Exercise and the Cardiovascular System
Oxygen Supply

- The Fick Equation
- $\text{VO}_2 = Q \times \text{a-v O}_2 \text{ difference}$
- or
- $\text{VO}_2 = \text{HR} \times \text{SV} \times \text{a-v O}_2 \text{ difference}$
Supply and Demand

- **Example**...at rest the muscles demand (or need) **0.21 Liters of O2/min**...

- Demand is met with a supply of = **60 beats/min** x **70 ml/beat** x **5 ml O2/100 ml blood**
  - = **4,200 ml/min x 5 ml of O2 / 100 ml of blood**
  - = **42 ml/min x 5 ml of O2**
  - = **210 ml of O2/min**
  - = **0.21 Liters of O2/min**
Supply and Demand

- Example...during exercise the muscles need $2.496$ Liters of O2/min...

- Then, the demand is met with a supply of...
  \[= 160 \text{ beats/min} \times 130 \text{ ml/beat} \times 12 \frac{\text{ml O2}}{100 \text{ ml blood}}\]
  \[= 208 \text{ ml/min} \times 12 \frac{\text{ml O2}}{100 \text{ ml blood}}\]
  \[= 2,496 \text{ ml of O2/min}\]
  \[= 2.496 \text{ Liters of O2/min}\]
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

- \( Q = HR \times SV \)
- Represents the amount of blood flow to the muscles

Submaximal Exercise
Heart Rate & Exercise

- Sympathetic nervous system
- Parasympathetic nervous system
- Catecholamines released
Stroke Volume & Exercise

1. ↑ Preload (or end-diastolic volume)
   - Muscle pump
   - Venoconstriction

2. ↑ Strength of contraction
   - Sympathetic stimulation

3. ↓ Afterload
   - Vasodilation

Submaximal Exercise
Preload

Venoconstriction

Increase Preload or blood flow into the heart

Muscle Pump
Afterload

Vasodilation

Decrease afterload leading to increase blood flow out of the heart
Vasodilation

*Autoregulation or Metabolic Vasodilation*
- Waste products from muscle contraction.
- $\uparrow$ CO$_2$ and $\uparrow$ acid
- Other
  - $\uparrow$ potassium, $\uparrow$ adenosine, and $\uparrow$ nitric oxide
a-v O₂ Difference & Exercise

- At rest: 5 ml of O₂/100 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

PO$_2$ = 0.2093 x 760 = 159 mmHg
Partial Pressure

- From pulmonary artery:
  - $PO_2 = 40$
  - $PCO_2 = 46$

- Alveoli:
  - $PO_2 = 105$
  - $PCO_2 = 40$
  - $O_2$
  - $CO_2$

- To pulmonary vein:
  - $PO_2 = 100$
  - $PCO_2 = 40$

- Right atrium and ventricle:
  - $PO_2 = 40$
  - $PCO_2 = 46$

- Systemic veins:
  - $PO_2 = 40$
  - $PCO_2 = 46$

- Body cells:
  - $PO_2 = 100$
  - $PCO_2 = 40$

- Systemic arteries:
  - $PO_2 = 100$
  - $PCO_2 = 40$

- Left atrium and ventricle:
Partial Pressure and a-v O₂ difference

Rest

PO₂ = 100

PO₂ = 100

PO₂ = 40

Exercise

PO₂ = 100

PO₂ = 15

Submaximal Exercise

no movement of O₂
Redistribution of Blood Flow

(a) Rest ($\dot{Q} = 5.8 \text{ L-min}^{-1}$)
- Skin (500 mL) 9%
- Skeletal muscle (1200 mL) 21%
- Coronary muscle (250 mL) 4%
- Cerebral (750 mL) 13%
- Splanchnic (1400 mL) 24%
- Other (600 mL) 10%

(b) Maximal Exercise ($\dot{Q} = 25 \text{ L-min}^{-1}$)
- Skin (600 mL) 2%
- Renal (250 mL) 1%
- Cerebral (900 mL) 3%
- Coronary muscle (1000 mL) 4%
- Other (~100 mL) 1%
- Splanchnic (300 mL)

88% Skeletal muscle (22,000 mL)
Redistribution of Blood Flow During Exercise

VASOCONSTRICTION

VASODILATION

Cardiac output = 25 l/min.

Heavy exercise

Rest

5 l/min.

Cardiac output = 5 l/min.
O₂ Supply Summary

- How is the increase in O₂ demand by the muscles during exercise met?
  - Increase Q
    - Increase HR
    - Increase SV
  - Increase a-v O₂ difference
Blood Pressure

Graphs showing the changes in blood pressure (BP) over time, with labels for SBP, MAP, and DBP. Another graph indicates the change in TPR (TPR) over time.
Upper Body Exercise

![Image of a person rowing]

**Graphs:**
- Mean Arterial Blood Pressure
- Heart Rate

**Axes:**
- Blood pressure (mm Hg)
- Heart rate (beats/min)
- Exercise oxygen uptake (ℓ/min)

**Lines:**
- Arm exercise
- Leg exercise
Cardiovascular Drift

- Heart rate
- Arterial pressure
- Cardiac output
- Pulmonary arterial pressure
- Blood volume
- Stroke volume

Heart Rate
Cardiac Output
Stroke Volume
Steady State, Submaximal Exercise
INCREMENTAL EXERCISE TO MAXIMAL EFFORT
Circulatory Responses to Incremental Exercise

Incremental Exercise
Circulatory Responses to Incremental Exercise

Cardiac Output

Heart Rate

Incremental Exercise
Maximum Heart Rate

- 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

[Graph showing stroke volume (ml/beat) increasing with treadmill speed (km/h) up to SVmax]
Circulatory Responses to Incremental Exercise

- Systolic blood pressure
- Diastolic blood pressure
Heart Rate

![Graph showing heart rate in beats per minute (min) against treadmill speed in kilometers per hour (km/h). The graph indicates an increase in heart rate with increasing treadmill speed, reaching a maximum (HR_max) at a specific speed.](image-url)
Stroke Volume

Note the plateau

![Graph showing stroke volume vs. treadmill speed]

- Stroke volume (ml/beat)
- Treadmill speed (km/h)
- SVmax

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

![Graph showing heart rate vs treadmill speed during pretraining and posttraining phases.](image-url)
## Lance by the Numbers

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tour de France victories</td>
<td>6</td>
</tr>
<tr>
<td>Most Tours won by anyone else</td>
<td>5</td>
</tr>
<tr>
<td>Americans who won Tour de France before Armstrong (Greg LeMond in 1986, 1989, 1990)</td>
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<tr>
<td>Armstrong’s resting heart rate</td>
<td>32</td>
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<tr>
<td>Average heart rate during a race</td>
<td>125</td>
</tr>
<tr>
<td>Average heart rate during a time trial</td>
<td>190</td>
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<tr>
<td>Pedal rpm during a time trial</td>
<td>100</td>
</tr>
<tr>
<td>VO$_2$ max*</td>
<td>84</td>
</tr>
<tr>
<td>Average male VO$_2$ max</td>
<td>40</td>
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<tr>
<td>Pedal strokes by Armstrong in 2004 Tour</td>
<td>about 465,000</td>
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<tr>
<td>Heartbeats during the race</td>
<td>2.1 million</td>
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<tr>
<td>Daily calorie intake during training</td>
<td>6,000</td>
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<tr>
<td>Body fat during race season</td>
<td>5–6%</td>
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<tr>
<td>Body fat during off-season</td>
<td>10–11%</td>
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<tr>
<td>Calories burned during 3 hours of racing</td>
<td>3,150</td>
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<tr>
<td>Calories expended during the race</td>
<td>132,000</td>
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<tr>
<td>Number of Big Macs represented by 132,000 calories</td>
<td>236</td>
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</tbody>
</table>

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*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 (VO2_{max}) by 25-30%
- Genetics: 40-66% of baseline VO2_{max}
- Improvements in VO2_{max}
  - 50% due to ↑ SV
  - 50% due to ↑ a-vO2
Adaptations from Chronic Exercise

-血
  - 全血容积
  - 血浆容积
  - 红细胞
  - 血细胞比容
Adaptations from Chronic Exercise

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

- Blood volume
- Heart size
- Heart strength
- Maximal cardiac output
- Stroke volume
- "Preload"
- "Afterload"
- Blood pressure
- Sympathetic N.S. activity to working muscle
- Muscle blood flow
- Capillaries Mitochondria
- $\dot{V}O_2$ max
- $a-\bar{V}O_2$ difference
## Adaptations from Chronic Exercise

<table>
<thead>
<tr>
<th>Metric</th>
<th>Rest</th>
<th>Submax</th>
<th>Max</th>
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<tbody>
<tr>
<td>Q</td>
<td>⇩</td>
<td>⇩</td>
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</tr>
<tr>
<td>SV</td>
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<tr>
<td>HR</td>
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<tr>
<td>a-vO2 diff</td>
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<tr>
<td>Plasma vol</td>
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<td>RBC</td>
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<td></td>
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<tr>
<td>Ht</td>
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<td></td>
<td></td>
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<tr>
<td>BP</td>
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</tbody>
</table>
Detraining

 Stroke Volume (Blood Volume)

 a-v O2 difference
Retraining

Graph showing changes in muscle fiber mitochondrial content over weeks of training or detraining. The graph illustrates the transition from untrained to trained states and back to detrained states. Key points include:

- **Training** phase shows an increase in mitochondrial content.
- **Detraining** phase shows a decrease in mitochondrial content.
- **Retraining** phase demonstrates recovery post-detraining.

Annotations include:
- Continue line labeled as Continued
- Re-training line labeled as Retraining
- Detraining line labeled as Detraining

The x-axis represents weeks of training or detraining, while the y-axis represents muscle fiber mitochondrial content in arbitrary units.
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.