UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATIONS, APRIL, 1998

Fourth Year - Program 5bme

MMS452S - BIOMATERIALS & BIOCOMPATIBILITY

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Part A - Short Answer Questions - Answer all 12 questions. Each question is worth 5 marks. (Total marks = 12 x 5 = 60). (Point form answers are acceptable). Part B - Essay-type Questions - Answer 3 of the 6 questions only. Each question is worth 20 marks. (Total marks = 3 x 20 = 60)

PART A: Answer all questions.

1. a) In addition to the general requirement of biocompatibility, list three (3) specific requirements for a biodegradable biomaterial for use as a bone substitute implant.
   b) Suggest a biomaterial that is likely to satisfy these requirements.
   c) What is Bioactivity Index. How could it be determined for the biomaterial proposed in 1b)?

2. a) Explain how vacuum mixing of an acrylic bone cement benefits its in-vivo performance?
   b) Draw Weibull distribution curves that you would expect for a vacuum-mixed bone cement compared with the same cement mixed under standard operating room conditions (i.e.without vacuum mixing). Highlight expected differences in mean fracture strength and strength variability on the curves.
   c) List three (3) other methods that can be used to enhance bone cement properties.

3. An orthopaedic implant manufacturer proposes to produce a porous-surfaced total hip replacement implant using a high temperature sintering process to bond metallic powders to a solid implant core. The choices for the core component include cast 316L stainless steel, cast CoCrMo alloy, wrought CoCrMo alloy (high-C), and wrought CoCrMo alloy (low-C). Which material would you recommend assuming that powder of the same composition is available for preparing the sintered porous surface region? Explain why you would recommend this material over the others. State specifically why each of the other materials would not be suitable.

4. Endoluminal procedures have recently been developed for blood vessel repair. These are less invasive than conventional surgery and involve the insertion of a catheter into a peripheral artery. The catheter is advanced to the diseased segment and used to expand an arterial stenosis (zone of vessel narrowing) or repair an aneurysm (zone of vessel dilation). Describe an implantable device, delivered via a catheter, which is used for treatment of either arterial stenosis or aneurysm. Once implanted, how does this device function?

5. Provide an example of a percutaneous access device and describe how it may become infected by microorganisms.

6. What is a microbial biofilm and what role can it play in infections of indwelling medical devices?

7. Polyurethanes are an extensive class of biomaterials that are used in a broad range of applications. One limitation of polyurethane biomaterials that has been recognized over the past two decades is their potential to undergo biodegradation by physiological enzymes and oxidants.
a) Which of the following two materials would you expect to undergo enzyme-catalyzed hydrolysis more readily; i) a polyurethane with soft segment based on a non-aromatic polyester, or ii) a polyurethane with soft segment based on a non-aromatic polyether? Briefly, justify your answer.
b) The ether bonds contained in the polyether segments of polyurethanes are often susceptible to in-vivo oxidation. What is the primary source for the oxidants involved in this process?
c) The segmented block structure of polyurethanes makes these materials a versatile family of biomaterials for the design of new biodegradable polymers for use in tissue engineering. If you were to select monomers for new polyurethanes that could undergo specific biodegradation in the in-vivo environment, which principle criterion (give only one) would you define for the selection consideration? Briefly, provide the rationale for your answer.

8. The blood compatibility of a biomaterial is most often characterized by the nature of the first blood proteins that bind to the surface of the material.
a) List three material surface attributes that will influence this process?
b) By which coagulation pathway is thrombus formation at the surface of a biomaterial most likely to proceed, intrinsic or extrinsic? Briefly explain why.
c) Provide a strategy for altering the pathway of thrombosis at the surface of a biomaterial. Briefly, provide the rationale for your selection.

9. Both synthetic and natural vascular grafts have been successfully used in many patients over the past several decades. However, the synthetic grafts commercially available today are limited in their area of use.
a) What principal mechanism of failure has precluded the use of synthetic vascular grafts for the replacement of diseased vessels with diameters of less than 10 mm?
b) One polymeric material which has been predominantly used in the manufacture of vascular grafts is a polyester fibre known as polyethyleneterephthalate (PET). Briefly, describe why manufacturers using this material have introduced highly textured features into these PET grafts known as velour grafts.

10. a) Define "tissue engineering".
b) List three tissues which you know have been engineered using tissue engineering principles. In each case name the cell and the scaffold employed.

11. a) List the three major requirements for a successful tissue engineering (TE) construct.
b) Name one ligand (you can use an acronym) with which you would functionalize a surface to increase cell adhesion to that surface. Which cells would you expect to bind to your chosen ligand?

12. Name two polymers which have been used in cell encapsulation devices, and three advantages of this type of tissue engineering strategy. What are the dangers of this type of patient therapy?

Part B - Answer, in essay form, three (3) of the following six (6) questions only.

1. During the review of polymer applications in the field of medicine, there were several examples given in class that stressed the careful selection of materials based on the processing methods used throughout the preparation of the final product as well as possible use of additives in the polymers. Explain, through examples, how these considerations might affect biological interactions at the surface of the material.

2. Describe the structure and function of a synovial joint with specific reference to the role of hyaline cartilage in providing suitable load-bearing characteristics hopefully for a person's normal lifespan. Indicate how breakdown leading to osteoarthritis may occur. From currently-used joint replacements, recommend a total hip replacement for an active 50-year old golf pro who wishes to continue playing on the pro-circuit? Indicate your choice of material(s) and design.

3. You are given the responsibility of designing a new material to replace conventional hip prostheses. Describe, from both materials and biological perspectives, the design criteria you would stipulate to arrive at an ideal solution to this problem. [In answering this question you do not have to rely on real materials. You should feel free to describe hypothetical materials].

4. Explain why the geometry of a tissue engineering scaffold has to be sometimes quite different from that of the same material when used as a conventional implantable bone biomaterial.

5. Define the principal differences between tissue-derived heart valves and mechanical heart valves with particular focus on the design parameters discussed in class.

6. The process of osseointegration of an endosseous dental implant can be compared to healing at a bone fracture site. Discuss the process of fracture healing indicating similarities and differences compared with that which occurs during osseointegration of a threaded Ti alloy dental implant placed in a mandibular site. Refer in your discussion to the common factors that could prevent bone union or osseointegration in the two situations and, assuming that a Ti alloy fixation plate is used for the fracture treatment, the possible undesirable long-term effects of good fixation of the implants.