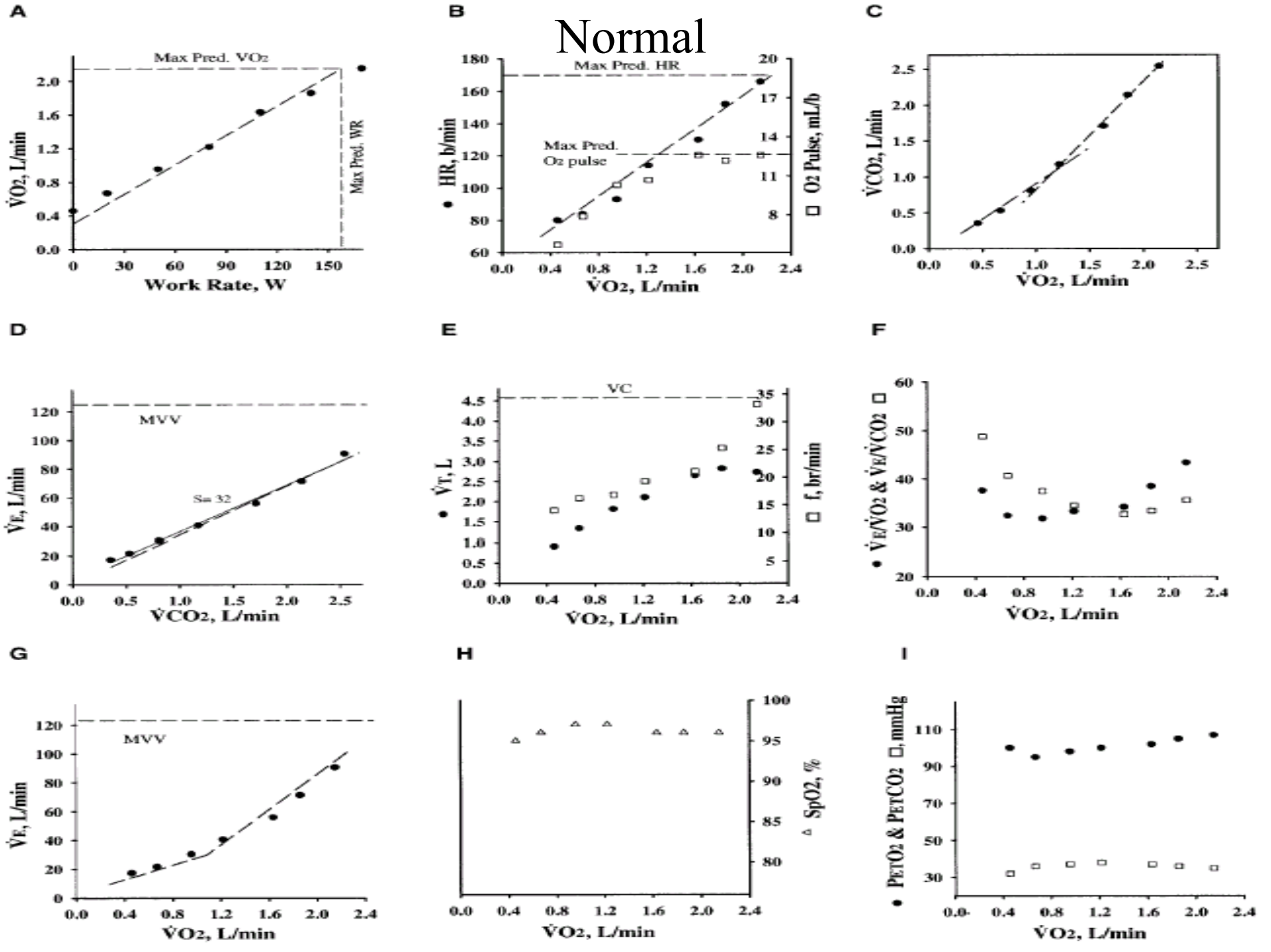
Variable	Respir Disease	Cardiac Disease	Pulm vascular	Deconditioning
VO_2 max	Low	Low	Low	Low
AT	N/low	Low	N/low	N/low
HR Reserve	Increase	reduced	N/low	Normal
Ventilatn Reserve	low	Normal	Normal	Normal
P(A-a) O_2	COPD ↑ ILD	Normal	Increased	Normal

Interpretation

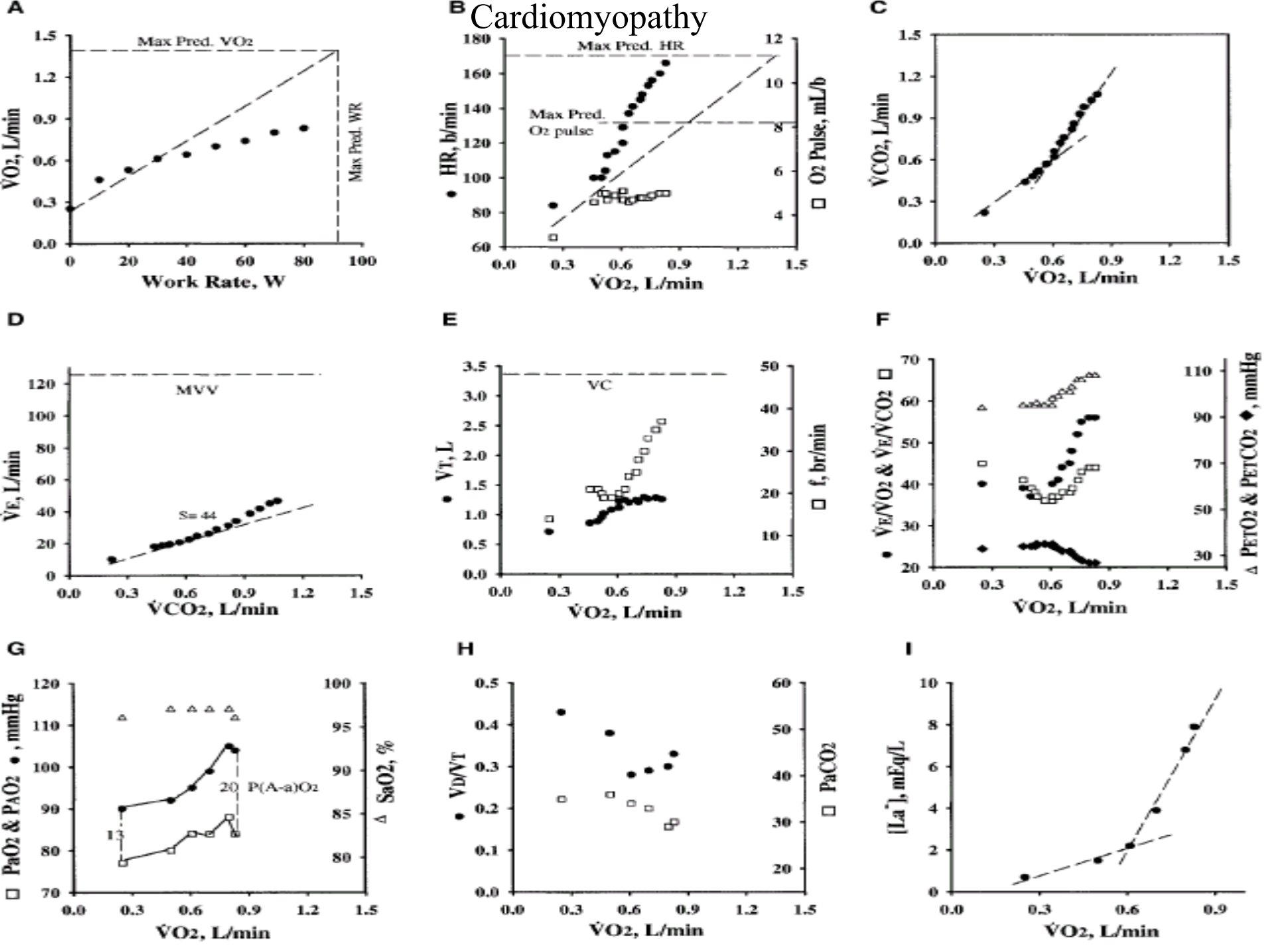
Results are rarely clear-cut ,and interpretation may be challenging,sometimes very difficult

- Review clinical and laboratory information
- Identify key variables: V_E max ,MVV, HR, SaO2
- Compare exercise responses with appropriate normal reference values
- Evaluate cause exercise limitation
- Patterns of exercise responses

Normal


A
Max Pred. V̇O2
V̇O2, L/min
Max Pred. WR
Work Rate, W
B
Max Pred. HR
Max Pred. O2 pulse
HR, b/min
O2 Pulse, mL/b
V̇O2, L/min
C
V̇CO2, L/min
V̇O2, L/min
D
MVV
Sa 32
V̇E, L/min
V̇CO2, L/min
E
VC
V̇T, L
f, br/min
V̇O2, L/min
F
V̇E/V̇O2 & V̇E/V̇CO2
V̇O2, L/min
G
MVV
V̇E, L/min
V̇O2, L/min
H
SpO2, %
V̇O2, L/min
I
PETO2 & PETCO2, mmHg
V̇O2, L/min

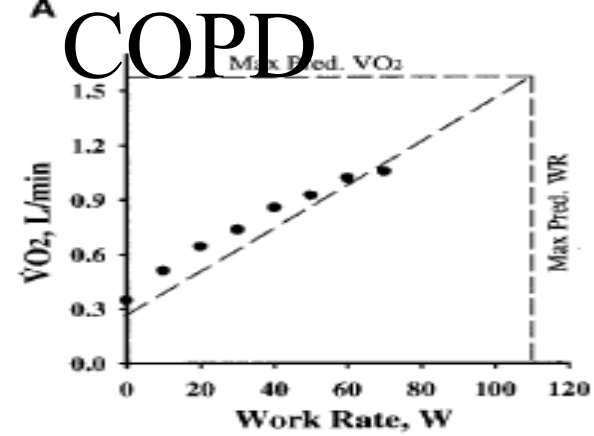
Cardiomyopathy

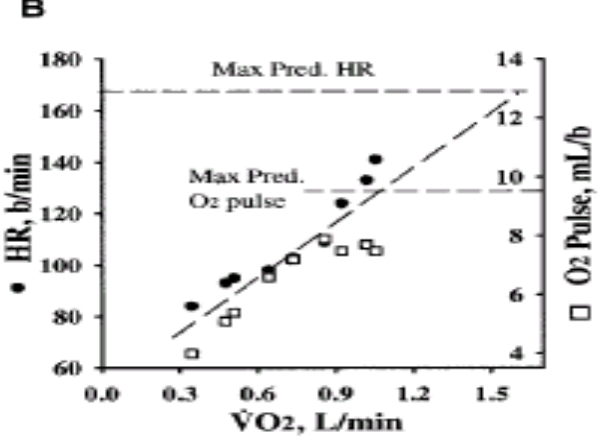


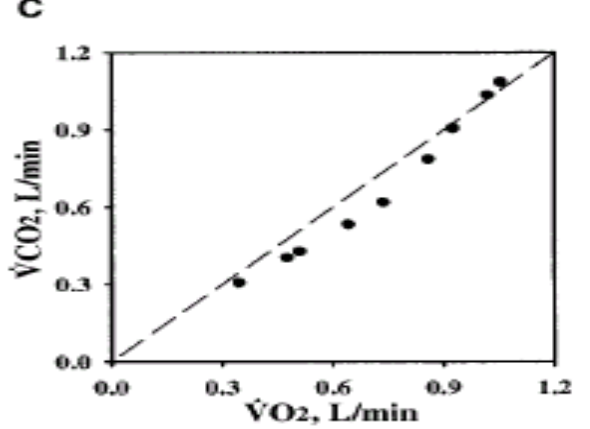
Cardiac disease

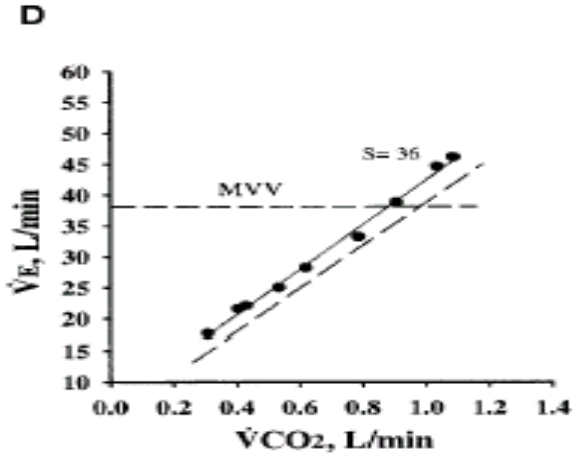
- Reduced peak work rate and peak VO2
- Low AT(early onset metabolic acidosis)
- Low oxygen pulse
- High HR response (↓ reserve)
- Ventilatory reserve normal
- No desaturation

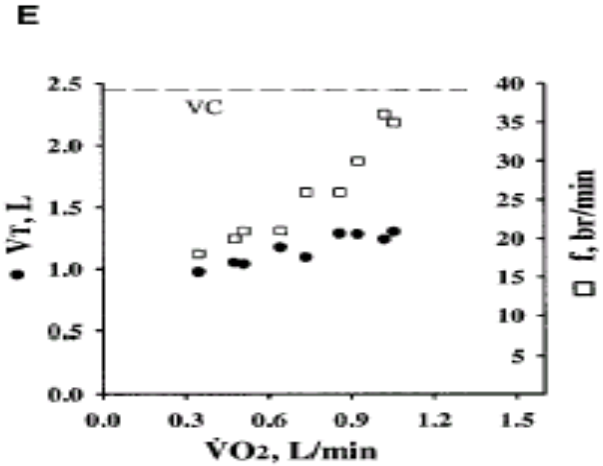
COPD

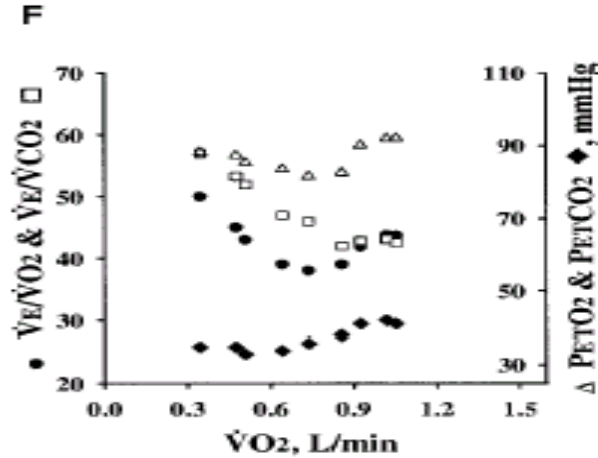

A
Max Pred. VO2
Max Pred. WR
V̇O2, L/min
Work Rate, W

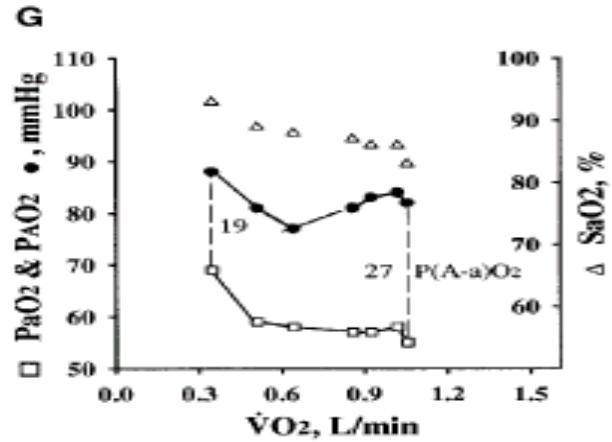

B
Max Pred. HR
Max Pred.
O2 pulse
HR, b/min
O2 Pulse, mL/b
V̇O2, L/min

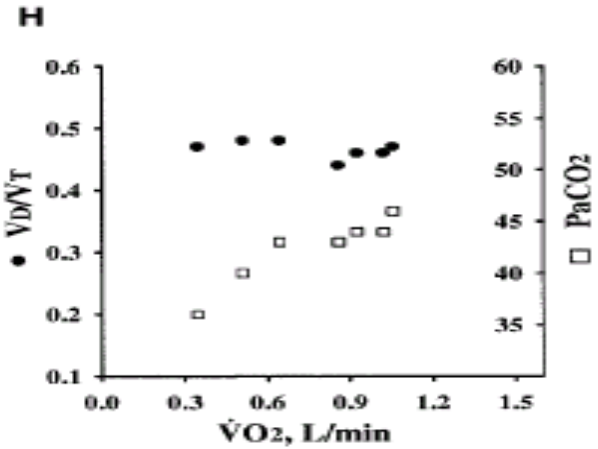

C
V̇CO2, L/min
V̇O2, L/min

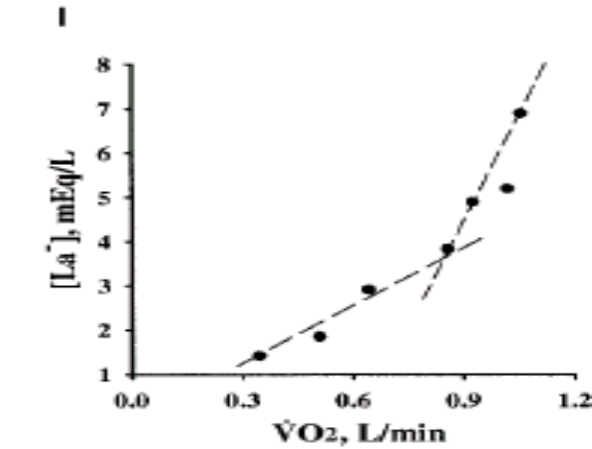

D
S= 36
MVV
V̇E, L/min
V̇CO2, L/min


E
VC
VT, L
f, br/min
V̇O2, L/min


F
V̇E/V̇O2 & V̇E/V̇CO2
PETO2 & PETCO2, mmHg
V̇O2, L/min


G
PaO2 & PAO2, mmHg
SaO2, %
19
27
P(A-a)O2
V̇O2, L/min

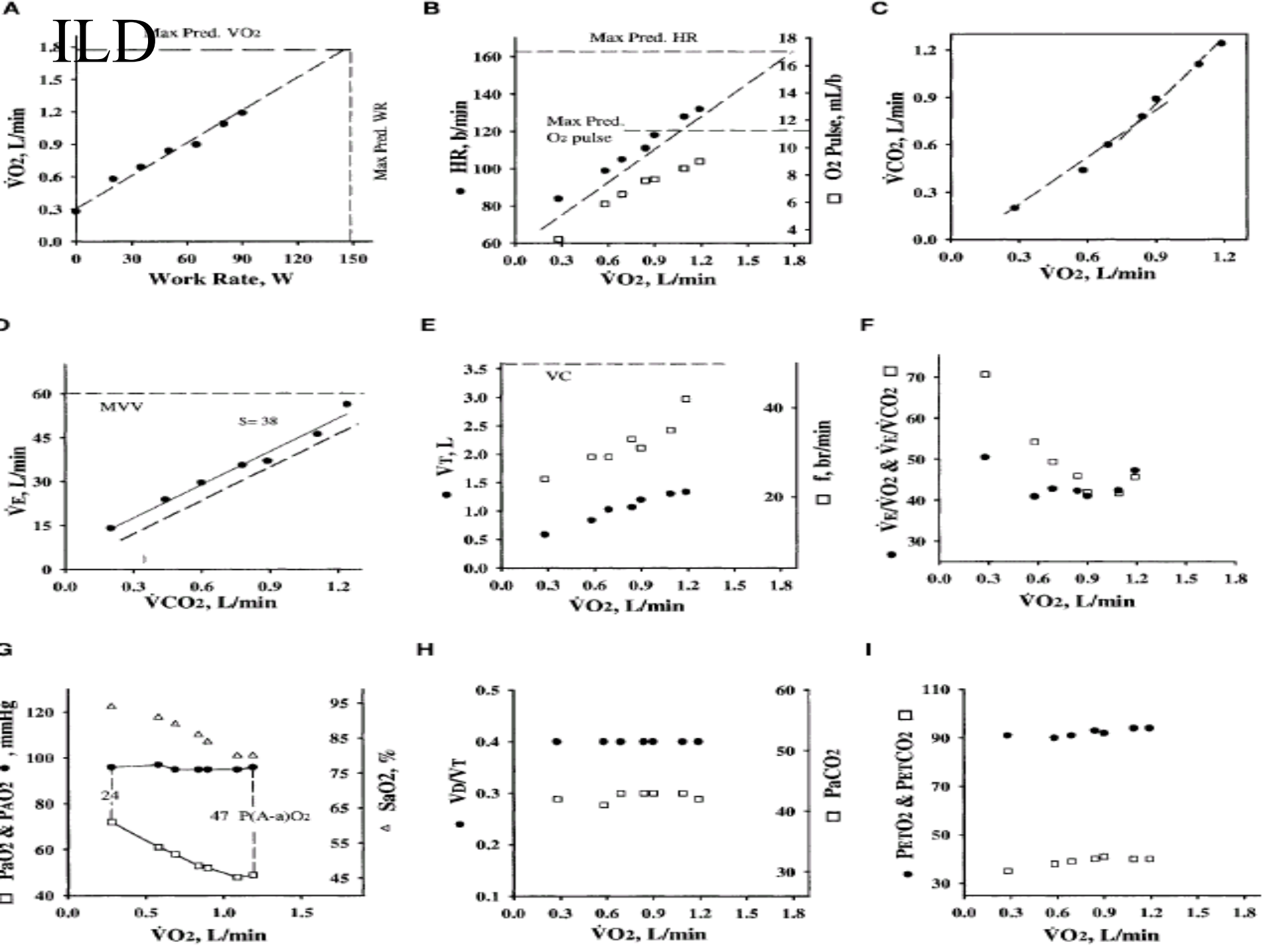

H
VD/VT
PaCO2
V̇O2, L/min


I
[La-], mEq/L
V̇O2, L/min

COPD

- Reduced peak work rate and peak VO_2
- Noninvasive AT : ABG may avoid false positive
- Reduced ventilatory reserve(>100%)
- Peak HR reduced(significant HRR)
- O2 pulse reduced proportionate to VO_2 peak
- Hypoxemia - especially in emphysema (~DLCO)
- Hypercapnia(V/Q abnormalities and reduced drive in severe cases)`

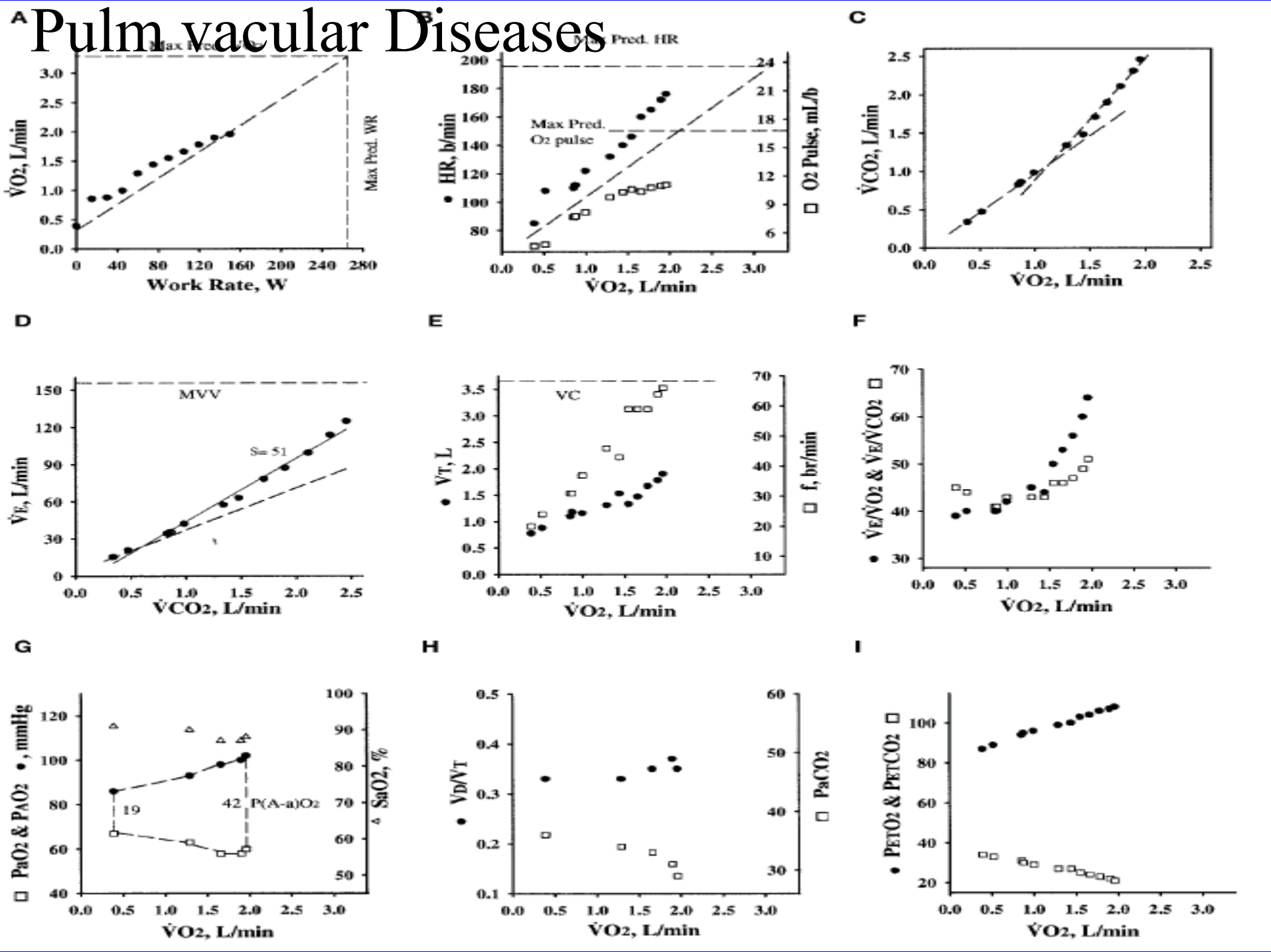
ILD


A
Max Pred. VO2
V̇O2, L/min
Max Pred. WR
Work Rate, W
B
Max Pred. HR
Max Pred. O2 pulse
HR, b/min
O2 Pulse, mL/b
V̇O2, L/min
C
V̇CO2, L/min
V̇O2, L/min
D
MVV
S= 38
V̇E, L/min
V̇CO2, L/min
E
VC
VT, L
f, br/min
V̇O2, L/min
F
V̇E/V̇O2 & V̇E/V̇CO2
V̇O2, L/min
G
PaO2 & PAO2, mmHg
SaO2, %
24
47 P(A-a)O2
V̇O2, L/min
H
VD/VT
PaCO2
V̇O2, L/min
I
PETO2 & PETCO2
V̇O2, L/min

ILD

- Reduced peak work rate and peak VO_2
- AT N/reduced
- Reduced ventilatory reserve(>100%)
- Abnormal breathing pattern(high Fr, low V_T)
- Significant hypoxemia (~ resting DLCO)
- Wide P(A-a)O2 gradient
- Low HRR- coexisting Cor pulmonale

Pulm vacular Diseases



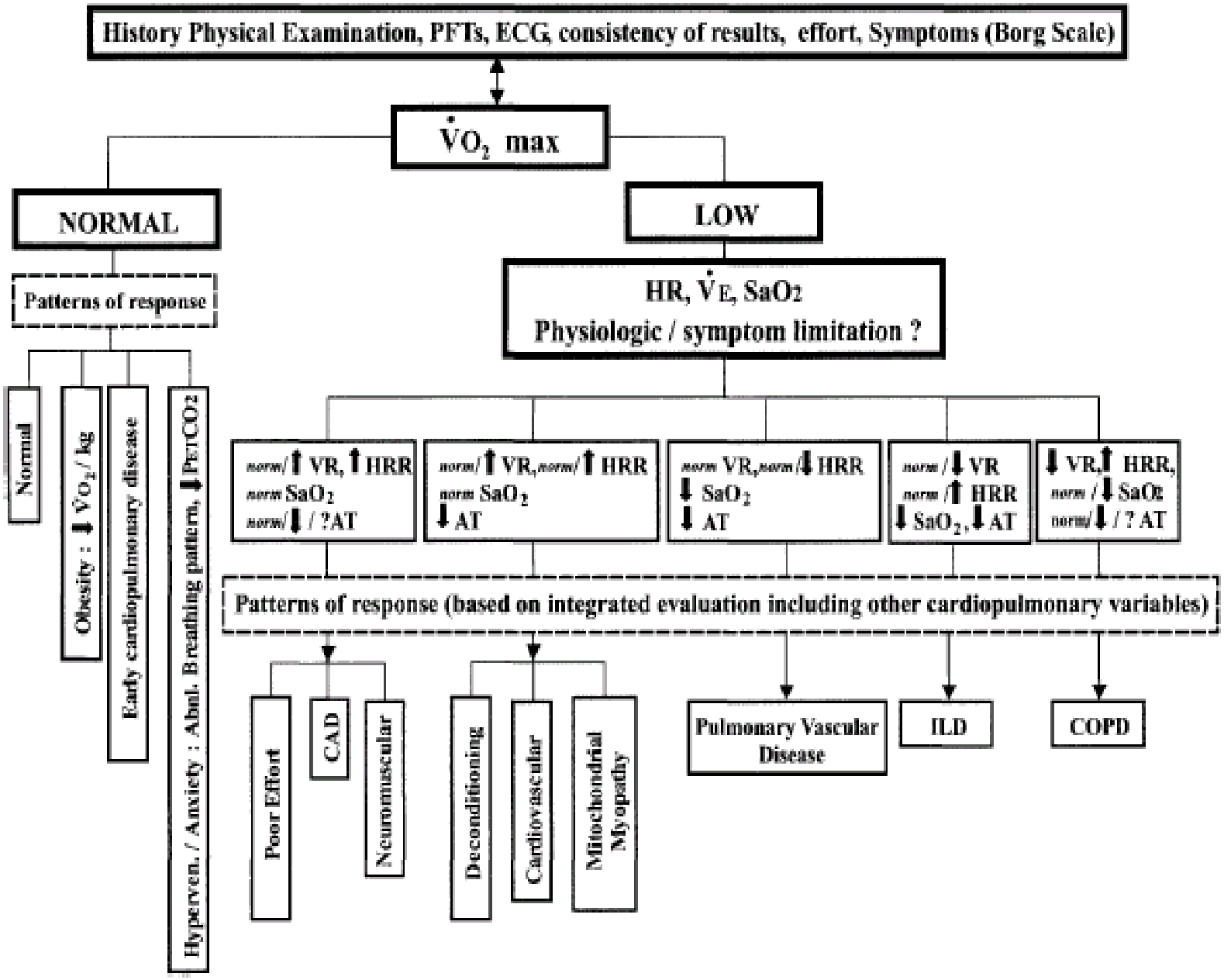
Pulm Vascular disease

- Reduced peak work rate and peak VO_2
- AT reduced (early metabolic acidosis)
- Reduced Oxygen pulse
- Ventilatory reserve normal
- HRR usually near normal (low- Cor pulmonale)
- Significant hypoxemia
- Wide P(A-a)O2 gradient

Deconditioning (Unfitness)

- Reduced peak peak VO_2 (lower limit of N)
- Low AT
- Reduced O2 pulse
- Normal peak HR (no HRR)
- Normal ventilatory reserve
- Diff to distinguish from early cardiac disease - history and response to training
- May be coexistent with chronic diseases

Interpretation of CPET



Future directions

- Reference normal values from multicenter studies required(few studies from India)
- Evidence based interpretation using standardized methodology& protocols
- Impact of pattern based analysis on clinical decision making
- Evaluate new exercise protocols(constant work rate,exponential exercise)
- Role of invasive vs noninvasive CPET