CHAPTER 3: The cardio-respiratory system

Exam style questions - text book pages 44 - 45

1) Describe the structures involved in gaseous exchange in the lungs and explain how gaseous exchange occurs within this tissue. 6 marks

Answer:
- *Gaseous exchange is the delivery of oxygen from the lungs to the bloodstream.*
- *And the elimination of carbon dioxide from the bloodstream to the lungs.*
- *It occurs in the lungs between the alveoli and a network of tiny blood vessels called capillaries, which are located in the walls of the alveoli.*

How gaseous exchange occurs within this tissue:
- *Gaseous exchange depends on the partial pressure of each gas, gas solubility and temperature.*
- *Via a process called diffusion.*
- *Gas molecules diffuse into the lungs and tissues down concentration gradients from higher concentration (high pressure) to lower concentrations (lower pressure) or results of differences in gas partial pressures.*
- *Hence, oxygen diffuses through the alveoli walls into the surrounding pulmonary capillaries.*
- *And carbon dioxide diffuses across in the opposite direction into the lungs.*
- *Because venous blood contains oxygen at lower pressure and carbon dioxide at higher pressure than alveolar gas.*

2) a) The diagram in figure 3.14 represents the lung volume changes based on a number of spirometer readings during various breathing actions. With reference to the trace, briefly explain resting tidal volume (TV), expiratory reserve volume (ERV), vital capacity (VC), and residual volume (RV). 4 marks

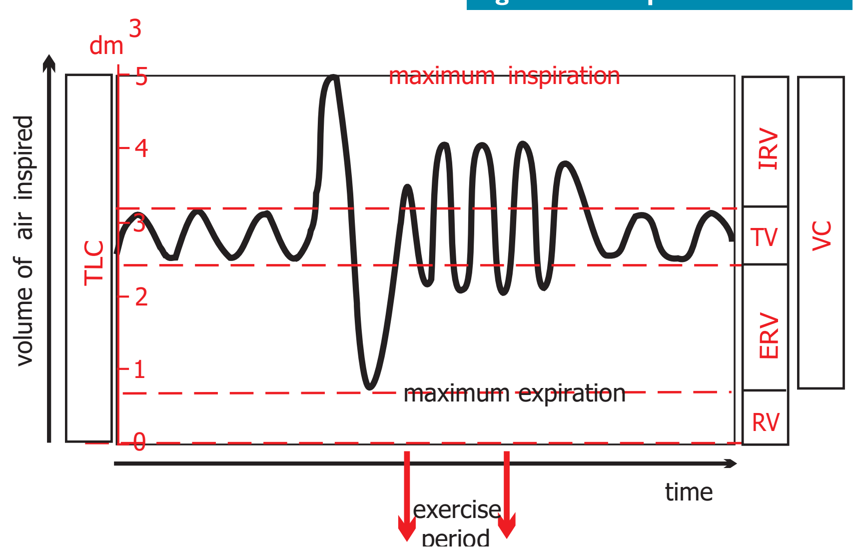
Answer:

Definitions:
- *Resting tidal volume is that volume of air that is breathed in* ***or*** *out during one breath at rest.*
- *Expiratory reserve volume is that volume of air that can be forcibly expired over and above resting tidal volume.*
- *Vital capacity is the maximal volume of air that can be forcibly expired after maximal inspiration in one breath.*
- *Residual volume is that volume of air remaining in the lungs after maximal expiration.*

b) Using the information in the spirometer trace, state what happens to the following volumes during the exercise period: residual volume, inspiratory volume (IRV), and expiratory volume (ERV). 3 marks

Answer:
- *Residual volume remains the same.*
- *IRV decreases.*
- *ERV decreases*

figure 3.14 – spirometer trace



c) Why does tidal volume change by only a small amount during the exercise period? 3 marks

Answer:
- *Major respiratory regulator is carbon dioxide.*
- *Which controls rate of breathing (f).*
- *And depth (TV) of breathing.*
- *Effect of exercise is to increase pCO_2.*
- *And stimulate a bigger increase in breathing rate when compared with tidal volume.*
- *So that the increased levels of CO_2 are removed quickly from the body.*

d) Identify two effects of regular aerobic training on lung volumes and capacities. 2 marks

Answer:

Two effects from the following:

- *Improved strength of respiratory muscles.*
- *Increase in TV, VC at expense of RV.*
- *At submaximal workloads slight decrease in frequency of breaths.*
- *During maximal workloads big increase in frequency of breaths, hence big increase in minute ventilation.*
- *Hence increased gaseous exchange and $\dot{V}O_{2max}$.*
- *At submaximal workloads $\dot{V}O_{2max}$ will be less because of greater efficiency of O_2 uptake.*

e) A student measured the volume of air that he or she ventilated at rest and during submaximal exercise. The results are shown in table 3.4 below.

Table 3.4 – **ventilation at rest and during submaximal exercise**

activity level	inhalation volume	breathing rate	minute ventilation
	(TV)	(f)	volume ($\dot{V}E$)
at rest	500 ml	one every 6 seconds	A
submaximal exercise	800 ml	one every 2 seconds	B

Define what is meant by the term 'minute ventilation volume' and calculate the values for A and B, clearly showing the method used. 4 marks

Answer:

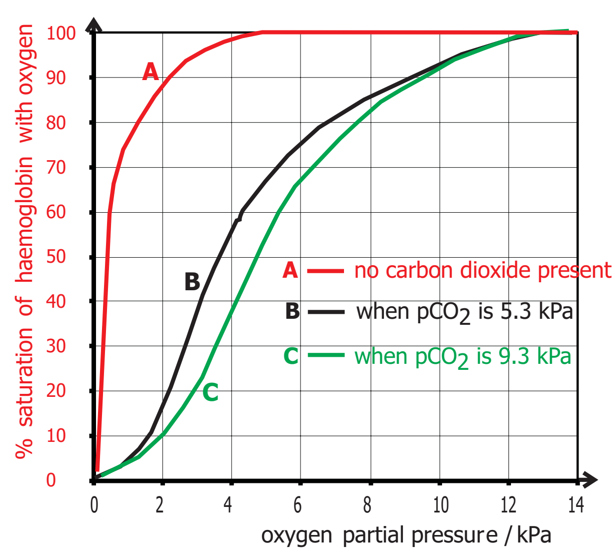
- *Minute ventilation volume is the volume of air inspired* ***or*** *expired in one minute - notated as $\dot{V}E$.*
- *It is a combination of tidal or inhalation volume (TV) and breathing rate (f).*

$\dot{V}E$ = *TV (inhalation volume) x f (breathing rate).*

- *At rest:* $\dot{V}E$ = *500 x 10.*
  = *5,000 ml min^{-1} or 5 dm^3 min^{-1} or 5 litres min^{-1}.*
- *During submaximal exercise:* $\dot{V}E$ = *800 x 30.*
  = *24,000 ml min^{-1} or 24 dm^3 min^{-1} or 24 litres min^{-1}.*

3) The binding of oxygen to haemoglobin depends on pO_2 in the blood and the affinity of haemoglobin with oxygen. The curves in figure 3.15 show how different concentrations of carbon dioxide affect the saturation of haemoglobin at varying partial pressures of oxygen.

figure 3.15 – oxyhaemoglobin dissociation curve



a) Explain what is meant by partial pressure of oxygen (pO_2). 1 mark

Answer:

- *The pressure that oxygen (pO_2) exerts within a mixture of gases.*

b) What are the values of percentage saturation of haemoglobin on the three curves when the partial pressure of oxygen is 5.0 kPa? 3 marks

Answer:

- *Curve **A** - haemoglobin is fully saturated with oxygen – 100%.*
- *Curve **B** - haemoglobin is 68% saturated with oxygen.*
- *Curve **C** – haemoglobin is 55% saturated with oxygen.*

3) c) What are the implications of the carbon dioxide values for curves **B** and **C** for an athlete? 2 marks

Answer:

2 marks for 2 of:

- *The greater pCO_2 the less % of HbO_2 saturation.*
- *This is because as more energy is released by respiring muscle cells.*
- *More CO_2 is produced as a waste product.*
- *Diffusing across into the blood capillaries.*
- *Therefore the more CO_2 in the blood and surrounding the red blood cells (and hence the haemoglobin in the red blood cells), the less oxygen can be carried by the haemoglobin.*
- *This means that the difference (in the case of curve **B** at 5.0 kPa – this is 100–68 = 32% of the oxygen carried).*
- *Detaches itself from the haemoglobin and diffuses into the muscle cells where it is available for respiration.*
- *When more CO_2 is present (during violent exercise) as in the case of curve **C** at pCO_2 = 9.3 kPa, at the same pO_2 (5.0 kPa) haemoglobin releases 100–55 = 45% of the oxygen carried.*
- *So the more exercise, the more oxygen released and made available for more exercise.*

d) Why is the partial pressure of oxygen (pO_2) important to the process of gaseous exchange? 3 marks

Answer:

- *The increased loading of CO_2 causes more unloading of O_2 from haemoglobin,*
- *And so more O_2 is released for tissue cell respiration to sustain the physical activity undertaken.*

Importance of pO_2 in gaseous exchange in the alveoli:

- *The pO_2 in the lung alveoli must be higher than the pO_2 in the pulmonary blood.*
- *In order for oxygen to diffuse into the bloodstream.*

Importance of pO_2 in gaseous exchange at tissue cell sites:

- *Similarly, the arterial pO_2 must be greater at the tissue site than in the tissue cells.*
- *In order for oxygen to diffuse into tissue cells.*

4) A hockey player has a match in one hour's time. Describe how inspiration occurs during this resting period. During the hockey match, the player must increase the volume of gas exchanged in the lungs and muscles.
Explain the changes in the mechanics of breathing (inspiration and expiration) which facilitate this increase. 12 marks

Answer:

Inspiration:

- *External intercostal muscles and diaphragm contract.*
- *Internal intercostal muscles relax.*
- *The action of these contracting muscles is to increase the volume of the thoracic cavity.*
- *As pleural and pulmonary pressures are reduced (air pressure within the lungs is reduced as their volume expands).*
- *Air in the lungs is at lower pressure than the air in the atmosphere outside.*
- *Since air moves from areas of high pressure to areas of low pressure.*
- *Air rushes into the lungs.*

Changes to inspiration:

- *Additional respiratory muscles contract.*
- *Namely sternocleidomastoid, scalenes and pectoralis minor.*
- *Effect is that the diaphragm contracts and flattens (moves downward away from the lungs) with more force.*
- *Increased lifting of sternum.*
- *Which gives increased thoracic cavity volume.*
- *Decreased pleural and pulmonary pressures (within the lungs).*
- *Lower pulmonary air pressure.*
- *So the pressure of air outside is still bigger than inside.*

- *More air rushes into the lungs.*

4) (continued)

During expiration:

- *Active respiratory muscles contract.*
- *Namely internal intercostal and rectus abdominus.*
- *The diaphragm relaxes and domes upward thereby compressing the lungs.*
- *The ribs and sternum are pulled in and down with more force.*
- *This decreases the size of the thoracic cavity volume.*
- *Gives increased pleural and pulmonary pressures (the pressure of the air inside the lungs is increased).*
- *So the sir inside the lungs is at a higher pressure than the atmospheric air outside.*
- *More air is forced out of the lungs.*

5) Identify the long-term adaptations an elite performer would expect to occur in the structure and functioning of the respiratory system as a result of an intense aerobic training programme. 12 marks

Answer:

Note: Long-term adaptations are physiological adaptations within the human body that are produced as a result of the effects of a training programme over a period of several weeks, months or even years.

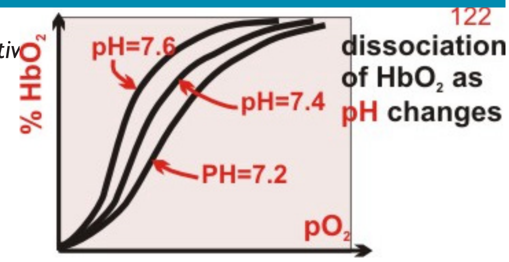
- *Intense aerobic exercise has the effect of forcing the person to breathe more deeply and more often (the vital capacity of the lung is fully utilised, and the breathing frequency (f) increases).*

- *Therefore, as a result of long-term exercise, the following adaptations take place within the body which tend to make more efficient the transfer (from air breathed in) of oxygen to working muscle.*
- *Long-term exercise has the regular effect of exercising the respiratory muscular system – namely, the diaphragm and intercostal muscles.*
- *When exercise is continued at least two to three times per week, these muscles will get fitter and stronger and more capable of working without cramps and conditions like stitches.*
- *The efficiency of the respiratory system will depend on the utilisation and capacity of the alveoli to take oxygen from air breathed in.*
- *And transmit it to blood flowing through the alveolar capillary bed.*
- *Long-term physical activity increases blood flow to the upper lobes of the lungs to increase utilisation of lung alveoli.*
- *Hence increases gaseous exchange.*
- *And therefore increase in $\dot{V}O_{2max}$ at high intensity aerobic workloads.*
- *At submaximal workloads $\dot{V}O_2$ will be less because of greater efficiency of oxygen uptake.*
- *And general improvements in lung function will occur such as increase in tidal volume (TV) and vital capacity (VC) at the expense of residual volume (RV).*
- *Increased efficiencies of the respiratory system will improve recovery from exercise.*
- *And reduce oxygen debt during exercise.*
- *At submaximal workloads there is a slight decrease in the breathing rate (f – the frequency of breaths).*
- *During maximal workloads there is a big increase in breathing rate (f), hence much bigger values in minute ventilation are achieved.*

6) A level. Describe the effect of exercise on pO_2, pCO_2 and pH and explain how ventilation might be increased during exercise.

15 marks

figure Q3.1 – oxyhaemoglobin dissociation curve showing chnages with pH - acidity



Answer:

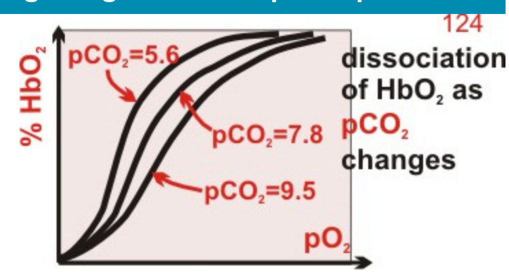
- *pO_2 and pCO_2 represent the partial pressure of oxygen and carbon dioxide respectively.*
- *pH is a measure of acid or alkaline.*
- *See graphs in figures Q3.1 and Q3.2.*

7 marks for 7 of:

Effects of exercise on pO_2, pCO_2 and pH:

- *These two graphs illustrate how oxygen is released from oxyhaemoglobin from rest to exercise.*
- *The maximum possible haemoglobin pO_2 is 13.3kPa*
- *At rest pH is fairly neutral at 7.6, and pCO_2 is 5.6.*
- *Increasing physical activity results in increased CO_2 or decreased pH.*
- *Causing a shift on the O_2 dissociation curve to the right.*
- *So that the percentage of saturated haemoglobin with oxygen is reduced.*
- *This is called the 'Bohr effect'.*
- *The Bohr effect becomes particularly important during physical activity because increased metabolic heat and acidity in active tissues augments oxygen release, as illustrated when pH decreases to 7.2.*
- *a-vO_2diff describes the difference in oxygen content between arterial and mixed-venous blood.*
- *During exercise tissue pO_2 decreases.*
- *This forces Hb to release greater quantities of oxygen to meet metabolic needs.*
- *This expands the tissue a-vO_2diff difference.*
- *And so more oxygen is released from the haemoglobin for active tissue cell respiration.*

figure Q3.2 – oxyhaemoglobin dissociation curve showing changes with CO2 partial pressure



6 marks for 6 of:

How ventilation might be increased during exercise:

- *Pulmonary ventilation increases linearly with oxygen uptake during light and moderate exercise.*
- *Towards maximal exercise, pulmonary ventilation, (expressed here as minute ventilation ($\dot{V}E$) – volume of air inspired or expired in one minute) increases disproportionally with increases in oxygen uptake.*

How does this happen?

- *Increase in ventilation is achieved by increasing the tidal volume or the volume of air inspired or expired in one breath (TV).*
- *And the frequency of breathing (f) or the number of breaths taken in one minute.*
- *Expressed as $\dot{V}E = TV \times f$.*
- *Changes in TV and f increase minute ventilation.*
- *During submaximal exercise tidal volume increases substantially.*
- *With an associated lesser increase in the number of breaths.*
- *Towards maximal exercise, tidal volume decreases slightly from submaximal values.*
- *Breath frequency increases dramatically.*
- *Thereby increasing pulmonary ventilation to meet exercise needs.*