生物材料學
Biomaterials

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生物材料學 BIOMATERIALS

Introduction to Biomaterials

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Purpose of the Class

To develop in the students a familiarity with the uses of materials in medicine and with the rational basis for these applications.

Reference

- 自行編纂

- ***Biomaterials***

  A synthetic material used to replace part of a living system or to function in intimate contact with living tissue (J.B. Park)

- ***Biological Material***

  A material (*e.g.,* bone matrix, tooth enamel) produced by a biological system

- ***Artificial Materials***

  A material simply in contact with the skin, *e.g.,* hearing aids and wearable artificial limbs → not biomaterial since the skin acts as a barrier with the external world

Biological Performance of Materials (Classification)

1. Problem area to be solved
2. A tissue level, an organ level, or a system level
3. Metals, polymers, ceramics, and composites.
4. Mechanical properties or interactions with tissues (the effect of the body environment on the material, and the effect of the material on the body)

Use of materials

Problem area	Examples
Replacement of diseases or damaged part	Artificial hip joint, kidney dialysis machine
Assist in healing	Sutures, bone plates and screws
Improve function	Cardiac pacemaker, contact lens
Correct functional abnormality	Harrington spinal rod
Correct cosmetic problem	Augmentation mammoplasty, chin augmentation
Aid to diagnosis	Probes and catheters
Aid to treatment	Catheters, drains

* influenced by antibiotics and surgical technique

Biomaterials in Organs

Organ	Examples
Heart	Cardiac pacemaker, artificial heart valve
Lung	Oxygenator machine
Eye	Contact lens, eye lens replacement
Ear	Artificial stapes, cosmetic reconstruction of outer ear
Bone	Bone plate
Kidney	Kidney dialysis machine
Bladder	Catheter

Biomaterials in Body Systems

System	Examples
Skeletal	Bone plate, total joint replacement
Muscular	Sutures
Digestive	Sutures
Circulatory	Artificial heart vales, blood vessels
Respiratory	Oxygenator machine
Integumentary	Sutures, burn dressings, artificial skin
Urinary	Catheters, kidney dialysis machine
Nervous	Hydrocephalus drain, cardiac pacemaker
Endocrine	Microencapsulated pancreatic islet cells
Reproductive	Augmentation mammoplasty, other cosmetic replacements

Materials for Use in the Body

Materials	Advantages	Disadvantages	Examples
Polymers			
Nylon Silicones Teflon® Dacron®	Resilient Easy to fabricate	Not strong Deform with time May degrade	Sutures, blood vessels, hip socket, ear, nose, other soft tissues
Metals			
Titanium Stainless steels Co-Cr alloys Gold	Strong, tough Ductile	May corrode Dense	Joint replacement, bone plates and screws, dental root implants
Ceramics			
Aluminum oxide Carbon Hydroxyapatite	Very biocompatible, inert Strong in compression	Brittle Difficult to make Not resilient	Dental; hip socket
Composites			
Carbon-carbon	Strong, tailor-made	Difficult to make	Joint implants; heart valves

Biomaterials according to mechanical properties or interactions with tissues

Classification of biomaterials using elastic modull (lowest to highest magnitudes)

Biomaterial	Modulus of elasticity ratio (biomaterial/bone)*	Electrical or thermal conductor	Color
Polymers	0.01 -0.5x	No	Cream-white to amber
PE, PTFE			
PTFE, PMMA, PSF			
Ceramics	0.5 – 5.0x	No	White
$CaPO_4$			
Carbons	1.0x	Yes	Black
C and C-Si			
Metals and alloys			
Ti and Ti-Al-V	5.0 – 5.7x	Yes	Metallic
Fe-Cr-Ni	8.0x		
Co-Cr-Mo	11.0x		
Ceramics			
Al_2O_3	20.0x	No	Cream-white

Classification of biomaterials using mechanical tensile strengths (lowest to highest magnitudes)

Biomaterial	Tensile strength ratio (biomaterial/bone)*	Ductility (% elongation) ratio (biomaterial/bone)†
Polymers	0.1 – 0.5x	1 – 300x
Ceramics		
$CaPO_4$	0.1 – 2.0x	0
Carbons		
C and C-Si	1.0 – 5.0x	0
Ceramics		
Al_2O_3	2.0 – 5.0x	0
Metals and alloys	1.5 – 7.0x	8 – 30x

* The tensile strength of compact bone was taken as $2x10^4$ psi for these ratios.

† The tensile elongation to fracture for compact bone was taken as 1% for these ratios.

Classification of biomaterials using chemical inertness (lowest to highest magnitudes)

Biomaterial	Relative ranking*
Ceramics	
TCP	Biodegradable
HA	Bioactive
Polymers	PMMA to PTFE
Metals and alloys	Fe to Ti alloys
Ceramics and carbons	Inert
Al_2O_3, C, C-Si	

* These relative rankings are dependent on the specific biomaterial product and the clinical application. For example, PMMA is presented as the bone cement product used in orthopedic surgery and the biochemical inertness of PTFE exceeds some of the metallic materials.

- **Inert (Passive)** biomaterials
  - – with resistance to chemical or biological degradation
- **Bioactive (Surface Active)** biomaterials
  - – slight interaction (positive response)
- **Bioresorbable (Biodegradable)** biomaterials
  - – intended to dissolve or to be absorbed in vivo

Generally, the high ceramics and carbons are most inert, the metals are intermediate, and the polymers are most subject to interfacial wear or to the leaching of lower molecular weight or plasticizer constituents.

Most current applications of biomaterials involve *structural* functions, or very simple *chemical* or *electrical* functions.

Complex chemical functions (*e.g.,* those of liver), and complex electrical or electrochemical functions (*e.g.,* those of brain and sense organs) cannot be carried out by biomaterials

→ *Transplantation* of organs and tissues is inevitable when biomaterials are not available

Performance of Biomaterials

The success of a biomaterial in the body depends on factors

1. Under control of the engineer
   - material properties
   - material design
   - biocompatibility of the material used

2. Not under control of the engineer
   - the technique used by the surgeon
   - the health and condition of the patient
   - the activities of the patient

-- If a numerical value *f* is the probability of failure, the *reliability (r)* can be expressed as

$$r = 1 - f$$

-- If there are multiple modes of failure, the total reliability r_1 is given by the product of the individual reliabilities $r_1 = (1 - f_1)$, etc:

$$r_1 = r_1 r_2 \ldots r_n$$

-- One mode of failure that can occur in a biomaterial but not in engineering materials

- an attack by the body's immune system on the implant

-- Another such failure mode is an unwanted effect of the implant upon the body, *e.g.,* toxicity, inducing an inflammation, or causing cancer

Consequently, biocompatibility is included as a material requirement

* ***Biocompatibility*** involves the acceptance of an artificial implant by the surrounding tissues and by the body as a whole

* Biocompatible materials

  - not irritate the surrounding structures, not provoke an inflammatory response, not incite allergic reactions, not cause cancer

Other characteristics of biomaterial

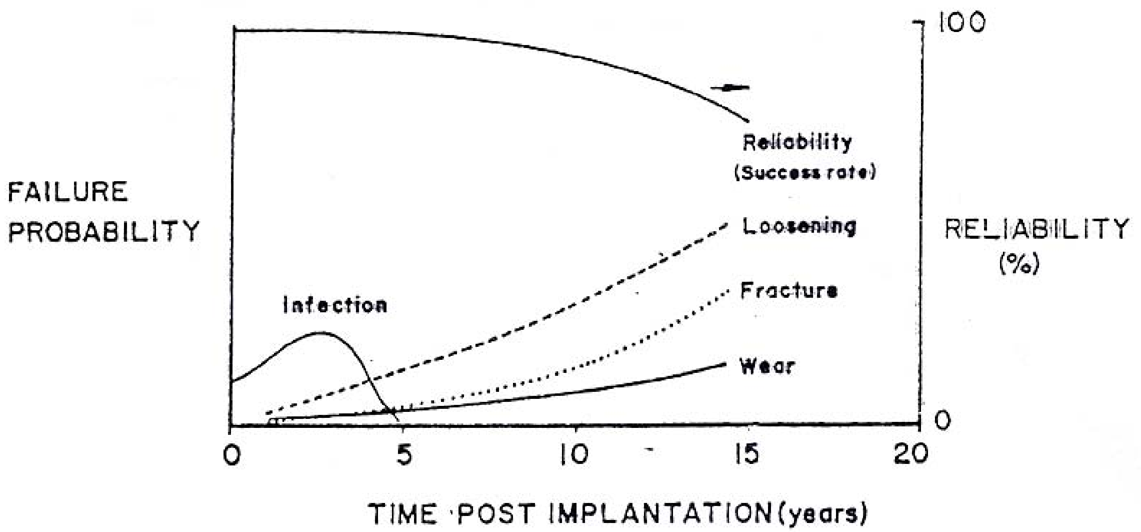
- adequate mechanical properties, *e.g.,* strength, stiffness, and fatigue properties; appropriate optical properties (used in the eye, skin, or tooth); appropriate density; manufacturability; and appropriate engineering design

The failure modes may differ in importance as time passes following the implant surgery

e.g., a total joint replacement

→ infection is most likely soon after surgery

→ loosening and implant fracture become progressively important



Failure modes also depend on the type of implant and its location and function in the body

e.g., artificial blood vessel

→ causing problem by inducing a clot or becoming clogged with thrombus than by breaking or tearing mechanically

Summary

- Biomaterials
- Biocompatibility
- Biological Environment
- Swelling and Leaching
- Interfacial-Dependent Phenomena in Biomaterials
- The Structure of Solids
- Characterization of Materials