Lecture 37

Biomaterials And Human Implants

Keywords: Biomaterials, Corrosion Resistance, Biocompatibility.

Recent innovations in the areas of biomedical engineering have resulted in the development of biomaterials for implantation in the human body. Biomaterials engineering concerns study of the structure and properties of biomaterials in relation to their interaction with biological systems. Biomaterials need to interface with human biological systems so as to evaluate, augment or replace any organ, tissue or function of the body. Use of metallic materials to repair fractured and diseased tissues and organs has been practiced since decades. Several developments have taken place in the use of advanced technology for manufacture of corrosion–resistant biomaterials for human body implants. [237-238, 242-243]

Human body environment is a complex corrosive medium to different implant materials, consisting of a highly oxygenated saline electrolyte at a pH of around 7.4 and temperature of 37°C, containing water, dissolved oxygen, sodium, chloride, bicarbonate, calcium, potassium, magnesium, phosphate, amino acids, proteins, plasma, lymph, saliva and various organic compounds. Biological molecules influence the electrochemical behavior of implant metals and alloys. Anodic and cathodic reactions are catalysed by interaction with biopolymers. For example, protein adsorption on implant materials can interfere with oxygen and hydrogen redox reactions. Microorganisms present in the human body can also influence the corrosion behavior of implant materials. Shifts in the physiological pH towards acidic and alkaline directions can occur due to biological reactions in the body. Release of metal ions from the implant can alter interfacial equilibrium and thus electrochemical kinetics. Acceptable corrosion rate for metallic implants is expected to be about 0.01 mils/year.
Chloride and oxygen contents as well as pH of body fluids control corrosion of implant metals and alloys.

In vivo corrosion of implants need be assessed with respect to effect on life span of the device and levels of metal ion dissolution and transport. Since control methods such as inhibition and altering environmental conditions will not be suitable to human implants, the best solution would only be proper material selection and design.

Several types of corrosion such as galvanic corrosion, pitting, intergranular attack, uniform corrosion, stress cracking, crevice and fatigue corrosion can manifest in different locations of the human body depending on the structural configuration and types of metallic implants. Both in vivo and in vitro tests need be carried out to assess corrosion resistance of biomedical materials. In vitro tests can be done simulating body fluids.

Surface oxide films formed on metals and alloys can reduce corrosion. Tissue compatibility and regeneration of surface oxides is thus important. Regeneration periods of passive alloys differ depending on alloy composition (stainless steels, titanium alloys, Co-Cr alloys etc.). Surface coatings on implant materials also can reduce corrosion rate.

**Biocompatibility**

Biocompatibility is an important criterion. A biocompatible implant material should not disrupt normal body function. Many factors such as size of implant, material properties and surface-chemical characteristics influence biocompatibility. Long-term stability of metal implants is critical for patient health and survival.
Ideal implant materials should be inert, nontoxic, corrosion-resistant, strong, inexpensive and biocompatible.

Most synthetic implant materials in the body can induce foreign-body reaction and presences of metal ions induce enhanced foreign body response. Corrosion and wear of implants can induce changes in blood chemistry. Corrosion of stainless steel and chromium – containing alloy implants in joints lead to dissolved chromium and nickel levels in serum. General chemical composition of some orthopaedic implant materials is given in table 37.1.

| Table 37.1: Some orthopaedic implant materials |
|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Alloy          | C   | Ni  | Ti    | V | Fe | Cr | Al | Co   |
| Co-cast        | 0.35| 1.0 | ....  | .... | 0.75 | 27-30 | .... | Bal |
| 316L Stainless steel | 0.03| 13-16 | ....  | .... | Bal | 17-19 | .... | .... |
| Titanium       | 0.1 | .... | Bal   | .... | 0.5  | .... | .... | .... |
| Ti 6Al 4V      | 0.1 | .... | Bal   | 3 – 4.5 | 0.3   | .... | 5 - 6 | .... |
| Co-forged      | 0.35| 1.0 | ....  | .... | 0.75 | 27-30 | .... | Bal |

Some examples of biomaterials include:

- Co-Cr alloys, Stainless steels, Gold, Titanium alloys, Vitallium and Nitinol (shape memory alloys), used in orthopedics, fracture fixation, dental and facial reconstruction as well as, stents.
- Ceramics such as alumina, zirconia, calcium phosphate and pyrolytic carbon, used in orthopedics, heart valves and dental reconstruction.
- Coatings such as bioglasses, hydroxyapatite, diamond like carbon, polymers, used in orthopedics, contact lenses and catheters.
Some of the most relevant corrosion types relevant to different implant materials are listed below:

Uniform corrosion: For an implant material, a uniform corrosion rate less than one micrometer per year is expected.

Galvanic corrosion: Dissimilar metal corrosion is common in orthopedic, dental and other biomedical uses.

Examples: (a) Hip prosthesis with 316 stainless steel ball and a socket made of Ti–6 Al–4V alloy.
(b) Gold crown contacted with amalgam as dental material.

Pitting and crevice corrosion:

Pitting is common in 304 stainless steel implants. Addition of molybdenum can reduce pitting tendency. Titanium is resistant to pitting.

Crevice corrosion

Motion between implant components results in fretting corrosion and crevice attack.

Crevice corrosion is a problem in Mo–containing stainless steels, 316 Stainless steels and Co–Cr–Mo alloys

Stress corrosion cracking can occur in orthopedic implants made of stainless steel.

Corrosion fatigue is common under conditions of cyclic stresses.

Fretting corrosion is common in orthopedic implants. Prosthesis implant materials such as stainless steels, Co-alloys and Ti–alloys are amenable to fretting corrosion. Oxidized corrosion products aggravate this type of corrosion.
Comparison between Ti – Ta and Ti – 6Al – 4V alloys indicate that addition of tantalum reduces metal release from surface oxides. Ni-Ti alloys (Nitinol) used for dental, orthopedic and cardiovascular implants have attractive properties and corrosion resistance. Shape memory effect in Nitinol allows reversion to original shape following deformation. Widespread applications for Nitinol as stent materials are being made. TiO₂, with smaller amounts of nickel oxides form a surface film in titanium alloys. Through surface treatments, its corrosion resistance can be further improved.

Very aggressive environment exists in the oral cavity, such as pH, saliva, temperature, proteins, food materials etc. Galvanic corrosion is very common in dental implants, especially when materials such as Co-Cr alloys, Ni – Cr, Ag – Pd, gold and titanium – implants are used. Pitting of Co, Ni and Cr containing alloys results in release of toxic metal ions into the body. Gold, palladium and platinum are nobler materials and corrosion resistant.

Dental amalgams are among the oldest of materials used in oral health care. Formed through mixing liquid mercury and a powder of Ag, Sn and Cu, the biomaterial is easy to manipulate for filling dental cavities. Since these amalgams are multiphased, galvanic and intergranular corrosion are possible.

Corrosion resistance properties can be further improved through surface engineering of biomaterials. Techniques such as plasma ion implantation, laser melting, laser alloying, ion implantation, vapour deposition and chemical and surface texturing are used. Carbon-based coatings improve corrosion resistance of Nitinol. Titanium dental implants can be surface treated using surface machining, electro - polishing, anodizing, and plasma-spraying.

Nitrogen-ion implantation, laser treatment and nitrogen-alloying increase the corrosion resistance of orthopedic implants.
Nanoceramic materials are newly introduced in orthopedic and dental implants. (Nanocrystalline diamond films coated onto titanium alloys and Co - Cr alloys, Nano Al₂O₃ – TiO₂ coatings, Nanoceramic hydroxy - apatite coatings).

Future Implants have been characterized as bioactive, corrosion resistant and antibacterial. The interaction of implant materials with biological tissues and inhabitant organisms pose challenges. Bacterial adhesion and biofilm formation on body implants create not only corrosion related problems, but also its biocompatibility. New developments in nanobiotechnology to improve biocompatibility are reported. Development of antibacterial surfaces and use of targeted drug delivery with the help nanobiotechnology are possible future applications.

Another development in orthopedic implants is to create a bioactive surface to promote cellular adhesion and bone-in-growth. Application of either hydroxyapatite or porous titanium coatings to implant surfaces is an example. Newer orthopedic implants having a titanium-rich core and a hydroxyapatite-rich casing with controlled levels of micro - and macro-porosity are in the process of development. Use of graphene coatings on metal-based medical implants to improve corrosion resistance is being investigated.
References (Lectures 34 – 37)


