UNIT V APPLICATIONS AND USES

Selection of Materials for Biomedical Applications, Medical Products, Materials in Electronic Packaging, Advanced Materials in Sports Equipment, Materials Selection for Wear Resistance, Advanced Materials in Telecommunications, Using Composites Manufacture and Assembly with Plastics, fiber and Diamond Films.

Selection of Materials for Biomedical Applications

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Load Support

Because of its primary role in mechanical support, the stem of a femoral prosthesis can realistically be manufactured from a metal, a ceramic, or a composite material. For this discussion, composite materials will not be included, as they have not yet been utilized in commercially available total joint replacements (they are available for bone plate applications).

Strength

The first property to be considered for a load-bearing implant is its mechanical strength. The loading of the femur is dynamic and, while estimated to range up to 8 times body

weight, is difficult to determine precisely. Therefore, as the implant will be loaded in essentially the same way as the natural bone, it is reasonable to assume that a material that will provide the same or greater load-bearing capacity as bone will meet the necessary mechanical requirements. Based on the cyclic loading that a material is likely to undergo when implanted in the body, it is reasonable when evaluating selections to compare the endurance limit of the materials under consideration to the experimentally determined strength values for bone.

Joint Motion

Friction. Frictional forces between the articulating surfaces of a joint have two primary effects: (1) to increase the muscle force required to overcome the internal friction and allow motion to occur and (2) to increase the torque experienced by the implant and/or bone, such as at the location of the femoral neck. Large internal bending moments due to high frictional forces may lead to failure of the implant, and therefore should be avoided.

Wear

Whenever contact surfaces and motion are combined, material wear must be taken into consideration. Wear is the process whereby one object, through motion, removes material from the surface of the contacting object. Generally, the harder material will cause wear to occur on the softer material. Three basic types of wear can occur: abrasive wear, adhesive wear, and third body wear. Abrasive wear exists when a hard material, such as a metal, moves cyclically against a soft material, such as a polymer. Adhesive wear involves the sliding motion of two similar materials, where molecular bonds can be formed at the interface of the structures. In rough materials, the surfaces appear as a series of peaks and valleys. The two articulating surfaces typically come into contact at the peaks of the surface roughness, concentrating the contact load over a much smaller area and increasing the contact stress. As the molecular bonds between the objects are broken through motion, they also break off particles of the underlying material. Third-body wear

includes the effect of particles between the articulating surfaces that tend to accelerate wear. The wear rate, or volume of wear particles produced (V), can be approximated for adhesive wear by the equation

$$V = \frac{kF_n x}{3p}$$

Biocompatibility

Once a material is selected for an implant application based on the functional requirements, it must be evaluated in terms of material–body interactions. An implant material will react chemically with the local environment, with the type of reaction dependent on the class of material. Metals are susceptible to corrosion, polymers experience leaching and absorption, while ceramics are generally considered to be chemically inert—unless designed to be bioactive. The effects of chemical degradation may affect both the tissue and the material itself, especially its mechanical properties, and so both aspects must be considered. In addition, degradation products can affect the physiology locally, at a remote location, or systemically.

Corrosion

Metallic materials are susceptible to corrosion, particularly in the ionic fluid environment of the body. To assess the corrosion potential of a metal, it is necessary to examine the half-cell potential of that metal—which will act as an anode when it releases electrons—with respect to the material acting as the cathode. This cathode may be another metal or the ionic environment itself. An electrochemical series lists the half-cell potentials of metals in order from the most noble (or cathodic) to the most anodic. When two materials are in contact with each other directly or through an ionic solution, the metal listed first in the list will act as the cathode while the other will behave as the anode. Practical electrochemical series typically relate half-cell potentials as measured in an application-specific environment and may include alloys. This contrasts with ideal series, which list only pure metals as measured with respect to a hydrogen half cell reaction.

Leaching and Absorption

Polymers placed in a fluid environment can experience two opposite phenomena. In leaching, unreacted monomer molecules, fillers, or small chains of polymers can diffuse from the bulk of the polymer to the surrounding fluid. As in corrosion products, these released molecules may have a negative effect on the local physiology or, if transported through the bloodstream or lymphatic system, on systemic or remote processes. In addition, significant leaching may reduce the density of the polymer and consequently have an adverse effect on the properties of the structure.

All materials, including metals and ceramics, can absorb molecules particularly water—from the surrounding environment. However, this occurs much more readily in the relatively loosely bonded polymers. Absorption in polymers can also result in swelling, due to their low elastic modulus, which may cause geometric changes that interfere with the performance of an implant. The strain that a polymeric object experiences due to swelling may induce cracks and may also reduce the ultimate strength of the object. This latter phenomenon occurs because, due to the new baseline strain in the material, less stress is needed to reach the material's ultimate strain. If the absorbed molecules are small, such as water, they will act as plasticizers and weaken the bonds between the polymer chains, thus reducing the Young modulus of the material. If a polymer is hydrophobic in nature, it is less likely to absorb water. However, absorption of nonpolar molecules such as lipids may still occur.

BLOOD-CONTACTING BIOMATERIALS: VASCULAR PROSTHESES

When blood vessels are damaged through injury or disease, they often must be replaced or bypassed in order to maintain adequate blood flow to and from the regions of the body. Disease-induced damage, such as atherosclerosis and aneurisms, occurs more often in arteries than in veins, due in large part to the higher working pressure of the blood within these vessels. Injury can occur to any blood vessel; however, collateral circulation typically eliminates the need to replace small veins, and the low venous return pressure

provides an environment in the larger veins that is much more conducive to traditional surgical repair or auto graft use. As a result, this section will focus on the selection of materials for the development of arterial prostheses.

Biocompatibility

The primary functional need of a blood vessel—transport of blood—can easily be met through general implant design. However, due to the delicate nature of blood cells and the ease at which the clotting cascade can be initiated, biocompatibility issues place substantial limitations on material selection for this application. The natural vessel provides an optimal environment for blood flow, and the mimicking or replacing of its intimal layer is one of the underlying ideas in work to improve biocompatibility in vascular grafts.

There are few, if any, current implants that can be described as perfectly meeting their design goals and constraints so that no further investigation of design or material selection is warranted. As materials continue to be developed, whether specifically for biomedical applications or in some different discipline, the selection of biomaterials for implants will remain a challenge in the design of the optimum implant. The evolution of tissue engineering from a bench-top science to a clinically workable tool for new implant design will also open new doors for the development and use of biomaterials. In all of these cases, however, the same principles apply to the selection of a material for a biomedical application.

The selection process can be summarized in the following way:

1. Determine the functional requirements of the material for the particular application (preferably with an idea of the overall design in hand).
2. Select a group of materials that appear to meet those functional requirements and ensure that all confirming tests are conducted in an environment that simulates human physiology.
3. Determine the biocompatibility of the materials in terms of material degradation, tissue effects, blood compatibility, implant fixation, and long term physiologic consequences.

4. Complete the design and approval process, with mechanisms in place to obtain data on functional or material complications for many years after clinical use is initiated.