**Instructions:**
- This exam has 4 pages and 10 questions.
- Answer 7 of 10 questions. Answer all subparts of the questions you choose.
- You have 180 minutes to complete this exam.
- This is a closed book exam; however, you are permitted to bring one 11”×17” sheet of notes.
- You are permitted to use a non network-connected calculator.
- Write your answers in an examination booklet.
- You may take this examination paper with you.

**Background:**
Robotic surgery uses small tools attached to a robotic arm, which are controlled by surgeons using a computer. Its development was motivated by the limitations of the minimally-invasive surgical procedures. In procedures ending in “-oscopy”, an endoscope is inserted: e.g. endoscopy, laparoscopy, arthroscopy. An endoscope is a flexible tube which can be inserted into the body with a light source and a lens or camera system. It contains a channel through which medical instruments can enter.

Minimally-invasive surgery, and also robotic surgery, often has less trauma than an equivalent open surgery, and thus reduced complications and improved recovery. Robotic surgery differs from endoscopy in that the instruments or tools which perform the surgery are robotically controlled. The world’s first robotic surgery was performed in Vancouver in 1983.

There are mixed reports on the benefits of robotic surgery. On the one hand, the flexibility of robotic surgery has been argued to improve the quality of procedures, resulting in better outcomes and reduced recovery time. However, robotic surgery is very expensive for the equipment and infrastructure support and requires extensive training. It has been linked to higher complications and several deaths. In spite of these concerns, robotic surgery has become popular, especially in the USA. One reason may be marketing: a clinic with a robot can attract patients as being “modern” and “high tech”.

One use for robotic surgery is for a gastric bypass, which “helps you lose weight by changing how your stomach and small intestine handle the food you eat.” The volume of the stomach is reduced, decreasing the physiological response to food. Gastric bypass is used to treat obesity. It can help reduce the associated risks: heart disease, type-II diabetes, and others. On the other hand, like all surgery, gastric bypass has risks, such as infection and hemorrhage.

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2. Wikipedia, en.wikipedia.org/wiki/Minimally-invasive_procedures
10. Wikipedia, en.wikipedia.org/wiki/Gastric_bypass_surgery
1. (Statistical Methods) You read the following abstract of a study into recovery times:

Recovery times were compared for patients undergoing gastric bypass surgery using traditional techniques vs. patients undergoing the same procedure using the new DrRobot robotic surgery platform. This study examined the recovery times for two groups of patients at two hospitals in Los Angeles, California: A) 25 patients who received robotic surgery at the (private) University Hospital, and B) 25 patients who received traditional surgery at the (public) Sisters of Mercy Hospital. Recovery times (measured in days) were significantly lower for Group A ($p = 0.04$).

(a) What was the null hypothesis? What was the alternate hypothesis? What are the dependent and independent variables?

(b) A $p$-value of 0.04 means that there is a 4% chance of what?

(c) Discuss one source of possible bias in this study. How might it affect the results?

(d) Assume that the study authors used a t-test to compare the means of the two populations. Should they have used a 1-tailed or 2-tailed test here? Why?

2. (Statistical Methods) You have now been hired by DrRobot to run their follow-up survey which will study the fatigue experienced by surgeons using traditional techniques vs. the DrRobot surgery system.

(a) They will measure fatigue using a scale from 1–5 (no fatigue . . . maximum exhaustion). They expect a difference in mean fatigue score of 0.02 between the groups of surgeons using the two systems and a variance of 0.2 ($\sigma^2 = 0.2$) within each group. They want to ensure that their $p$-value will be 0.05 or lower which requires a $t$-value of 1.32 (assuming a large DOF). How many surgeons must they recruit in each group to achieve this $p$-value?

(b) Based on the results of the first study (in Q#1), your colleagues in marketing creates an image (figure 1) to illustrate the mean recovery time (in days) of patients undergoing surgery using traditional techniques vs. the new DrRobot robotic surgery system. Do you feel comfortable that this is a fair representation? Discuss at least three issues with this figure that may bias the reader.

3. (Biomedical Engineering Practice) When a hospital is planning to install a surgical robot, there are many different tasks which require involvement from biomedical engineering. Discuss a function which a biomedical (clinical) engineer would play in each of (a) procurement, (b) planning, (c) construction, (d) maintenance and (e) reporting related to the robot.
4. (Ethics) The expensive of many medical devices raises a question: is it better to use the money to provide a less expensive treatment to more people?

Consider a hospital debating whether to buy a surgery robot which will be specialized for gastric bypass surgery. This system is designed to treat three patients a day, and improve recovery times. As discussed, a gastric bypass has been shown to help patients reduce weight and the associated problems.

At the same time, a group on the hospital board are making the argument that the money can be better used to hire staff to improve the community outreach and support offered to obese patients. They argue that, for the amortized cost of one robot and its maintenance over ten years, ten nurses can be hired to work with young people vulnerable to becoming obese using proven support strategies to help prevent obesity.

You are a hospital executive who needs to make the decision about how to best use this money.

(a) Explain why this decision would need to involve ethical considerations.
(b) Create a table of the at least 3 of the groups of people impacted by the decision, and list benefits and disadvantages of the two options to each group.
(c) What decision would you make? Choose an ethical theory and justify your decision.

5. (Research Ethics) One source of bias (which you can’t use to answer 1(c), above) is that patients who believe they are receiving robotic surgery will have a more positive attitude towards the “high tech” surgery they will receive; this attitude may improve their recovery times. For best scientific evidence, one should remove the possibility that the outcomes are biased by patients’ knowledge of the type of surgery.

Consider a study sponsored by DrRobot which aims to eliminate this bias. All patients are told they will receive robotic surgery, but 50% of patients are randomly selected to receive standard care instead. Since they are not awake during surgery, they’ll never know anyway. It is decided not to tell them, since their emotional reaction may influence recovery.

(a) Discuss the ethics of this study. Identify at least two ethical concerns.
(b) How could the interactions with patients be modified to address this concern? Describe the stages of interaction with patients in your modified study.
(c) List four subjects that would need to be addressed in your modified consent form.

6. (Cells + DNA) Sterilization is very important to surgery, to prevent infection. There is some concern that a complex system like a surgical robot may be harder to sterilize than more simple surgical instruments.

(a) Assume that you have isolated a strain of fungus growing on a component of the system. Describe how microarrays could be used to measure the gene expression of the fungus (include a figure illustrating the technology).
(b) It is discovered that Diet Coke® is able to kill the fungus and sterilize the robotic system. How could functional genomics assays (tests) be used to help determine the method of action of the diet coke in attacking the fungus?

7. (Electrophysiology) One adverse outcome during surgery is the risk of hemorrhage if the surgical instruments cut major blood vessels. If the stomach or abdomen is cut, the resulting bleeding can increase the potassium concentration in the blood and result in hyperkalemia.11

(a) Describe and sketch the voltages along an axon during a normal action potential in a motor nerve.
(b) What happens to ions of $K^+$, $Na^+$ and $Cl^-$ (i) during the action potential and (ii) at rest?

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(c) How will hyperkalemia affect the action of nerves? Base your answer on the activity of ions of the previous question.

8. (Heart function) Consider again the possibility of blood loss in the previous question, but here consider only the effect of the loss of blood volume. Before blood loss a patient has cardiac output, $\text{CO} = 6 \text{ L/min}$, end-diastolic volume, $\text{EDV} = 150 \text{ ml}$ and an ejection fraction, $\text{EF} = 66\%$. Blood pressure (in mmHg) is 130/80.

(a) Sketch a graph of the normal function of the heart over the course of two beats. Show the timing of i) left ventricular volume, ii) left ventricular pressure, iii) aortic pressure, iv) when the aortic valve is open and closed, and v) the PQRST waves of the ECG. (Draw separate $y$-axes for quantities with different units. Vertical and horizontal axes must have units.)

(b) As blood is lost, end-systolic volume (ESV) stays constant while EDV is reduced to 100 ml. The body compensates to maintain CO. What will change in the graph of left ventricular volume in the previous question?

(c) Discuss the change in the work which the heart is required to perform.

9. (Oxygen transport) Abdominal surgery is made easier if the patient is held in a head-down position (i.e. with the head of the bed at approximately $15^\circ$ below the horizontal). This means the diaphragm and abdomen will be pulled by gravity toward the head (cranial direction).

(a) Sketch the curve of the static chest pressure-volume characteristics, showing the contributions of the lungs and the chest wall. Which components of this graph change when the patient is in a head-down posture. Show on the graph how this will affect functional residual capacity (FRC)?

(b) When FRC is lower, some lung tissue may collapse, causing shunt. Assume that an otherwise healthy patient entered surgery with a shunt of 5%, and venous blood with a saturation, $S_vO_2 = 70\%$. The patient has healthy lungs in which all the blood which interacts with air in the alveoli becomes completely saturated. During surgery, the decreased FRC makes shunt increase from 5% to 30%. Calculate $S_aO_2$ before and during surgery.

(c) During surgery, the body is anesthetized and its requirement for oxygen is lower, thus $\dot{V}_O_2$ decreases by 20%. The body increases cardiac output so that venous saturation remains at 70%. By what fraction does CO need to increase? (Take into account the change in shunt in the previous question, but no other changes in physiology)

10. (Biomechanics) While working for DrRobot, you are assigned to a team which needs to calculate the forces required to cut various types of tissue in the body.

(a) In order to save money, you buy meat samples from a grocery store. The forces to cut these samples are measured. Describe three factors in the mechanical testing of biological tissue samples that would influence the relevance of your results on meat samples to the actual results in a live body.

(b) If the robot cuts arteries or veins, bleeding will occur. Describe the difference between arteries and veins in terms of the (i) pressure of blood, (ii) elasticity, (iii) smooth muscle, (iv) pre-stress, and (v) valves.