Introduction

This class of material is known for their high stiffness, ductility, wear resistance, thermal and electrical conductivity. Metals and their alloys are commonly used in implants, medical device manufacture and related accessories. Due to their mechanical reliability, metallic biomaterials are difficult to be replaced by ceramic and polymer substitutes . One of advantages of using metals as biomaterials is their availability and relative ease of processing from raw ore to finished products. The material properties of metals have been studied in the context of biocompatibility, surface interaction and structural integrity . Moreover, customized properties including flexibility, high strength and abrasion resistance can be developed by alloying constituent elements of different metals. Metallic biomaterials are classified as inert because they illicit minimal tissue response. Given their higher fatigue strength and chemical resistance to corrosion they are used in load bearing applications. This section describes the different types of metals and their alloys that are commonly used.

Advantages and disadvantages of metallic Biomaterials:

Advantages

- High strength.
- High hardness.
- Fatigue and impact resistance.
- Wear resistance.
- Easy fabrication.
- Easy to sterilize.
- Shape memory.
- inert

Disadvantages

- High modulus.
- High corrosion.
- Metal ion sensitivity and toxicity.
- High density.

- Metals and their alloys are widely used as biomedical materials. On one hand, **metallic biomaterials cannot be replaced by ceramics or polymers at present because the mechanical strength and toughness are the most important safety requirements for a biomaterial under load-bearing conditions.** On the other hand, **metallic materials sometimes show toxicity and are fractured because of their corrosion**

and mechanical damages . Therefore, development of new alloys is continuously trialed.

STAINLESS STEELS

Stainless steel is an iron (Fe) based alloy with at least 11 wt. % chromium (Cr).It may also contain several other alloying elements, such as nickel (Ni), molybdenum (Mo),and manganese (Mn).

High corrosion resistance, in combination with good mechanical properties, is the main reason for its wide use also in relatively aggressive environments ,such as sea water, food, or the human body. Even though the corrosion resistance is high, or very high for a given grade, low levels of metals can be released from the stainless steel surface in contact with different fluids.

Metal release is here defined as all metal species released from the stainless steel surface into solution due to electrochemical (metal corrosion/oxidation), chemical/electrochemical (dissolution of the surface oxide), or physical processes (removal of metal or oxide particles via, e.g., friction). Knowledge on the extent of metal release is of highest concern in sensitive environments such as within the human body, upon skin contact, and if released into food and drinking water, as it, for instance, may induce allergic and toxic reactions.

Specific stainless steel grades are designed and used in biomedical applications, such as orthopedic, dental ,or cardiovascular implants, to achieve biocompatibility and maintained function with time .

Stainless steel is stronger and more resistant to corrosion than **the vanadium steel.**

Stainless steel is a versatile class of material that has high strength and resistance to oxidation. Typically, stainless steels have a minimum of 11% chromium content that forms a thin oxide film which resists oxidation. The addition of nickel and molybdenum further enhances the corrosion and pitting resistance.

As compared to titanium it is easy to machine and thus commonly used for surgical instruments, bone screws, stents and other medical equipment. Of the numerous grades of stainless steels the 300 series is used in medical applications.
Typical medical grades include the 304 and the 316L. It can be also electro polished for aesthetic appeal. Because of its high strength and chemical inertness to bodily fluids, blood and enzymes. Moreover, it can be processed using multiple methods including forming, welding, bending and machining. Medical grade stainless is available in various stock forms making it is easy to fabricate the material into its final form. However, it is heavier than titanium which can lead to heavier implants and fatigue during repeated handling of surgical tools. Based on their microstructure and the resulting properties steels are broadly classified as austenitic, martensitic and ferritic.

The advantages of stainless steels, especially type **316** and **316L** over other grades of steel:

1- Biocompatible.
2- This group of stainless steels is **nonmagnetic** and possesses better corrosion resistance than any others.

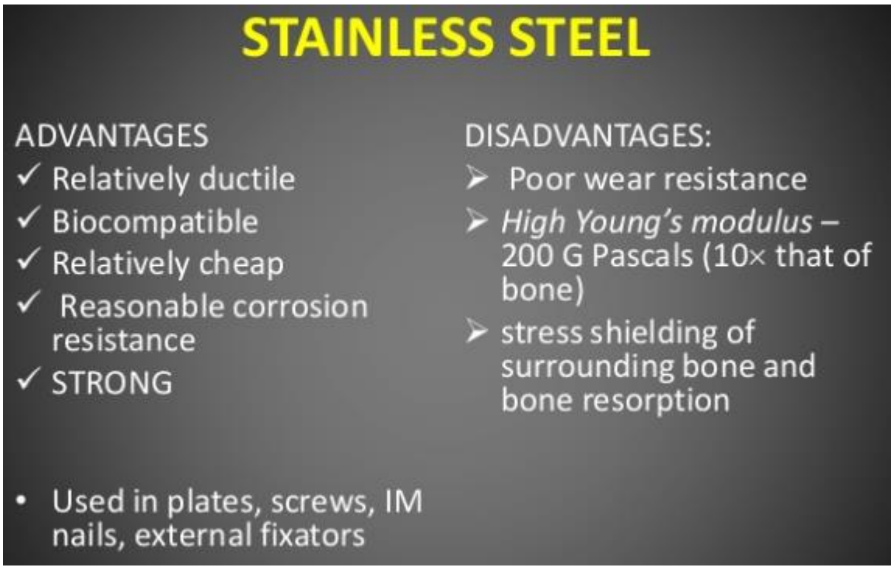
A wide range of properties exists depending on the heat treatment (annealing to obtain softer materials) or cold working (for greater strength and hardness).

Applications

Commercial-grade stainless steel is used to manufacture operating room accessories, dental and surgical instruments which involve superficial contact of the device with the human tissue. Austenitic steels are used for implant fabrication, hypodermic needles, sterilizers, work tables and autoclave compartments where moderate strength, formability and corrosion resistance is desired.This class of stainless steel is nonmagnetic, can be cold hardened and possesses higher corrosion resistance than other types. 316L is the most common stainless steels used in medical industry. The ‘‘L’’ within the 316L designation stands for low carbon steel. As compared to the 0.08% carbon content in regular 304 or 316 steel, the 316L contains 0.03% carbon. **The lower carbon content reduces carbide precipitation thereby minimizing in vivo corrosion.**

Higher percentages of nickel (11%) are added to stabilize the austenitic phase of steel. Other alloying elements include chromium, molybdenum, manganese, silicon, sulfur, phosphorous and nitrogen. Type 316L austenitic steels can be heat treated for wide range of mechanical properties. Because they corrode under highly stressed and oxygen-depleted environments they are generally used for temporary implant devices. BioDur 108 is a nickel-free **austenitic stainless steel** alloy with high nitrogen content . It has higher tensile and fatigue strength as compared to nickel-containing alloys such as 316L. It is a non-magnetic alloy that can be fabricated by forging or machining. Due to its high strength and corrosion resistance it is used in bone plates, spinal fixation, screws, hip and knee components and medical devices.

Martensitic stainless steels contain iron, chromium and carbon alloys with other additives including niobium, silicon, tungsten and vanadium.



(Co Cr) ALLOYS

The castable CoCrMo alloy.

The castable CoCrMo alloy has been used for many decades in dentistry and, relatively recently, in making artificial joints.

The corrosion products of CoCrMo are more toxic than those of stainless steel 316L.

The advantages and disadvantage of CoCrMo:

- wrought or forged forms has the highest strength/wear resistance,
- Hardest to fabricate,
- may produce cobalt or chromium ion sensitivity/toxicity.

Ti ALLOYS

Titanium has one of the highest strength-to-weight ratio and corrosion resistance of metals. It has a lustrous metallic-white color and exhibits high hardness. In its pure form titanium is ductile and is often alloyed with other elements for enhanced toughness. Titanium is extracted from rutile (TiO_2) a **mineral deposit and is processed in multiple steps [to obtain the finished material. Due to it noncorrosive properties titanium has excellent biocompatibility. The material passivates itself in vivo by the formation of an adhesive oxide layer .** Titanium also displays a unique property of osseointegration where it connects both structurally and functionally with the underlying bone. It is commonly used in total joint replacements , dental implants , internal and external fixators, artificial heart valves, spinal fusion and medical devices. However, due to the high processing cost titanium is expensive.

Comparison betweenTitanium alloy (Ti-6Al-4V) versus Titanium (Ti) metal

-titanium alloy is stronger than titanium metal,

-both have the best corrosion resistance,

-both have excellent bone bonding.

The modulus of elasticity of these materials is about (110 GPa.) This is much lower than stainless steels and Co-base alloys modulus (210 and 240 GPa.) respectively.

Applications

Due to its high strength, low weight and non-corrosive properties, titanium and its alloys are used in a wide range of medical applications. Titanium is a major material used in the skeletal system for joint replacement such as hip ball and sockets and in internal fixators such as plates and screws. A titanium implant has high fracture toughness and enhanced fatigue properties over competing metals. These load bearing implants can stay in place for 15–20 years thereby,improving the quality of human life. The acetabular shell (socket portion) and the femoral stem. The socket is made of metal shell with a medical grade plastic liner which acts like a bearing. The femoral stem is made of metal such as titanium alloy.

Titanium is also used for bone-fracture fixation in spinal fusion devices, pins, bone-plates and screws. Due to its non-magnetic properties it does not pose any threat to patients with implants during magnetic resonance imaging and exposure to electronic equipment. Titanium is also used for wide range of surgical instruments. It does not corrode or lose surface properties with repeated sterilization and its light weight reduces surgeon fatigue during repetitive operations.

Titanium is used in craniofacial and maxillofacial treatments to replace facial features of patients.

In general , The advantage and disadvantage of Ti alloys are :

Advantages

- Easily formed.
- Highly biocompatible.
- Outstanding corrosion resistance.
- Better than stainless steel and cobalt-chromium alloys.
- Forms protective oxide (TiO_2) layer.
- Low elastic modulus.

Disadvantages

- •Poor wear resistance.
- •Should not be used in articulated surfaces such as hip or knee joints unless surface-treated through ion implantation which improves wear resistance.

The Titanium alloys used **in implants** present three main problems:

- High cost because the amount of processing energy and melting and casting difficulties.
- Higher elastic modulus compared to bone.
- Although the inert behavior of Ti is a good property, its bone attachment is difficult because it do not react with the human tissues.

The following table represents the comparison of mechanical properties of metallic biomaterials with bone.

Table (1): Comparison of mechanical properties of metallic biomaterial with bone.

Material	Young's Modulus, E (GPa)	Yield Strength, σy (MPa)	Tensile Strength, σUTS (MPa)	Fatigue Limit, σend (MPa)
Stainless steel	190	221–1213	586–1351	241–820
Co-Cr alloys	210–253	448–1606	655–1896	207–950
Titanium (Ti)	110	485	760	300
Ti-6Al-4V	116	896–1034	965–1103	620
Cortical bone	15–30	30–70	70–150	

Noble Metals

Noble metals show a marked reluctance to combine with other elements to form compounds. As such they have excellent resistant to corrosion or oxidation and good candidate for biomaterials. Noble metals such as gold, silver and platinum are used when there is a need for functionality other than the basic mechanical performance. Typically, they are used in devices requiring specific electrical or mechanical properties.

Gold

Gold is an inert metal that has high resistance to bacterial colonization. Gold and its compounds have been historically used in oriental cultures for the treatment of ailments. It has been one of the first materials to be used as an implantable material (dental tooth implant). Due to its high malleability it is used in restorative dentistry for crowns and permanent bridges. Gold possesses excellent electrical conductivity and biocompatibility and is used in wires for pacemakers and other medical devices.

Platinum

Platinum possesses excellent corrosion resistance, biocompatibility, and stable electrical properties. It is used for manufacture of electrodes in devices such as cardiac pacemakers and electrodes in cochlear (cavity within the inner ear) replacement for the hearing impaired. A typical pacemaker uses platinumiridium electrodes that send electrical pulses to stabilize the rhythm of heartbeat.

Miniaturized platinum coils are used in endovascular therapy for the treatment of aneurysms.

Silver

Silver is used in surgical implants and as a sanitizing agent. They are used as studs of earrings to prevent infection of newly pierced ears. Silver compound is used in burn therapy to improve the healing and prevent infection of burns.

Silver is also used in urinary bladder catheters and stethoscope diaphragms.

Bio metals applications

Table (2): Implants division and type of metals used

Division	Example of implants	Type of metal
Cardiovascular	Stent Artificial valve	316L SS; CoCrMo; Ti Ti6Al4V
Orthopedics	Bone fixation (plate, screw, pin) Artificial joints	316L SS; Ti; Ti6Al4V CoCrMo; Ti6Al4V; Ti6Al7Nb
Dentistry	Orthodontic wire Filling	316L SS; CoCrMo; TiNi; TiMo AgSn(Cu) amalgam, Au
Craniofacial	Plate and screw	316L SS; CoCrMo; Ti; Ti6Al4V
Otorhinology	Artificial eardrum	316L SS

Failure of metals for biomedical devices

1- Corrosion

Metal implant is prone to corrosion during its services due to corrosive medium of implantation site.

2- Fatigue and fracture

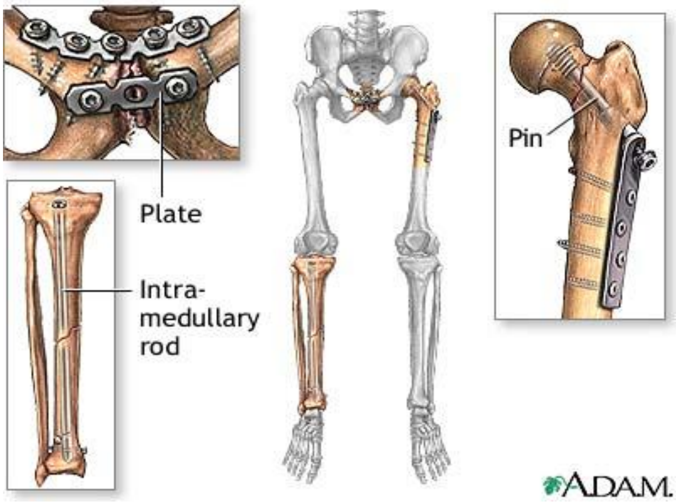
During its service most of metallic implants are subjected to cyclic loading inside the human body which leads to the possibility for fatigue fracture. Factors determine the fatigue behavior of implant materials include microstructure of the implant materials.

3- Wear

Together with corrosion process, wear is among the surface degradation that limits the use of metallic implant such as Ti alloy. Removal of dense oxide film which naturally formed on the surface of this metallic implant in turn caused wear process. In fact, the major factor that causing premature failure of hip prostheses is due to the wear process with multiple variables interact and thus increase the resultant wear rates.



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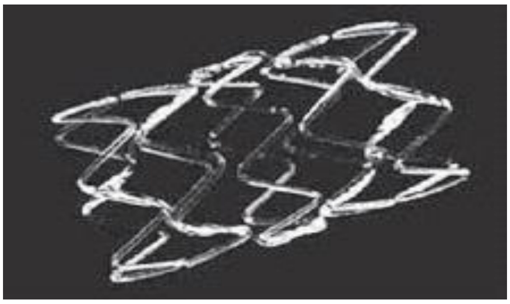
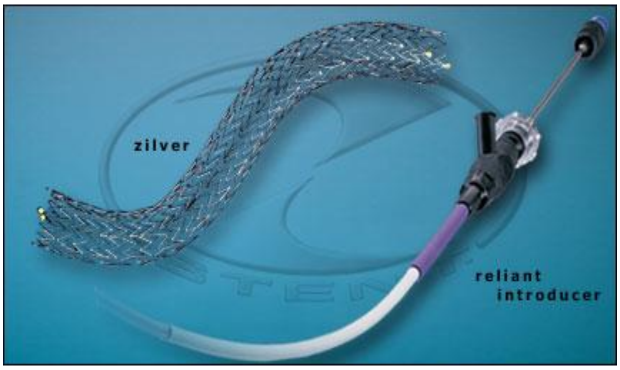
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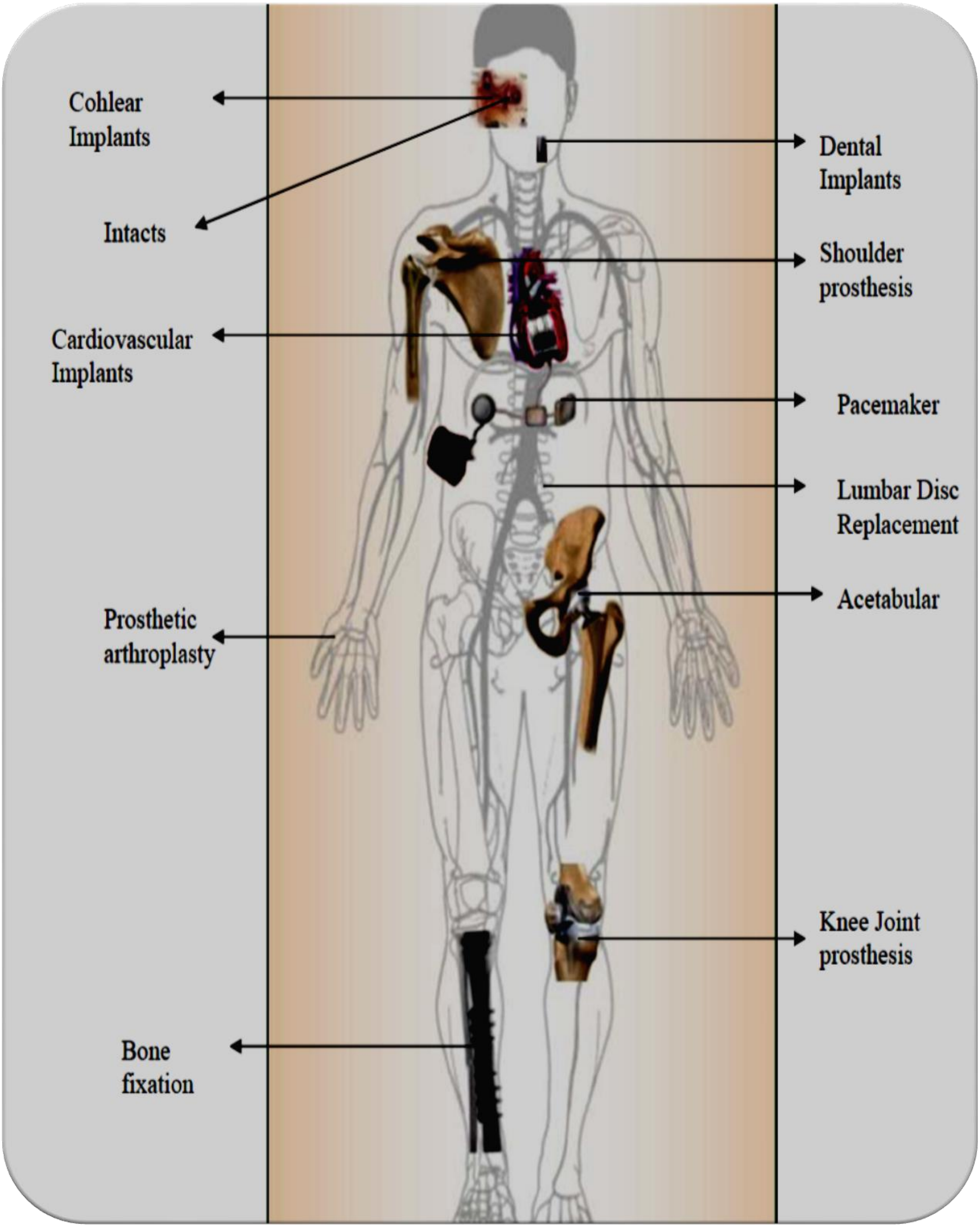
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arthroplasty
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fixation
Dental
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Shoulder
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Pacemaker
Lumbar Disc
Replacement
Acetabular
Knee Joint
prosthesis