EXERCISE II

Cardiovascular Changes with Exercise

Major difference between dynamic exercise and static exercise is that, in the former peripheral resistance falls, whereas, with the latter, sustained muscular contraction tends to occlude that part of the vascular bed.

Vasodilation

Vasodilation of muscle during exercise arises through the effects of a cocktail of local ‘metabolites’ including:
Hypoxia
CO₂
H⁺
Breakdown products of ATP (ADP, AMP, Adenosine, Pᵢ)
K⁺
Increase in osmolarity (increase in lactate, K⁺ + others).
Mechanics of action are varied, with some involving the endothelium and others not.

The metabolic vasodilation of the small vessels causes an increased flow and hence an increase in shear stress in layer vessels. This increases the local production of NO, currying vasodilation in the vessels.
Predicted Effect of Peripheral Vasodilation on the Circulatory System

(Starling’s Law)

Note: rise in CO and PV associated with fall in Pa

Rest

Vasodilation

Note: rise in CO and PV associated with fall in Pa
Consequence of vasodilation is a rise in CO and $P_V$, and a fall in Pa.

However, a fall in a Pa would trigger a baroreflex response to elevate blood pressure by squeezing on the capacitance vessels and increasing the contractility of the heart.

This increases CO further and helps to restore blood pressure.

Nevertheless to drive this, one would have to have some smaller reduction in blood pressure from rest in order to drive the baroreflex (the error signal).

**Measured Cardiovascular Response to Exercise**

One of the most important observations is that the predicted fall in blood pressure associated with vasodilation on starting dynamic exercise does not occur.

Reason is “feed forward” control over the circulating system. Two main hypotheses:

**“Central Command”**  Krogh and Lindhard (1913).

Partial neuromuscular blockade using tubocurarine (so a given movement requires a greater command) produces an enhanced rise in blood pressure and heat rate.

**“Peripheral Reflex”**

Inflation of a cuff around a limb to retain chemical stimulants in the muscle causes the “pressor” response to be partially sustained after the end of exercise (Alan and Smirk, 1938).

A good unanswered question is how does feed-forward control became so well calibrated that it holds blood pressure almost constant.
Respiratory Changes with Exercise

Incremental exercise

Step-change into exercise

Predicted Effect of Increase in Metabolic Rate on Respiratory System

Respiratory controller

Controlled system

\[ V_{CO2} = P_{ACO2} \times V \]

A rectangular hyperbola with an area constant of \( V_{CO2} \)
Rest

Increased metabolic rate

\[ \dot{V} \]

\[ P_{ACO2} \]

Note the rise in both \( \dot{V} \) and \( P_{ACO2} \)

Measured Respiratory Response to Exercise

Again, one of the most important observations is that the predicted rise in \( P_{ACO2} \) associated with the rise in metabolic rate on starting exercise does not occur.

\[ \dot{V} \]

\[ P_{ACO2} \]

\[ \text{CO}_2 \] response line shifted upwards.

Not really understood why breathing increases, given that the major chemical stimuli \( P_{CO2}, P_{O2}, \text{pH} \) are all unchanged in mild/moderate exercise.
Dejour (1963) proposed a neurohumoral theory

**Neural component**

May be central command.
May be afferents from muscle.
Ideas are similar to those for control of cardiovascular system.

**Humoral component**

Many theories (e.g., increase in arterial $[K^+]$, increase in oscillations of $P_{CO2}$ in arterial blood), but no clear understanding – or indeed proof that it is humoral.
What Limits Exercise?

1. Rate of O\textsubscript{2} utilization by muscles or O\textsubscript{2} supply to muscles?

   It is O\textsubscript{2} supply to muscles because exercising larger muscle masses (e.g. arms and legs) does not deliver an increase in O\textsubscript{2} consumption compared with exercising just legs. N.B. for exercise of small groups of muscles, limiting factor is within muscle.

2. Inadequate oxygenation by lungs or limitation of supply of O\textsubscript{2} laden blood to muscles?

   It is supply of O\textsubscript{2} laden blood to muscles, since arterial blood is almost totally oxygenated by the lungs in most cases.

   But
   
   i) there is some diffusion gradient in lungs, but modest elevation of alveolar P\textsubscript{O\textsubscript{2}} in hard exercise means this does not affect O\textsubscript{2} saturation of blood in most cases.
   ii) arterial blood not necessarily fully oxygenated in elite athletes, who may show some arterial desaturation.
   iii) oxygen not totally extracted by muscles, and so diffusion limitation in muscle remains significant.
Effects of Training

Isometric exercise – mainly training for muscle bulk.

Endurance exercise –

a. Increases number of capillaries in muscle to minimize diffusion distance as muscle increases in bulk.
b. Increases the size of heart and thickness of myocardium.

Skilled exercise –

Can learn to do tasks more efficiently e.g. swimming

<table>
<thead>
<tr>
<th></th>
<th>After bed rest</th>
<th>After training</th>
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</thead>
<tbody>
<tr>
<td>Maximal O2 uptake</td>
<td>2.5 l/min</td>
<td>3.9 l/min</td>
</tr>
<tr>
<td>Cardiac output</td>
<td>15 l/min</td>
<td>23 l/min</td>
</tr>
<tr>
<td>Heart rate</td>
<td>190</td>
<td>190</td>
</tr>
<tr>
<td>Stroke volume</td>
<td>80 ml</td>
<td>120 ml</td>
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Table above suggests improvement in $V_{O2\max}$ from enforced bed rest to the fully trained state is around 50%. This is accomplished through increases in stroke volume of the heart.
Review

Following this lecture you should:

- Understanding the basic mechanisms underlying vasodilation of the skeletal muscle vascular bed with exercise.
- Understand the effect that such vasodilation would have on an uncompensated cardiovascular system.
- Understand the reflex effects that would result from these changes.
- Understand the role of “feed forward” control in minimising disturbances and feedback error signals within the cardiovascular system.
- Understand the basic theories in relation to feed forward control of the cardiovascular system.
- Understand the basic effect of an increase in metabolic rate on the respiratory system and understand the feedback compensation in ventilation that would occur in the absence of “feed forward” control.
- Understand the role of “feed forward” control in minimising disturbances in blood gases.
- Understand the basic theories in relation to “feed forward” control in the respiratory system.
- Understand the major factors that limit power in humans.
- Know the major effects of physical training.

Reading