Introduction to Modern Biomaterials

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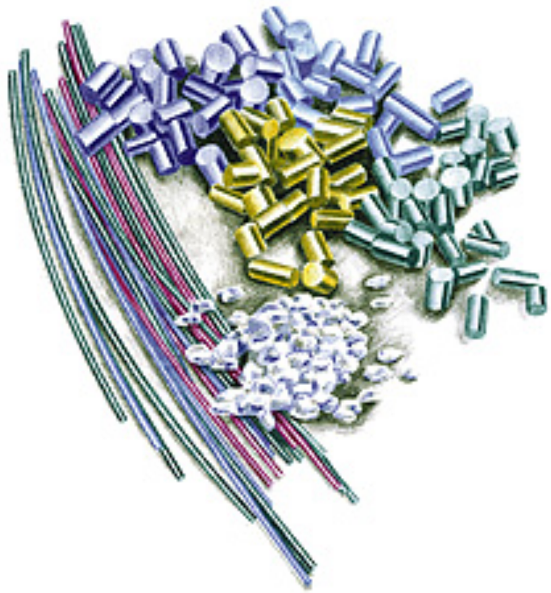
Lecture 2

Classes of Materials Used in Medicine

How many different types of biomaterials are in use today?



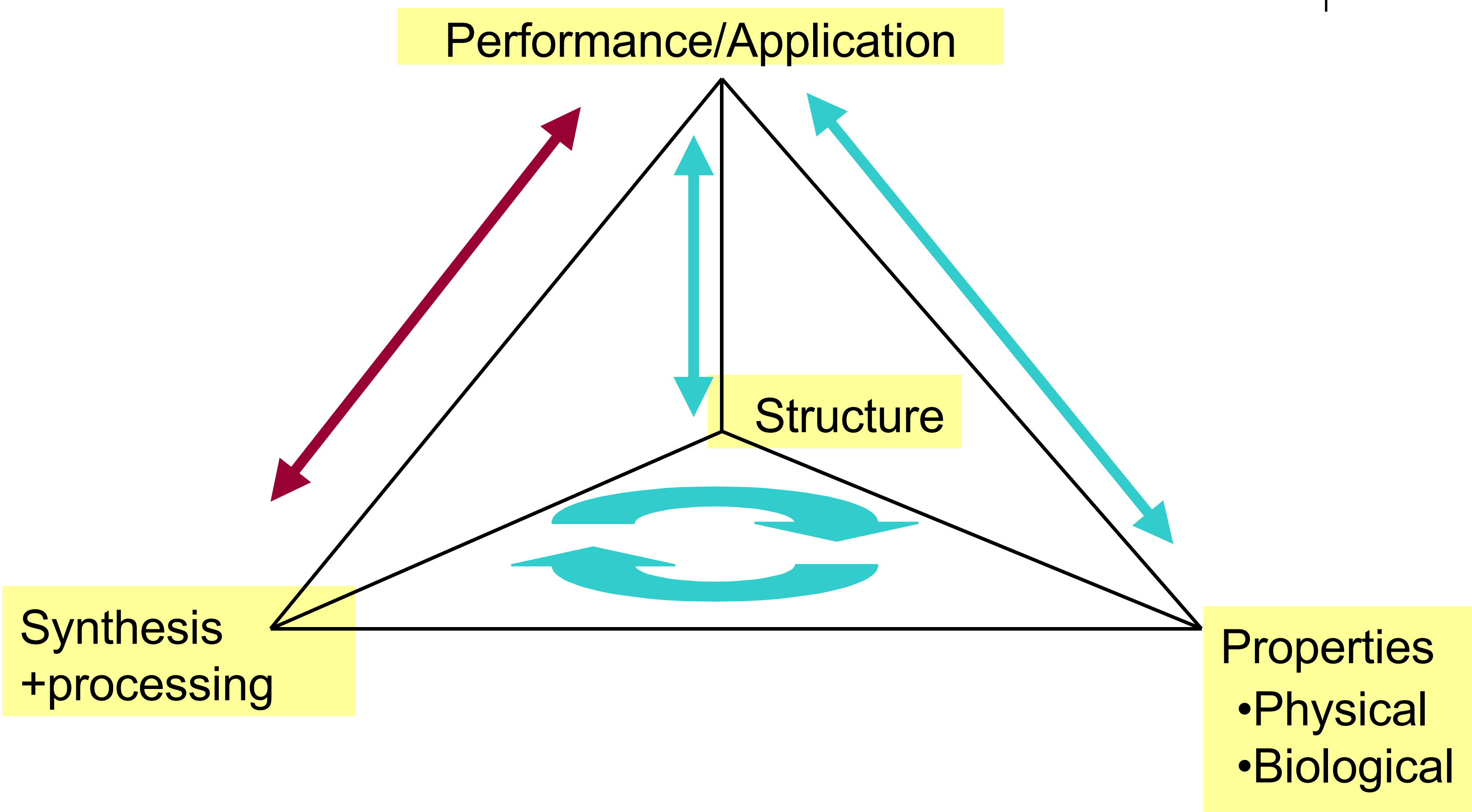
Fact-

The FDA regulates 100,000 different products that represent at least 1,700 Different Types of Biomedical Devices

Broad Classification-
Types of Biomaterials

- ceramics
- metals
- polymers, synthetic and natural
- composites

Material Science Logic



Ceramics

- Inorganic compounds that contain metallic and non-metallic elements, for which inter-atomic bonding is ionic or covalent, and which are generally formed at high temperatures.
- Derivation: From the Greek word *"keramos"* meaning the art and science of making and using solid articles formed by the action of heat on earthy raw materials.
- Most ceramics occur as minerals:
- (1) The abundance of elements and geochemical characteristics of the earth's crust govern mineral types.
- (2) Composition of *Earth's Crust*: [84% = O + Si + Al]

  O = 50% Fe = 5% K = 2.5%

  Si = 26% Ca = 3% Mg = 2%

  Al = 8% Na = 2.5% H = 1%

Ceramics

- Advantages:

  - inert in body (or bioactive in body)

  - high wear resistance (orthopedic & dental applications)

  - high modulus (stiffness) & compressive strength

  - fine esthetic properties for dental applications

- Disadvantages:

  - brittle (low fracture resistance, flaw tolerance)

  - low tensile strength (fibers are exception)

  - poor fatigue resistance (relates to flaw tolerance)

Ceramic Applications

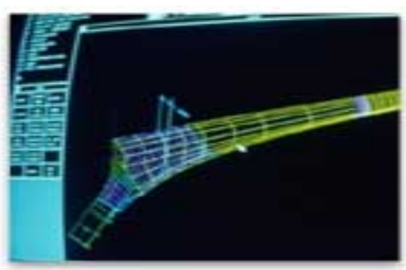
- femoral heads and cup inserts for ceramic on polyethylene; or
- ceramic on ceramic hip replacement bearings;
- knee prostheses;
- spinal fusion devices;
- orthopedic instrumentation;
- dental-crowns;
- bridges, implants and caps;
- inner ear implants (cochlear implants);
- drug delivery devices; and,
- cochlear implants.

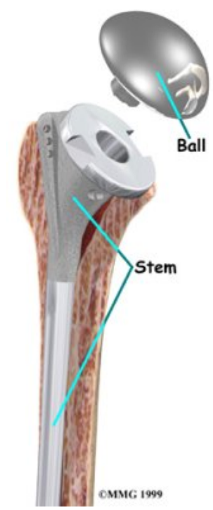
Ceramics

- Alumina, Zirconium, Calcium phosphate, Silica, pyrrolytic carbon, hydroxyapatite are common;
- Porous ceramic materials exhibit much lower strengths but have been found extremely useful as coatings for metallic implants;
- The coating aids in tissue fixation of the implant by providing a porous surface for the surrounding tissue to grow into and mechanically interlock; and,
- Certain ceramics are considered bioactive ceramics if they establish bonds with bone tissue.

Metals

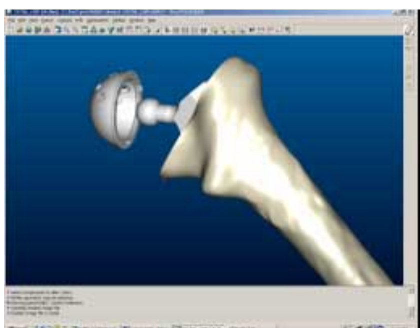
- closely packed crystal structure; the type of bonding in metals and metal alloys render them valuable as load bearing implants as well as internal fixation devices used for orthopedic applications as well as dental implants;
- when processed suitably they contribute high tensile, fatigue and yield strengths; low reactivity and good ductility to the stems of hip implant devices; and,
- Their properties depend on the processing method and purity of the metal, however, and the selection of the material must be made appropriate to its intended use.



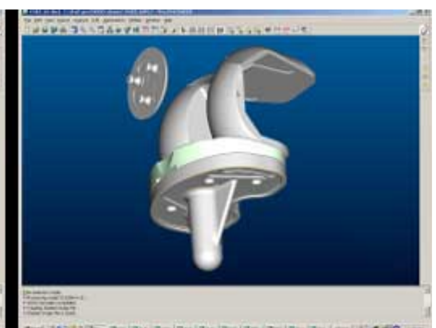


Metals Manufacturing

High Temperature Vacuum Furnaces



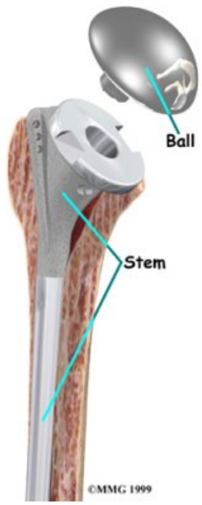
Solid Model of Total Hip System



Solid Model of Total Knee System

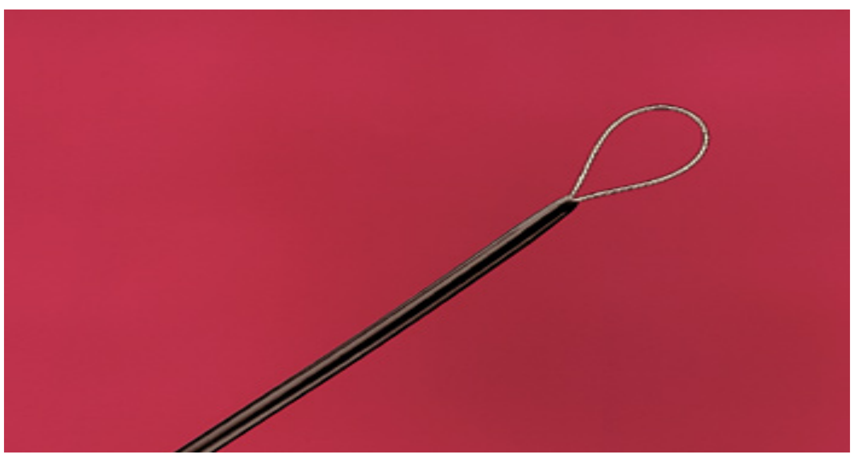
Metals

- One complication that can occur from the use of metals in orthopedic applications is the phenomenon of stress shielding;
- In some situations, such as hip implantation, the high strength of the metal in the implant induces it to assume more than its share of responsibility for the load in that region;
- This decreases the load born by the surrounding tissue and therefore shields it from experiencing stress;
- Lack of stress causes bone density to decrease as bone tissue resorbs, eventually causing complications in the implant/tissue interface.



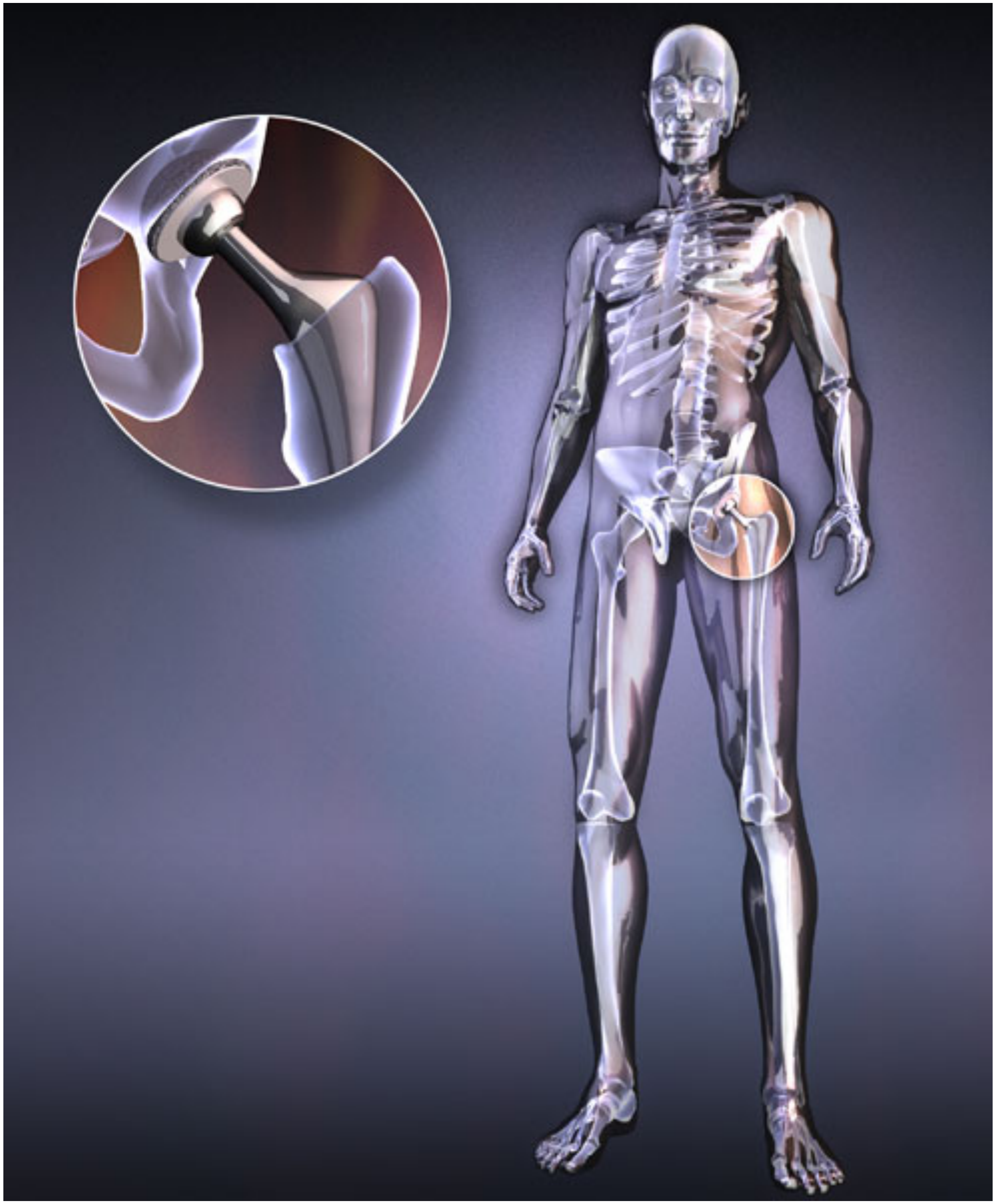
Other Uses of Metals

Medical Tubing



Stents

Catheters



Polymers

- consist of small repeating units strung together in long chains;
- flexible structure of polymers has enabled this group of materials to be useful in applications from plastic garbage bags to rubber tires;
- Even DNA has found this structure useful, storing genetic information in thousands upon thousands of repeating sequences of polymers;
- In many materials, processing conditions can induce the polymer chains to link with each other along the length of the chain to produce a wide variety of mechanical properties;
- These parameters are easily varied in order to suit current biomedical applications.

Polymers

- Hydrophilic
- Hydrophobic
- Biostable
- Biodegradable
- Natural
- Synthetic
- Highly processable

Composites

- individual strengths and weaknesses of polymers, ceramics, and metals benefit different applications;
- The porosity and hardness of ceramics support tissue integration into the tissue/implants interface, but these properties could hardly suit a ligament replacement;
- A composite material incorporates the desired characteristics of different materials to meet the stringent demands of living tissue;
- Most composite designs combine strength and flexibility by reinforcing a relatively flexible material with a harder, stronger one; and,
- In some cases, one or more of these materials may be degradable in order to encourage tissue integration.

What Do Biomaterials All Share in Common?

The answer is: that they were **not originally engineered for biomaterials applications**!

Bio-inertness vs. Bioactivity

Bioactive materials play a more aggressive role in the body. While a biocompatible material should affect the equilibrium of the body as little as possible, a bioactive material recruits specific interactions between the material and surrounding tissue.

Bioactive Materials

- encourage tissue integration to aid in the fixation of an implant in the body. Many total hip implants operations today rely partially on a porous coating of Hydroxyapatite (HA), a normal component of bone, to help permanently stabilize the stem of the implant in the bone. The coating encourages ingrowth from the surrounding tissue that interlocks within the pores much like the pieces of a puzzle lock together. Although many current medical procedures call for inert biocompatible materials, the increasing understanding of tissue interaction promises many more applications for aggressive bioactive materials.

Commonly Used Biomaterials

Material	Applications
Silicone rubber	Catheters, tubing
Dacron	Vascular grafts
Poly(methyl methacrylate)	Intraocular lenses, bone cement
Polyurethanes	Catheters, pacemaker leads
Stainless steel	Orthopedic devices, stents
Collagen (reprocessed)	Cosmetic surgery, wound dressings

Requirements of Biomaterials

A biomaterial must be:

- inert or specifically interactive
- biocompatible
- mechanically and chemically stable or
- biodegradable
- processable (for manufacturability)
- nonthrombogenic (if blood-contacting)
- sterilizable

Progress in Healthcare

Technology moves on

- from bio-inert & current biocompatible materials with limited useful life
- to ‘second generation’, structurally and functionally advanced materials
- to body replacement and augmentation devices active in a physiological and pathology-correcting way over an entire life-time
- **Tissue engineering**, **microsystems** and **nanotechnology** will address many of these needs