BEENG 100b: Frontiers in Biomedical Engineering

Spring 2008

FINAL EXAMINATION

May 7, 2008

INSTRUCTIONS: You have three hours to complete this exam. This is a closed book exam. You may use a calculator. Only work shown in the space provided will be graded. Partial credit will be given when warranted. The exam is worth a total of 100 points.

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Question 1. *(20 points)* Cardiovascular physiology

As you know from our section meeting, blood pressure is measured using an inflatable cuff and a stethoscope. Describe how this blood pressure measurement works by answering the following questions:

a) What happens in your arm as the inflatable cuff is pressurized? Why is it usually inflated to ~200 mmHg?

The pressure cuff is inflated 200 mmHg, to insure that the pressure is higher than the highest pressure generated by the heart (which is usually near 120 mmHg). At this high cuff pressure, the superficial arteries of the arm are collapsed, halting blood flow.

b) Blood pressure is recorded as (systolic pressure)/(diastolic pressure), with a typical value of 120/80 (in mmHg). These pressures are determined by listening with a stethoscope as the pressure in the cuff is decreased. What physical process creates the sounds?

The sounds are created by the opening and closing of the arteries in the arm. When the pressure in the artery is higher than the cuff pressure, the artery opens; when the pressure in the artery is lower, the artery is closed.

If the blood pressure is 120/80:

cuff pressure > 120 no sound
120 > cuff pressure > 80 sounds are heard
cuff pressure < 80 no sound

c) How are pressures measured in the arm related to pressures in the heart?

The key assumption is that the pressure of fluid flowing in the arteries of the arm is equal to the pressure of fluid in the left ventricle. As we discussed in class, the resistance to flow of the large vessels (aorta and first braches) is low, and therefore there is little pressure drop from the ventricle to the large arteries of the arm. This fact makes it reasonable to measure ventricular pressures in the arm

Question 2. *(20 points)* Renal Physiology

The nephron is the functional unit of the kidney.

a) Describe the structure of the nephron, using a diagram, if you like.

Diagram of the nephron showing clearly the following structures:

- **Glomerulus (including capillary tuft and Bowman's capsule)**
- **Proximal convoluted tuble**
- **Loop of Henle**
- **Distal convoluted tubule**
- **Collecting duct**

b) Describe an experimental approach for measuring the glomerular filtration rate using the tracer molecule inulin.

Inulin is a tracer that is neither metabolized in the blood nor reabsorbed by the kidney tubules. If a dose of inulin is injected into the blood, it is filtered by the glomerulus and excreted into the urine. Therefore, the amount of inulin that appears in the urine is directly related to the concentration in the plasma and the filtration rate. By measuring the rate of inulin output in the urine, and the plasma concentration of inulin, one can calculate the GFR.

It is not necessary for complete credit to write the equation, but it is derived as follows:

Rate of flow from plasma into tubules=rate of excretion

(GFR) P_{inulin} = (Urine Production Rate) U_{inulin}

where P_{inulin} and U_{inulin} are concentrations of inulin in the plasma and urine. Therefore,

GFR = (Urine Production Rate) U_{inulin}/ P_{inulin}

Question 3. *(20 points)* Tissue Engineering

Many people believe that tissue engineering may someday offer an alternative for patients who now can only by treated by whole-organ transplantation. List three **other** possible uses for tissue engineering and provide an example of each.

In class, we talked about these general uses:

- **Tissue engineering involves control or regulation of the normal healing process.**

An example here might be the addition of a material to a wound to regulate the rate of remodeling within the wound bed.

- **Tissue engineering uses cellular processes to control drug delivery.**

An example here might be the transplantation of cells that produce a hormone (such as insulin)

- **Tissue engineering produces new models for the study of human physiology**

An example here might be the creation of tissue engineered liver to study the response of liver to drugs or toxic chemicals.

Tissue engineering strategies can generally be divided into 2 categories; cell-based and biomaterial-based. Discuss the strengths and weaknesses of each approach using examples from the lectures and address some of the challenges of integrating the two approaches.

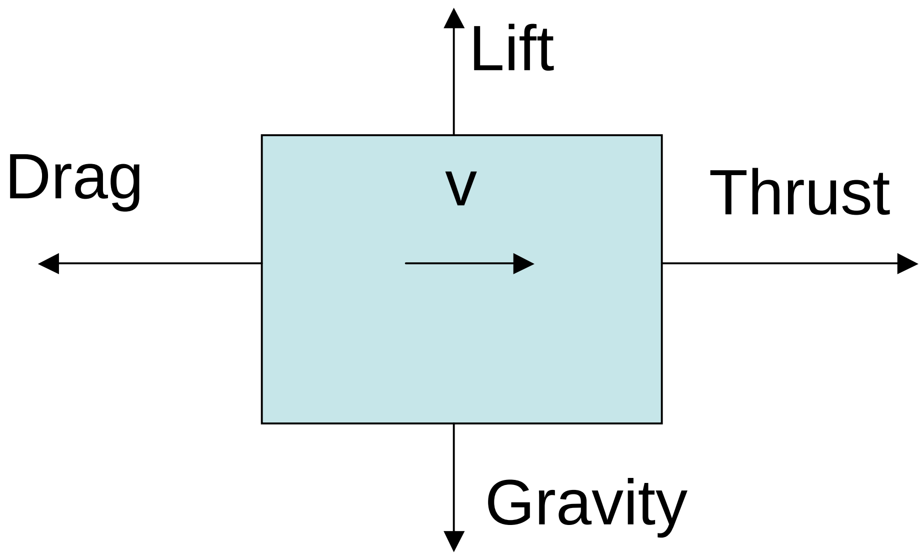
	Strengths	**Weaknesses**
Cell-based	**Takes advantage of the complex behavior and regulated function of cells**	**Where do the cells come from?** **How do we maintain cell viability?** **How do we maintain differentiated cell function**
Biomaterials-based	**Easier to control the quality of the implant, because it is completely non-living**	**Are the materials safe?**

Integration of these two general categories requires the identification of materials that can be used safely with cells, and might mean identification of materials that provide the appropriate signals to cells to encourage the function that is desired. Integration also requires identification of a specific method for combining cells with the material, which is often difficult because the methods used to make or fabrication materials often involved chemicals or processing conditions that are not compatible with cells.

Question 4. *(20 points)* Biomechanics

a. A bird in flight (or an airplane in flight) experiences forces that move it in a forward direction and that keep it aloft. Draw a diagram showing the forces that are acting on a bird (or airplane) that is moving forward at a constant velocity and maintaining a constant altitude.

b. Label the forces in the diagram.



c. What physical mechanisms does a bird use to generate the forces necessary to move forward and stay aloft?

Forward thrust is created by the movement of the wings. The wings are tilted and moved from front to back, generating force in the forward direction.

The lift force is created by two components. When the wings are in motion, they are usually positioned such that the front to back motion creates some upperward lift, as well as forward thrust. Second, during gliding when the wings are held steady, the shape of the wings is similar to an airfoil on an airplane wing: lift is created by the relative speed of movement of air over the top and bottom surface of the wing.

Question 5. *(20 points)* Imaging

a) What is ionizing radiation?

Ionizing radiation is that portion of electromagnetic radiation that is capable of ionizing molecules within tissue; it is high frequency, short wavelength radiation. Due to its highly energetic nature, ionizing radiation can eject or deviate electrons, which are on its trajectory (ionization). X-rays and gamma rays are examples of ionizing radiation.

b) Ionizing radiation from a variety of sources is used for creating images in humans. Select any two sources of ionizing radiation and describe a method for imaging based on that type of radiation.

X-ray images, CT imaging, nuclear medicine (with a gamm camera), and PET imaging are all acceptable examples. If they choose both X-ray and CT, it is important that the two be distinguished: both use the same source of radiation, but differ in the way that the radiation is applied. CT also requires a mathematical process, called reconstruction by back projection, to create a 3D image.

c) Ultrasound imaging does not involve ionizing radiation. What physical principle does it use? How is an image created using this principle (i.e. what properties of tissues does it detect)?

Ultrasound imaging utilizes the movement of sound waves, or pressure waves, through tissue. Images are created by the reflection of sound waves at interfaces in the tissue: interfaces between soft tissue and bone for example, or between soft tissue and blood, or reflections of individual cells in the flowing blood.

Bonus. *(10 points)*
Describe one interesting biomedical engineering principle that you learned from reading the research papers prepared by your peers.