Biomaterials

First Course

Third Stage

By

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Lecture No. (6)

Bio-ceramic Materials

Bio-ceramic Materials

Ceramics used for repair and replacement of diseased and damaged parts of human body are named as bio-ceramics materials. Bio-ceramics are used as many parts of human body as shown in Figure (1):

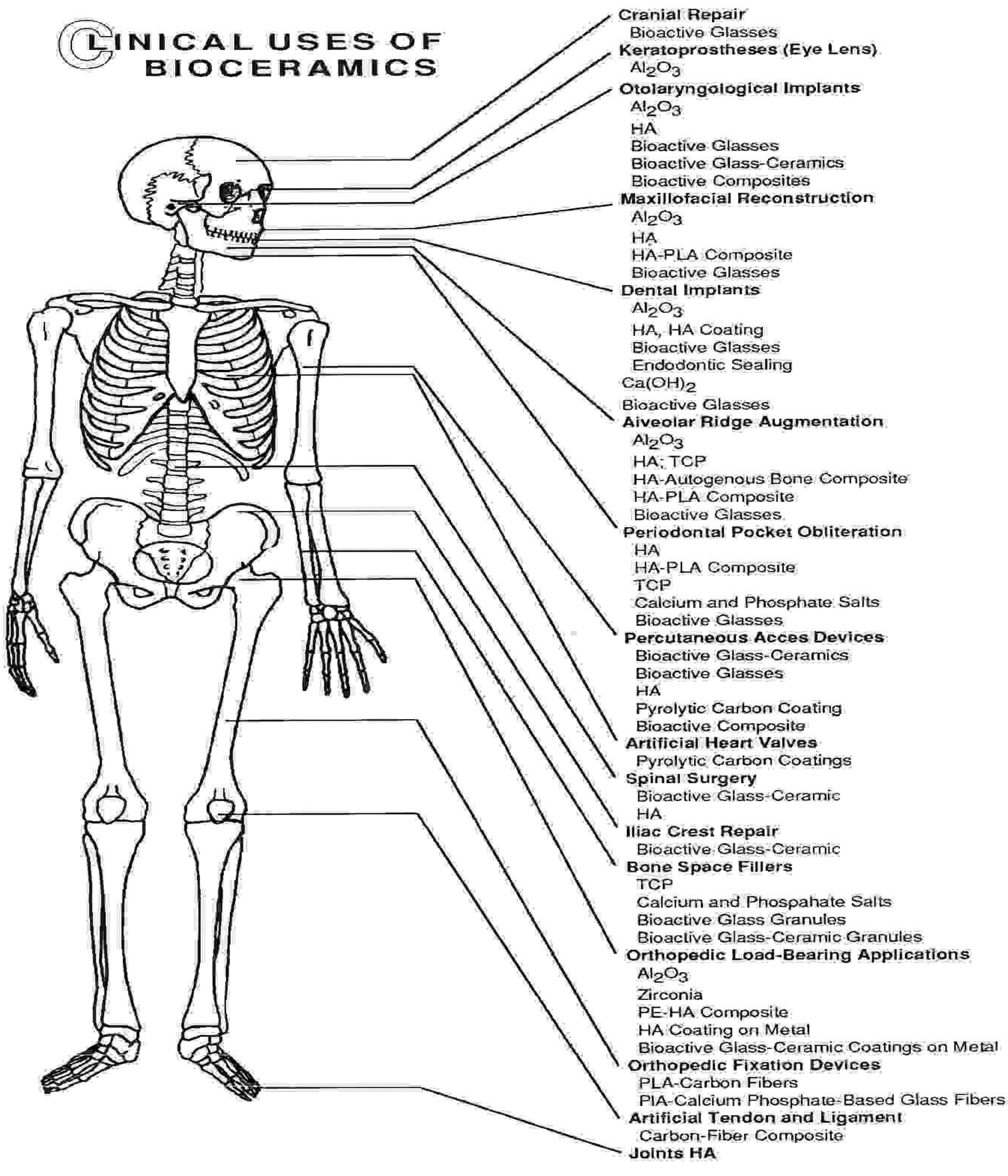


Figure (1): Show used Bio-ceramics Materials in Human Body.

Bio-ceramics are used as parts of:

- The musculoskeletal system.
- Dental implants.
- Orthopedic implants.
- Orbital and middle ear implants.
- Cardiac valves.

Also Bio-ceramics are used as coatings to improve the biocompatibility of metallic implants. Bio-ceramics are made in many different phases. They can be single crystals (sapphire), polycrystalline (alumina or hydroxyapatite), glass (Bio-glass, glass ceramics) or composites (polyethylene-hydroxyapatite). The phase or phases used depend on the properties and function required. **For example,**

- Single crystal sapphire is used as a dental implant because of its high strength.
- Glass-ceramic is used to replace vertebrae because it has high strength and bonds to bone.
- Bio-glass is used to repair of bony defects because of its bond rapidly to bone.

Advantages of Bio-ceramics:

- High biocompatibility.
- Less stress shielding.
- No disease transmission.
- High compression strength.
- Wear & corrosion resistance.
- Low thermal and electrical conductivity.
- Can be highly polished.

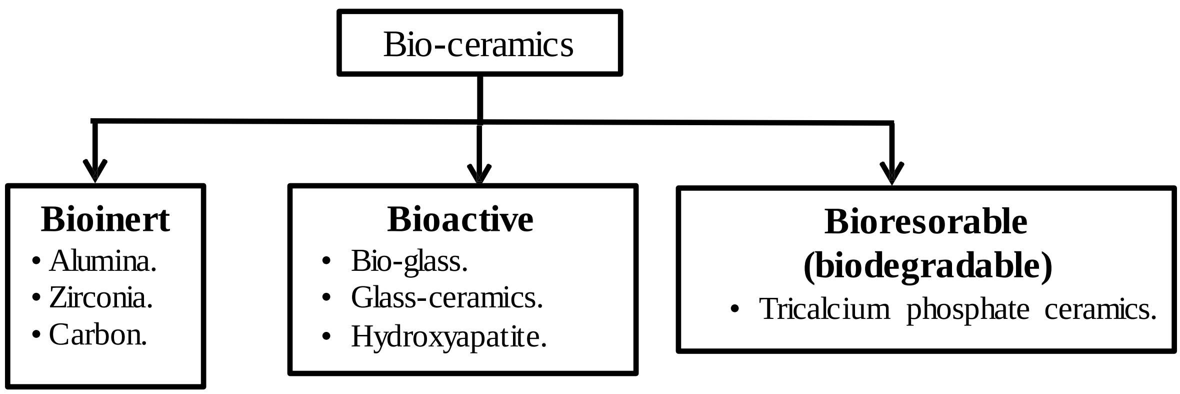
Disadvantage of Bio-ceramics:

- Brittleness.
- Low strength in tension.
- Low fracture toughness.
- Difficult to fabricate.
- Susceptibility to micro cracks.
- Not resilient.
- High modulus (mismatched with bone).

In order to be classified as a bio-ceramic, the ceramic material must meet the following properties:

1- Nontoxic.
2- Non-carcinogenic.
3- Non-allergic.
4- Non-inflammatory.
5- Biocompatible.
6- Bio-functional for its life time in the host.

<u>The three basic types of bio-ceramics are</u>:



Bioinert high strength ceramics: maintain their physical and mechanical properties while it is in the host. The term bioinert refers to any material that once placed in the human body has minimal interaction with its surrounding tissue.

Examples of these are alumina (Al_2O_3), zirconia (ZrO_2) and carbon. It is used for knee prostheses and dental implants…..etc.

None of the three-bioinert ceramics (Alumina, Zirconia and Carbon) exhibited bonding with the bone. However, the bioactivity of the bioinert ceramics can be achieved by forming composites with bioactive ceramics.

Bioactive: is nontoxic and biologically active ceramic materials which form direct chemical bonding with bone or even with soft tissues in biological medium (i.e. forms a very strong biological bond after a small amount of dissolution and small time of implant), examples of these are bio-glass, glass ceramics, calcium phosphates and hydroxyapatite.

The applications of bioactive ceramics:

- Bone void filler.
- Coatings of metal prostheses.
- Composites.
- Middle ear implants.
- Dental implants.

The properties of bioactive ceramics:

- Excellent biocompatibility.
- High bone bonding ability.
- Low mechanical strength.

Biodegradable (bio resorbable) ceramics: this material is nontoxic and dissolves, degrade to implants in the host and the surrounding tissue replaces it, **i.e.** the bio resorbable ceramics refers to a material that placement within the human body which start to dissolve or gradually resorbed before they finally disappear and slowly, totally replaced by new tissues in vivo (such as bone), examples of these are tricalcium phosphate ceramics. The biodegradable (resorbable) ceramics are used for many bio applications such as:

- Drug delivery systems.
- Repairing of damaged or diseased bone, bone loss.
- Filling spaced void by bone screws.
- Repairing herniated discs.
- Repairing of maxillofacial and dental defects.

The biodegradable (resorbable) ceramics properties:

- High compatibility.
- Low chemical resistance.
- Poor mechanical strength.

The rate of degradation varies from material to another. Generally, degradation rate of materials depends on material composition, their functions and components of biological medium.

In general, **five main ceramic materials** are used in the musculoskeletal reconstruction / regeneration:

- Alumina (Al_2O_3)
- Zirconia (ZrO_2).
- Carbon.
- Bioactive glasses and glass ceramics.
- Hydroxyapatite.

Alumina (Al_2O_3)

The main source of high purity alumina is bauxite and native corundum. The commonly available alumina (α) can be prepared by calcining alumina trihydrate. Alumina ceramic defined as bioinert ceramic and with strength decreases in time during the immersion in simulated body fluids.

ASTM specifies that alumina for implant uses should be contain (99.5 %) of Al_2O_3 and less than (0.1 %) of SiO_2.

The typical properties of alumina are:

1- High hardness.

2- High mechanical strength.

3- Minimal or no tissue reaction.

4- Good biocompatibility.

5- Blood compatibility.

6- Nontoxic to tissues.

7- Good corrosion resistance.

8- Excellent wear and friction behavior.

The reason for the excellent wear and friction behavior are associated with the surface smoothness of this bio-ceramic.

The strength of alumina depends on its grain size and porosity. Generally, the smaller the grains and lower porosity lead to higher strength.

The applications of Al_2O_3 are:

- Orthopedics:
  a- Hip prosthesis ball.
  b- Bone screws.
  c- Knee prosthesis.
  d- Middle ear implants.

- Dental implants: crowns and bridges.
- Maxillofacial reconstruction.

Zirconia (ZrO_2)

Pure zirconia can be obtained from chemical conversion of zircon. Zirconia has some mechanical properties and biocompatibility better than alumina; therefore, it's represented as an alternative to alumina. It can be used in bulk form or as a coating. The zirconia exists in three crystalline form **i.e.** monoclinic at normal temperature (naturally occurring), cubic and tetragonal at higher temperature.

Typical properties of zirconia are:

- High strength.
- High fracture toughness.
- Excellent wear resistance.
- High hardness.
- Excellent chemical resistance.

The applications of zirconia are:

- Femoral head in total hip joint replacement.
- Acetabular cup in total hip joint replacement.

One reason for the excellent wear and friction characteristics of zirconia are attributed to the fact that zirconia has less porosity.

Carbon

Carbon is a versatile element and exists in different forms. It can be fabricated as powders, fibers, sheets, blocks, and thin films.

- Crystalline diamond.
- Graphite.
- Non-crystalline glassy carbon.
- Quasi-crystalline carbon.

Moreover, the **properties** that make carbon desirable for a number of applications include:

- excellent electrical and thermal conductivity.
- low density.
- sufficient corrosion resistance.
- low elasticity.
- low thermal expansion.

However, their brittleness and low tensile strength limits their use in major load bearing applications. It is used as biomaterial particularly in contact with blood due to blood compatibility, no tissue reaction and nontoxicity to cells; therefore, it is used for repairing diseased heart valves and blood vessels.

Due to their good compatibility of carbon materials, it is used as a surface coating. There are **three types** of carbon are used in biomedical devices:

1- Low-temperature isotropic.
2- Ultra low-temperature isotropic.
3- Glassy carbons.

The first time the low-temperature isotropic (LTI) carbon coatings were used in humans was a prosthetic heart valve. Almost all commonly used prosthetic heart valves today have LTI carbon coatings for the orifice and/or occlude because of their excellent resistance to blood clot formation and long fatigue life.

Bio-glass and Glass Ceramic

Certain compositions of glasses, ceramics, glass-ceramics, and composites have become known as bioactive ceramics. Some more specialized compositions of bioactive glasses will bond to soft tissues as well as bone. A common characteristic of bioactive glasses and bioactive ceramics is a time dependent modification of the surface that occurs upon implantation. The surface forms a biologically active carbonated or (Hydroxy Apatite) HA layer that provides the bonding interface with tissues.

Bio-glasses are different materials but have the same basic building block of SiO_4. Glasses of various compositions can be obtained and they show very different properties. Typical properties of Bio-glass and Glass Ceramic are:

- Nontoxic.
- Chemically bond to bone.

Applications of Bio-glass & Glass Ceramic are:

- Orthopaedics.

  Filling bone defects.

- Dental prosthesis.

  Teeth filling.

Hydroxyapatite

The hydroxyapatite (HAp) $Ca_{10}(PO_4)_6(OH)_2$ is a well-known as a valuable material for bone substitution. It is one of a few bioactive implantation materials capable of creating a direct bond with bone tissue.

Typical properties of hydroxyapatite are:

- Biocompatibility.
- Bioactivity.
- Osteoconductivity.
- Noninflammatory.
- Nontoxicity.

Applications of hydroxyapatite are:

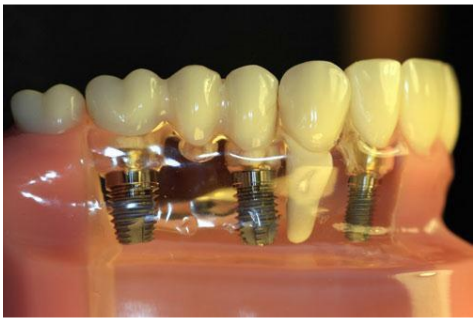
- Artificial bone substitutes in orthopedic.
- Dental applications.

The following Figure (2) represents some of ceramic products for medical applications.

(A) ceramic crown

(B) hydroxyapatite block ceramic

(C) ceramic implant systems



(D) Dental implant (“root”)

(E) Hip joint

Figure (2): Ceramic Products for Biomedical Applications.