Exercise and the Cardiovascular System

Oxygen Supply

- **The Fick Equation**
- VO_2 = <u>Q x a-v O_2 difference</u>
- or
- VO_2 = <u>HR x SV x a-v O_2 difference</u>

Supply and Demand

- Example...at rest the muscles demand (or need) **0.21 Liters of O_2/min**...
- demand is met with a supply of = **60 beats/min** x **70 ml/beat** x **5 ml O_2/100 ml blood**
    - = 4,200 ml/min x 5 ml of O_2 / 100 ml of blood
    - = 42 ml/min x 5 ml of O_2
    - = 210 ml of O_2/min
    - = **0.21 Liters of O_2/min**

Supply and Demand

- Example...during exercise the muscles need **2.496** Liters of O_2/min...
- Then, the demand is met with a supply of... = **160** beats/min x **130** ml/beat x **12** ml O_2/100 ml blood
    - = 20,800 ml/min x 12 ml of O_2 / 100 ml of blood
    - = 208 ml/min x 12 ml of O_2
    - = 2,496 ml of O_2/min
    - = **2.496** Liters of O_2/min

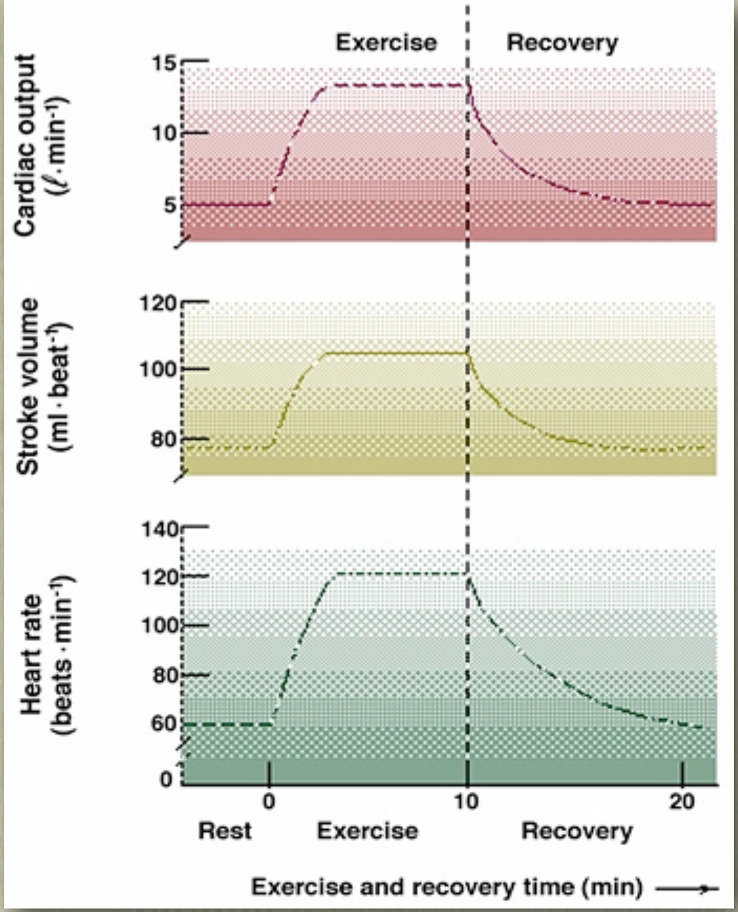
Supply and Demand

- During exercise the O_2 **demand** of the muscles increase
- Therefore the CV systems needs to increase O_2 **supply**
- The next series of slides will answer how this is accomplished.

SUBMAXIMAL EXERCISE

- Steady state, continuous exercise

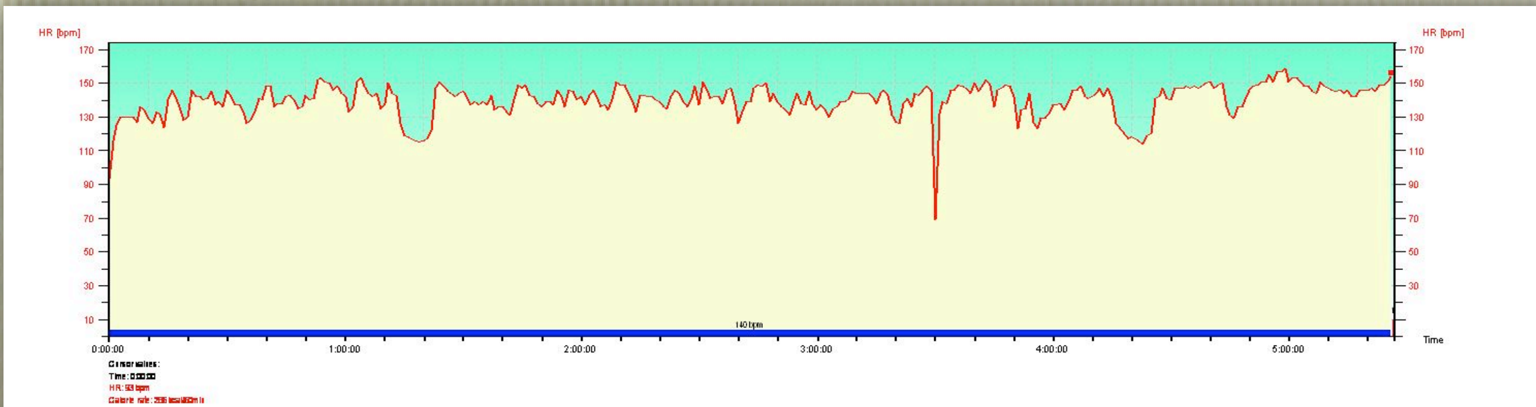
Cardiac Output & Exercise



- Q = HR x SV
- Represents the amount of blood flow to the muscles

Heart Rate & Exercise

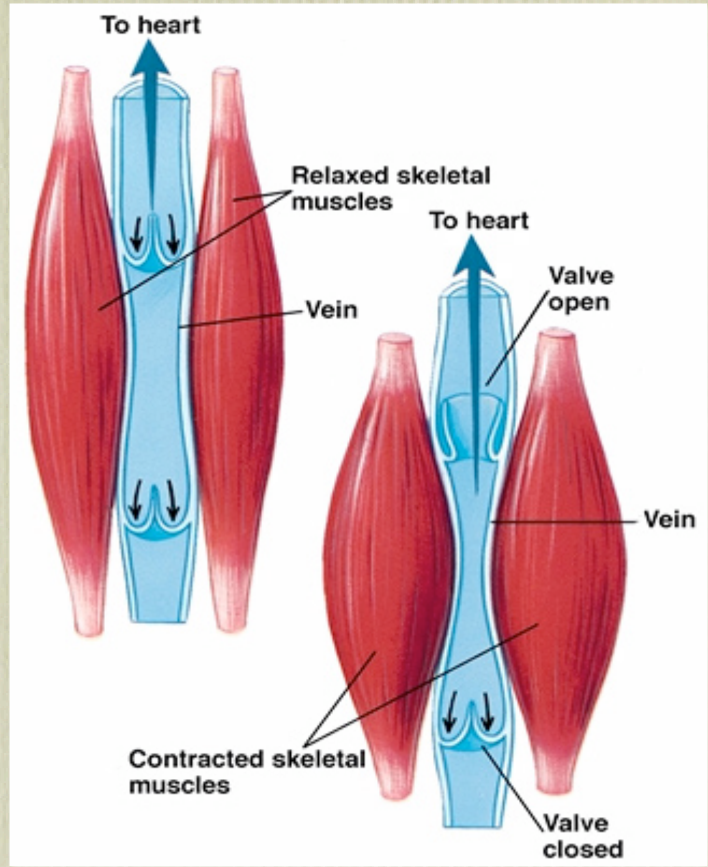
- Sympathetic nervous system
- Parasympathetic nervous system
- Catecholamines released



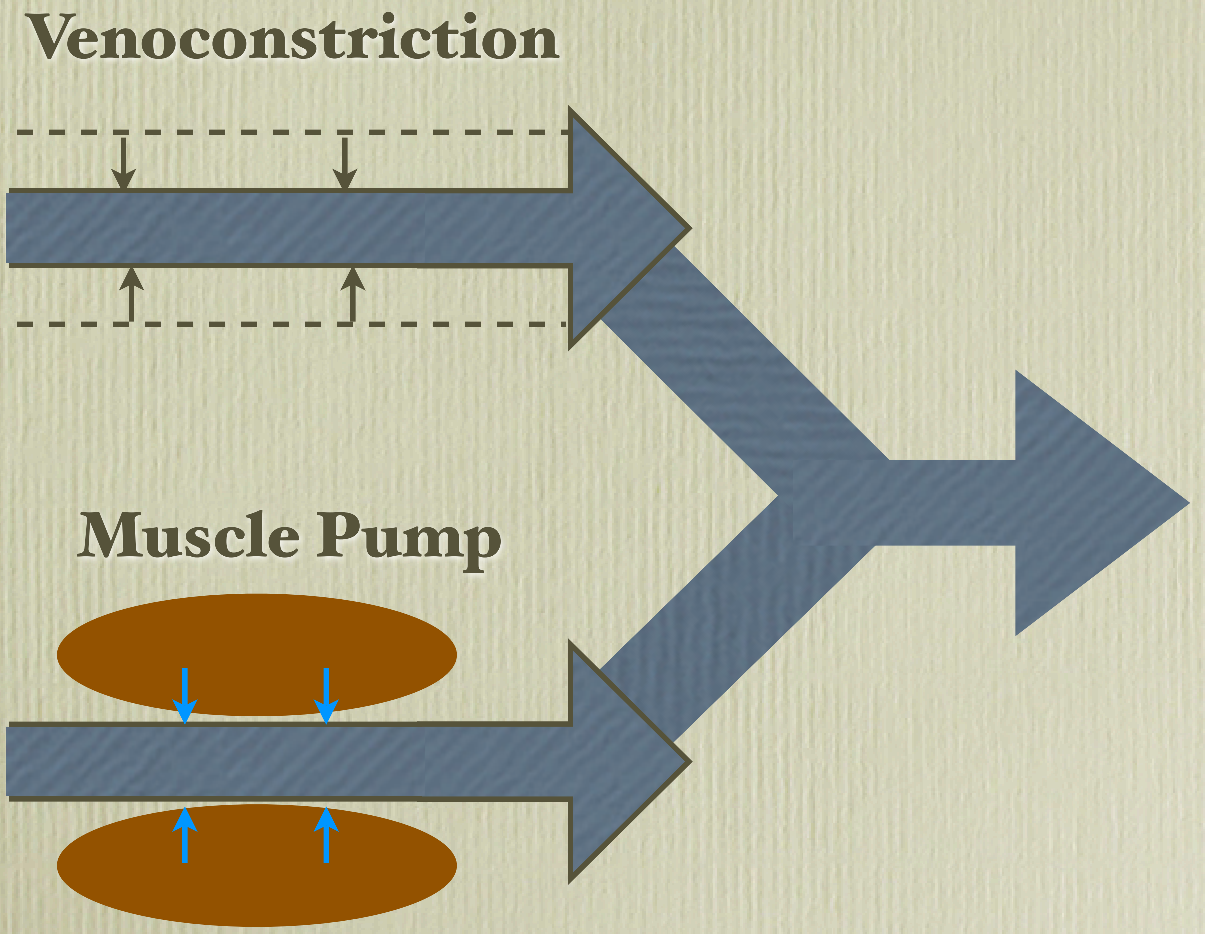
Person	Jake Emmett	Date	10/25/2006	Heart rate average	140 bpm		
Exercise	10/25/2006 7:31 AM	Time	7:31:44 AM	Heart rate max	159 bpm		
Sport	Running	Duration	5:26:29.6				
Note				Selection	0:00:00 - 5:26:00 (5:26:00.0)		

Stroke Volume & Exercise

1. ↑ Preload (or end-diastolic volume)
   - Muscle pump
   - Venoconstriction
2. ↑ Strength of contraction
   - Sympathetic stimulation
3. ↓ Afterload
   - Vasodilation

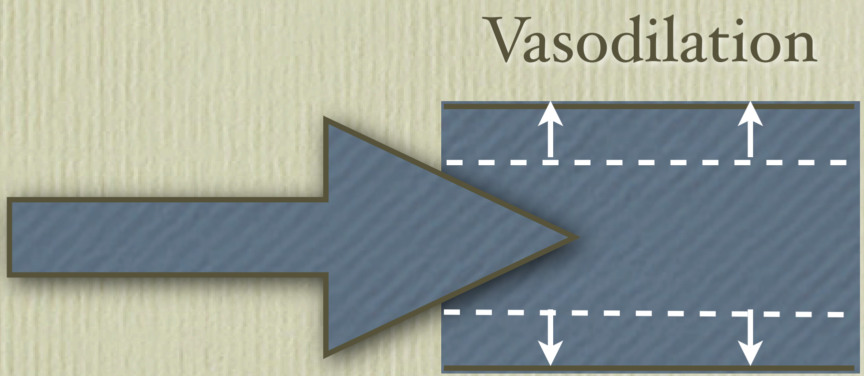


Preload



Increase Preload or blood flow into the heart

Afterload



Decrease afterload leading to increase blood flow out of the heart

Vasodilation

Autoregulation* or *Metabolic Vasodilation

- Waste products from muscle contraction.
  - ↑ CO_2 and ↑ acid
  - Other
    - ↑ potassium, ↑ adenosine, and ↑ nitric oxide

a-v O_2 Difference & Exercise

- At rest: 5 ml of O_2/100 ml of blood
- Increase during exercise
  - ↓ partial pressure
  - redistribution of blood flow

Partial Pressure

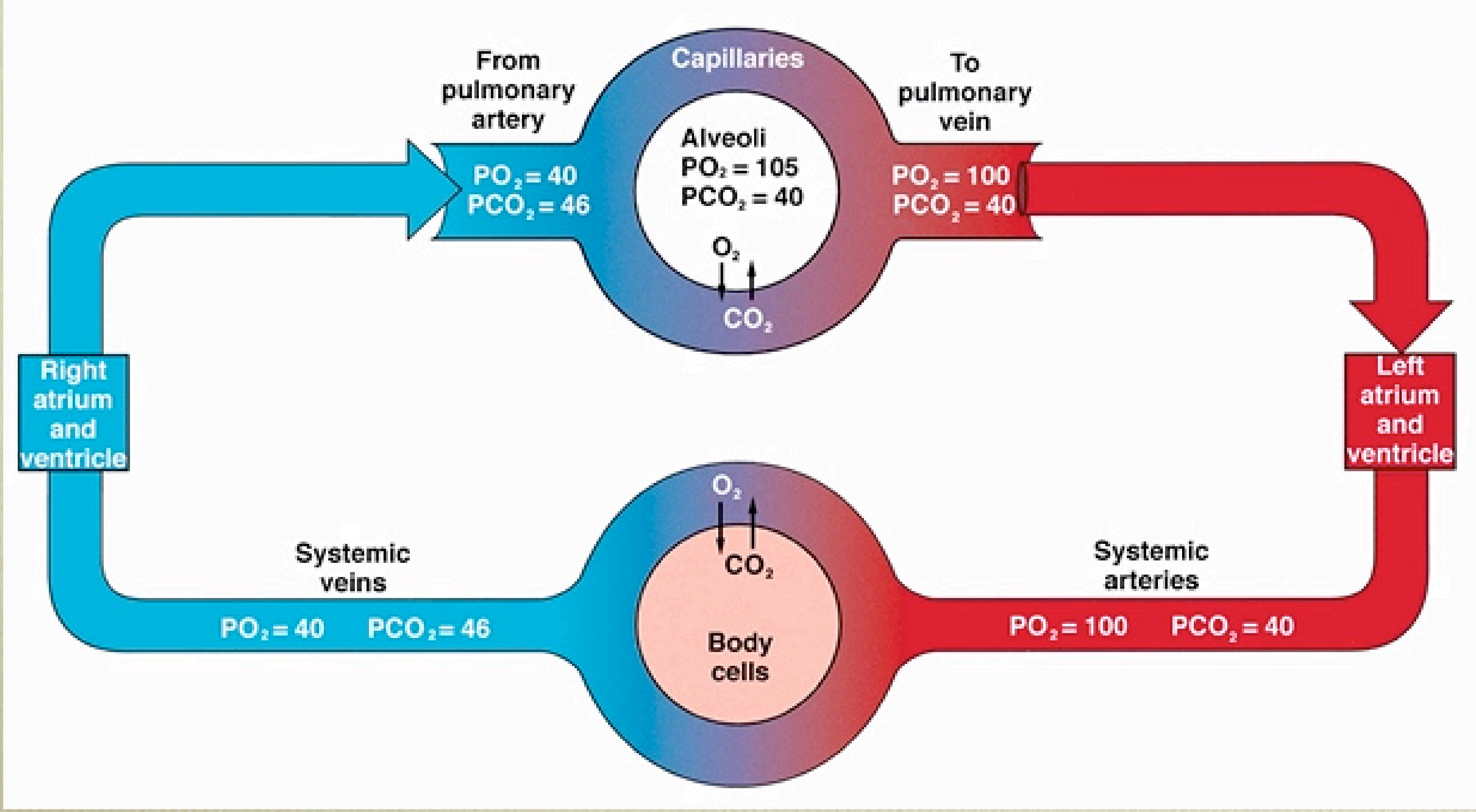
The total pressure of a gas = sum of the partial pressures of each gas

Example: partial pressure of oxygen (PO_2)

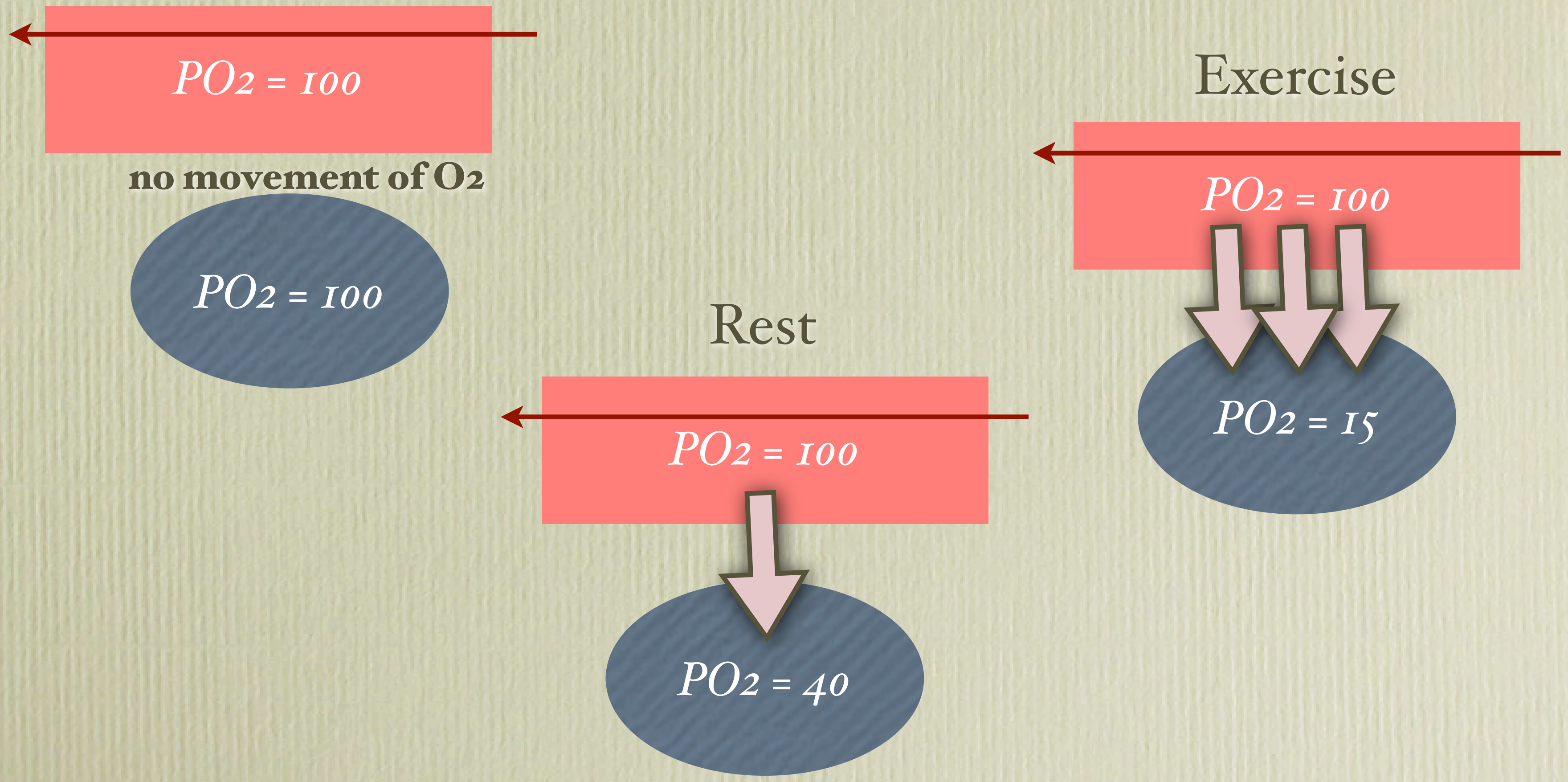
- Air is 20.93% oxygen
- Expressed as a fraction: 0.2093
- Total pressure of air = 760 mmHg

PO2 = 0.2093 x 760 = 159 mmHg

Partial Pressure



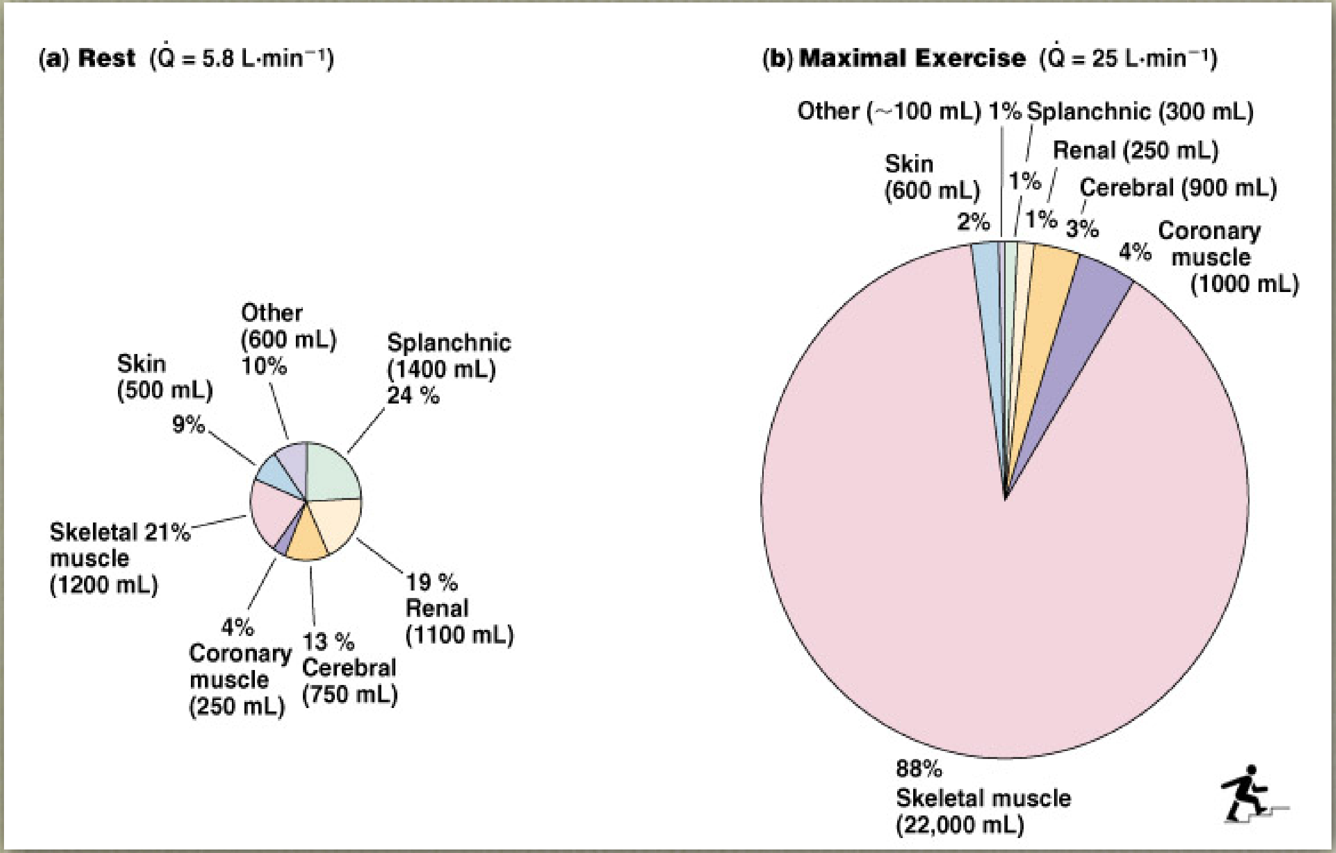
Partial Pressure and a-v O2 difference



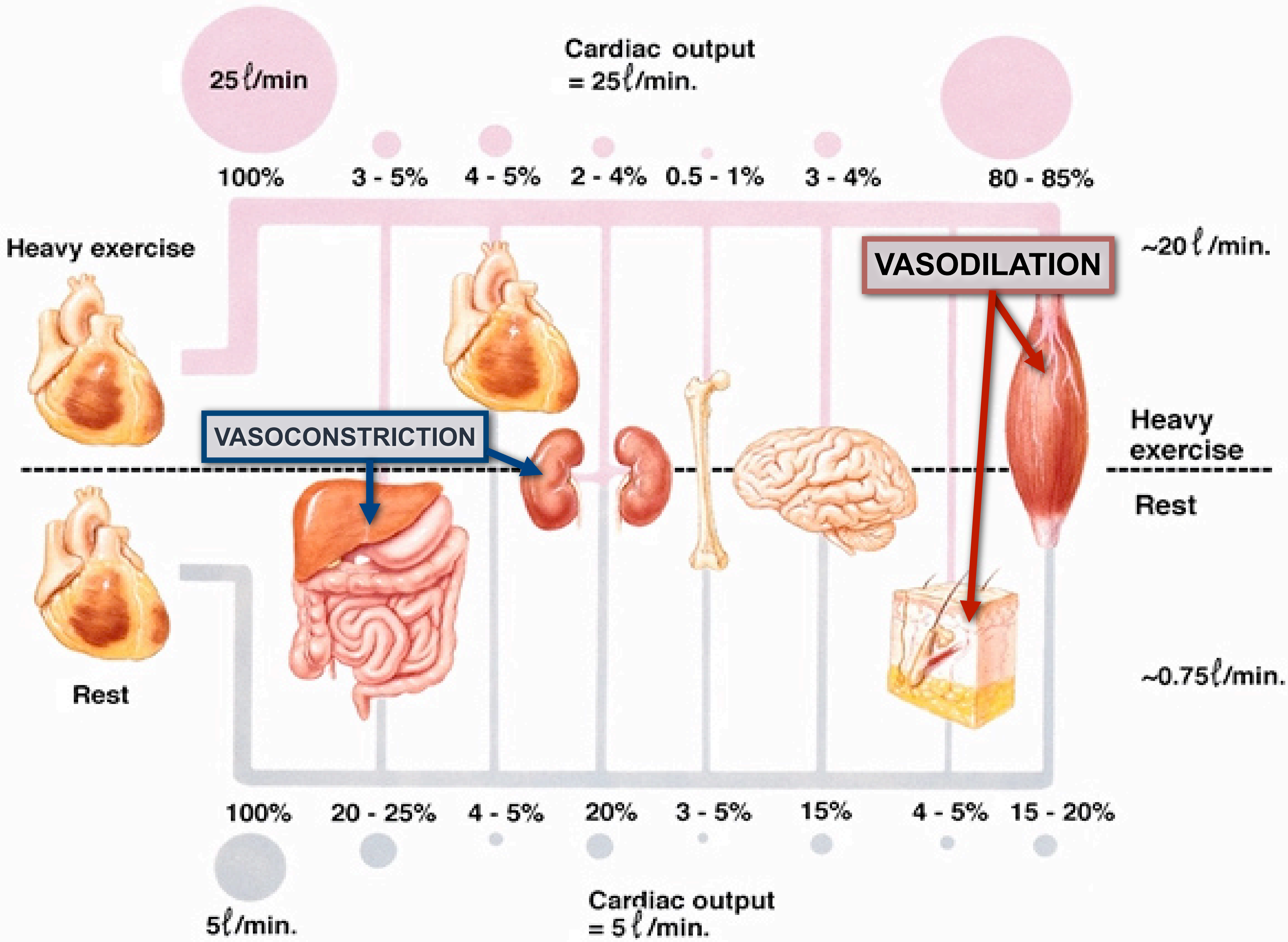
Submaximal Exercise

Redistribution of Blood Flow

VASOCONSTRICTION



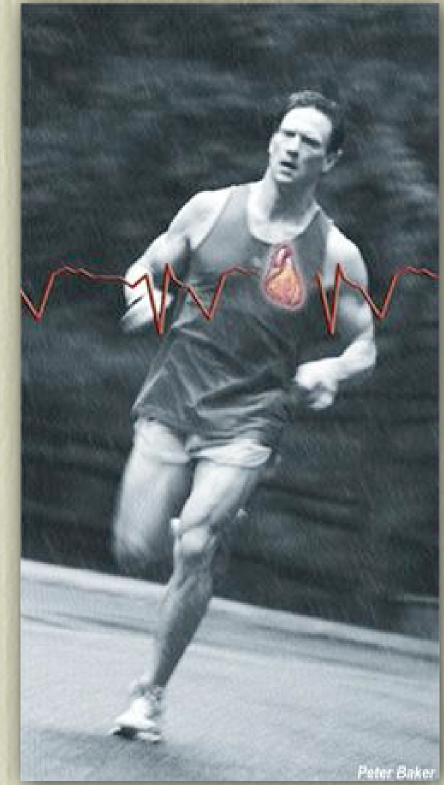
VASODILATION



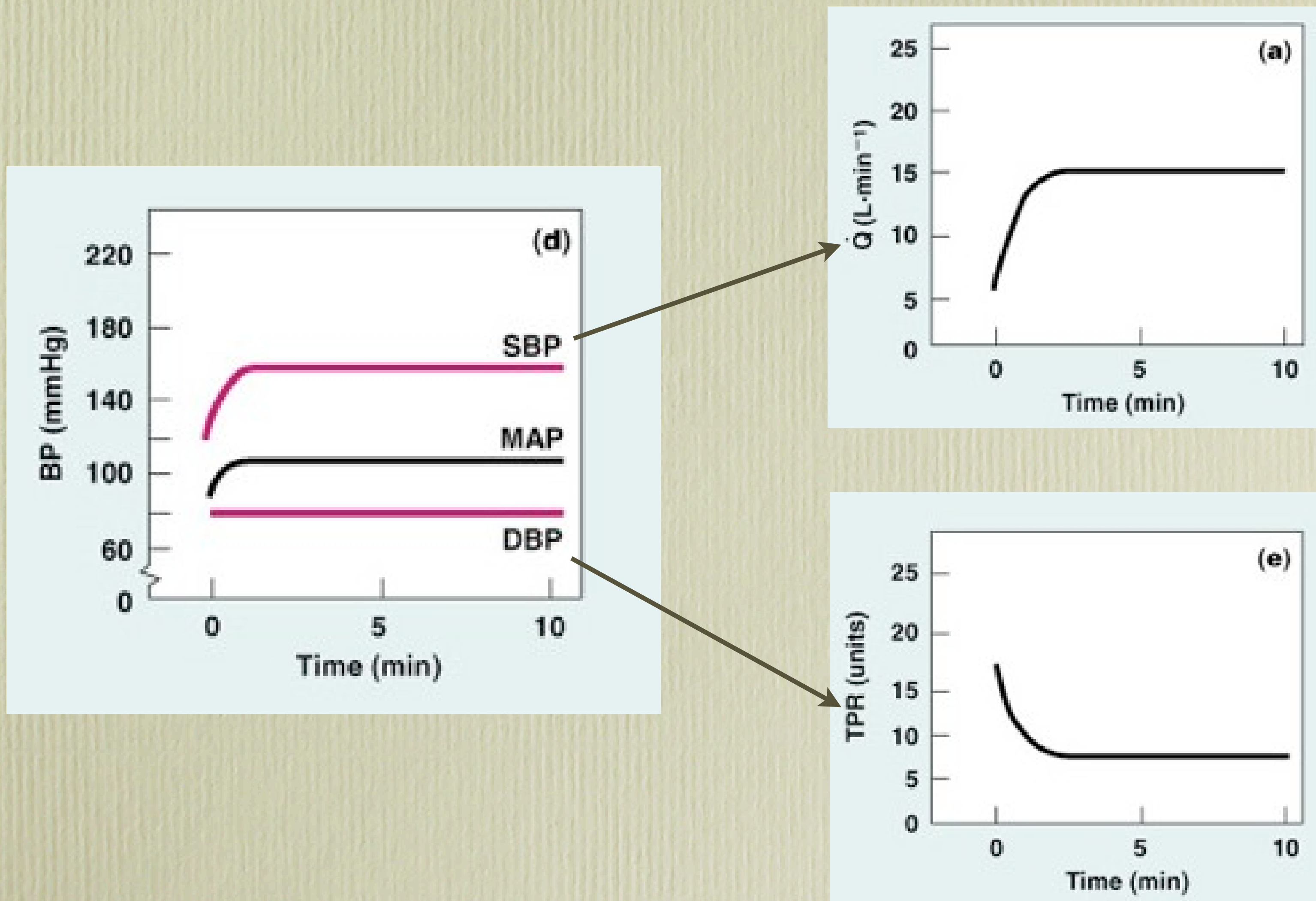
Cardiac output
= 25ℓ/min.
25 ℓ/min
100%
3 - 5%
4 - 5%
2 - 4%
0.5 - 1%
3 - 4%
80 - 85%
Heavy exercise
~20 ℓ /min.
VASODILATION
VASOCONSTRICTION
Heavy exercise
Rest
Rest
~0.75ℓ/min.
100%
20 - 25%
4 - 5%
20%
3 - 5%
15%
4 - 5%
15 - 20%
5ℓ/min.
Cardiac output
= 5 ℓ /min.

O_2 **Supply** Summary

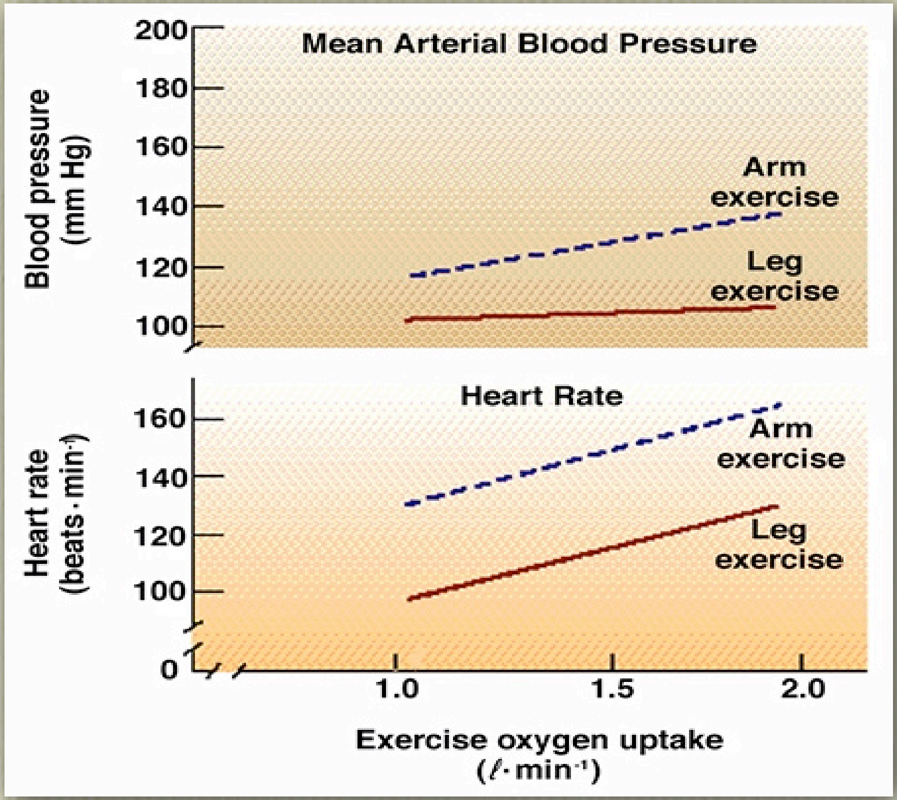
- How is the increase in O_2 demand by the muscles during exercise met?
  - Increase Q
    - Increase HR
    - Increase SV
  - Increase a-v O_2 difference



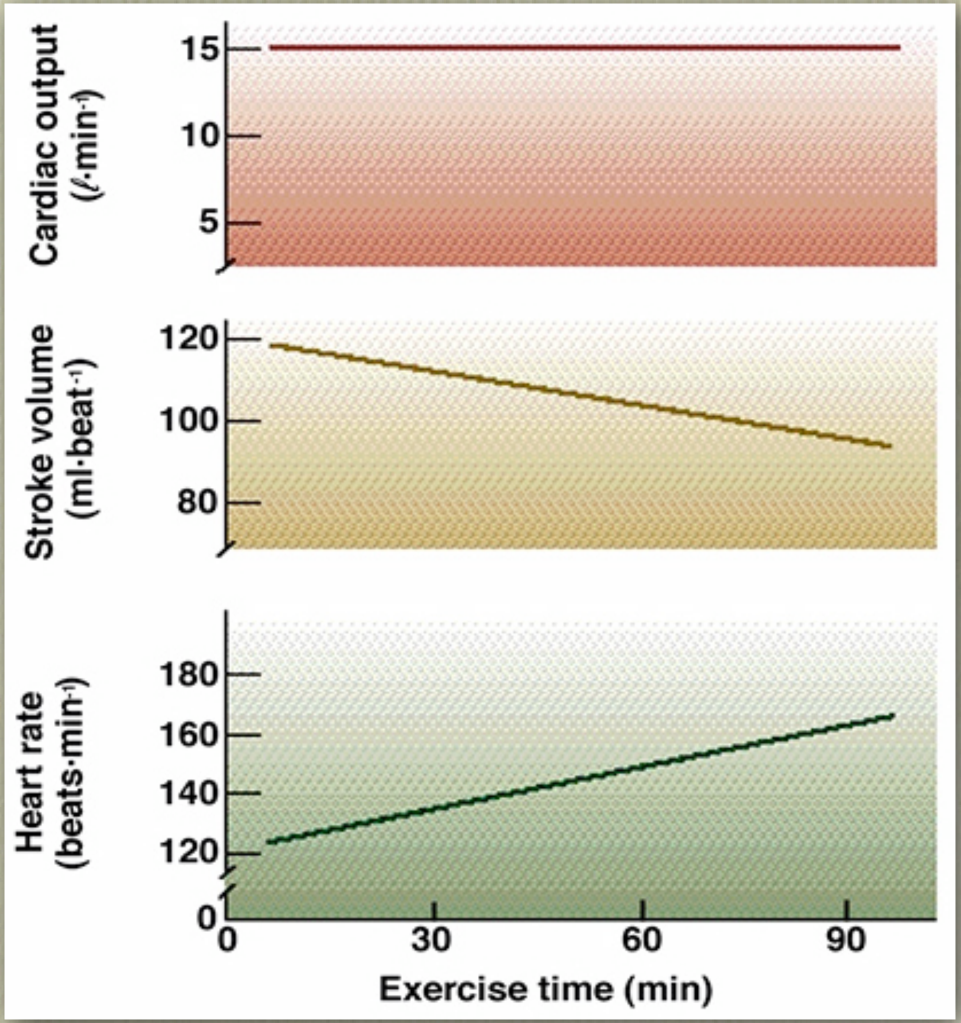
Blood Pressure



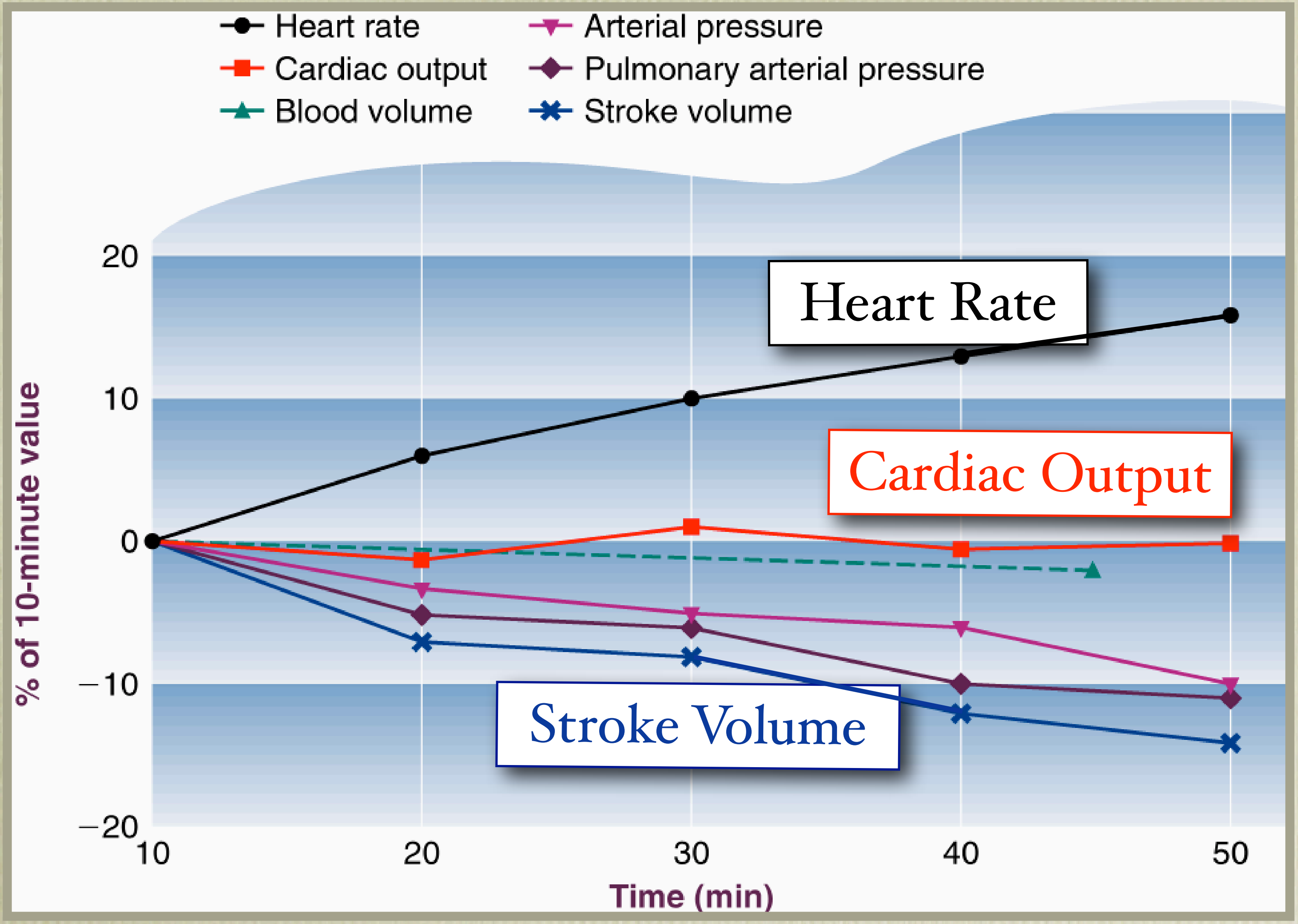
Upper Body Exercise



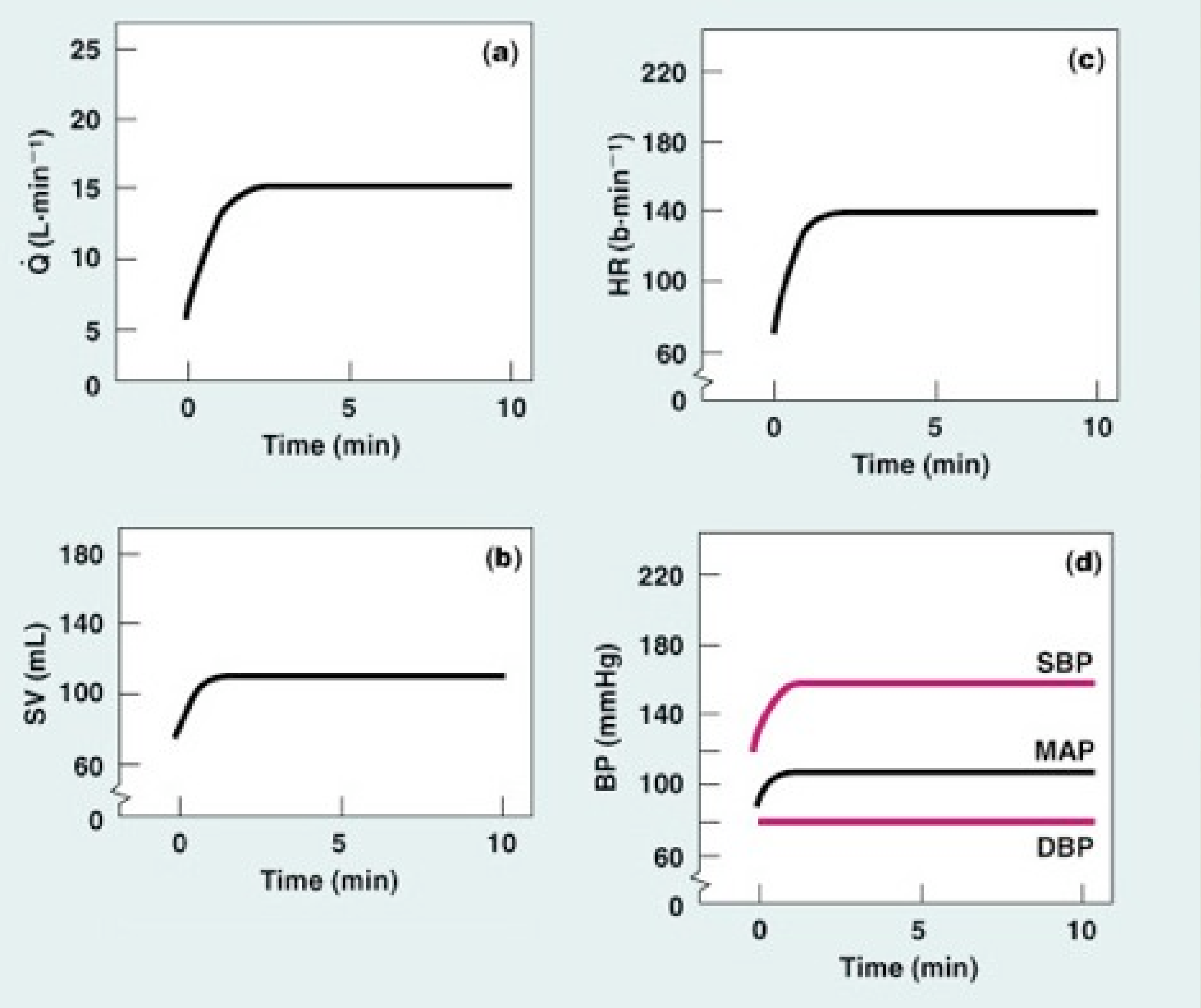
PROLONGED, SUBMAXIMAL EXERCISE



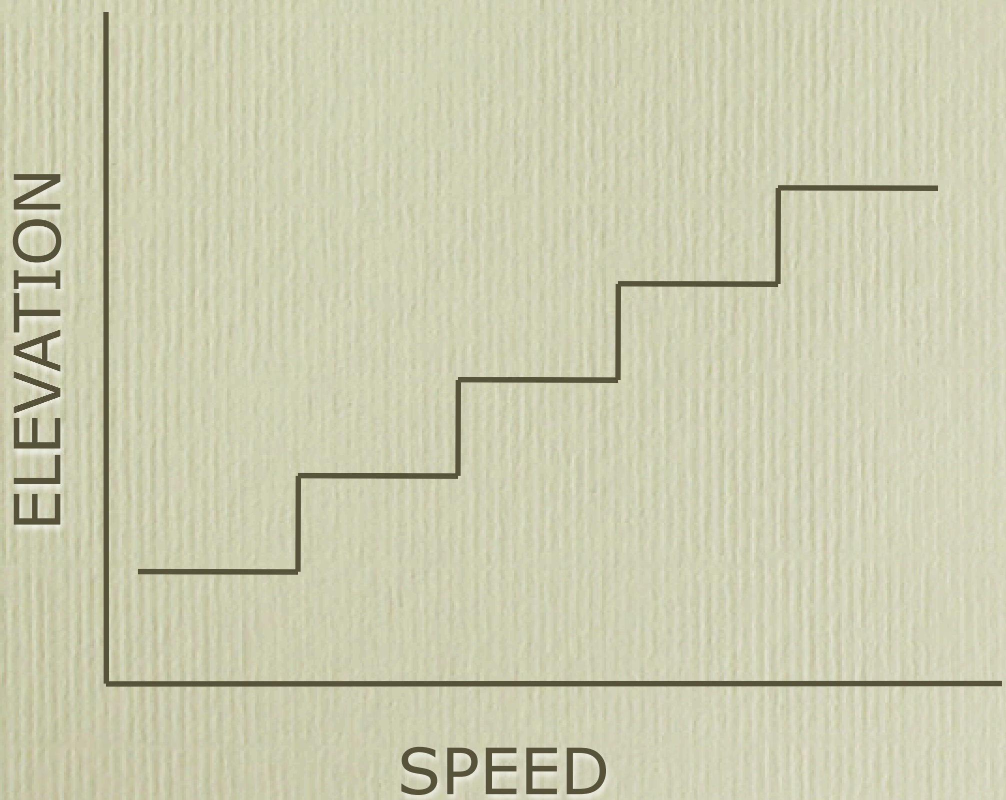
Cardiovascular Drift



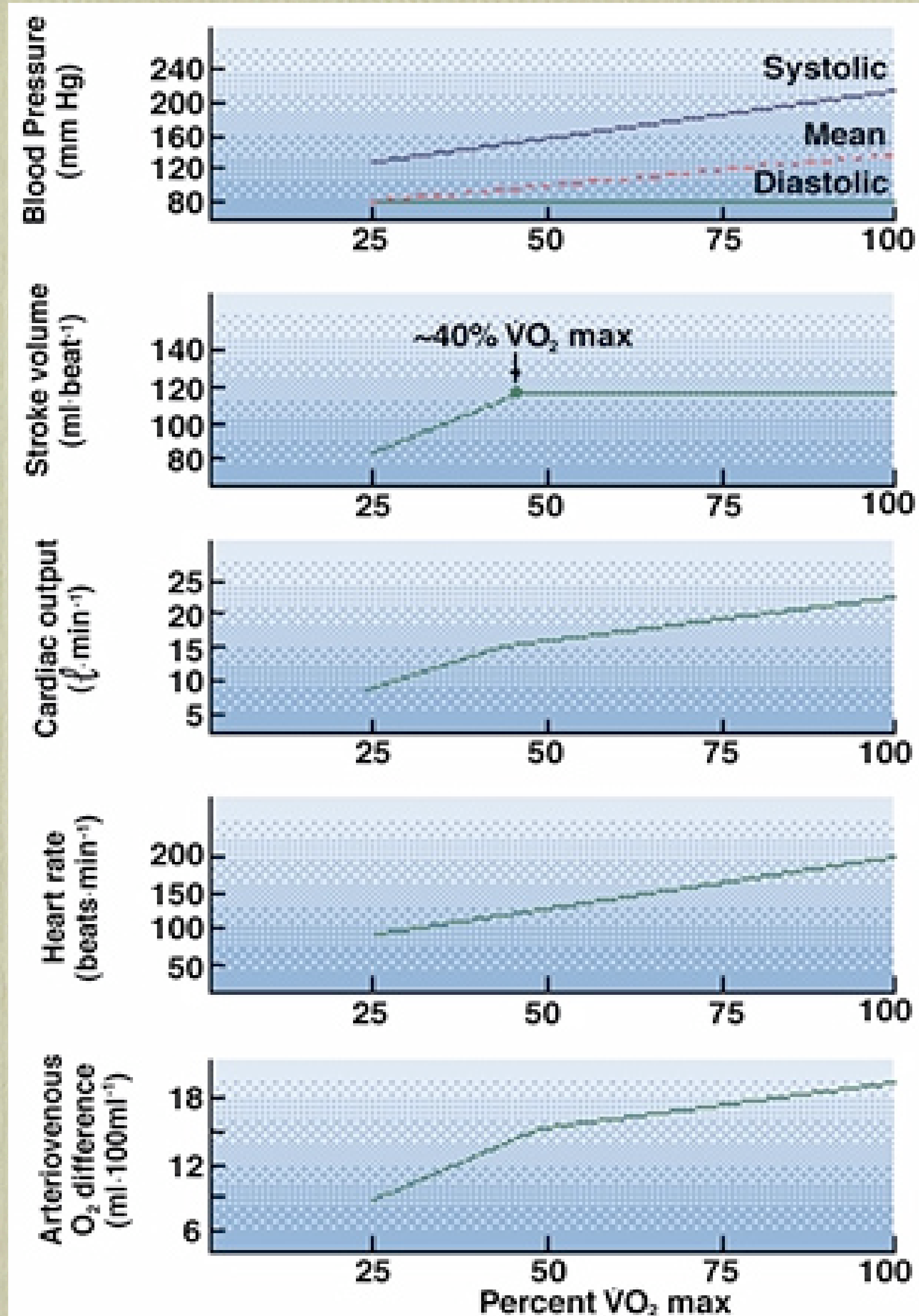
Steady State, Submaximal Exercise



INCREMENTAL EXERCISE TO MAXIMAL EFFORT

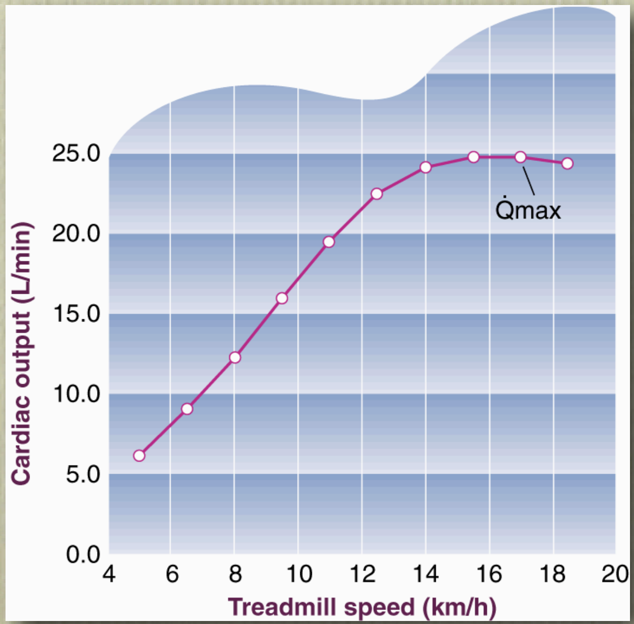


Circulatory Responses to Incremental Exercise

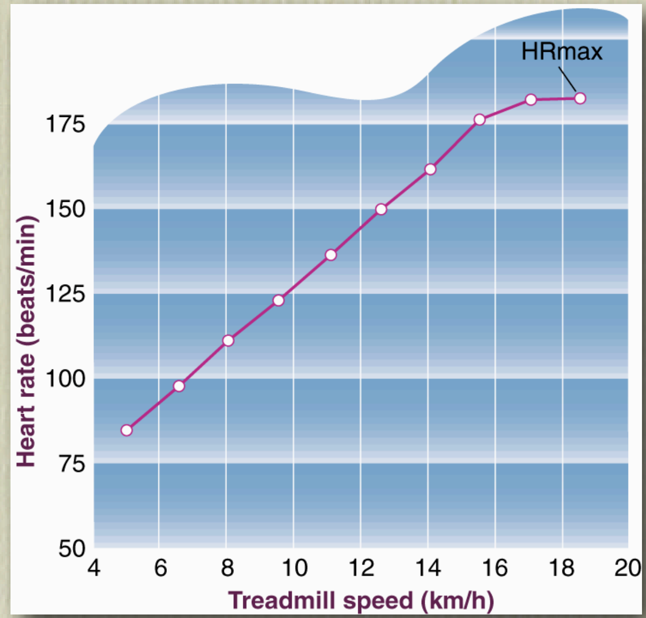


Circulatory Responses to Incremental Exercise

Cardiac Output



Heart Rate



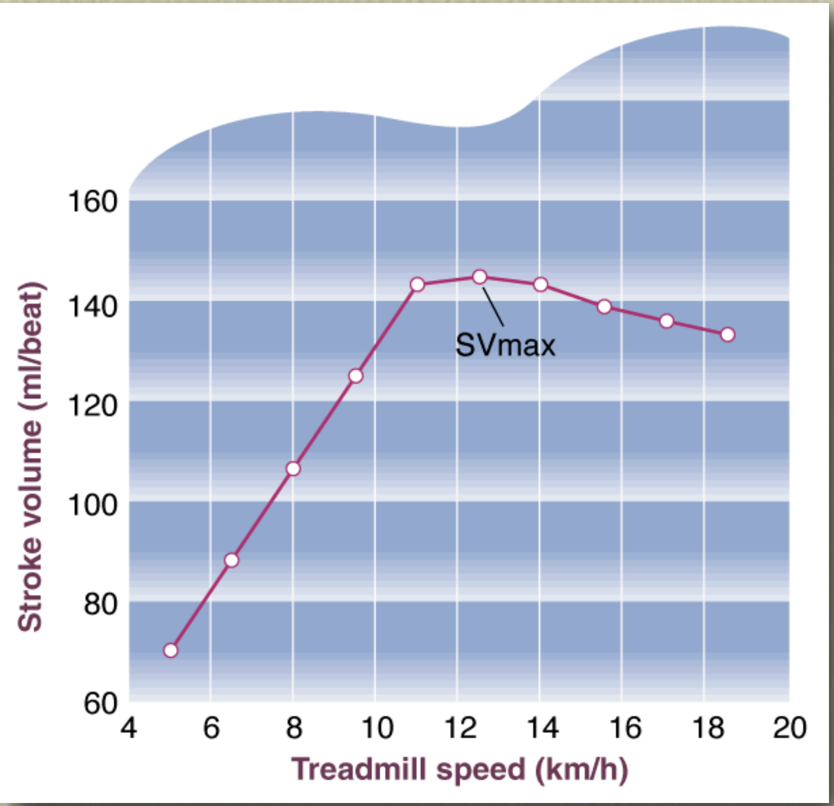
Maximum Heart Rate

F.Y.I.

- HRmax = 220 – age is an *estimation*, only
  - Margin of error ± 12 bpm
- ALTERNATIVE FORMULA
- **HRmax = 208 – (0.70 x age)**

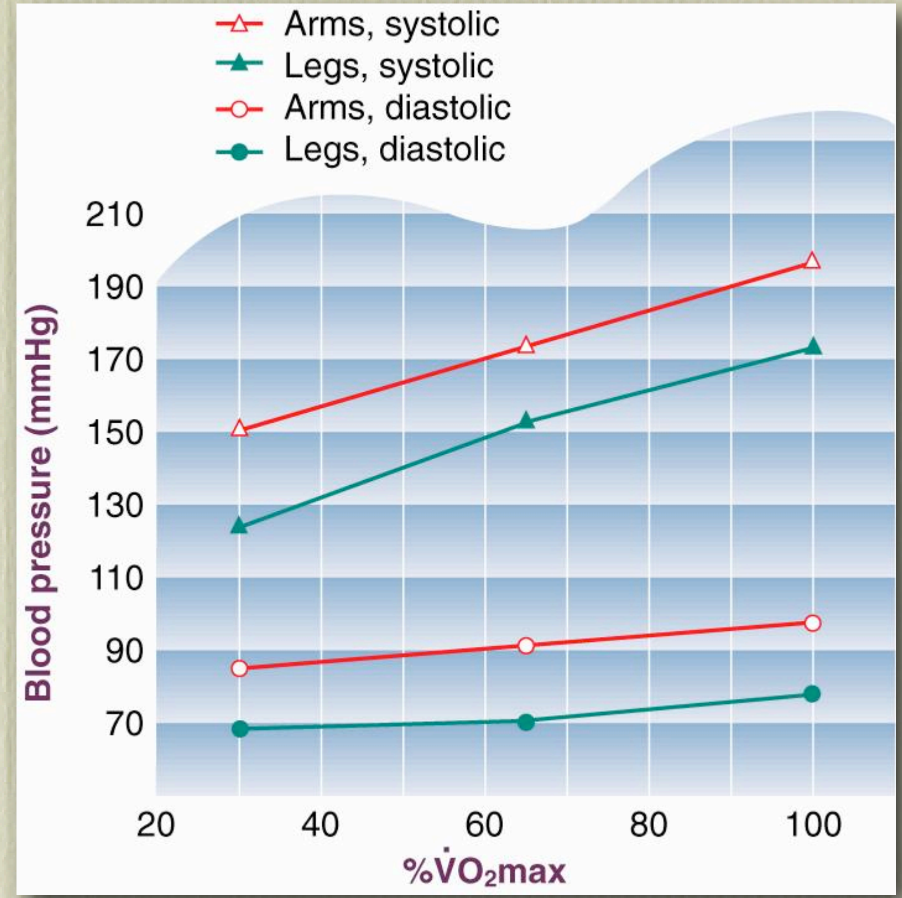
Circulatory Responses to Incremental Exercise

- Stroke Volume

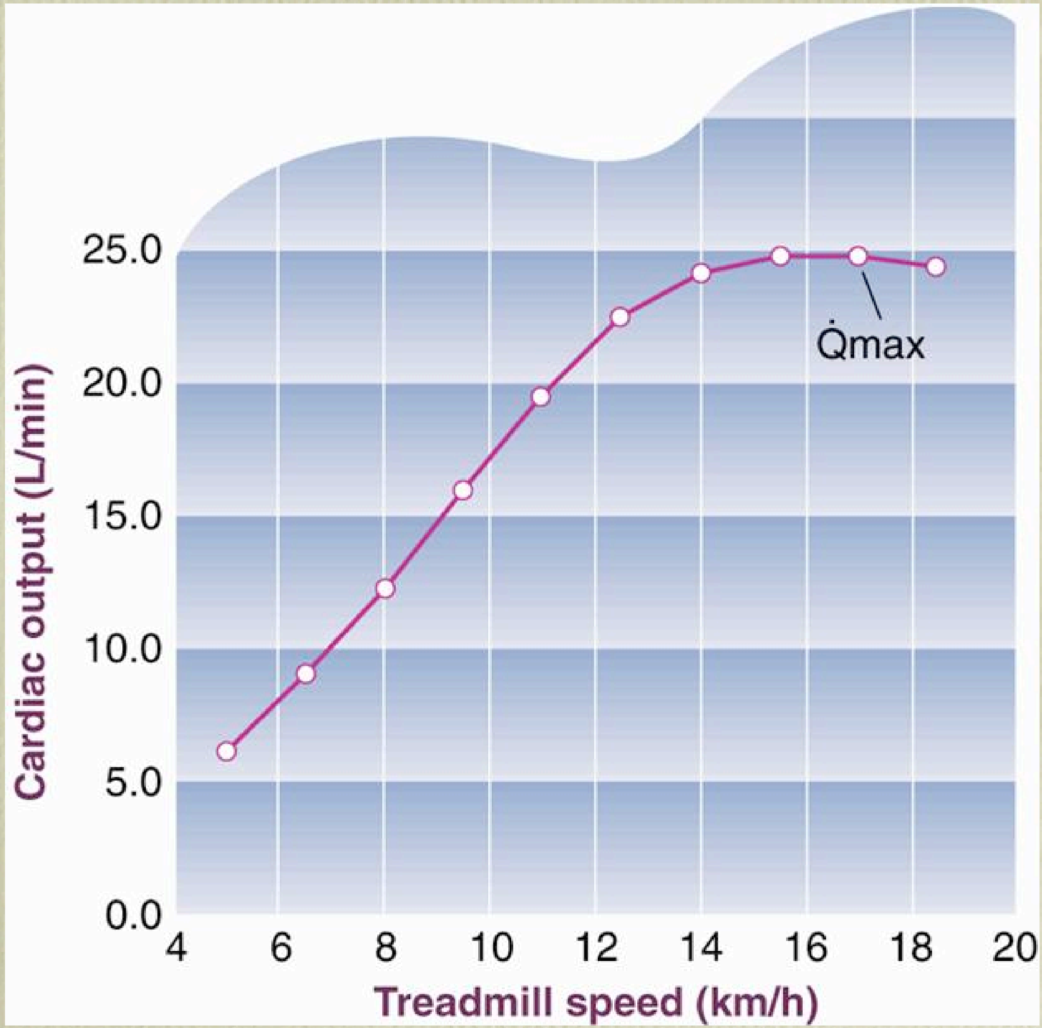


Circulatory Responses to Incremental Exercise

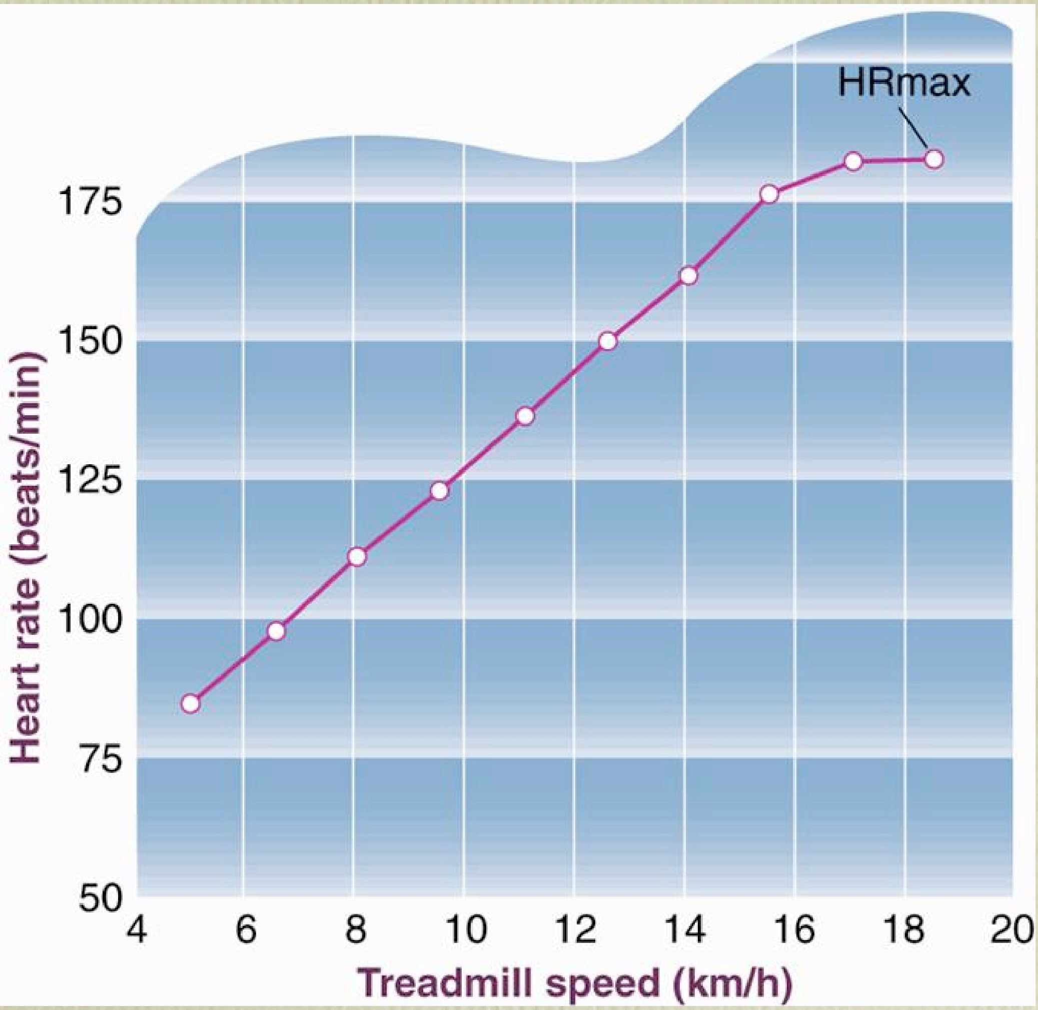
- Systolic blood pressure
- Diastolic blood pressure



Cardiac Output

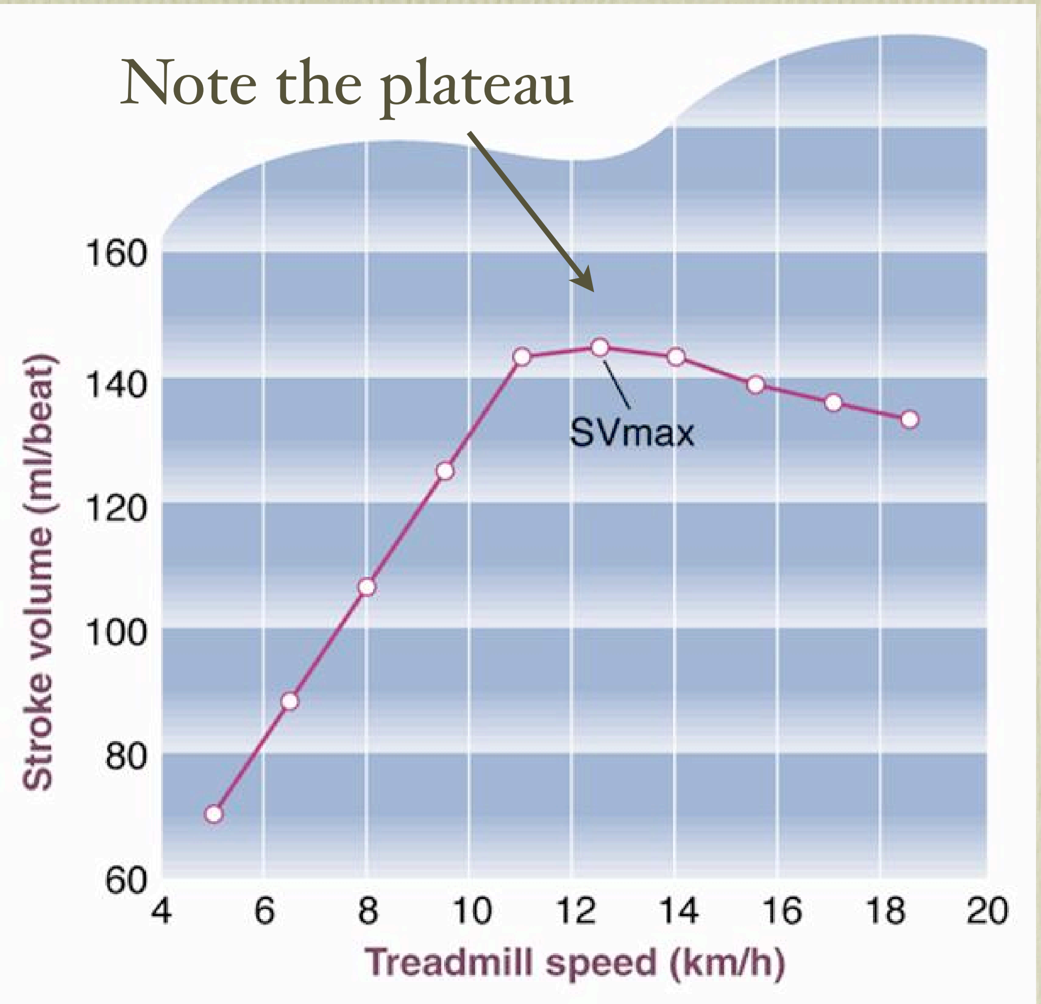


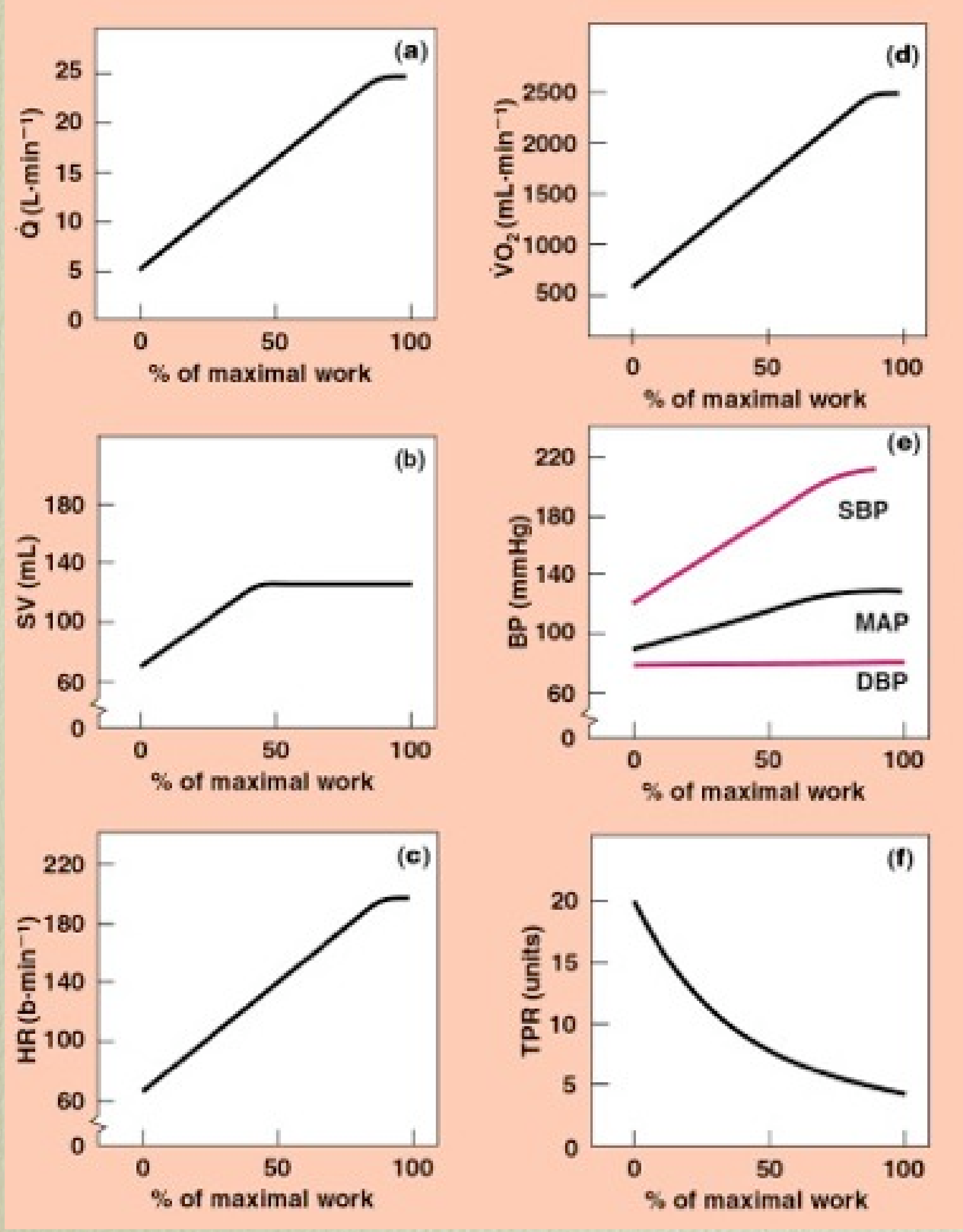
Heart Rate



HRmax
175
150
125
100
75
50
Heart rate (beats/min)
4
6
8
10
12
14
16
18
20
Treadmill speed (km/h)

Stroke Volume



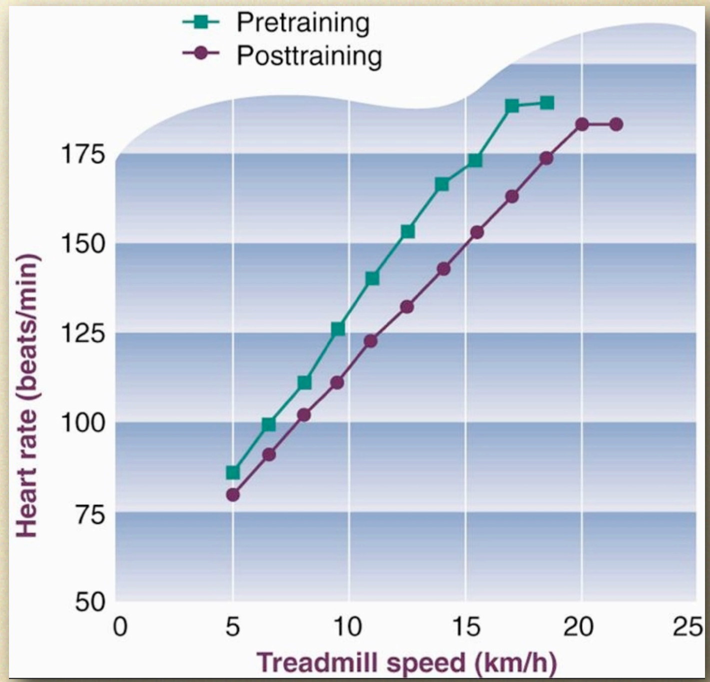

(a)
Q̇ (L·min⁻¹)
25
20
15
10
5
0
0
50
100
% of maximal work
(d)
V̇O₂ (mL·min⁻¹)
2500
2000
1500
1000
500
0
50
100
% of maximal work
(b)
SV (mL)
180
140
100
60
0
0
50
100
% of maximal work
(e)
BP (mmHg)
220
180
140
100
60
0
SBP
MAP
DBP
0
50
100
% of maximal work
(c)
HR (b·min⁻¹)
220
180
140
100
60
0
0
50
100
% of maximal work
(f)
TPR (units)
20
15
10
5
0
0
50
100
% of maximal work

Endurance Training

Pages 264-270

Adaptations from Chronic Exercise

- **Heart rate**
  - At rest
    - Increase parasympathetic stimulation
    - Increase in SV
  - During steady state exercise
  - At maximal exercise



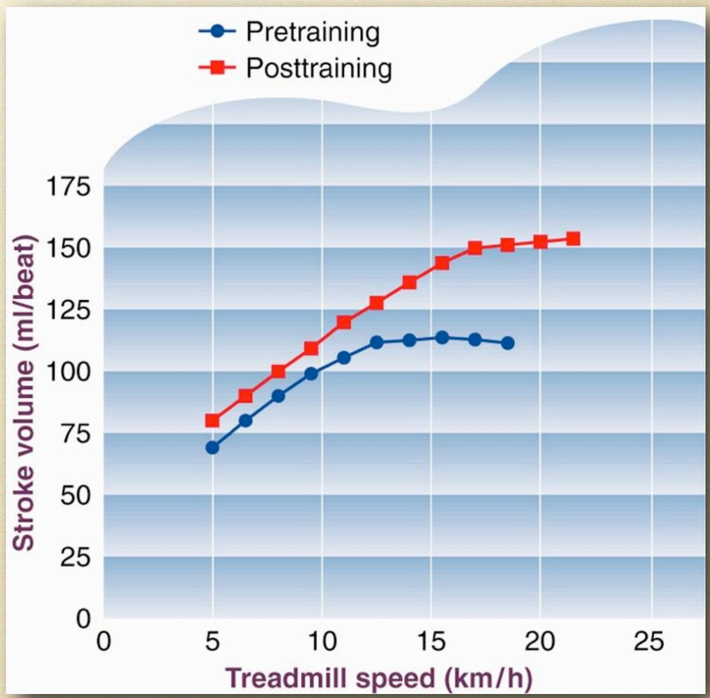
Lance by the Numbers

Tour de France victories	6
Most Tours won by anyone else	5
Americans who won Tour de France before Armstrong (Greg LeMond in 1986, 1989, 1990)	1
Armstrong's resting heart rate	32
Average heart rate during a race	125
Average heart rate during a time trial	190
Pedal rpm during a time trial	100
VO_2 max*	84
Average male VO_2 max	40
Pedal strokes by Armstrong in 2004 Tour	about 465,000
Heartbeats during the race	2.1 million
Daily calorie intake during training	6,000
Body fat during race season	5–6%
Body fat during off-season	10–11%
Calories burned during 3 hours of racing	3,150
Calories expended during the race	132,000
Number of Big Macs represented by 132,000 calories	236

*Maximum amount of oxygen (in milliliters) lungs retain during a minute of exercise per kilogram of body weight—a measure of physical efficiency

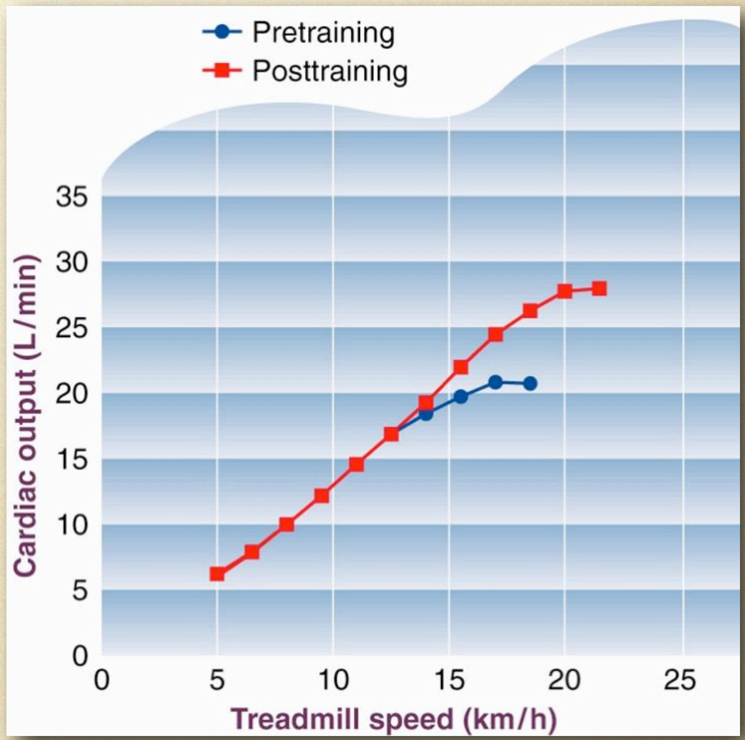
Adaptations from Chronic Exercise

- **Stroke Volume**
  - At rest
  - Steady state exercise
  - Maximal exercise



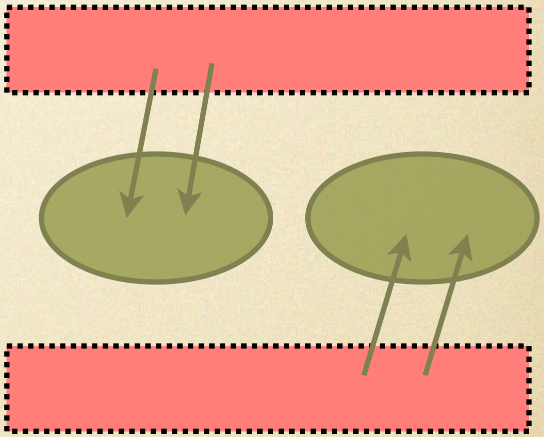
Adaptations from Chronic Exercise

- **Cardiac Output**
  - At rest
  - Steady state exercise
  - Maximal exercise



Adaptations from Chronic Exercise

- **a-v O2 difference**
  - At rest
  - During steady state exercise
  - At maximal exercise

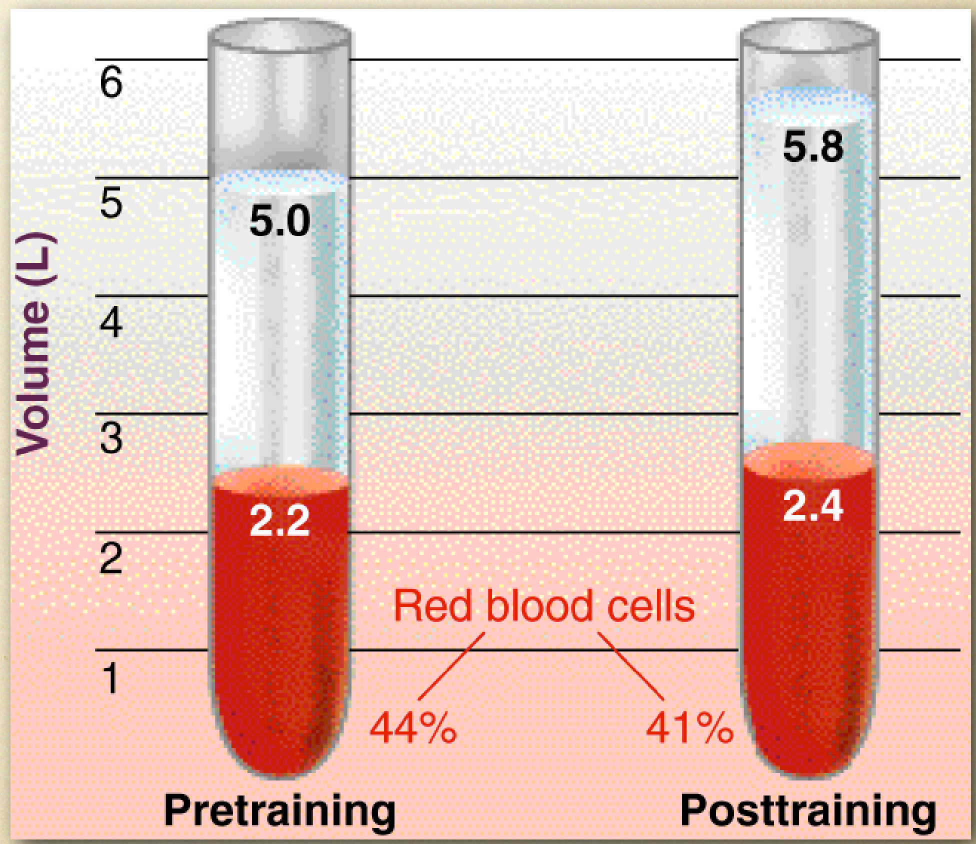


Adaptations from Chronic Exercise

- **Oxygen Uptake (VO2)**
  - At rest
  - Submaximal exercise
  - Maximal exercise (**VO2max**) by 25-30%
- Genetics: 40-66% of baseline VO2max
- Improvements in VO_{2max}
  - 50% due to ↑ SV
  - 50% due to ↑ a-vO_2

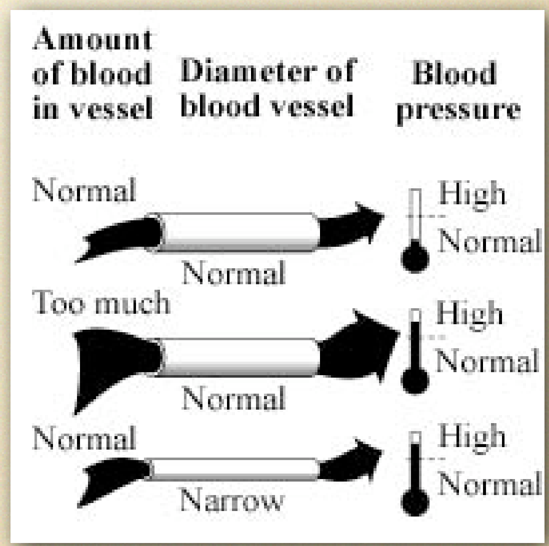
Adaptations from Chronic Exercise

- **Blood**
  - Total blood volume
  - Plasma volume
  - Red blood cells
  - Hematocrit

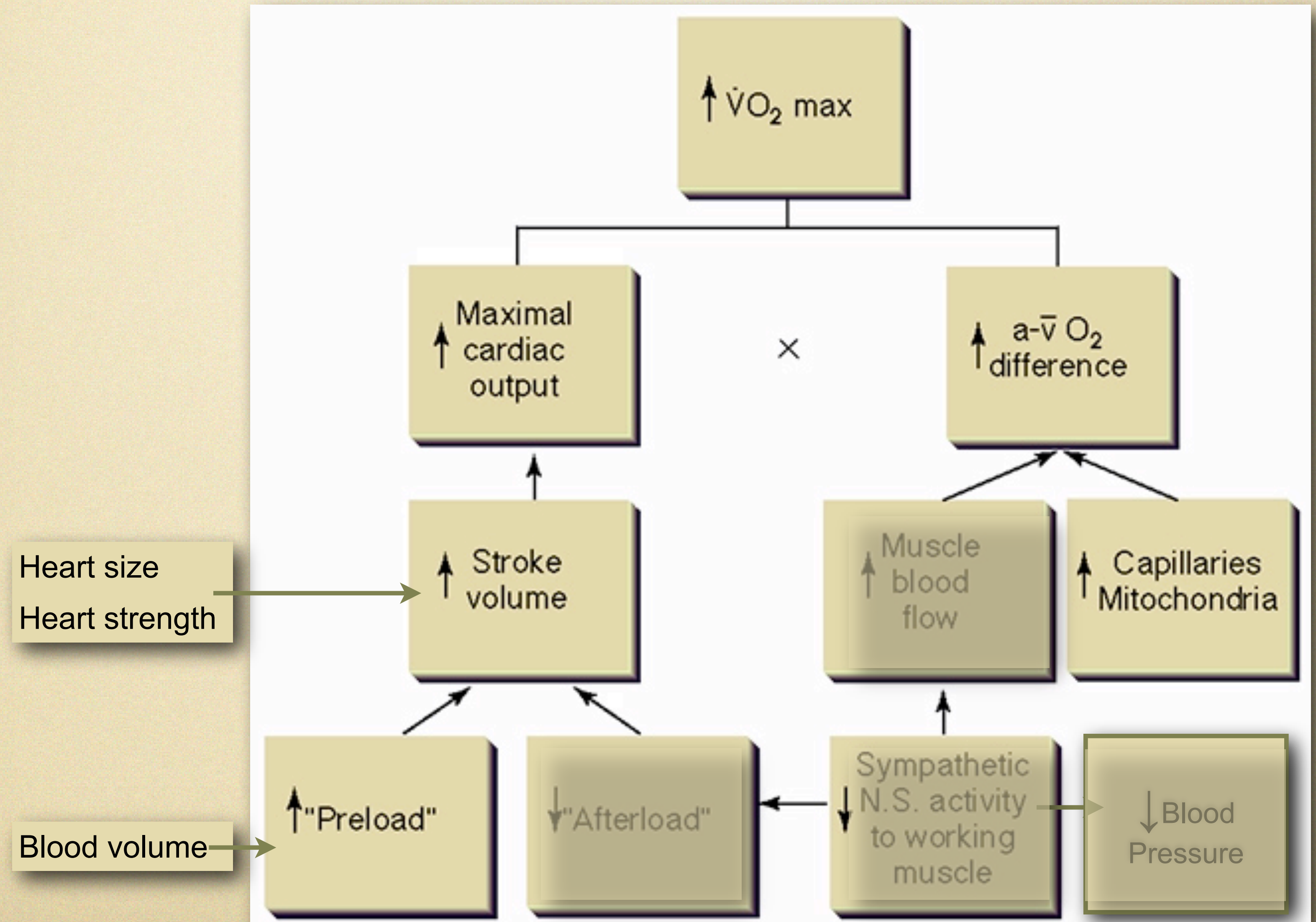


Adaptations from Chronic Exercise

- **Blood Pressure (p. 333)**
  - What is hypertension?
  - What affect does chronic exercise training have on hypertension?



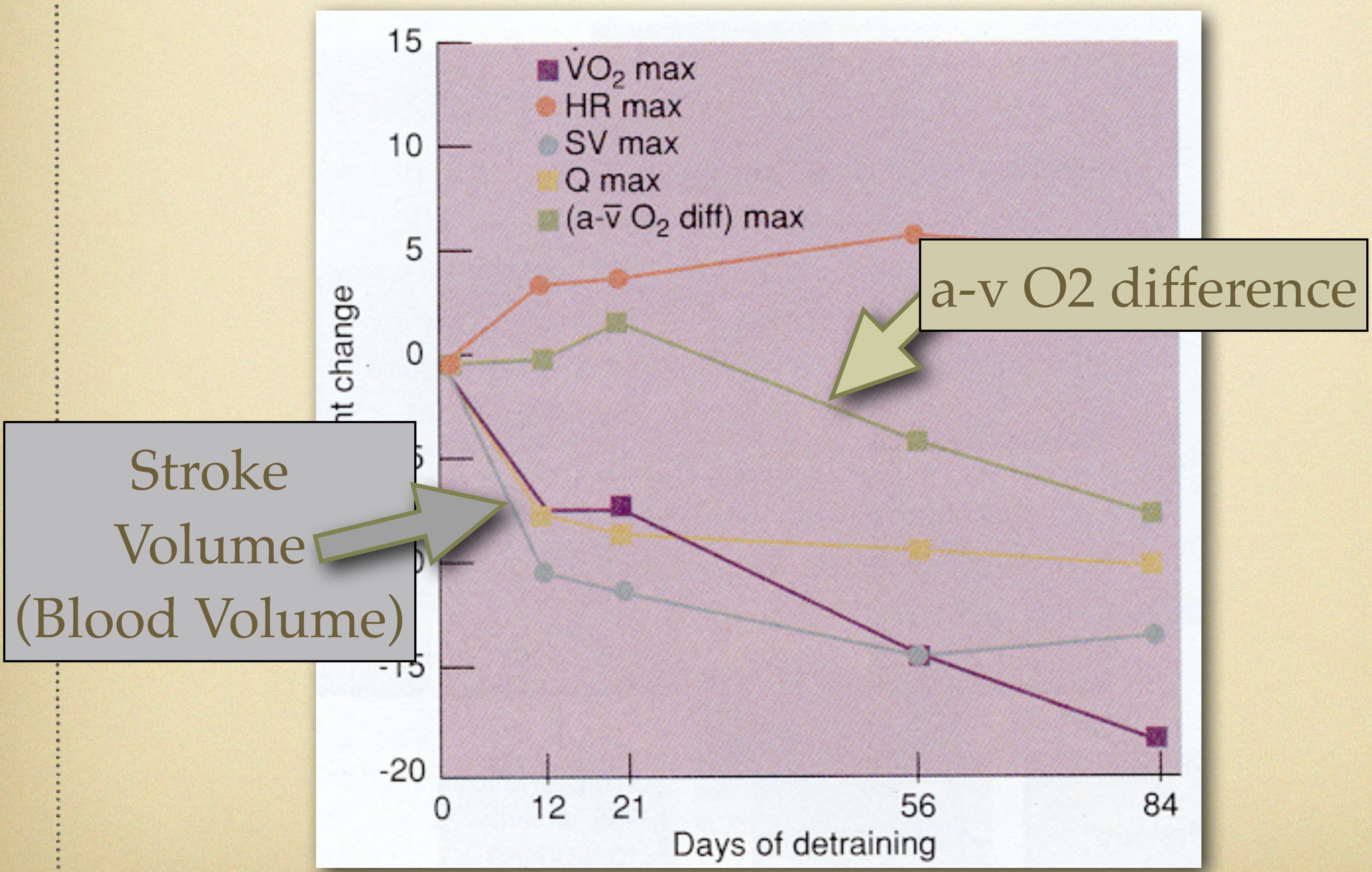
Overview


↑ V̇O2 max
↑ Maximal cardiac output
×
↑ a-v̄ O2 difference
↑ Stroke volume
↑ Muscle blood flow
↑ Capillaries Mitochondria
↑ "Preload"
↓ "Afterload"
↓ Sympathetic N.S. activity to working muscle
↓ Blood Pressure
Heart size
Heart strength
Blood volume

Adaptations from Chronic Exercise

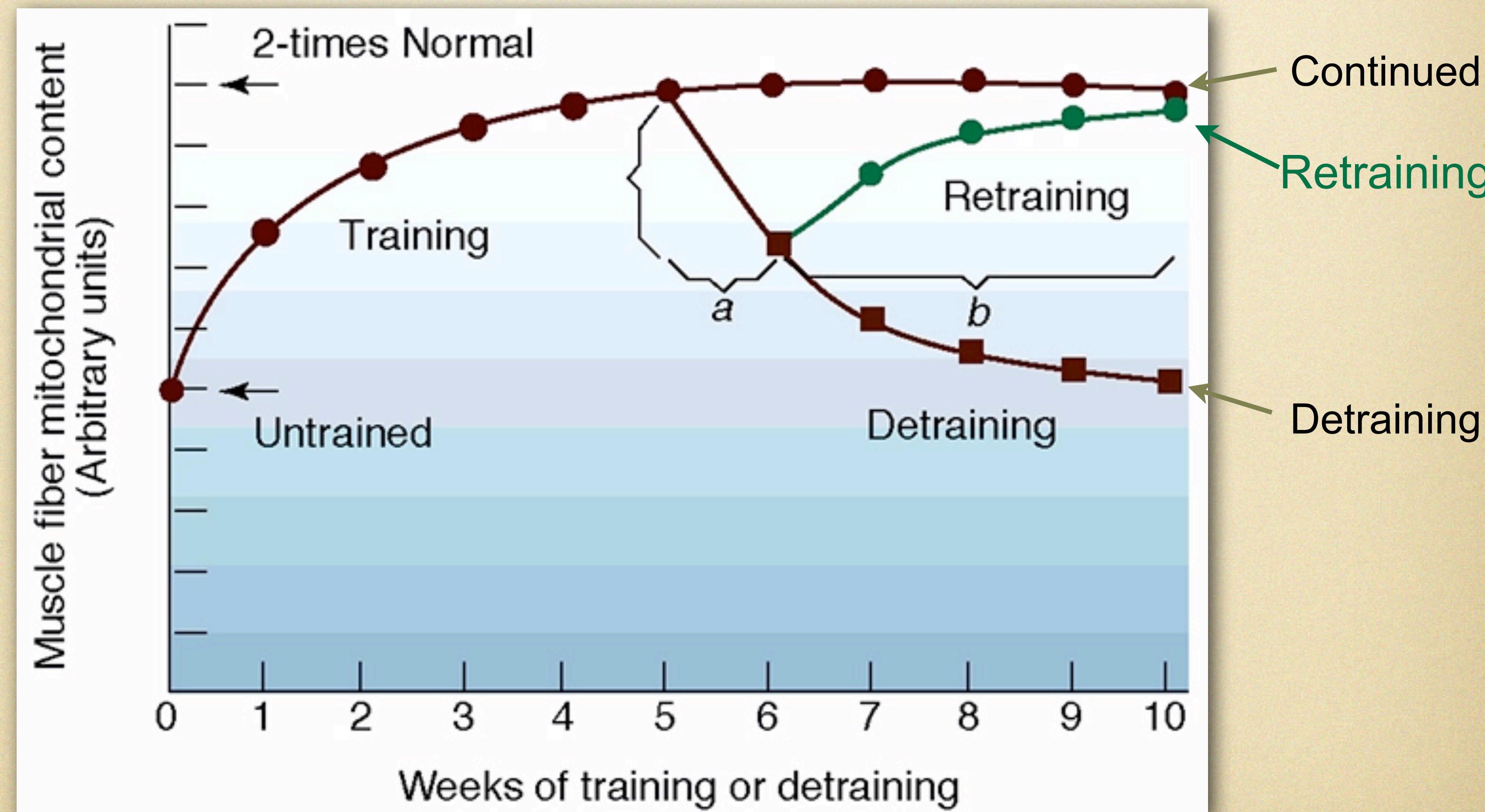
	Rest	Submax	Max
Q	↔	↔	↑
SV			
HR			
a-vO2 diff			
Plasma vol			
RBC			
Ht			
BP			

Detraining



VO2 max
HR max
SV max
Q max
(a-v O2 diff) max
15
10
5
0
-20
0
12
21
56
84
Days of detraining
a-v O2 difference
Stroke Volume (Blood Volume)

Retraining



2-times Normal
Training
Untrained
a
b
Retraining
Detraining
Muscle fiber mitochondrial content (Arbitrary units)
0
1
2
3
4
5
6
7
8
9
10
Weeks of training or detraining
Continued
Retraining
Detraining

Detraining & Retraining

- About 50% of the increase in mitochondria was lost after one week of detraining
- All of the adaptations were lost after five weeks of detraining
- It took four weeks of retraining to regain the adaptations lost in the first week of detraining