Ceramics (9)

Ceramics are polycrystalline materials. The main characteristics of ceramic materials are hardness and brittleness, great strength and stiffness, resistance to corrosion and wear, and low density. They work mainly on compression forces; on tension forces, their behavior is poor. Ceramics are typically electrical and thermal insulators. Ceramics are used in several different fields such as dentistry, orthopedics, and as medical sensors. [32]. Overall, however, these biomaterials have been used less extensively than either metals or polymers. Ceramics typically fail with little, if any, plastic deformation, and they are sensitive to the presence of cracks or other defects.

Ceramics have become a diverse class of biomaterials presently including three basic types: bioinert, bioactive, bioresorbable ceramics [33]. Alumina (Al_2O_3), Zirconia (ZrO2) and Pyrolytic carbon are termed bioinert. Bioglass and glass ceramics are bioactive. Calcium phosphate ceramics are categorized as bioresorbable.

Bioinert refers to a material that retains its structure in the body after implantation and does not induce any immunologic host reactions.

Alumina ($A1_2O_3$):

High density high purity (>99.5%) alumina (Al_2O_3) was the first ceramic widely used clinically. It is used in loadbearing hip prostheses and dental implants, because of its combination of excellent corrosion resistance, good biocompatibility, and high wear resistance, and high strength. The reasons for the excellent wear and friction behavior of (Al2O3) are associated with the surface energy and surface smoothness of this ceramic. The biocompatibility of alumina ceramic has been tested by many researchers. Noiri et al. [34] evaluated the biocompatibility of alumina-ceramic material histopathalogically for eight weeks by implanting in the eye sockets of albino rabbits. The results showed no signs of implant rejection or prolapse of the implanted piece. After a period of four weeks of implantation, fibroblast proliferation and vascular invasion were noted and by eighth week, tissue growth was noted in the pores of the implant [34]. Single crystal alumina screws and pins were implanted in the femoral bone of mature rabbits. Changes in the implant-bone interface were observed. Alumina was never in direct contact with the bone and hemidesmosomes were not observed in the interface [35]. The cytotoxicity of single crystal alumina ceramics was studied in L cell line culture. They displayed the same colony formation and survival rates as the controls showed that they have no cytotoxicity and if implanted in bone marrow they would not be toxic to circumferential tissue [36].

Zirconia (ZrO_2):

Zirconia is a biomaterial that has a bright future because of its high mechanical strength and fracture toughness. Zirconia ceramics have several advantages over other ceramic materials due to the transformation toughening mechanisms operating in their microstructure that can be manifested in components made out of them. The research on the use of zirconia ceramics as biomaterials commenced about twenty years ago and now zirconia is in clinical use in total hip replacement (THR) but developments are in progress for application in other medical devices. Today's main application of zirconia ceramics is in THR ball heads [37].

The osteointegration of zirconia was investigated in normal and osteopenic rats by means of histomorphometry. The data showed that the tested material was biocompatible in vitro and confirmed that bone mineral density is a strong predictor of the osteointegration of an orthopedic implant and that the use of pathological animal models is necessary to completely characterize biomaterials [38]. It is said that very small traces of radioelements, which can be found even in fully refined ceramics, have a negative effect on organs and tissues. Zirconia contains very small traces of radioelements [39]. The cytotoxicity of polycrystalline zirconia was speculated in L cell line culture. The study revealed its noncytotoxicity [36].

Pyrolytic Carbon:

Carbon is a versatile element and exists in a variety of forms. Good compatibility of carbonaceous materials with bone and other tissue and the similarity of the mechanical properties of carbon to those of bone indicate that carbon is an exciting candidate for orthopedic implants [40]. Unlike metals, polymers and other ceramics, these carbonaceous materials do not suffer from fatigue. However, their intrinsic brittleness and low tensile strength limits their use in major load bearing applications. The mechanical bonding between the carbon fiber reinforced carbon and host tissue was investigated. The bonding developed three months after intrabone implantation and is accompanied by a decrease of the implant strength [41].

Bioactive refers to materials that form direct chemical bonds with bone or even with soft tissue of a living organism.

Bioglass & Glass Ceramic:

A common characteristic of such bioactive materials is a modification of the surface that occurs upon implantation. Bonding to bone was first demonstrated for a range of bioactive glasses, which contained specific amounts of SiO_2, CaO, and P_2O_5 [42]. This material has been widely used for filling bone defects. The porosity of bioglass is beneficial for resorption and bioactivity [43]. The interface reaction was interpreted as a chemical process, which includes a slight solubility of the glass ceramic and a solid- state reaction between the stable apatite crystals in the glass ceramic and the bone [44].

Bioresorbable refers to materials that degrade (by hydrolytic breakdown) in the body while they are being replaced by regenerating natural tissue; the chemical byproducts of the degrading materials are absorbed and released via metabolic processes of the body.

Calcium phosphate ceramics:

Different phases of calcium phosphate ceramics are used depending upon whether a resorbable or bioactive material is desired.

Calcium phosphate (CaP) biomaterials are available in various physical forms. One of their main characteristics is their porosity. The ideal pore size for bioceramic is similar to that of spongy bone [45]. The prime requirement for calcium phosphate materials to be bioactive and bond to living bone is the formation of a bone like apatite layer on their surface [46].

The major drawbacks to the use of ceramics and glasses as implants are their brittleness and poor tensile properties (Table 5). Although they can have outstanding strength when loaded in compression, ceramics and glasses fail at low stress when loaded in tension or bending. Among biomedical ceramics, alumina has the highest mechanical properties, but its tensile properties are still below those of metallic biomaterials.

TABLE 5 MECHANICAL PROPERTIES OF CERAMIC BIOMATERIALS [47]

	Young's Modulus, E (GPa)	**Compressive Strength, (MPa)**	**Tensile Strength UTS (MPa)**
Alumina	380	4500	350
Zirconia	150-200	2000	200-500
Pyrolytic carbon	18-28	517	280-560
Bioglass-ceramics	22	500	56-83
Calcium phosphates	40-117	510-896	69-193

TABLE 6 APPLICATION OF CERAMICS AS IMPLANTS USED IN HUMAN BODY

Types of Materials	Applications
Alumina	Artificial total joint replacement, acetabular and femoral components, vertebrae spacers and extensors, orthodontic anchors, dental implant for tooth fixation
Zirconia	Replacement for hips, knees, teeth, tendons and ligaments, repair for periodontal disease, bone fillers after tumor surgery
Pyrolytic carbon	Prosthetic heart valves, End osseous tooth replacement implants, permanently implanted artificial limbs
Bioglass-ceramics	Dental implants, middle ear implants, heart valves, artificial total joint replacement, bone plates, screws, wires, intramedullary nails, spinal fusion, tooth replacement implants
Calcium phosphates	Skin treatments, dental implants, jawbone reconstruction, orthopedics, facial surgery, ear, nose and throat repair, dental implant