BME205 – Fundamentals of Biomedical Engineering: Final Assessment 2020

Final Assessment Window: April 22 - 23, 2021 Duration: 2 and ½ hours

Exam Type: Open book Calculator Type 2: Non-programmable

Examiners: J.C. Bouwmeester

Instructions for this Exam:

1. **All answers must be completed individually, no collaboration in any form is allowed.**

2. Textbook, lecture, and lab materials are permitted to be used as part of the open-book policy of this test.

3. Once you start this exam, you will have 2.5 hours to complete it.

4. No submissions will be accepted after 09:00 (EDT) on April 23.

5. The maximum number of marks for this exam is 95.
   There are 17 short answer questions that are worth 71 points.
   There are 24 multiple choice questions that are worth 24 points.

6. The number of marks available per short answer question is indicated in parentheses at the end of each question.

7. If a sentence limit is specified, one mark will be deducted for each sentence above that limit.

8. Screenshots sourced from the internet or notes of any kind will not be accepted as answers to questions. You must answer in your own words or drawings created specifically in response to questions in this exam.

9. You must sign the academic honesty pledge question. If no signature is recorded your exam will not be graded and will be forwarded for consideration of academic misconduct.

Writing a take-home exam will require you to invoke a high level of integrity and honesty, in other words to conduct yourself like an engineer. Please add your signature to the following blank spaces. (1)

In submitting this assessment, I, _____, confirm that my conduct during this take-home exam adheres to the Code of Behaviour on Academic Matters. I confirm that I have not acted in such a way that would constitute cheating, misrepresentation, or unfairness, including but not limited to, using unauthorized aids and assistance, impersonating another person, and committing plagiarism. I, pledge upon my honour that I have not violated the Faculty of Applied Science & Engineering's Honour Code during this assessment.

Short Answer Section

Includes question groups Alpha to Foxtrot

Question Group Alpha

Read the following case study to answers questions 1 to 4. (10 total)

Our story begins with Charles, a man who was around 40 years of age, 6 foot tall and weighed approximately 200 pounds. His friends called him "Unlucky Chucky" because of his unusual tendency to find himself in unfortunate and often life-threatening situations. Chucky had decided to go with his good friend Melody on a restorative vacation to an eco-spa, a health resort focusing on natural healing products with low ecological impact, in the rain forests of Colombia. Chucky and Melody were perusing the list of activities that could be experienced at the eco-spa when they noticed that a demonstration of local culture was about to begin in the outskirts of the resort.

"That demonstration looks like a lot of fun!" exclaimed Melody.

"The brochure describes it as 'a whirlwind of exciting culture, from dancing to native dart hunting techniques.'"

"I've always wondered how dart hunting works," Chucky replied.

And so, the two ventured to the demonstration, making it just in time before the show began. They watched with interest as the demonstrators danced, sang, and described unique elements of the local culture, although it wasn't until the emcee began mentioning that the dart hunting demonstration would be next that they were truly excited.

"Please everyone, no flash photography, this technique needs utmost silence so that our hunter won't misfire." The emcee was very explicit in his warning to the audience as the hunter prepared a blowgun with a special dart. "This dart is tipped with curare, a potent compound from a local plant that can stop a charging jaguar in its tracks by interfering with the animal's muscles and nervous system, so please be careful!"

Chucky and Melody shifted to the edge of their front row seats as the hunter aimed his blow gun at a small animal only a few feet away from them. The hunter took a large breath inward as he prepared his attack; suddenly there was a bright flash! The hunter, momentarily blinded, then misfired his dart and hit Chucky in the neck, piercing his jugular vein. Chucky was stunned by the impact and quickly experienced difficulty breathing and an inability to talk or move the side of his body the dart had hit. No longer able to stand, Chucky fell to the ground.

1) What might be causing Chucky's muscle weakness? In one sentence, state what is occurring at the neuromuscular junction and the effect that has on Chucky. (2)

2) Chucky's muscle weakness continues, and his breathing is more labored - his tidal volume is decreased and his breathing rate has slowed down. Answer the following:
    a) Using keywords, list four sequential actions (starting with the action potential propagating into the T-tubules) that explain what is happening in a skeletal muscle cell to cause contraction. (4)
    b) What key step or factor would be the most important cause of Chucky's decreased ventilation? (1)

3) Chucky's breathing remains weak and shallow, his breathing rate remains depressed, and is described by Melody as "twitchy". Comment on the factors related to the muscle contraction of his diaphragm muscle. (1)

4) Muscle fibres in different locations in your body and withing muscles are not equal, as they have different abilities to generate force and power. Using keywords and only one sentence: What is the most common muscle fiber type in the human diaphragm? and what function would it accomplish? (2)

Question Group Bravo

Read the following case study to answers questions 5 to 7. (12)

Steve was studying for a big exam and his level of anxiety was higher than normal after drinking two Red Bulls and an espresso to keep him awake for his all-night study session. After drinking these caffeinated drinks, he had an extra awareness of his heart having irregular beats and had a sensation of a fluttering in his chest.

Usually, these sensations went away on their own but this time they did not. These symptoms persisted to the point where Steve was able to get a cardiologist (Dr. Stephanie Ng) to measure his heart activity. Luckily, Dr. Ng just completed her training in a new technology that allowed the pressure in his left ventricle and aorta to be measured at the same time as the flow through his aortic valve and his ECG (i.e., his hemodynamics).

Look at the figure to see what Dr. Ng recorded: there was something happening between his regular heart beats. The electrical activity looked very different from the normal ECG pattern and the flow through the aortic valve was quantitatively different from a regular beat. Dr. Ng told Steve that the "abnormal" electrical activity was the hallmark pattern of a premature ventricular contraction that can sometimes happen between regular beats of the heart. In fact, Dr. Ng told Steve that she sees this type of heart behaviour in her clinical practice commonly and that generally, cases are regarded as benign. However, Dr. Ng told Steve to reduce his intake of caffeine as she learned, in her training, that it would be logical to assume that caffeine usage could increase the frequency of ventricular ectopic beats.

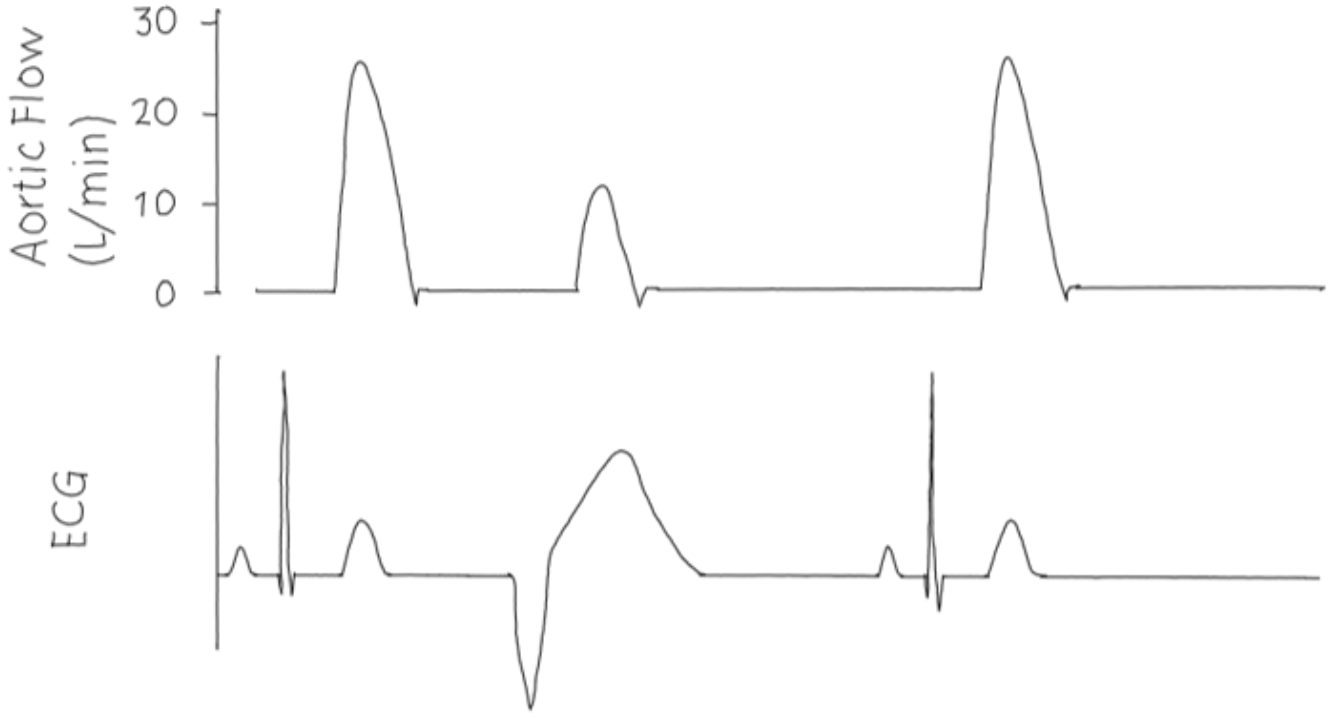


Figure 1: Steve's hemodynamics for reference

5) In one sentence: What might be the cause of the sharp, negative deflection of the ECG associated with the abnormal beat and what does this tell you about how the electrical activity is influencing the contraction of the heart? (2)

6) A section of the left ventricular and aortic pressure tracings has been eliminated from the top panel in Figure 2. Add the following information to this figure and submit your drawing/sketch:
    a) Label which line is the aortic and left ventricular (LV) pressure. (2)
    b) Draw what the missing information would look like accurately. (4)

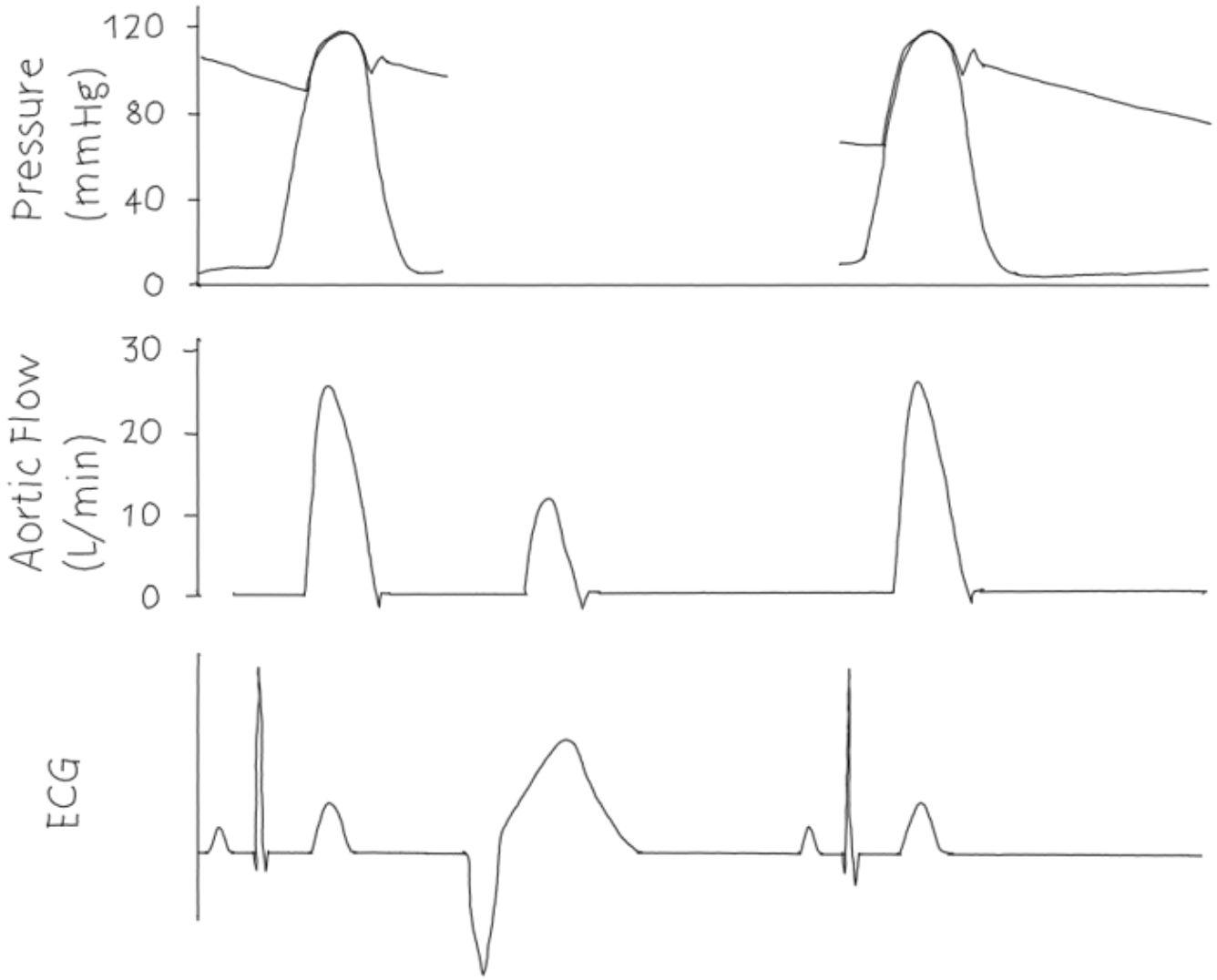


Figure 2: Draw on Steve's hemodynamics data to answer Question 6

7) Steve remembered from his study material that the muscle cells in the heart have a variety of different characteristics. Thinking of his experience he went back to studying to test his knowledge on the membrane potential of his ventricular cardiac muscle cells. The membrane potential of an endocardial cardiac myocyte is shown in the figure below. Draw the shape of an epicardial cardiac myocyte on top of the tracing provided. (4)

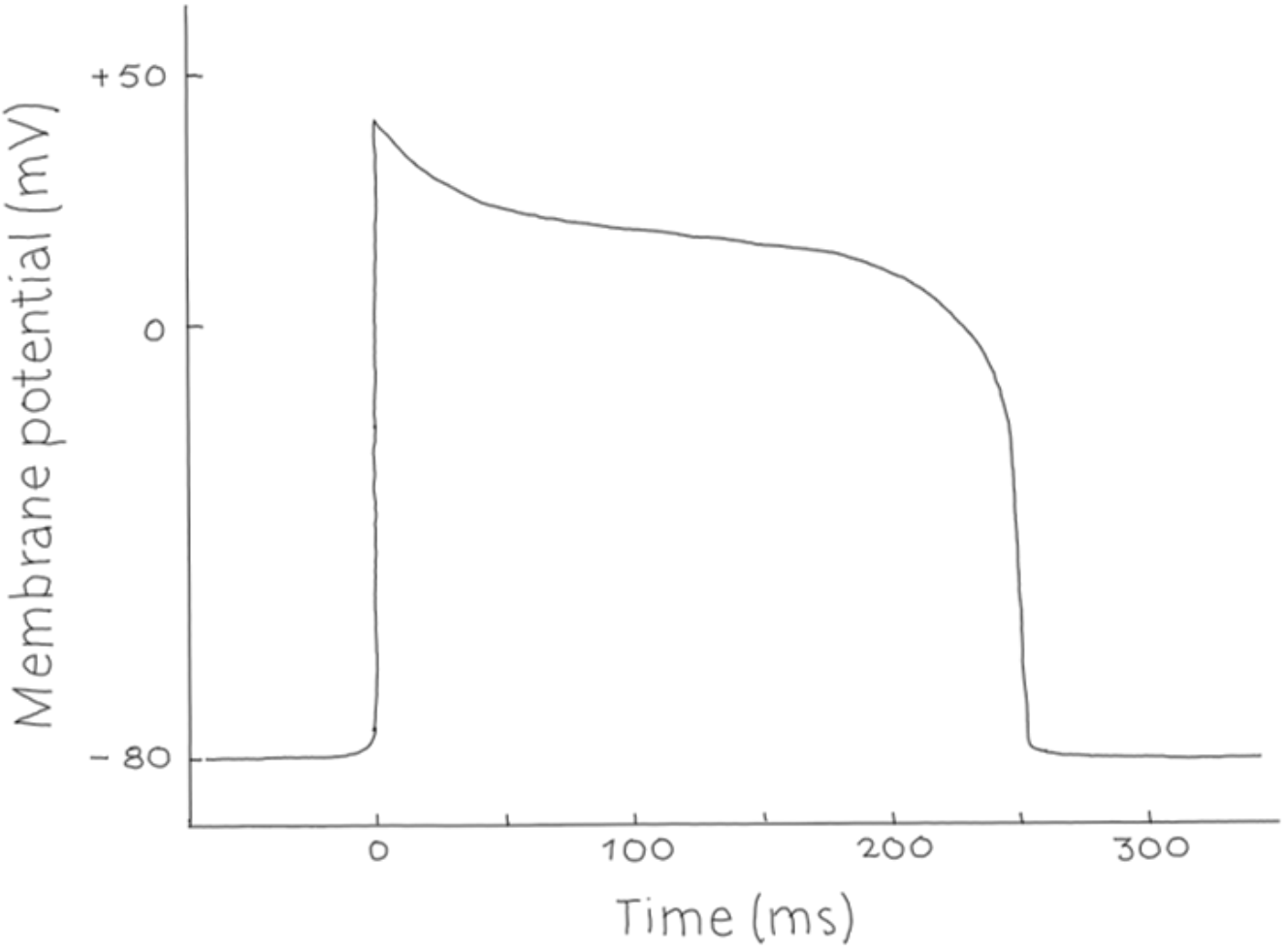


Figure 3: Draw on Steve's cardiomyocyte membrane potentials to answer Question 7

Question Group Charlie

Read the following case study to answers questions 8 to 9. (12)

Mr. Ying is an 84 year-old Asian male who lives in an apartment that adjoins his son's house. Mr. Ying is accompanied to this clinic visit by his son, who assists with the history. Although previously outgoing and social, Mr. Ying recently has been limiting his outside activities. He has started using a cane but doesn't like to use it inside. When asked about previous falls, he says he hasn't fallen. However, he says his elderly neighbor recently fell and is now in a nursing home. Now he is fearful about falling and becoming a burden to his family.

Mr. Ying stated that for the past year he has felt dizzy when he stands up after sitting or lying down and that he often needs to "catch himself" on furniture or walls shortly after standing. His dizziness is intermittent but happens several times per week. Mr. Ying cannot identify any recent changes in his medications or other changes to his routine that would explain his symptom. He says there is no pattern, and he experiences dizziness at different times during the day and evening. He denies experiencing syncope (a temporary loss of consciousness), dyspnea (difficult or labored breathing), vertigo (a sensation of whirling and loss of balance), or pain accompanying his dizziness. However, the doctor at the clinic notes that Mr. Ying has a history of high blood pressure (also known as hypertension).

After doing a full physical exam and measuring Mr. Ying's blood pressure while sitting and standing, the doctor tells Mr. Ying that he has postural hypotension and provides counsel on self-management of this condition. He is advised to drink 6-8 glasses of water a day, do ankle pumps (lying down on your back, perhaps elevating your legs, and pointing toes away from your head and then pulling them back towards your head repeatedly) and hand clenches for a minute before standing and to refrain from walking if he feels dizzy.

8) The figure below shows you a reference of what Mr. Ying's left ventricular (LV) blood pressure and blood volume look like as a function of time, when he is lying down, for a single beat of his heart.
    a) Using the reference information provided, draw the relationship between LV pressure and volume on the blank, Pressure-Volume Graph provided [i.e., Figure 5] (6).
    b) Provide information on when the valves are opening and closing. Add the following labels, in the correct locations, to the Pressure-Volume Graph you have drawn in part a. (4)

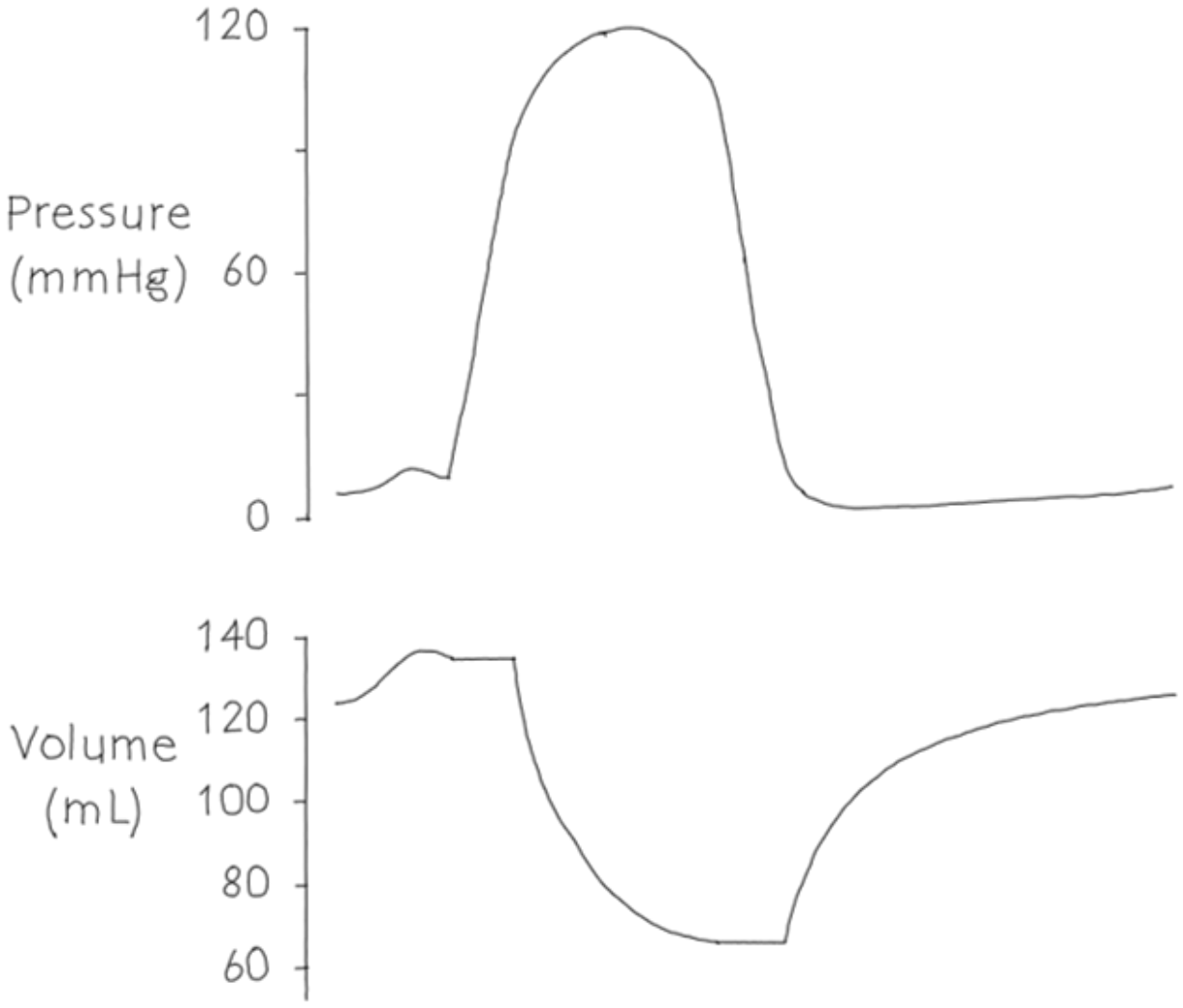


Figure 4: Mr. Ying's left ventricular pressure and volume for reference

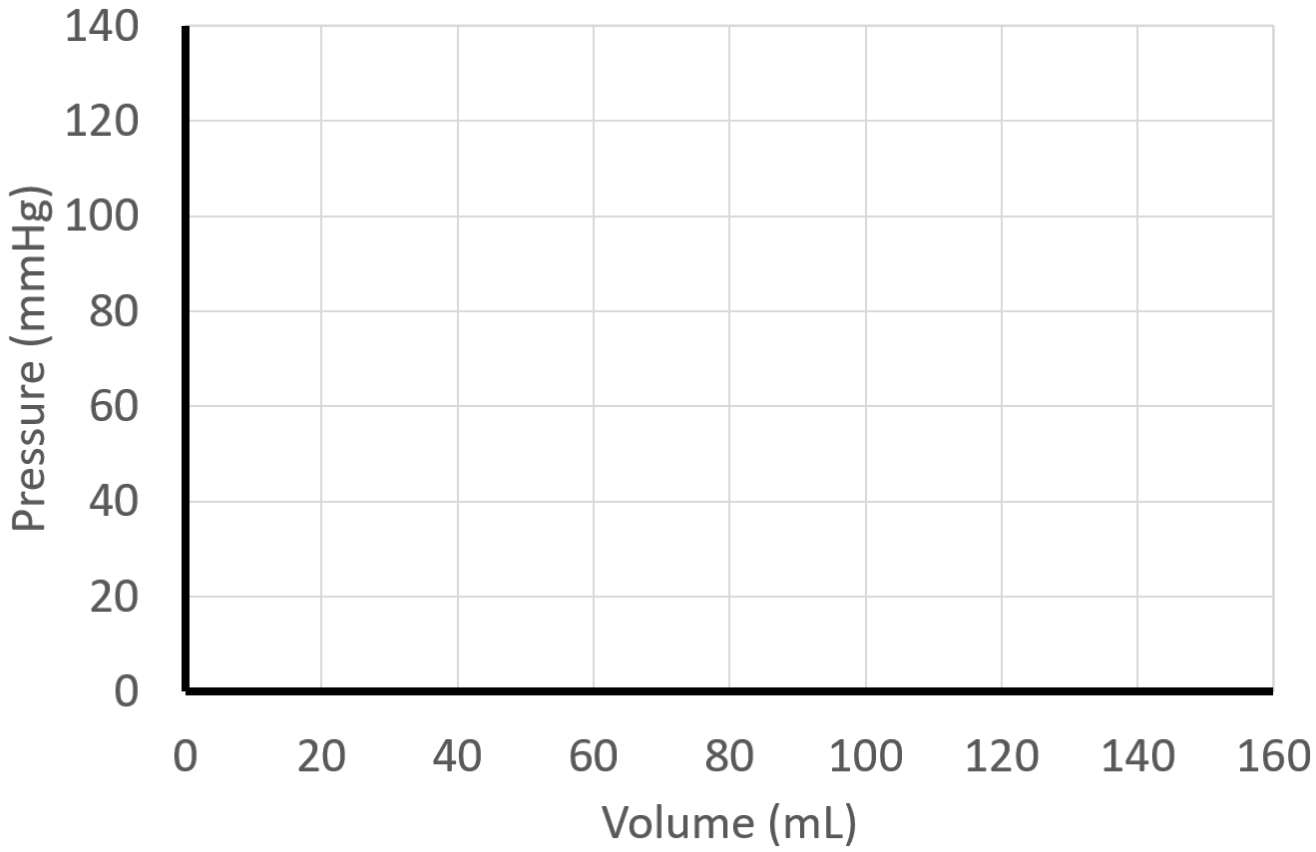


Figure 5: Empty pressure versus volume graph to draw your answer for Question 8

9) Mr. Ying was lying in bed and quickly stood up. He noticed that his heart rate quickly started to increase as a result. Redraw your result from Question 8 on the blank graph and add, with a label, a dashed or dotted line that shows what the pressure-volume relationship of the left ventricle would look like just after he stands up. (2)

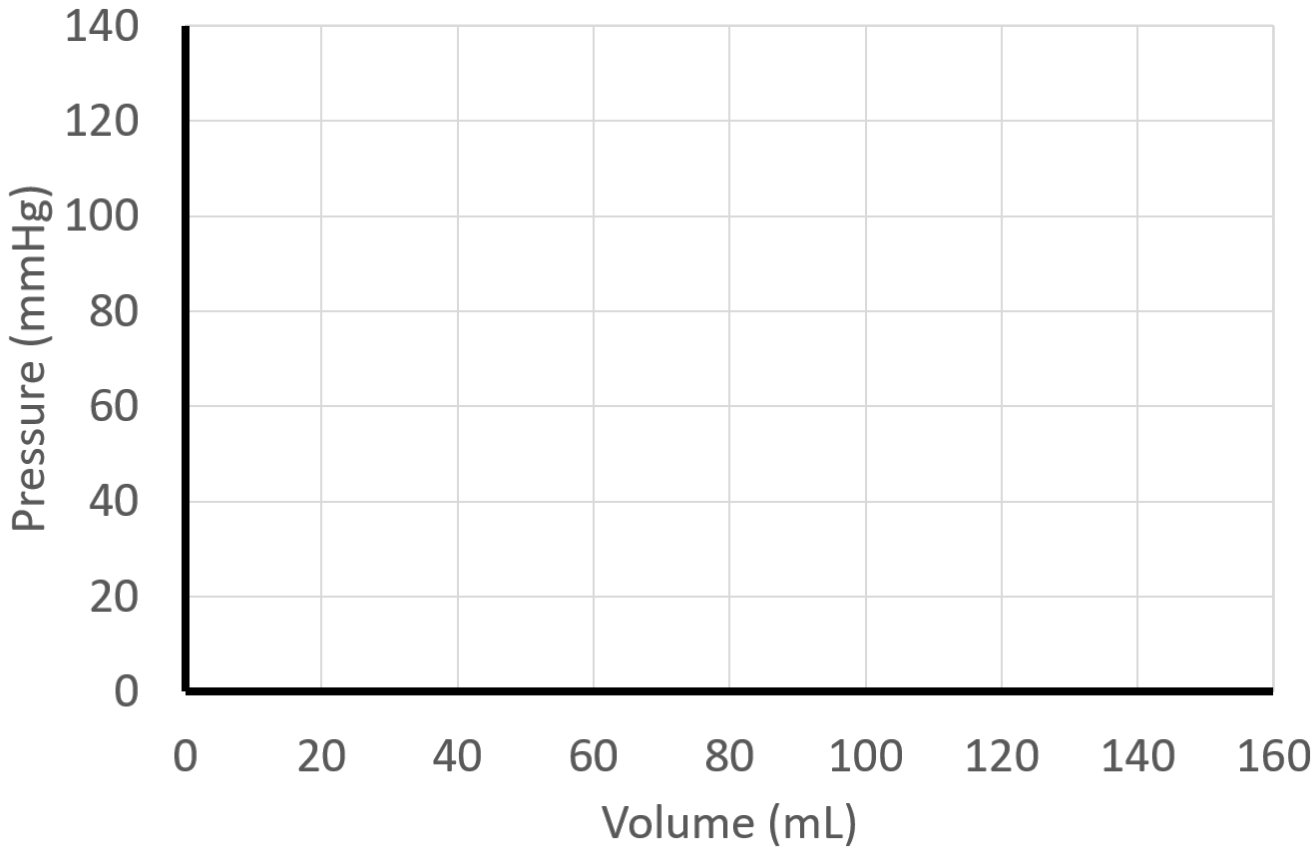


Figure 6: Empty pressure versus volume graph to draw your answer for Question 9

Question Group Delta

Read the following case study to answers questions 10 to 11. (15)

Sixty minutes before rowing practice, Alison was sitting quietly on the dock next to Lake Ontario. She donned her HexoSkin garment to make sure that all her vital signs (for example: heart rate, breathing rate, acceleration) were being measured. For part of a study of rowing biomechanics, her trainer measured her resting blood pressure with an arm cuff sphygmomanometer to be 123 / 75. Sitting there, she was calm and relaxed, and her heart rate was just 65 beats per minute, and she was breathing 12 breaths per minute. She was well hydrated.

That was an hour ago. Now, she was sitting in the bow seat of the Women's Varsity Eight. She was preparing for a moderately intense rowing session. She took one last sip of water. "All hands are down," she heard the coxswain say. She tensed her muscles in her starting position. "Prêts... PARTEZ!" Which was French for "Ready... GO!". Three short strokes to get the rowing shell moving, and then twenty strokes at maximum power. At the end of that first minute, Alison's heart rate was 100 beats per minute. She was taking a breath every stroke, quick and measured. The rowing stroke rate was now 25 strokes per minute. She was sweating more now.

10) One minute into the race: rowing at a moderate speed is putting new demands on Alison's body. Considering only the influence of the autonomic nervous system, think about these new demands and how the body is responding to them. Using just keywords (or if necessary, as few words as possible), and the empty table as a guide, what are the effects of different receptors and neurotransmitters on arterioles for the following organs: (6)
    a) Brain
    b) Digestive organs
    c) Skeletal muscles in arms and legs

This table is for your reference to guide your answers to part a), b), & c).

Organ	Which receptors and neurotransmitters are causing a change?	What is the effect on arterioles?
a) Brain		
b) Digestive organs		
c) Skeletal muscles in arms and legs		

11) After the training session, Alison is still monitoring her vital signs and notices that she is back to her "resting" values. After the shell is put away in the boathouse, she goes to her trainer and receives a neck massage for some minor pain she has felt after the session. The trainer is pressing gently on left and right side of the front of her neck, right where her main carotid artery branches into her external and internal carotid arteries. It is a firm pressure but not so hard as to collapse the arteries. As a result, Alison noticed changes to her heart rate. Use the blanks in the control loop diagram as a guide but you must only choose one pathway through the cardiovascular control center (i.e., cardioacceleratory or cardioinhibitory). (9)

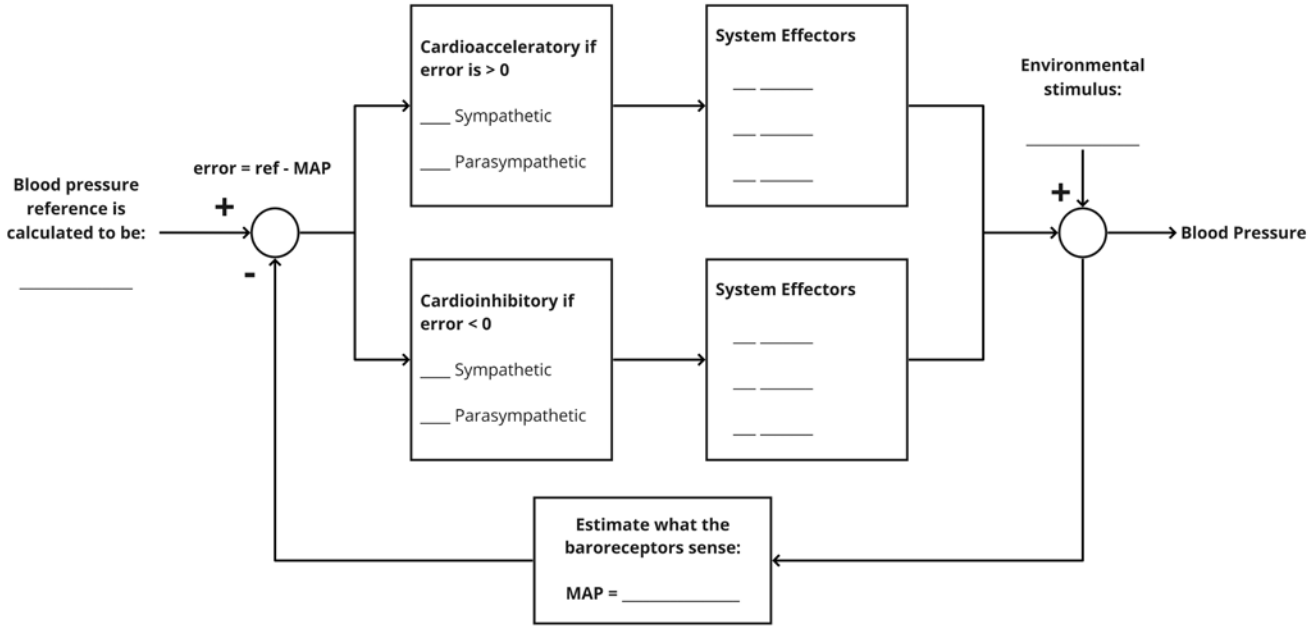


Figure 7: Flow chart to guide answering Question 11

a. What is the environmental stimulus that is sensed by the cardiovascular system? (1)
b. What mean arterial pressure (MAP) value might the baroreceptors sense? (1)
c. What would Alison's blood pressure reference value be calculated to be? (1)
d. What is the error signal and the cardiovascular center pathway? (1)
e. How is nervous activity changing? (2)
f. How are system effectors changing? (3)

Question Group Echo

Read the following case study to answers questions 12 to 14. (12)

12) Numa is working on an engineering design project to detect the early signs of lung infection and she is trying to decide whether to focus on the sounds the lung makes during ventilation or how blood is oxygenated when the lung is diseased. After completing her background research, she learned that the Type II alveolar cells (also known as pneumocyte II or alveolar epithelial type II cells) are very easily infected. What effects could the infection of Type II alveolar cells cause? (2)

13) Numa found some research that suggested that there may be significant differences between the amount of infection of one lung compared to the other. Therefore, she thought that a device that compares the sounds in each lung make help a family doctor detect the early warning signs of a lung infection. Her next challenge was to imagine different scenarios that may influence the ideal placement of acoustic sensors, so she went back to her physiology textbook and found the notes she took on ventilation/perfusion matching and the different zones of the lung.

    Imagine the scenario where only the left lung is infected and the right lung is healthy. Also assume that the intrinsic abilities of the whole lung to redirect blood flow and air remain intact. Look at this flow chart to see how one can describe five sequential events and a final outcome that happen because of decreased left lung function. Rearrange the descriptions provided (A – F; as they are in a jumbled order) to the correct order that matches the flow chart. Submit your text response as a string of letters separated by semicolons (e.g., letter; letter; letter; etc.). (6)

    A: Increased partial pressure of carbon dioxide in alveoli (of right lung)
    B: Decreased partial pressure of oxygen in alveoli (of left lung)
    C: Blood to be shunted to right lung
    D: A match between ventilation & perfusion; or just ventilation/perfusion
    E: Increased vasoconstriction in pulmonary arterioles in left lung
    F: Increased bronchodilation in right lung

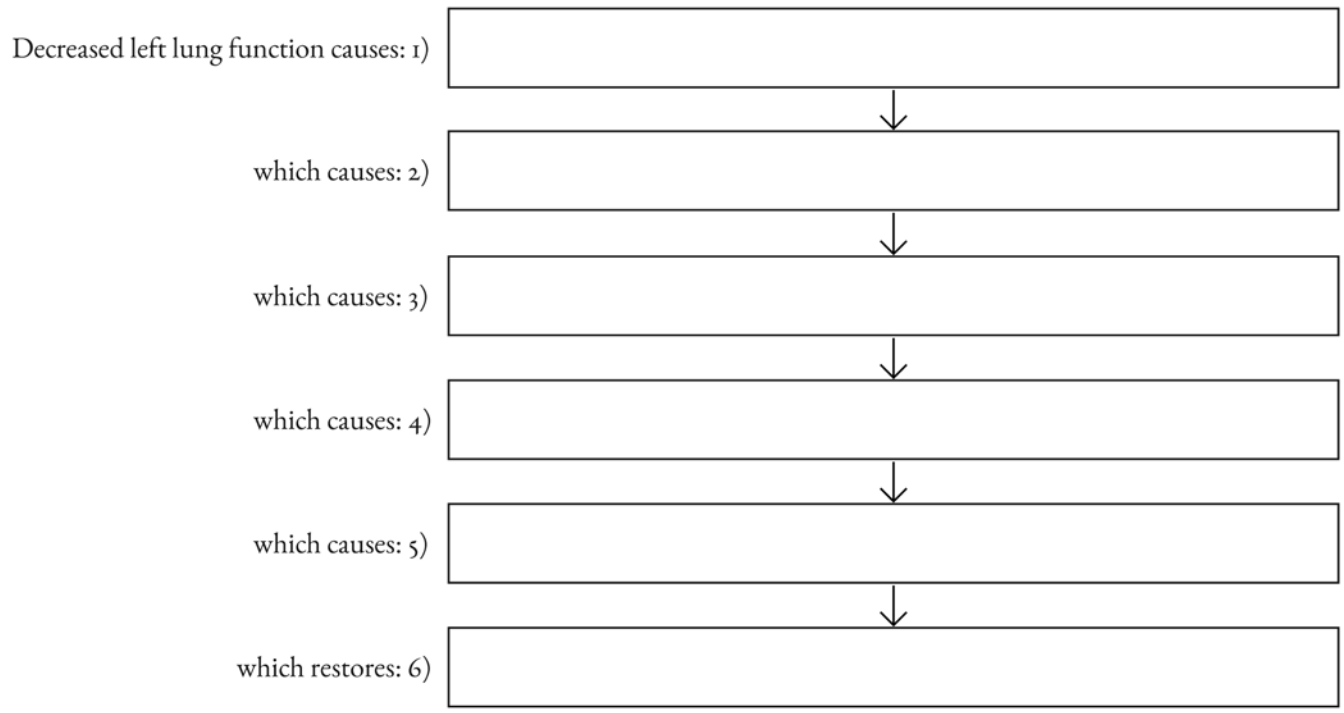


Figure 8: Flow chart to guide answering Question 13

14) Numa was thinking of the different sounds that the lung might make when you are lying down or sitting/standing up. In one sentence answers, consider the effect that sitting or standing has on: (4)
    a) The blood flow through the lungs. What is the difference in blood flow in top compared to the lung? Why?
    b) The pleural pressure in the lung. What might be the difference in pleural pressure at the top of the lung compared to the bottom? Why?

Question Group Foxtrot

Read the following case study to answers questions 15 to 17. (10)

Mary, a 25-year-old female non-smoker, follows a strict vegan diet and has not been able to purchase more Vitamin B12 supplements for some time. She came to her physician's office in mid-January complaining of breathing problems and feeling much more fatigued than usual. She had felt well enough until two days earlier when suddenly she developed a high fever and a headache that was compounded by a dry cough. That night, the fever and body aches came and went, and by morning her cough was worse. She didn't feel well enough to eat or drink and stayed in bed all day. What was more concerning to Mary was a shortness of breath she hadn't felt before, constantly trying to keep up, almost as if she had a "hunger for air" that she couldn't fulfill.

The next morning, Mary decided to visit her physician again and upon arrival the nurse was concerned about Mary's breathing and told her she was experiencing dyspnea (the medical term for shortness of breath). The nurse attached a pulse oximeter to Mary's finger and found her peripheral oxygen saturation was 90%. She seemed to be in a dangerous state of dyspnea, so the physician drew a blood sample and sent it to the lab next door to get results as fast as possible. The blood test results came back, and one result stood out: the haemoglobin levels were at 60 g/L (where the normal range for women is 120 – 155 g/L).

The physician treated Mary immediately with some supplemental oxygen an intranasal spray of Vitamin B12 and wrote a prescription for Vitamin B12 and iron supplements. She improved gradually and her breathing pattern returned to normal and she stopped experiencing abnormal fatigue.

15) How is peripheral oxygen saturation calculated? List keywords that describe the numerator and denominator of this equation. (2)

16) Considering the number that the pulse oximeter provided in the physician's office, what would be the partial pressure of oxygen in Mary's arterial blood? (1)

17) Consider the link between Mary's blood test results and her symptoms.
    a) Using only keywords: What is the term that describes the blood test results? (1)
    b) Considering the answer to Part a) as the "stimulus" that causes dyspnea. In one or two sentences maximum: Which receptor detects this stimulus? And Why? (2)
    c) Using keywords: What region of the brainstem would be sending signals to Mary's respiratory muscles to breath quicker faster than normal? (2)
    d) Using keywords: What signals are sent to which respiratory muscles? And, compared to normal, how have these signals changed in Mary's case? (2)

Multiple Choice Section

18. Which of these statements describes myosin?
    a. It is the main structural component of the thin filaments.
    b. It is referred to as a contractile protein.
    c. It is spherical in shape.

19. Which of these statements describes actin?
    a. It forms a helical chain that forms the main structural component of the thin filaments.
    b. It is shaped like a golf club.
    c. It has ATPase activity.

20. Which of these statements does NOT describe cross bridges?
    a. They are formed by the globular heads of the myosin molecules as they protrude from the thick filaments.
    b. They bind to actin during muscle contraction.
    c. They bind with troponin and tropomyosin during muscle contraction to pull them away from the actin helical chain.

21. Which of the following is the first step in excitation–contraction coupling?
    a. Calcium is released from the sarcoplasmic reticulum.
    b. Exposed actin sites bind with myosin cross bridges.
    c. Sodium channels open in the fibre's membrane.

22. Which of these statements describe cardiac muscle cells?
    a. They are produced constantly after infancy
    b. Either all of them contract in the heart or none of them contract
    c. The do not have an abundance of mitochondria

23. Inactivation of _____ channels brings about the slow drift of membrane potential to threshold in the cardiac autorhythmic cells.

a. K^+

b. Na^+

c. Ca^{2+}

24. Explosive increase in membrane permeability to _____ brings about the rapidly rising phase of the action potential in contractile cardiac cells.

a. K^+

b. Na^+

c. Ca^{2+}

25. Slow inward diffusion of _____ is largely responsible for the plateau portion of the cardiac action potential.

a. K^+

b. Na^+

c. Ca^{2+}

26. The rapid falling phase of the cardiac action potential is brought about primarily by the outward diffusion of _____.

a. K^+

b. Na^+

c. Ca^{2+}

27. Changes in cytosolic _____ concentration bring about changes in the strength of cardiac contraction.

a. K^+

b. Na^+

c. Ca^{2+}

28. Parasympathetic stimulation increases the permeability of the SA node to _____, whereas sympathetic stimulation decreases the permeability to this same ion.

a. K^+

b. Na^+

c. Ca^{2+}

29. Which of these statements refers to the Frank–Starling law of the heart?

a. Increasing the venous return increases the end-diastolic volume, which leads to an increased stroke volume.

b. As cardiac output is reduced, blood pools in the vasculature so that arterial blood pressure increases.

c. The shorter the initial length of the cardiac muscle fibres prior to contraction, the more forceful will be the subsequent contraction.

30. Which of these events occurs at rapid heart rates?
    a. The length of systole stays almost constant, but the length of diastole shortens considerably.
    b. The lengths of systole and diastole shorten equally.
    c. The length of systole increases at the expense of diastolic time shortening.

31. On a normal ECG, a wave for repolarization of the atria is not recorded. Why?
    a. No repolarization of the atria occurs normally.
    b. It occurs simultaneously with ventricular depolarization and is masked by the QRS complex.
    c. The leads are not placed in a position to pick it up.

32. Which statement applies to vascular resistance?
    a. It is a measure of the opposition to blood flow through a vessel caused by friction between the moving fluid and stationary vascular walls.
    b. It is doubled when the radius of the vessel is wider than normal.
    c. It is inversely proportional to blood viscosity.

33. Because the arteries have large radii, they serve as excellent rapid-transit passageways for blood. What is their second function—which is related to their elasticity—in maintaining blood flow during diastole?
    a. cardiac reserve
    b. venous reserve
    c. pressure reservoir

34. What is the major function of the arterioles?
    a. to serve as a pressure reservoir
    b. to regulate flow of blood through capillary beds
    c. to distribute cardiac output to large blood vessels

35. Where and why does blood flow increase during strenuous exercise?
    a. in the brain because of reflex control factors
    b. in the heart because of local control factors
    c. in the skeletal muscles because of local and reflex control factors

36. Which of these statements describes intrapulmonary pressure?
    a. It is always greater than atmospheric pressure.
    b. It is always less than intrapleural pressure.
    c. It is the pressure within the air sacs of the lung.

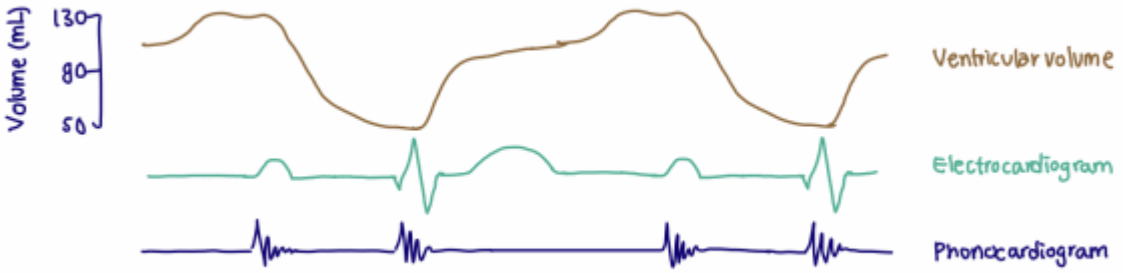
37. Which of the following happens during inspiration?
    a. The internal intercostal muscles contract.
    b. The volume of the thoracic cavity decreases
    c. The external intercostal muscles contract.

38. Where and why does the amount of air in the lung increase with chronic obstructive pulmonary disorder?
    a. In the total lung capacity because air is trapped in alveoli.
    b. In the tidal volume because the lung is full of mucus
    c. In the functional residual capacity because air is trapped in alveoli.

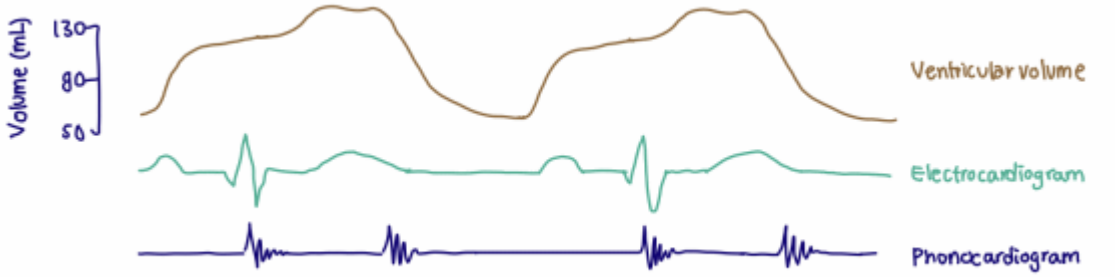
39. Which of these factors would result in bronchoconstriction?
    a. increased carbon dioxide concentration
    b. parasympathetic stimulation
    c. sympathetic stimulation

40. Which of the following Wiggers Diagrams accurately represent the events of the cardiac cycle?

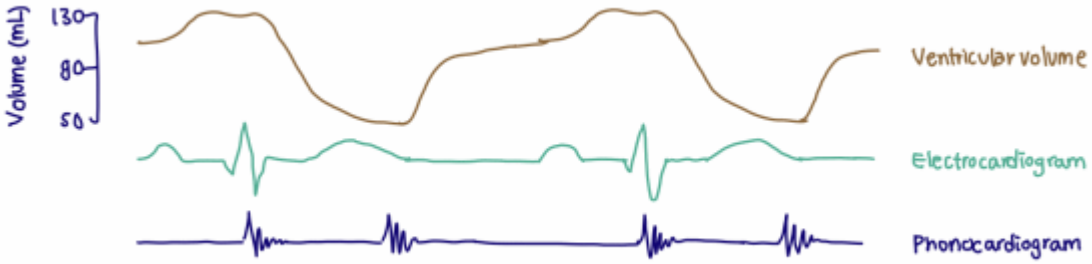
a.



b.



c.



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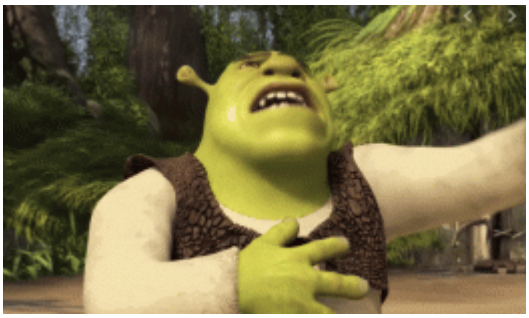
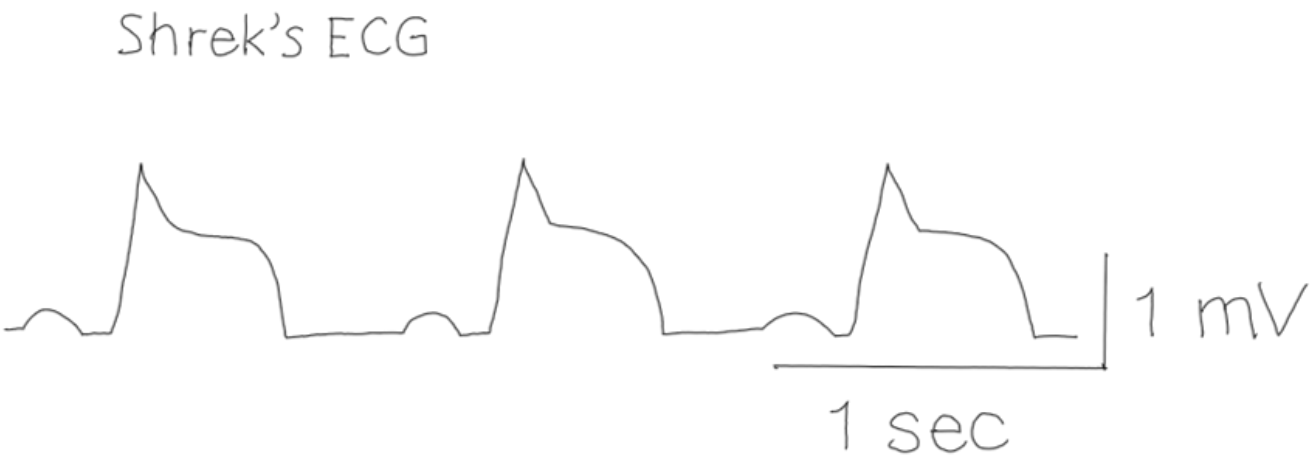


"Ogres are like onions..." was what was running through your mind as you watched Shrek roll in on a gurney. Your green-skinned friend had used those words when he tested you on ogre anatomy while you were still in medical school. A few hours ago, Shrek (see image above) collapsed in his mud bath and was quickly rushed to the nearby Duloc General Hospital. From knowledge of his past medical history, you believe Shrek has underlying coronary artery disease (CAD). This disease was likely amplified by Shrek's poor diet which often solely consisted of Donkey's waffles. You know that you can use an ECG to determine whether or not myocardial infarction (commonly referred to as a heart attack) has occurred. Below is the print-out of Shrek's ECG, compared to a "normal human" ECG, what looks to be abnormal?



a. ST segment
b. TP interval
c. PR segment