BIO 3302 Animal Physiology II
Midterm #1

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80 min

NAME: MASTER

STUDENT #: _____

Part A: Answer the following questions in the space provided on the question sheet. (1 mark per answer unless otherwise stated; 22 marks in total)

1. Distinguish between vasomotor tone and vagal tone. (2 marks)

   Vagal tone refers to the background level of activity in the parasympathetic neurons (0.5 marks) innervating the heart (0.5 marks), whereas vasomotor tone refers to the background or resting level of activity in the sympathetic neurons (0.5 marks) innervating the smooth muscle of the vasculature (0.5 marks).

2. According to the **Frank Starling relationship**, the volume of blood ejected by the heart in a single beat (i.e. stroke volume) is proportional to diastolic filling. Explain how this phenomenon is used during exercise to increase cardiac output.

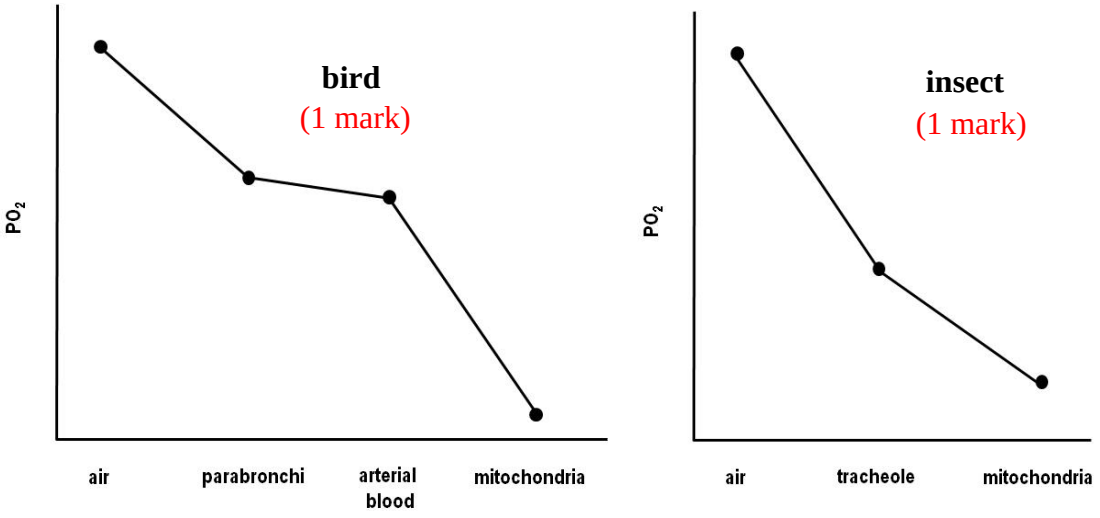
   During exercise, sympathetic activity in the neurons innervating the smooth muscle of the vasculature is increased, causing venous vasoconstriction that increases venous return and hence the filling of the heart. At the same time, increased activity of the skeletal muscle pump also increases venous return and hence the filling of the heart. Through the Frank Starling relationship, this increased filling of the heart contributes to increased stroke volume and hence increased cardiac output (since Q = HR x SV).

   0.5 marks for noting one or both of the mechanisms through which venous return is increased and 0.5 marks for linking the increase in venous return to an increase in cardiac output via stroke volume.

3. To maintain a constant alveolar PO_2 as you snorkel about a coral reef admiring the diverse and spectacular piscine fauna, you must increase OR decrease **(select one)**
   tidal volume to compensate for the additional
   dead space provided by the snorkel.

4. The functional unit of gas exchange for a bird is **the parabronchus**
   whereas that of an insect is **the tracheole**.

5. Sketch the oxygen cascade for a bird and an insect, and explain the similarities and differences between them. (4 marks)



They are similar in that the partial pressure of O_2 decreases from the ambient air to the point of O_2 use at the mitochondria – it is this PO_2 gradient that drives O_2 movement into the animal. (1 mark)

They differ in the number of steps – in birds, O_2 enters the animal across the gas exchange surface (parabronchi of the lungs) and is carried by the blood to the tissue site of use. In insects, on the other hand, gas diffuses via the tracheal system directly to the tissues and so moves from the tracheole into the mitochondria. (1 mark)

6. Which one of the following statements about the regulation of blood pressure in vertebrates is incorrect?
   a. Baroreceptors are stretch-sensitive mechanoreceptors found in the carotid body and the aorta that function in the acute regulation of blood pressure.
   b. Blood pressure regulation is essential both for the maintenance of blood flow to critical tissues (the brain, heart and gas-exchange organ) and for the maintenance of fluid balance.
   c. Chronic regulation of blood pressure involves the regulation of fluid volume by adjusting the rate of urine production.
   d. An appropriate response to a sudden fall in blood pressure is to increase sympathetic activity to the vasculature, as this will increase both total peripheral resistance and, indirectly, cardiac output.
   e. Individuals suffering from hypertension are often treated with ß$_2$ blockers and blood thinners to limit increases in heart rate and to decrease blood viscosity (and hence total peripheral resistance), respectively.

7. _____**Active hyperemia**_____ is a term that refers to the increased blood flow to a tissue resulting from elevated activity. It reflects an automatic vasodilation that is independent of nerves or hormones, being achieved instead through changes in metabolic conditions such as (**provide two examples**): _____**↓ O_2, ↑ CO_2, ↑ adenosine, ↑ H^+ (or ↓ pH), ↑ K^+, ↑ temperature**_____ or _____**(pick 2 for 2 marks)**_____. A tissue in which this phenomenon is particularly highly developed is _____**Skeletal muscle**_____.

8. In an experiment to determine the role of the air sacs in the avian lung, physiologists tied off an air sac so that gas from that air sac could no longer enter the lung. The researchers then replaced the O_2 in the sealed air sac with carbon monoxide, a gas that readily bind to haemoglobin, displacing O_2. However, addition of carbon monoxide to the sealed air sac had no impact on the O_2 saturation of haemoglobin in the arterial blood. What does this experiment demonstrate about the nature of the air sacs in birds?

   The fact that addition of carbon monoxide to the sealed air sac had no impact on the O_2 saturation of haemoglobin in the arterial blood implies that carbon monoxide did not exit the air sac into the blood, implying that air sacs are non-respiratory organs, i.e. no gas exchange occurs across the air sac wall. (1 mark)

9. List <u>two</u> structural characteristics of capillaries that are essential to their function, briefly explaining the functional significance of each structural characteristic. (2 marks)

   2 needed – 0.5 marks for structure, 0.5 marks for significance

   - Thin wall (single layer of endothelial cells on basement membrane): Thin walls maximize the rate of transfer of substances by diffusion according to the Fick equation ($MO_2 = \Delta PO_2 \cdot KO_2 \cdot SA/T$) by minimizing the diffusion barrier (T).

   - High SA (although small diameter, very numerous): As above, but by maximizing the surface area (SA) over which diffusion can occur. Also, high total area means low velocity of flow, which is important for facilitating exchange.

   - Variable permeability (continuous, fenestrated, sinusoidal – types varying in the number and size of aqueous channels): As above, but by affecting the permeability term K. Differences in permeability affect the rate of transfer and allow transfer in particular areas to be matched to functional requirements (e.g. sinusoidal capillaries in liver allow proteins to be added to the plasma).

10. The viscosity of a milkshake is 64 times the viscosity of diet coke. Therefore, the resistance to sucking a milkshake through a straw that is 15 cm long and 0.5 cm in diameter is _____**2**_____ times the resistance to sucking diet coke through a 30 cm long, 0.25 cm diameter straw.

Part B: Answer the following questions in the exam booklet. (20 marks in total)

1. Metabolic rate in reptiles is limited by structural features of the circulatory and gas exchange systems. Provide two examples, explaining for each how it limits metabolic rate. (4 marks)

   2 needed – 1 mark for structure, 1 mark for significance
   Reptiles have an incompletely divided ventricle – This limits metabolic rate by limiting the maximum systemic pressure that can be achieved. With what is effectively a single pump driving blood through both the pulmonary and systemic circulations, the maximum pressure that can be achieved is the pressure that the lungs can withstand (which is low). Low systemic pressure limits O_2 delivery to the tissues and hence limits metabolic rate.

   Reptiles have a simple lung of low total surface area – This limits metabolic rate via the Fick equation, $MO_2 = \Delta PO_2 \cdot K_{gas} \cdot SA/T$. Low total surface area limits O_2 transfer across the lung and hence O_2 delivery to the tissues, and metabolic rate.

   Reptiles lack a diagphragm and rely on movements of the body wall to ventilate the lungs – This relatively ineffective mechanism of ventilating the lungs again limits O_2 uptake and hence metabolic rate. Moreover, it results in conflicts between breathing and other activities that rely on the body wall, such as locomotion such that many reptiles are unable to breathe and move at the same time.

2. As Myrtle the muskie speeds after a tasty-looking perch, her respiratory and circulatory systems kick into high gear. The extraction efficiency of her gills reaches 60% (Myrtle is breathing water that is fully equilibrated with air, and the atmospheric pressure is 760 Torr), resulting in an arterial-to-venous blood O_2 concentration difference of 2.5 mmol L^{-1}. Her ventilation volume doubles as she switches to ram ventilation, achieving a value of 1.5 L min^{-1}. What is Myrtle's cardiac output in this high activity situation? You may assume a value of 2 µmol L^{-1} $Torr^{-1}$ for the solubility of O_2 in water. (6 marks)

   Extraction efficiency = $(PiO_2 - PeO_2)/PiO_2$ x 100% = 60% (1 mark)
   PiO_2 = 21% of 760 Torr = 160 Torr (1 mark)
   Therefore, PeO_2 = 64 Torr (1 mark)

   $MO_2 = Vb(CaO_2 - CvO_2) = Vw(CiO_2 - CeO_2) = Vw\ ßwO_2\ (PiO_2 - PeO_2)$ (1 mark)
   $Vb \cdot 2.5$ mmol $L^{-1} = (1.5$ L $min^{-1})(0.002$ mmol L^{-1} $Torr^{-1})(160 - 64$ Torr) (1 mark)
   Vb = 0.115 L min^{-1} (1 mark)

3. Bimodal breathers among fish, such as lungfish, utilise both simple lungs (similar in structure to those of a frog) and gills as gas exchange surfaces. Contrast and compare these two organs in terms of their function in gas exchange. Based on your knowledge of basic gas transfer principles, why do lungfish use their gills for CO_2 excretion but not O_2 uptake? (10 marks)

Points of similarity:

- high surface area, relatively low diffusion distance, good vascularization, high permeability… in other words, both have the characteristics of a good gas exchange surface. (2 marks)

Points of difference:

- Lungs are internalised gas exchange surfaces that are ventilated in a tidal fashion, whereas gills are externalised gas exchange surfaces that are ventilated in a continuous, unidirectional flow fashion. (1 mark)
- Because lungs are blind-ended structures, the model of gas transfer that best describes them is that of a circulated pool-type mechanism. (1 mark) Thus, oxygenated blood leaving the lung can achieve at best a PO_2 (PaO_2) that is less than the PO_2 in the expired air (PeO_2). (1 mark) PeO_2 in turn reflects the composition of air in the lung, which will have lower O_2 levels than the inspired air (PiO_2) owing to the fact that in most lungs, there is only partial turnover of the air in the lung on any given breath (lung ventilation << lung residual volume). (1 mark) By contrast, the flow through nature of gills enables counter-current blood and water flow to be established. (1 mark) This is a highly efficient mechanism of gas exchange and results in PaO_2 values that are greater than PeO_2 and in fact approach PiO_2. The strength of this mechanism is the maintenance of a constant partial pressure gradient across the entire gas exchange unit, the lamella. (1 mark)
- Typically, gills have to be sturdier structures than lungs to withstand the higher flow of a denser, more viscous medium. Thus, on average the diffusion distance in a fish gill is about 10x higher than that in a lung (~5 µm to 0.5 µm). (1 mark)
- Overall, the extraction efficiency for O_2 is typically substantially lower in a lung than in a gill, but because air is an O_2-rich medium relative to water, the lower efficiency does not limit O_2 uptake. By contrast, the high extraction efficiency of the gill for O_2 is essential because of the low capacitance of water for O_2, and this also necessitates much higher flow rates of the ventilated medium at gills vs lungs. (1 mark)

Why do lungfish use gills for CO_2 excretion but not O_2 uptake?

- The capacitance of water for O_2 is much lower than the capacitance of air for O_2, whereas the capacitances of air and water for CO_2 are similar. Thus, while CO_2 excretion into the water is relatively easy, O_2 uptake from water is difficult, favouring O_2 uptake from the lung. (1 mark)

Total marks to a maximum of 10.

Bonus: With Valentine's Day just around the corner, it may interest you to learn that many fish are considered to be aphrodisiacs. For a bonus mark that, in the spirit of socialism will be applied to the entire class if even one person answers correctly, fill in the name of aphrodisiac fish in the following statements...

Salmon flesh has a deliciously rosy colour, is an excellent source of protein and is loaded with omega 3 fatty acids, thought to elevate serotonin levels in the brain and thereby enhance "mood".

Sturgeon can grow to over 3,000 lb but usually average 60 lb. These fish live in saltwater but spawn in freshwater. The lightly salted eggs, or roe, of this fish are highly prized as caviar.

Puffer fish is considered both a delicacy and an aphrodisiac in Japan. If the fish tissue is not properly prepared, the tiniest taste is deadly. The flirt with death is said to enhance libido.

Hagfish are bottom-dwelling jawless marine fish that feed on rotting flesh and are considered to be so repulsive that they made a cameo appearance on TV's "Fear Factor". Nevertheless, the so-called "slime eel" has found popularity as an aphrodisiac in Korea.