BME205 – Fundamentals of Biomedical Engineering: Final Assessment 2020

Final Assessment: April 15, 2020 | Suggested Duration: 2 and ½ hours

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

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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. This exam is designed to take 2.5 hours, but you will have access to this exam beginning at April 15 at 00:00 Toronto time (EDT or UTC-4 hours). No exams will be accepted after April 15 at 23:59 Toronto time (EDT or UTC-4 hours).

4. The maximum amount of points for this exam is 70
   The is one academic integrity statement worth 2 points.
   There are 8 short answer questions that are worth 60 points.
   There are 8 multiple-choice questions (individually worth 1 point each) that are worth 8 points.

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. This test must be completed independently, meaning you will not work with anyone else nor share any of your answers on any platform.

Please add your signatures to the following blank spaces. (2)

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.

I, _____________, have completed this test by myself and I will not share any of my answers with anyone until the final exam grades have been posted on Quercus (date to be determined by FASE registrar).

1) Read the following case study and answer the questions below. (9)

Sarah is a 50-year-old female and a mother of three children. She was injured in a motor vehicle accident three years ago. She suffered a fracture between her C4 and C5 vertebrae and is a quadriplegic.

She is in the hospital for a urinary tract infection. One evening, the nurse noticed:

- Sarah's blood pressure was elevated at 170/115.
- Her pulse rate was slow at 56 beats per minute.
- Her face and neck were flushed and very warm.
- She complained of a headache and blurred vision.
- Her pupils were constricted.

The nurse paged the doctor on call, but her experiences working with quadriplegics led her to suspect autonomic dysreflexia (AD). She began an assessment and noticed that Sarah's urinary catheter was kinked and her bladder was distended. The nurse immediately changed the catheter and within a few minutes, as the bladder emptied, the symptoms subsided, and Sarah's vitals began to return to normal.

AD is caused by a sympathetic response from a painful or irritant stimulus—in this case, the distended bladder. In a patient with a spinal cord injury, a noxious stimulus below the injury level triggered a sympathetic response. Since the spinal cord was disconnected from the brain, the sympathetic response was isolated to body parts below the level of the spinal cord injury.

The sympathetic response due to the distended bladder produced vasoconstriction of the blood vessels below C5 causing an elevation in blood pressure. The status of the elevated blood pressure was then relayed to the brain. Under normal conditions, the brain would send signals to decrease sympathetic activity; however, in Sarah's case, the brain–spinal cord connections were lost due to the injury. The sole response to the hypertension was increased parasympathetic activity and these signals were isolated to body areas above the spinal cord injury.

Sarah's parasympathetic response led to the low heart rate as well as pupil constriction and blurred vision. The elevated blood pressure combined with an absence of sympathetic-induced vasoconstriction in the head and neck region resulted in a flushed face.

In cases of AD, body systems above the injury are in parasympathetic mode, while the areas below are in sympathetic mode. This imbalance will continue until the stimulus is resolved. Because a stroke is likely in prolonged and severe cases, the patient often requires medications to control blood pressure. Fortunately for Sarah, her nurse's quick response resolved the issue.

1a) Define autonomic preganglionic and postganglionic cells. What are autonomic ganglia and where are they located? (3)

1b) Describe the basic structure of the two neuron chains of the sympathetic and parasympathetic systems. Which neurotransmitter does each system utilize at the target organ? (4)

1c) Explain what dual innervation means and how it was affected in Sarah's case. (2)

2) Read the following case study and answer the questions below. (11)

Mary Berry is a 35-year-old female. She is a cookbook author and spends many hours reading on her computer, as well as searching through printed materials. She has never needed glasses but has noticed recently that her eyes feel tired. Sometimes it's even hard to keep her eyes open.

Recently a colleague asked her if she was overly tired, because it looked like she was falling asleep at her desk. Mary noticed that if she took some time to relax between intense bouts of reading her eyes felt better. She assumed that her issues were work-related. Over the next few weeks, however, things got progressively worse, and at times she would have double vision (diplopia). Mary had a friend who was an ophthalmologist and asked him if he would take a look at her eyes.

The doctor did a complete neurological work-up on Mary, and other than issues with her eyes, all the results were negative. However, her eye exam indicated issues with the muscles controlling her eyelids and eye movements. The doctor performed a series of tests that allowed him to assess Mary's eye movements.

- He had her follow his finger up, down, side to side, as well as on a diagonal. These are known as the six "Cardinal" directions of movement.
- He also assessed her eyelids both in the opened and closed positions. He noted muscle weakness in both sets of muscles. This would account for her dropping eyelids and the double vision she was experiencing.

The doctor suspected myasthenia gravis and he confirmed the diagnosis through blood tests that indicated the presences of acetylcholine receptor antibodies as follows:

M. Berry – Test Results

Test	Result	Normal Range
Blood Pressure	115/73	90-120/60-80
Hematocrit (%)	36.5	36-38
Glucose (mg/dl)	94	70-110
Sodium (mmol/L)	144	135-145
Potassium (mmol/L)	4.3	3.5-5.0
AChE Activity Test (%)	100	100
Antibodies	Present	Not Present

Myasthenia gravis is an autoimmune neuromuscular disease in which the body produces antibodies that alter or destroy the acetylcholine receptors in the neuromuscular junction.

There are various medications used to treat the disorder, including anticholinesterase drugs such as neostigmine and pyridostigmine. Immunosuppressive drugs such as prednisone may also be used to reduce the body's immune response and suppress abnormal antibody production. Like many autoimmune diseases, myasthenia gravis may go into remission or disappear completely. With regular medical visits and treatment, Mary can expect to live a normal life.

2a) Describe the role of acetylcholine in skeletal muscle contraction. (3)

2b) How would antibodies against the ACh receptors affect the influx of Na+ into a skeletal muscle cell? (2)

2c) How is acetylcholine stimulation linked to calcium release in skeletal muscle? What role does calcium play in muscle contraction? (3)

2d) Why are the muscles that control eye movement usually the first muscles to weaken in myasthenia gravis? Relate the answer to a description of motor units. (3)

3) Read the following case study and answer the questions below. (10)

Sixty minutes before the race, Alison was sitting quietly on the dock next to Lake Ontario. She was visualizing the race she was about to row: two thousand meters of intense physical activity, pushing his body to the very limits of its capabilities. But 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. Her body temperature was 37° C (98.6° F). She was well hydrated. Her weight was 130 pounds.

That was an hour ago. Now, she was sitting in the bow seat of the Women's Varsity Eight. These last few seconds before the race were the most stressful—you could feel the tension in the air. She knew that all 48 rowers and even the six coxswains on that starting line were feeling the same as she was. She was sweating although the air was cool. Her heart rate was now 85 beats per minute, and he was breathing 18 breaths per minute. She felt a nervous excitement. Her mouth was dry.

She took one last sip of water. "All hands are down," she heard the starter say. She tensed her muscles in her starting position. "Prêts... PARTEZ!" Which was French for "Ready... GO!". Three short strokes to get the 60-foot-long shell moving, and then 20 strokes at maximum power. At the end of that first minute, Alison's heart rate was 201 beats per minute. She was taking two breaths per stroke, fast and forced. Their stroke rate was now 34 strokes per minute. She was sweating more now. Her body temperature was 37.5° C (99.5° F). Her muscles hurt—they felt like they were burning.

Two minutes later, her heart rate was 180. Her respiratory rate was also down slightly. Her body temperature was 38° C. With 250 meters to go to the finish line, her coxswain was talking to the team, keeping them focused, getting them ready for the sprint.

As Alison crossed the finish line, six minutes and 58 seconds after starting, her heart rate was 208 beats per minute. She stopped rowing and slumped over her oar, breathing nearly 80 times per minute but still not feeling like she could get enough air. Sweat was pouring out of every pore of her body profusely. She felt light-headed. Her body temperature was 102° F. It felt like her arms and legs were on fire due to the buildup of lactic acid produced by strenuous exercise. Seven minutes of intense exercise, especially at the beginning and the end, have produced what is called an oxygen debt. This means that the only way to rid the muscle fibres of the large amount of lactic acid they have accumulated is to provide them with oxygen.

3a) What is responsible for raising Alison's heart and respiratory rate and stimulating sweating just before the race? (1)

3b) What changes do you think are occurring in the digestive and urinary systems just before the race? (2)

3c) One minute into the race: rowing full speed is putting new demands on Alison's body. What are these new demands and how does the body respond to them? (2)

3d) Just past the finish line, Alison has stopped rowing and her muscles are now at rest. Why are her heart rate and breathing rate still so high? (4)

3e) Why is she sweating more now than during the race? (1)

4) Read the following case study and answer the questions below. (6)

Bode, a young male freestyle skier, showed up for his routine physiological tests in the off season. After the completion of a standard questionnaire and an informed consent form, it was established that the athlete had no medical history of note, including no family history of heart disease, and he was a non-smoker, took occasional alcohol, and was not taking any drugs at the time of investigation.

Routine physiological assessment included a heart rate monitor. After the test, the athlete's heart rate failed to fall as expected. Further, he complained of chest pain and shortness of breath. He was consequently attached to a 12-lead electrocardiograph (ECG), which revealed atrial fibrillation with a ventricular rate of 155 beats/min. The athlete was monitored for two hours, during which time the atrial fibrillation (uncoordinated chaotic contractions) persisted. He became mildly compromised, indicated by a fall in blood pressure and worsening discomfort associated with chest pain and shortness of breath. After an echocardiographic interrogation to determine the absence of structural heart disease and normal cardiac function, he was admitted to the coronary care unit and was successfully treated with a 150 mg dose of Flecanaide (a Na+ channel blocker) for 30 minutes and was discharged after 24 hours of observation.

On follow up examination, the athlete admitted to consuming 8 shots of tequila, which was an excessive amount compared with his normal consumption, two days before the initial physiological assessment. The observed atrial fibrillation was diagnosed as a lone episode of alcohol induced atrial fibrillation and the athlete was counselled on alcohol consumption and vigorous exercise. (The term: "lone atrial fibrillation" is used to describe an isolated occurrence and generally applies to young patients without clinical evidence of cardiopulmonary disease.) No further action was taken and Bode has reported no further occurrence of symptoms indicative of atrial fibrillation.

4a) How would left atrial fibrillation contribute to the left ventricle's ability to eject blood into the aorta? (2)

4b) Why does the volume of blood pumped by the atria become more important with elevated heart rates? (2)

4c) How would blocking Na+ channels potentially contribute to a reduction in the rate of pacemaker cell activity and the conduction velocity of ventricular myocytes? (2)

5) This is a two-part question related to acquiring ECG data. (4)

5a) Dale acquires an ECG (electrocardiogram) signal shown in Figure 1 (below). List 2 things that Dale can potentially do to improve the signal quality. (2)

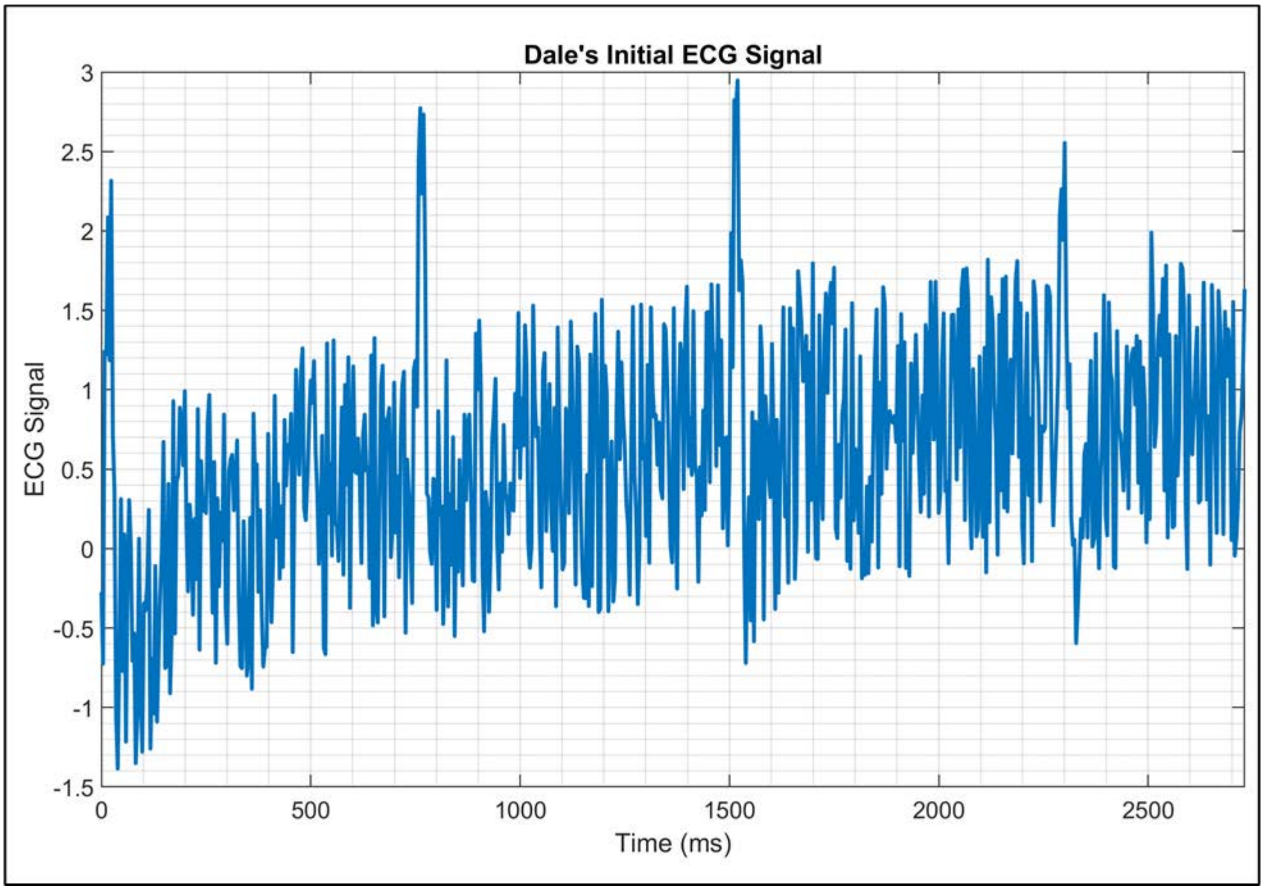

Figure 1: Dale’s initial raw ECG signal.

5b) With his newfound skill in acquiring ECG signals, Dale decides to try his setup on Jason, his 77-year-old grandfather with known cardiac problems. Jason's ECG is shown in Figure 2 (see below). How is the shape of Jason's ECG different from one that is normal? What is a possible cause of these differences? (2)

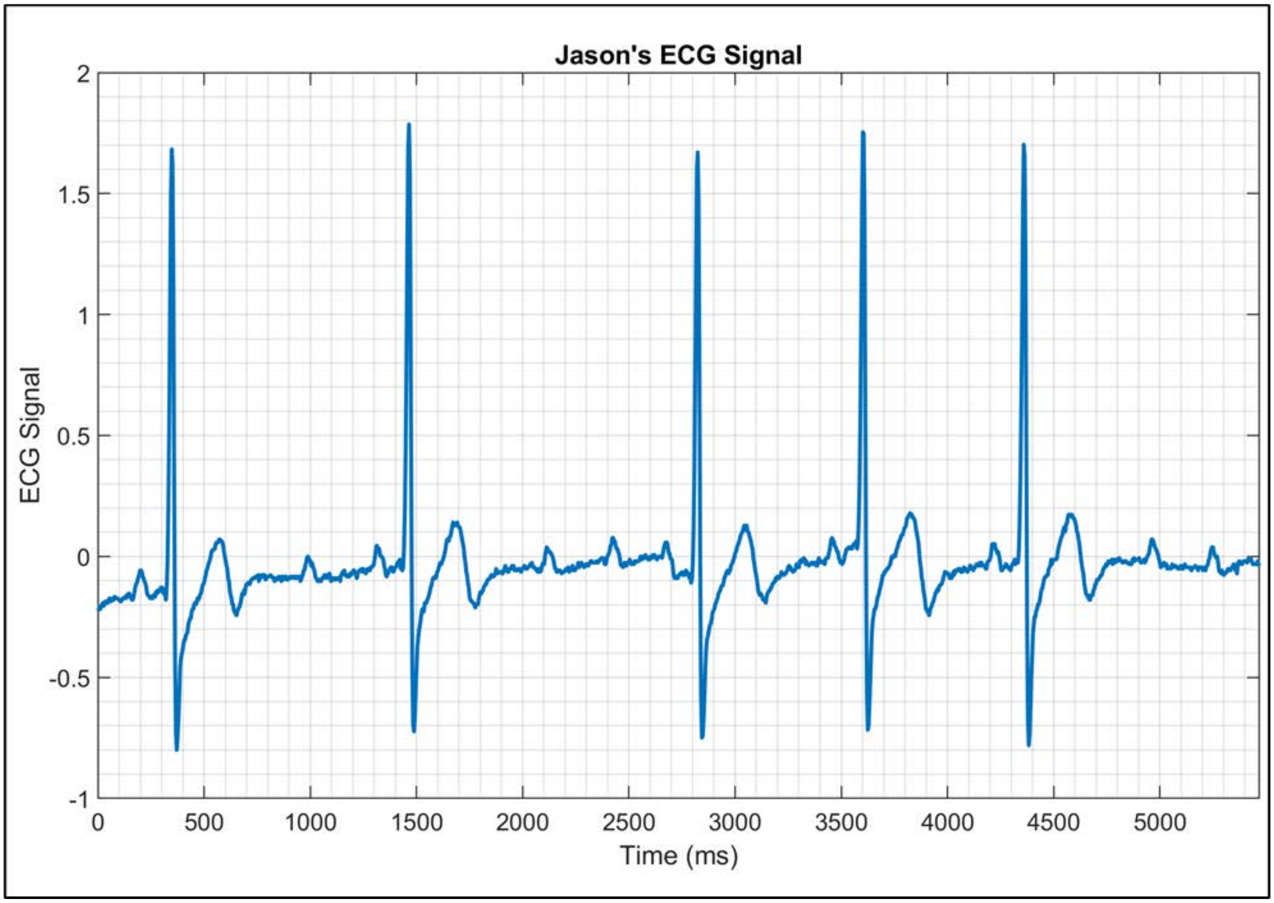

Figure 2: Jason's ECG signal.

6) Read the following case study and answer the questions below. (5)

Mr. Helms was admitted to the hospital with chest pains and shortness of breath. His wife was panicked since her 72-year-old husband had a history of heart disease. After examination and an echocardiogram, Dr. Collins spoke with Mrs. Helms. "I'm very sorry, but your husband has had another heart attack resulting in valve failure. A papillary muscle that controls a valve in his heart has been severely damaged and is no longer working."

Dr. Collins called Nurse Nan from the patient's room and confided, "Mr. Helms is in bad shape. His left posteromedial papillary muscle was damaged from his heart attack. The papillary muscle is no longer able to maintain closure of the valve, and this has resulted in mitral valve prolapse. With decreasing cardiac output, this patient is in for a fight for his life." Nurse Nan knew that maintaining cardiac output was necessary for adequate blood flow through the body. As Dr. Collins walked away, Nurse Nan composed herself to tell Mrs. Helms the bad news and returned to the patient's room. Nurse Nan explained to Mrs. Helms that her husband had left-sided heart failure and that his blood pressure was slowly and steadily decreasing.

6a) Figure 3 (below) shows the normal pattern of blood flow through the mitral valve, where positive values are flow into the left ventricle and an ECG is shown for reference. Assuming that the mitral valve prolapse (a misalignment of the valve) is severe, what would Mr. Helms' abnormal mitral flow pattern look like? For your answer draw the x- and y-axes with the units given in Figure 3 and begin by drawing the normal mitral flow pattern as a solid line. What would Mr. Helms' abnormal mitral flow pattern look like in comparison to a normal mitral flow pattern (show the abnormal pattern as a dashed or coloured line). (3)

6b) If the mitral valve is not fully closing, why does the cardiac output through the pulmonary circulation increase, decrease, or remain unchanged? (2)

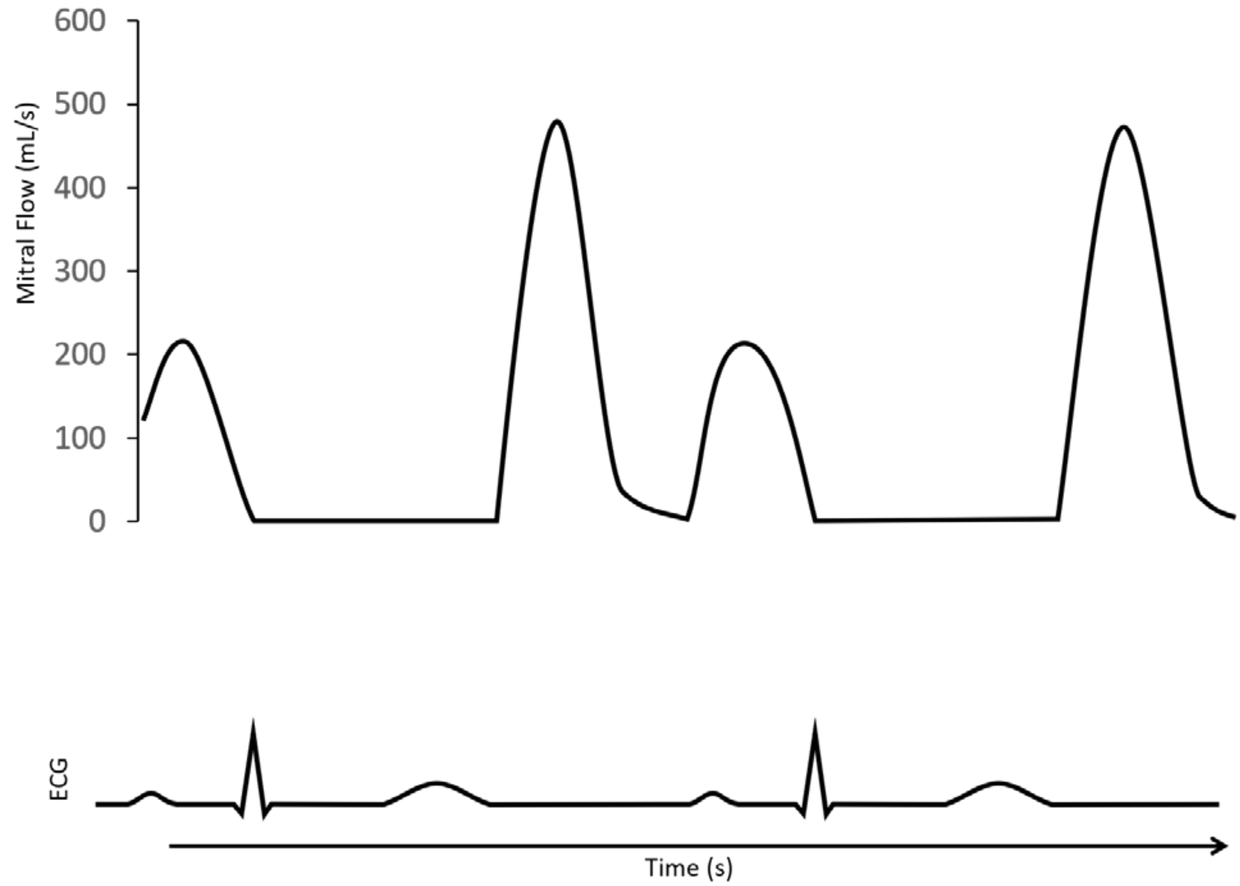

Figure 3: Mitral flow and ECG waveforms for reference

7) Read the following case study and answer the questions below. (6)

7a) Jim gets a new job in research and development for a prosthetic limb company and his first project is to create a prosthetic hand that can be controlled using electromyography. Jim's client has a transradial (below the elbow) amputation as shown below in Figure 4. To overcome some of the drawbacks of placing the sensors below the elbow, Jim decides to place electrodes (black dots) as shown in Figure 4. List one benefit and one drawback of this sensor placement and provide a rationale for each. (4)

7b) For the final iteration of Jim's design, he must place a grounding electrode on the arm. Where should he place this electrode and why? (2)

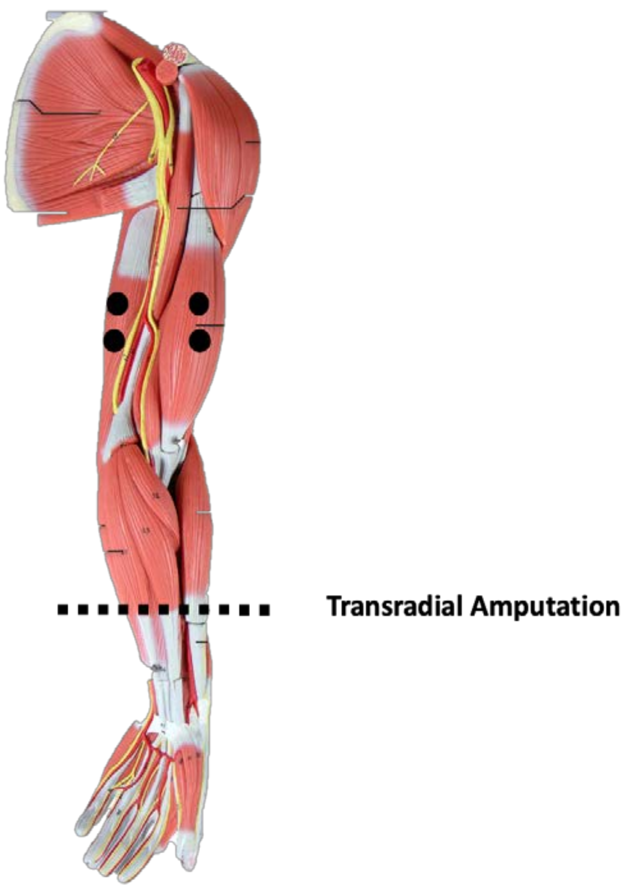

Figure 4: Arm anatomy

8) Read the following case study and answer the questions below. (9)

Matthew, a 23-year-old male non-smoker, came to his physician's office in mid-January complaining of breathing problems. He had felt well until two days earlier when suddenly he 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 his cough was worse. He didn't feel well enough to eat or drink and stayed in bed all day.

Later he awoke about midnight struggling to breathe. He realized he was having the worst asthma attack he had experienced in many years. He was unable to find an inhaler and considered going to an emergency room but decided to wait until morning to see his physician. He spent the rest of the night sitting up in bed struggling to breathe.

Early the next morning, when Matthew called his physician, he was still in respiratory distress. On arrival at the physician's office, the nurse attached a pulse oximeter and found his arterial oxygen saturation was only 82%. He was in a dangerous state of respiratory distress. He still had a fever of 102°F and he was slightly dehydrated.

The physician treated Matthew immediately with medication delivered through a nebulizer to open airways narrowed by his asthma. He improved within minutes, but even repeated nebulizer treatments failed to stabilize his breathing and improve his oxygen saturation. He was admitted to the hospital where he remained for two days.

He improved gradually as he received regular nebulizer treatment for his asthma and an intravenous synthetic corticosteroid called prednisone. A nasal swab performed in the physician's office confirmed the suspected diagnosis of influenza A. Matthew was discharged with medication to use at home in case of another asthma attack and a reminder to come in next fall for the flu shot.

8a) What does the term oxygen saturation refer to? And what would be the partial pressure of oxygen in his arterial blood when he visited his physician's office. (2)

8b) Describe which chemoreceptor or chemoreceptors would respond when Matthew's PaO_2 = 82% and how they would signal the brain. (2)

8c) Why would it be important for chemoreceptors to respond when Matthew's PaO_2 = 82%? (1)

8d) What region of the brain would respond to the signals sent by chemoreceptors at a PaO2 = 82% and what actions would be triggered in response? (4)

Indicate the answer choice that best completes the statement or answers the question. (worth 1 point each)

1. Patients with lesions below the level of T6 commonly have symptoms of autonomic dysreflexia.
   a. True
   b. False
   c. Unknown

2. Which of the following does NOT promote elastic recoil of the lungs?
   a. Elastic fibres in the lung
   b. Surface tension of the fluid lining the alveoli
   c. Pulmonary surfactant

3. You have discovered a new bacterium living on a hydrothermal vent that produces a toxin and your research has discovered how it works on muscle fibres. You find that the toxin can only bind to the myosin filament complex during its phosphorylated conformation. When bound, the toxin "freezes" the complex such that ADP and Pi cannot detach. Out of the symptoms below, which is the most likely to occur due to this muscle?
   a. Affected muscles spasm uncontrollably in fits of random contraction/relaxation.
   b. Affected muscles gradually lose their ability to contract.
   c. Affected muscles gradually increase their intensity of contraction until tetanus is reached.

4. Bob's resting heart rate is 70 beats per minute. He is abducted by aliens and they experiment on him by cutting off the nerves connected to his heart. Would his heart rate be likely to increase, decrease, or stay the same?
   a. Increase
   b. Decrease
   c. Stay the same

5. When the baroreceptors increase their rate of firing action potentials, which of the following would we expect to see?
  a. Increased vagal tone and increased sympathetic tone
  b. Increased vagal tone and decreased sympathetic tone
  c. Decreased vagal tone and increased sympathetic tone

6. Which of the following is caused by hypoventilation
  a. Lower than normal pH
  b. Lower than normal partial pressure of alveolar CO2
  c. Constriction of smooth muscle of the airways

7. An embolism completely blocks blood flow to one lobe of the lung. Which of the following is true?
  a. Vascular resistance of the non-occluded lung is increased
  b. Vascular resistance of the overall lung is increased
  c. Alveolar PO2 in the occluded lobe is decreased

8. Which of the following root causes a is unrelated to a fall in blood pressure?
  a. Heart failure
  b. Septic shock
  c. Sustained dehydration