Hemodynamics of Exercise

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Exercise Physiology - Acute Effects

- Cardiac Output ↑
  - (Stroke volume ↑, Heart Rate ↑)
- Oxygen Extraction ↑
  - (Arteriovenous O_2 difference ↑, “A-V O_2 difference”)
- Metabolic change
  - more carbohydrate metabolism, less fat
  - hepatic gluconeogenesis, use of muscle glycogen
  - Respiratory quotient ↑ (resting ~0.7, exercise ~1.0)
- Blood flow distribution from splanchnic to muscle

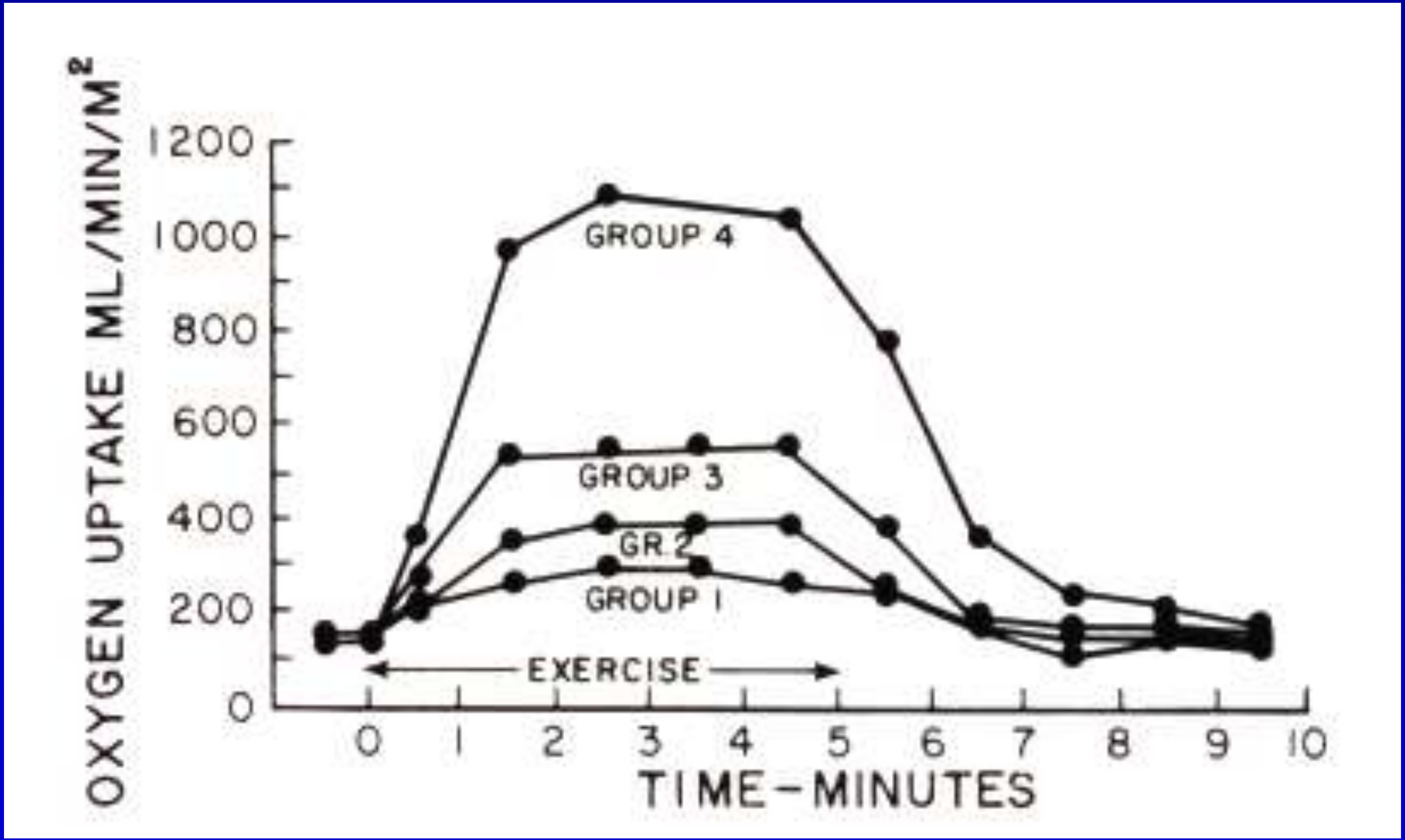
Exercise Physiology - Pulmonary Effects

- Progressive increase in minute ventilation, especially above anaerobic threshold
- Above anaerobic threshold - accumulation of H^+
  - skeletal muscle weakness
  - RQ >1.0
  - severe dyspnea
  - exhaustion

Exercise During Catheterization

- Steady state, submaximal
- Measurements:
  - Expired air collections or metabolic cart measurements (O_2 consumption)
  - Arterial and venous O_2 content for A-V O_2 difference
  - Heart rate
  - Systemic and pulmonary pressures

Oxygen Consumption during Exercise



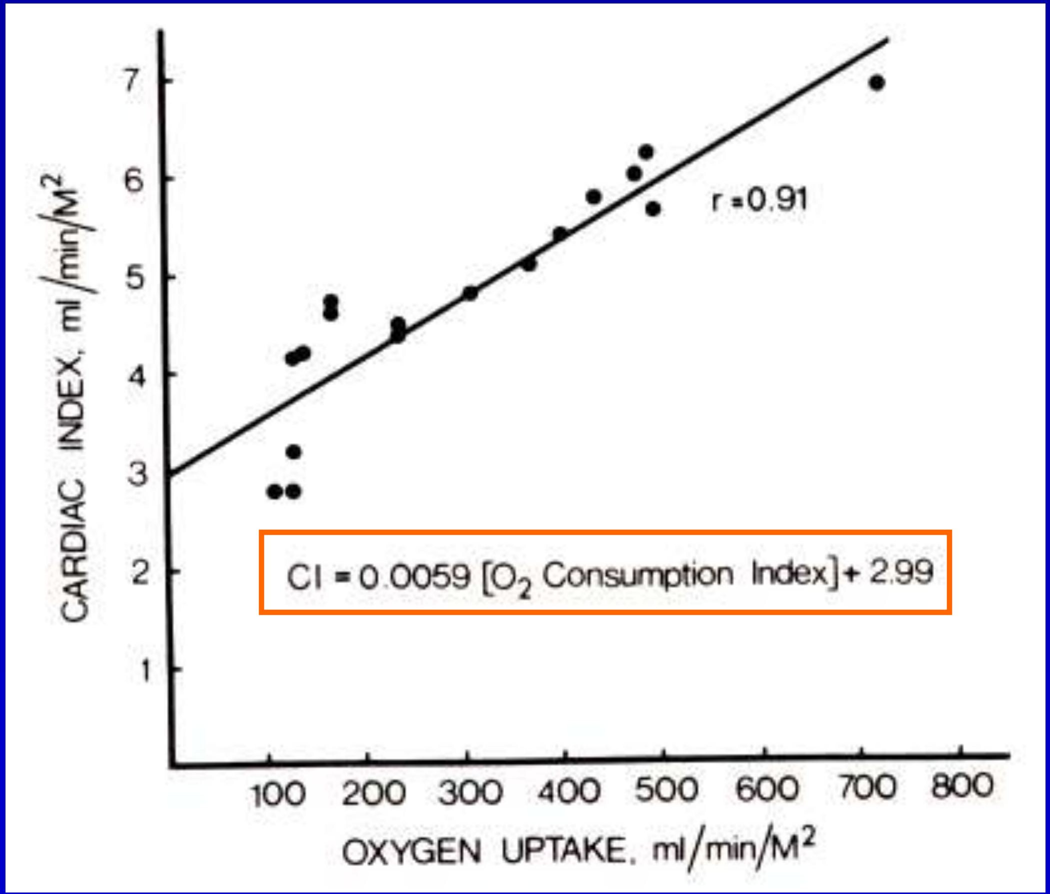
From Grossman, 5th ed, 1996, p. 282; original 1955 Donald et al.

Oxygen Consumption and Cardiac Output

Data in 7 normal subjects.

Exercise Factor:
C.O. should increase by 600cc/min for each 100cc/min increase in Oxygen consumption:
$\Delta C.O./\Delta O_2 \geq 6$.

Measured C.O. should be >0.8 of predicted.



From Grossman, 5th ed, 1996, p. 283; original 1951 Dexter et al.

Effect of Exercise on Cardiac Pressures and Volumes - 1

- Systolic and mean arterial pressure increase with oxygen consumption
- Systemic vascular resistance decreases considerably
- Mean pulmonary artery pressure increases with cardiac output
- Pulmonary vascular resistance decreases only slightly
- Heart rate increases linearly with oxygen consumption and in supine exercise accounts for almost all of the increase in C.O.

Effect of Exercise on Cardiac Pressures and Volumes - 2

- Increase in HR gives increase in contractility (Treppe effect)
- LV diastolic volume decreases in supine exercise
- LV ejection fraction increases
- LV end systolic volume decreases (stroke volume changes little)

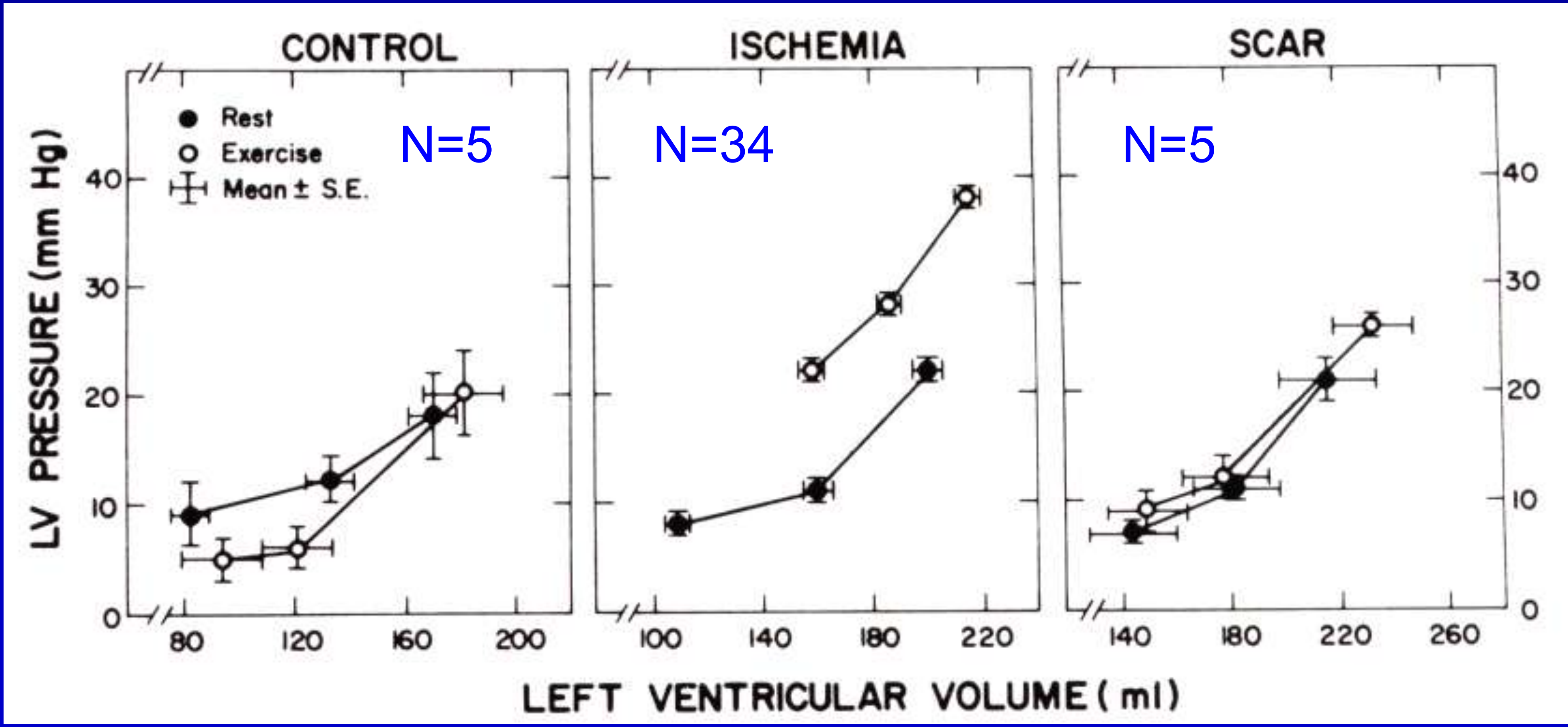
Upright vs Supine Exercise

- Resting cardiac output, LVEDV and SV are lower in upright posture
- With upright exercise, LVEDV and SV increase up to a point of about 50% of peak Oxygen consumption, then plateau

Effects of Age and Gender on Exercise Response

- In youth, LVEDP decreases or is constant during supine exercise
- In elderly, LVEDP generally rises
  - 10 normal men age 46, supine LVEDP rose from 8 to 16, and sitting LVEDP rose from 4 to 11
- In women, increase in SV sitting is from increase in LVEDV without increase in EF, but in men the EF increases progressively

LV Diastolic Function in Exercise



Ischemia results in increase in diastolic volume & decrease in distensibility.

From Grossman, 5th ed, 1996, p. 285; original 1983 Carroll et al.

Exercise in Diastolic Dysfunction

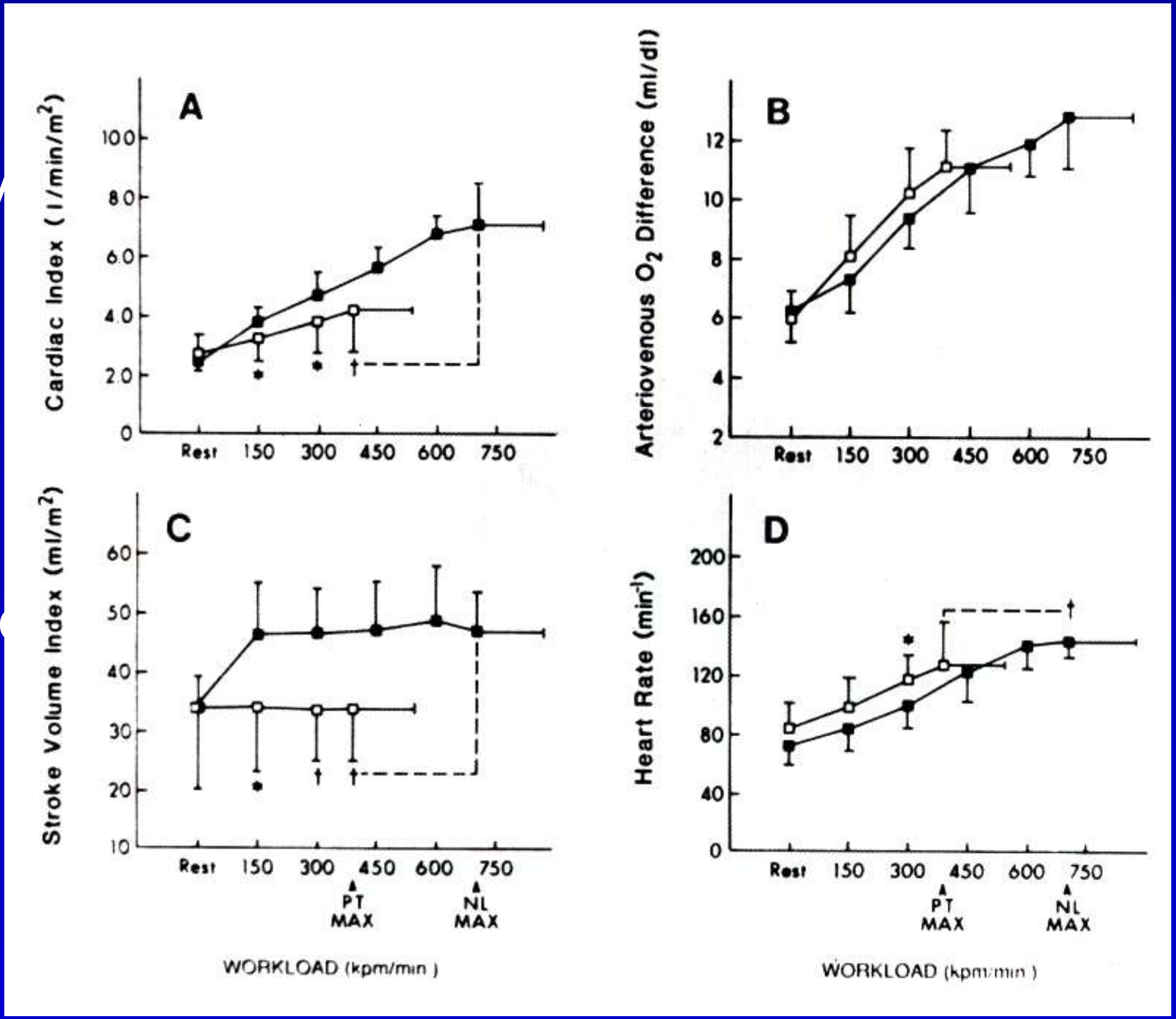
- LV relaxation is slow (long tau)
- Depressed relaxation worsens in tachycardia
- With small resting LV end-systolic volume, exercise enhancement is attenuated
- Ischemia during tachycardia is more likely in hypertrophy - impaired distensibility

Exercise in Diastolic Dysfunction

7 patients with heart failure class III or IV and pulmonary edema at least once, and normal LV EF, most with increased wall thickness and mass (open symbols)

Controls matched for age and closed symbols

Upright bicycle exercise

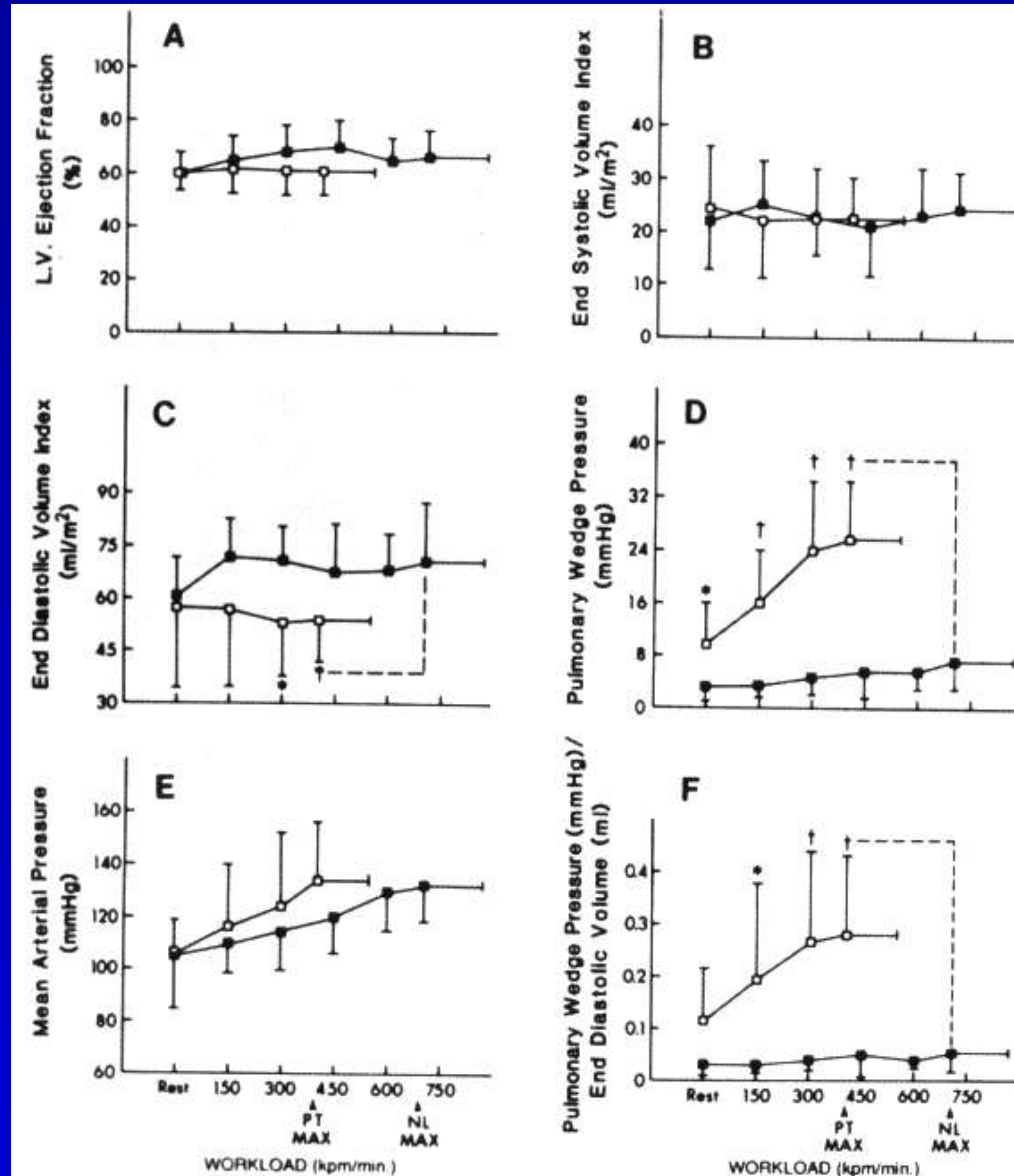


From Grossman, 5th ed, 1996, p. 287; original 1991 Kitzman et al.

Exercise in Diastolic Dysfunction - 2

Note:

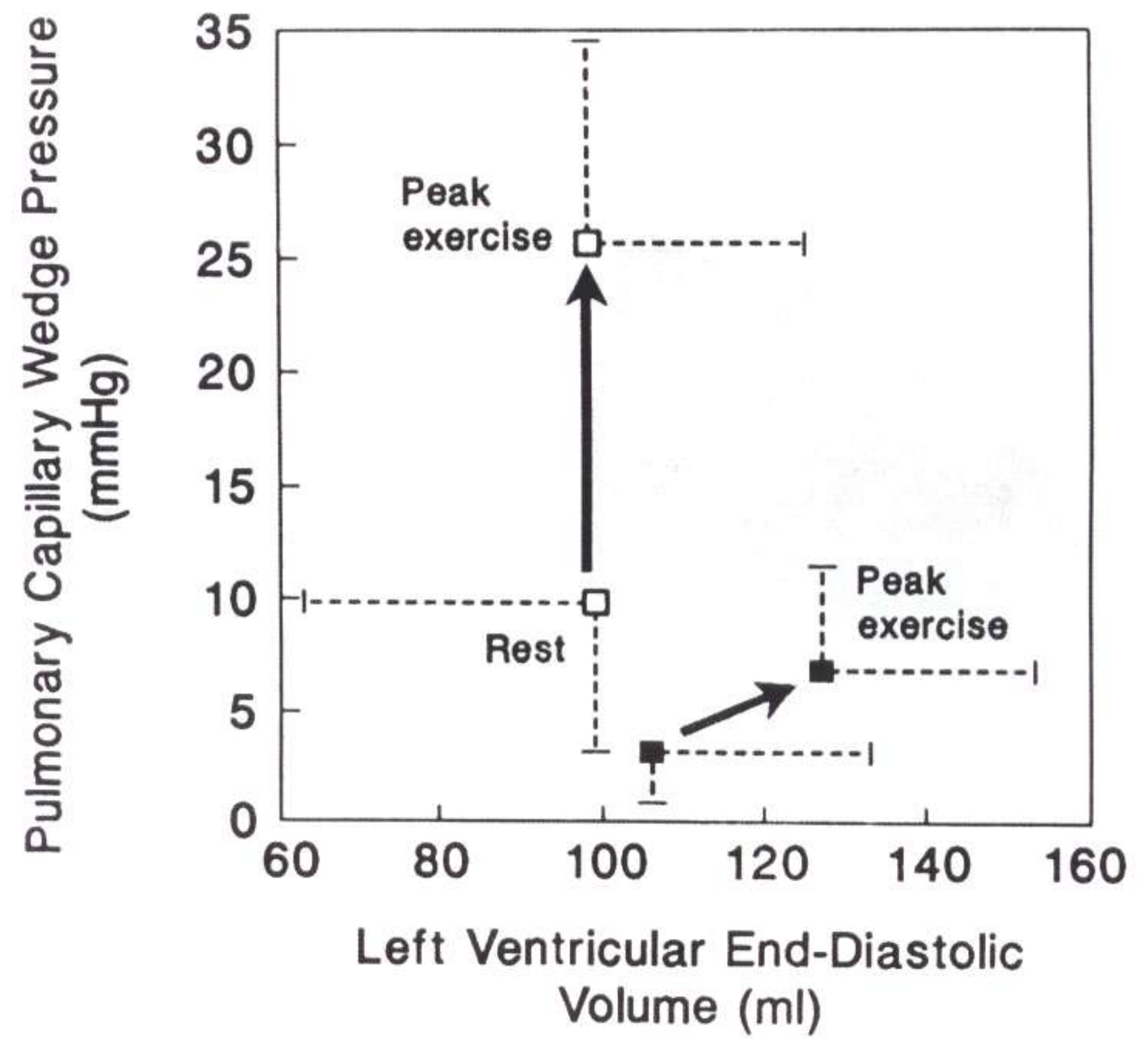
A - No difference in LV EF
B - EDV doesn't increase
C - No difference in BP
D - No difference in ESV
E - Large increase in PCW
F - Large increase in stiffness



From Grossman, 5th ed, 1996, p. 288; original 1991 Kitzman et al.

Exercise in Diastolic Dysfunction - 3

Summary of exercise response in diastolic dysfunction versus normal subjects



From Grossman, 5th ed, 1996, p. 289; original 1991 Kitzman et al.

Exercise Function Assessment - 1

	Resting	Exercise
36 year old woman, supine bicycle exercise		
Oxygen consumption index (ml/min/m2)	117	504
AV Oxygen difference	34	75
Cardiac Index	3.4	6.7
Heart rate	80	140
Systemic arterial pressure	130/70(95)	142/83(110)
RA mean pressure	6	7
PCW mean	11	27
LV pressure	130/17	142/28
Exercise index		1.1
Exercise factor		8.5

DCM, LV EF 40%,

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DCM, LV EF 40%, Nl exercise factor, but abnl PCW, so dyspnea=cardiac

Exercise Function Assessment - 2

	Resting	Exercise
60 year old man, supine bicycle exercise		
Oxygen consumption index (ml/min/m2)	128	469
AV Oxygen difference	40	96
Cardiac Index	3.2	4.9
Heart rate	90	141
Systemic arterial pressure	91/62(73)	107/67(88)
RA mean pressure	5	20
PCW mean	12	34
LV pressure	91/16	107/34
Exercise index		0.85
Exercise factor		4.9

DCM

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DCM with severe exercise intolerance; borderline exercise factor, high R+L diastolic pressures

Exercise in Evaluation of Valvular Heart Disease

Valvular Stenosis

- Provocation of significant gradient
- Most useful when resting results are of borderline significance
- Valve area usually slightly larger with exercise
- Useful during mitral valvuloplasty

Exercise in Evaluation of Valvular Heart Disease

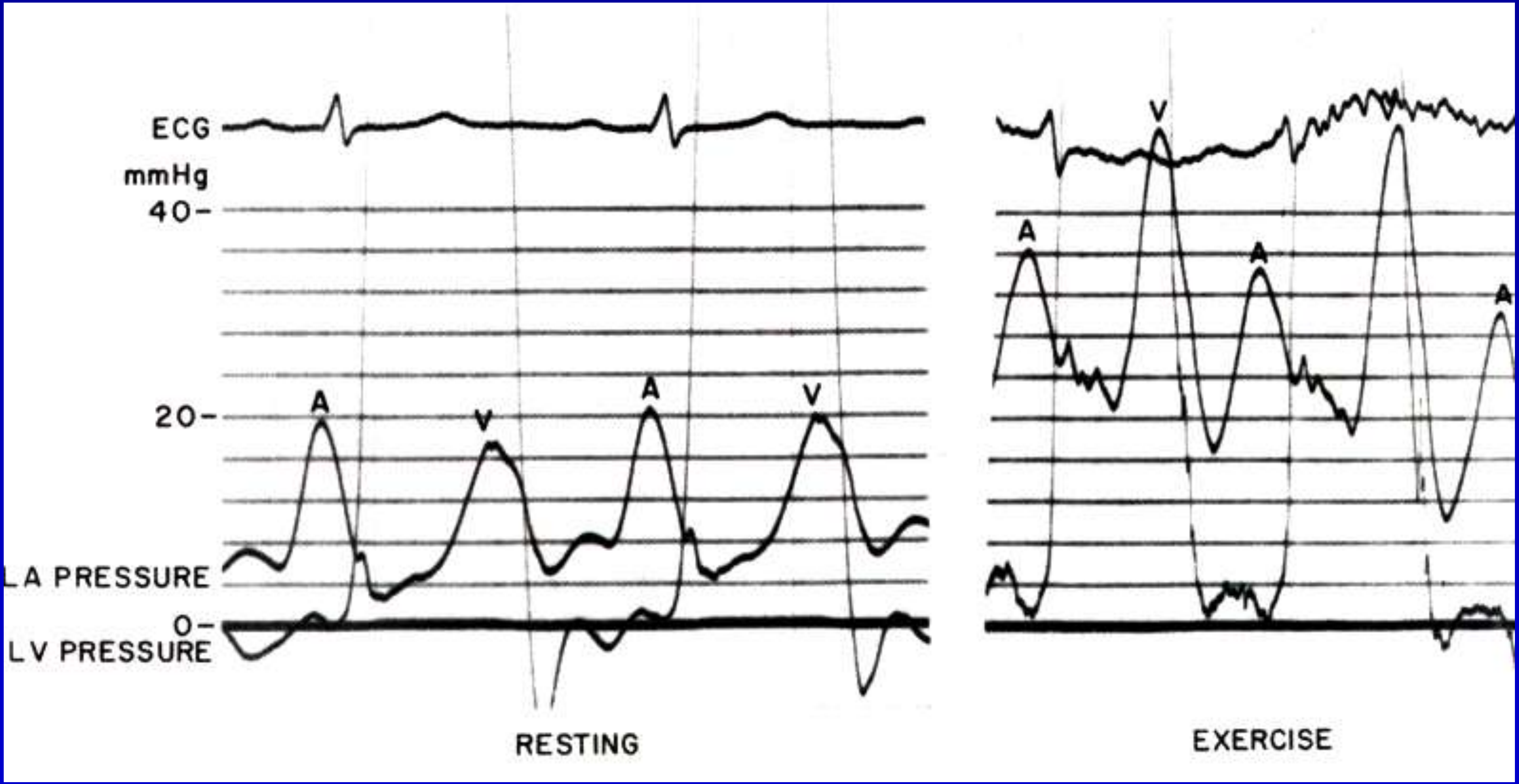
Valvular Regurgitation:
- Angiographic assessment
  - May be unreliable
  - May not predict symptoms
- Hemodynamic response may elucidate symptoms

Exercise in Evaluation of Valvular Heart Disease

Patient with mitral stenosis, supine bicycle exercise

	Resting	Exercise
Oxygen consumption (ml/min)	207	688
AV Oxygen difference	31	74
Cardiac Output	6.5	9.3
Heart rate	72	108
LA pressure		
A	20	34
V	18	46
mean	10	26
LV mean diastolic pressure	1	4
Mitral valve area	1.6	1.8
Exercise index		1.2
Exercise factor		5.8

Exercise in Evaluation of Valvular Heart Disease



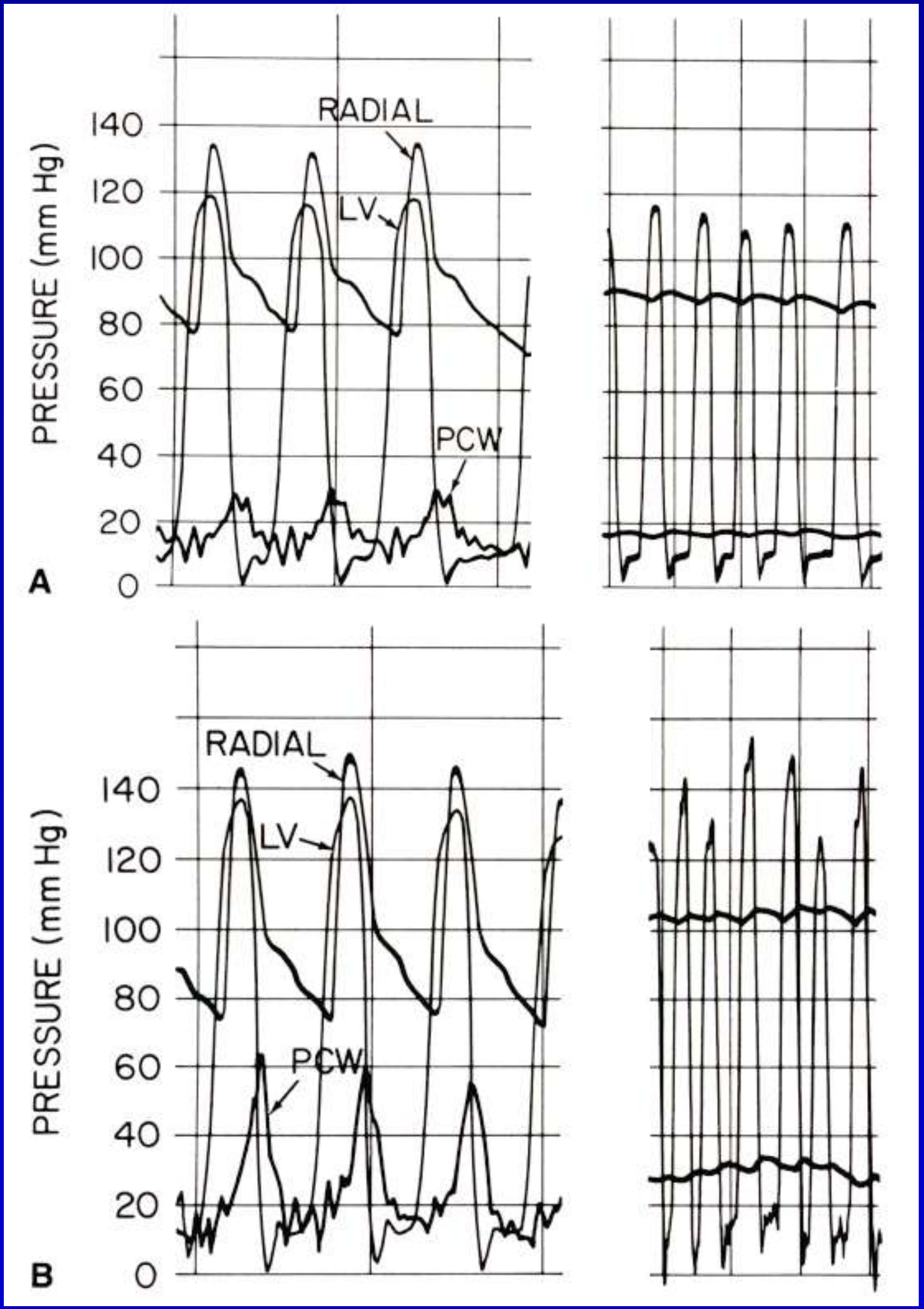
From Grossman, 5th ed, 1996, p. 291

Exercise in Evaluation of Valvular Heart Disease

55 year old man with mitral regurgitation

A. Resting
B. 6 minutes supine bicycle

Substantial increase in PCW mean and in PCW V wave



From Grossman, 5th ed, 1996, p. 292

Performing a Dynamic Exercise Test

- Supine bicycle, arm or femoral
- Choose measurements
- After baseline measures
- Before angiography
- Feet up in stirrups
- Oxygen consumption apparatus placed
- Instruct patient
- Steady state level of stress
- Zero and calibrate all transducers with feet up
- Repeat pressures feet up
- Exercise: all pressures displayed at slow sweep
- Repeat pressures, exercise

Measurements during Exercise

<u>Flow/metabolic</u>

- Thermodilution
- Arterial and venous saturations
- Oxygen consumption
  - Douglas bag
  - Waters hood (MRM)
  - Metabolic cart

<u>Pressure</u>

- LV phasic
- Arterial phasic, then mean
- Pulmonary capillary phasic, then mean
- During exercise slow sweep, except each minute

Isometric Exercise

- Hemodynamic response
  - HR, BP, CO, Stroke work, EF increase
  - SVR, EDP, SV constant
  - ESV and EDV decrease
- Heart disease
  - Stroke work variable
  - LVEDP increases
- Sustained handgrip
  - Determine maximal voluntary contraction
  - Grip at 30-50% MVC
  - Avoid Valsalva
  - 3 minutes
- Repeat measures at baseline and at 2.5 minutes

Safety in Exercise Testing

- Monitor for arrhythmia
- Monitor for hemodynamic decompensation
- Monitor for ischemic decompensation
- Avoid in high risk settings
  - Suspected unstable coronary syndrome
  - Suspected left main coronary disease
  - Poorly compensated baseline hemodynamics