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Integrated Cardiac Output and Respiratory Function

M1 – Cardiovascular/Respiratory Sequence

Louis D’Aleyc, Ph.D.

Fall 2008
Exercise

Ventilation → Circulation → Muscle Utilization
Exercise

• With exercise, \( \dot{V}O_2 \) increases
• one initially increases both ventilation and cardiac output
  – Ventilation and perfusion remain matched
  – \( DO_2 \) remains much greater than \( \dot{V}O_2 \)
Strenuous Exercise

Skeletal Muscle

<table>
<thead>
<tr>
<th></th>
<th>REST</th>
<th>STRENUOUS EXERCISE</th>
</tr>
</thead>
<tbody>
<tr>
<td>cardiac output</td>
<td>6 liters/min</td>
<td>18 liters/min</td>
</tr>
<tr>
<td>heart rate</td>
<td>70 beats per minute</td>
<td>160 beats per minute</td>
</tr>
<tr>
<td>ejection fraction</td>
<td>60%</td>
<td>80%</td>
</tr>
<tr>
<td>arterial pressure</td>
<td>120/80 mmHg</td>
<td>150/80 mmHg</td>
</tr>
<tr>
<td>central venous pressure</td>
<td>2 mmHg</td>
<td>2 mmHg</td>
</tr>
</tbody>
</table>

Figure 11-4  Cardiovascular adjustments to strenuous exercise.


M&H 10.4
Change in cardiac output/heart rate/stroke volume

![Graph showing changes in cardiac output, heart rate, and stroke volume with trained and untrained conditions.](image-url)
Exercise

• At higher levels of exercise, DO₂ can not keep up with increasing \( \dot{VO}_2 \)
  – \( \dot{VO}_2 \) is maintained by increasing oxygen extraction
    • \( \dot{VO}_2 = CO \times (CaO_2 - CvO_2) \)
      – CvO₂ falls and eventually MvO₂ falls
• Eventually, oxygen delivery is inadequate for the level of work, and the muscle shifts to anaerobic metabolism
  – Anaerobic threshold
Oxygen delivery and oxygen saturation of mixed venous blood

• Normal mixed venous oxygen saturation (MvO2) = 75%
• If oxygen delivery falls, and tissue metabolism continues, then MvO2 will fall
• In principle, we should know that oxygen delivery is sufficient if we know that MvO2 is normal
• There are a few caveats…
Caveats

• Suppose blood moves from the arterial circulation to the venous circulation without unloading oxygen
  – Large shunts, congenital and man-made
  – Micro shunts
  – Toxins poisoning mitochondria

• If oxygen isn’t removed from arterial blood, the MvO2 may be normal, despite inadequate oxygen delivery
REVIEW OF Worked Problems as time permits.
Prior questions

• What is the total $O_2$ content of 100 ml of plasma ($PO_2$ 100 mmHg)?

  Ans. 0.31 ml
Henry’s Law for $O_2$

The content of dissolved oxygen is equal to the product of the oxygen solubility coefficient and oxygen partial pressure.

$$CdO_2 = aO_2 \cdot PO_2$$

$CdO_2$ = content of dissolved $O_2$  mL/dL

$aO_2$ = solubility coefficient for $O_2$ in blood

$$aO_2 = 0.0031 \text{ mL/mm Hg/dL}$$

dL = 100 mL
Prior questions

• What is the $O_2$ content of 100 ml of blood (Hb 15 gm/dL; PO2 100 mmHg)?

Ans. 20 ml
Typical Arterial Blood Oxygen Content

\[ P_{O_2} = 100 \text{ mm Hg} \quad S_{O_2} = 97\% \quad [\text{Hb}] = 15 \text{ gm/dL} \]

1.34 mL O_2/gm Hb = O_2 capacity =Hb_s

Dissolved O_2

\[ C_{dO_2} = a_{O_2} \quad P_{O_2} = 0.0031 \times 100 = 0.31 \text{ mL / dL} \]

Bound O_2

\[ C_{bO_2} = S_{O_2} \times [\text{Hb}] \quad Hb_s = 0.97 \times 15 \times 1.36 = 19.79 \text{ mL / dL} \]

Total Oxygen Content

\[ C_{dO_2} + C_{bO_2} = 0.31 + 19.79 = \boxed{20.1 \text{ mL / dL}} \]
Integrated Question 1

- \( \text{CaO}_2 = 19 \, \text{ml/dL} \)
- \( \text{CvO}_2 = 14.5 \, \text{ml/dL} \)
- Cardiac output by thermal dilution = 8 liters/min
- What is the \( \dot{\text{VO}}_2 \)?

\[
\dot{\text{VO}}_2 = \text{CO} \times (\text{CaO}_2 - \text{CvO}_2)
\]

\[
\dot{\text{VO}}_2 = 80 \, \text{dL/min} \times (19 - 14.5 \, \text{ml/dL}) = 360 \, \text{ml/min}
\]
Integrating Question 2

\[ \dot{V}O_2 = 250 \text{ ml/min} \]
\[ CaO_2 = 20.5 \text{ ml/dL} \]
\[ CvO_2 = 16 \text{ ml/dL} \]

- What is the cardiac output?

\[ CO = \dot{V}O_2 / (CaO_2 - CvO_2) \]

\[ CO = 250 \text{ ml/min} / (20.5 - 16 \text{ ml/dL}) \]
\[ = 250/4.5 = 55 \text{ dL/min} = 5.5 \text{ L/min} \]
Integrated Question 3

• Determine oxygen delivery
  \[ \text{PaO}_2 = 96 \text{ mmHg} \]
  \[ \text{O}_2 \text{ saturation} = 97\% \]
  \[ \text{Hb} = 12 \text{ gm/dL} \]
  \[ \text{Cardiac output} = 6 \text{ liters/min} \]

\[ \text{DO}_2 = \text{CO} \times \text{CaO}_2 \]

\[ \text{CaO}_2 = (1.34 \times 12 \text{ gm/dL} \times 0.97) + (96 \times 0.003) \]
\[ = 15.6 + 0.29 = 15.9 \text{ ml/dL} \]

\[ \text{DO}_2 = 60 \text{ dL/min} \times 15.9 \text{ ml/dL} = 954 \text{ ml/min} \]
Integrated Question 4

Which of the following maneuvers will increase oxygen delivery to the greatest degree (all else being equal)?

A. supplemental oxygen to increase PO$_2$ from 90 to 120 mmHg – little effect
B. supplemental oxygen to increase O$_2$ saturation from 88% to 98% - <12% increase
C. transfusion to increase hemoglobin from 9 gm/dL to 12 gm/dL – 33% increase
D. increase cardiac output from 5 liters/min to 8 liters/min – 60% increase
A healthy individual is given a drug that increases cardiac output from 5 to 7 liters/min. One would anticipate which of the following as a consequence of this change?

A. Oxygen consumption increases
B. Arterial oxygen saturation increases
C. Arterial oxygen saturation decreases
D. Mixed venous oxygen saturation increases
E. Mixed venous oxygen saturation decreases
Hemoglobin affinity for oxygen is not static

**Left shift (lungs)**

- At any PO$_2$ more O$_2$ bound.
- $\downarrow$ H$^+$
- $\downarrow$ CO$_2$
- $\downarrow$ temperature
- $\downarrow$ 2,3 BPG

**Right shift (tissues)**

- At any PO$_2$ less O$_2$ bound.
- $\uparrow$ H$^+$ (Bohr shift)
- $\uparrow$ CO$_2$
- $\uparrow$ temperature
- $\uparrow$ 2,3 BPG

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