METALLIC BIOMATERIALS FOR HUMAN BODY IMPLANT: A REVIEW STUDY

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***Abstract*-Human body parts implant by using biomaterials is in practice from last seven decades. Rapid growth in research activities over the years in the field of biomedical science have developed the biomedical products such as dental implants, craniofacial plates and screws, parts of artificial hearts, pacemakers, clips, valves, balloon catheters, medical devices and equipments, bone fixation devices, dental materials, medical radiation shielding products, prosthetic and orthodontic devices, tools of machining metallic biomaterials. The materials that are used to build biomedical devices such as orthopaedic, dental, bone cements etc. are broadly classified into metallic materials, ceramics, polymers and composites. Metallic materials within these four categories are widely used due to their high tensile strength, high yield strength, fatigue strength, toughness, and good biocompatibility despite some shortcomings such as the release of metallic ions and wear debris. Metals are extensively used in a variety of applications in the medical field for internal support and biological tissue replacements, such as joint replacements, dental roots, orthopaedic fixation and stents. The purpose of this paper is focused on various types of metals and metallic alloys used as the biomaterials for human body implant. This paper also highlights their mechanical properties, applications and future developments in human body part replacement.**

***IndexTerms*—Biomaterials, biocompatible, metal implants, tissue engineering.**

I. INTRODUCTION:

The safe use of materials to replace body parts did not come into practice until the advance of surgical techniques at the end of 19th century. Many man-made materials and devices have been developed and are used successfully to replace parts of living systems in the human body. These special materials, capable to function in intimate contact with living tissue are called biomaterials that interact and are compatible with biological systems. Biomaterials science, which has a history of about 70 years, includes elements of medicine, biology, chemistry, physics, metallurgy and tissue engineering. According to the European Society for Biomaterials, a biomaterial is 'A material intended to interface with biological systems to evaluate, treat, augment or replace any tissue, organ or function of the body. Biomaterial deals with science or engineering discipline for studying and developing materials or devices that interact with human tissue and body fluids to treat, improve, or replace anatomical element(s) of the human body. Some key classes of materials and their evolution from commodity materials to the engineered/synthesized biomaterials are silicones, polyurethanes, teflon, hydro-gels, polyethylene glycol, poly lactic-glycol acid, hydroxyapatite, titanium, bio glass etc. Biomaterials cause minimal adverse reaction or rejection by the body. Biomaterial devices used in orthopaedics are commonly called implants; which are manufactured for various orthopaedic applications. This implant is fixed in a human body for the short period like soft contact lenses or lifetime period in case of hip replacement. To design, develop and manufacture the suitable, harmless and effective biomaterials, the scientist from various disciplines like physics, chemistry, biology, medical science and metallurgy share their knowledge. Recently the new field is evolved from the biomaterial science by their continuous efforts known as Tissue Engineering. Tissue Engineering has the tendency of growing out of the biomaterials field to become a separate field. Tissue engineering is concerned with the use of a combination of cells, engineering and materials methods, and suitable biochemical and physio-chemical factors to improve or replace biological functions.

II. ESSENTIAL FEATURES OF BIOMATERIALS:

A biomaterial should satisfy the features given below.

- **Biocompatibility:** Biocompatibility is defined as 'the ability of a material to perform with an appropriate host response in a specific situation'. It is the first significant criterion to inspect while selecting a biomaterial. The metallic implant has a tendency to corrode in the environment which leads to deteriorate the implant and the breakdown of the implant material will occur. Due to which adverse effects on the nearby tissues and organs will occur. It is to be taken care that the developed biomaterial should be compatible with the human body and may not generate any unwanted harmful effects.
- **Mechanical properties**: The implant material should exhibit the desirable mechanical properties to extend the service period by preventing the chances of revision surgery. The mechanical properties include low modulus with high strength to avoid loosening. The modulus of elasticity of biomaterials should be equivalent to that of bone, which varies from 4 to 30 GPa. It will prevent the chances of stress shielding.
- **Long fatigue life:** The material should exhibit a long fatigue life. The fatigue failure of implants has been observed for hip prostheses.
- **High corrosion resistance:** A biomaterial, implanted in a human body with a low corrosion resistance can discharge metal ions into the body will produce toxic reactions. Therefore the implant material with high corrosion resistance should be selected. Metal

implant is prone to corrosion during its services due to corrosive medium of implantation site and in most cases subjected to cyclic loading. Types of corrosion that frequently found in implant applications are fretting, pitting and fatigue.

- **High wear resistance:** The material should have a high wear resistance and show a low friction coefficient. It is due to the fact that an increase in the friction coefficient or a decrease in the wear resistance can cause the implant to loose, when sliding against body tissues. Moreover, the wear remains generated can cause inflammation that is destructive to the bone supporting the implant.
- **Osseointegration:** Osseointegration was first defined as “a direct structural and functional connection between ordered, living bone and the surface of a load-carrying implant”. Currently, an implant is considered as osseointegrated when there is no progressive relative movement between the implant and the bone with which it has direct contact. From the study of Branemark research work, titanium implants could become permanently integrated within bone. It means that the living bone could become so fused with the titanium oxide layer of the implant that the two could not be separated without fracture.
- **Non-toxic:** The biomaterial should be non-toxic so that it can satisfy its purpose without adversely affecting the biological system of the human tissues and organs. Thus the material should be neither geno-toxic (which can alter the DNA of the genome) nor cyto-toxic (causes damage to individual cells).
- **Cost of the Biomaterial:** The final consideration for choosing a metal for a medical implant is cost. Some metals cost much more than others as a raw material and processing and machining costs can vary considerably depending on their application.

III. SIGNIFICANCE OF METALS OR ALLOYS AS BIOMATERIALS:

Metals have played an elementary role in establishing a scientific and technological development due to advances in engineering materials in last few decades. Metallic implants have a significant economic impact in biomaterial field. Metals are used as biomaterials due to their excellent electrical and thermal conductivity provided with desired mechanical properties. While metals in general exhibit properties that make them appropriate for load-bearing applications, the high strength and resistance to fracture those metals with proper processing method, gives reliable long-term implant performance in major load-bearing situations. Metals have different mechanical properties which make some advantageous compared with others for certain situations. Metals with equal compositions can behave differently depending on processing operation. An understanding of material properties and processes used to achieve desired properties during fabrication of metallic components is essential for ensuring desired performance of implants in service.

Metallic biomaterials continue to be used for the fabrication of surgical implants that led to their selection for these devices. Metals have various applications throughout the body as implants. Electrically conductive metals such as platinum have tested as effective as electrodes in implantable cardiac pacemakers and defibrillators. In practice, a metallic implant will require a high load to cause deformation and will resist failure caused by repeated loadings. Metals are not prone to brittle fracture therefore avoids sudden breakdown and prevents injury to a patient. Some metals are used as substitutes for hard tissue replacement such as total hip and knee joints, for fracture healing aids as bone plates and screws, spinal fixation devices, and dental implants because of their excellent mechanical properties and corrosion resistance. Some metallic alloys are used for more active roles in devices such as vascular stents, catheter guide wires, orthodontic arch wires and cochlea implants.

Meanwhile mechanical properties of metals depend on their purity and processing method. Most metals that were used to make alloys for manufacturing implants can only be tolerated by the body in minute amounts. Metals such as iron (Fe), chromium (Cr), cobalt (Co), nickel (Ni), titanium (Ti), tantalum (Ta), niobium (Nb), molybdenum (Mo), and tungsten (W) are present in a human body with a little amount. Sometimes those metallic elements, in naturally occurring forms are essential in red blood cell functions (Fe) or synthesis of a vitamin 812 (Co), but cannot be tolerated in large amounts in the body.

IV. METALS OR ALLOYS USED AS BIOMATERIALS:

The first metal alloy developed specifically for human use was the “vanadium steel” which was used to manufacture bone fracture plates and screws. Commonly used metals or metallic alloys as biomaterials are stainless steels, Co based alloys, Titanium, Ti-6Al-4V, β-Ti and Near β-Ti alloys, (α + β) Ti alloys, Tantalum, Zr-Nb alloy, Ni-Ti alloys (Nitinol), dental amalgam, etc. These materials are discussed in this section.

1. Stainless Steels: During the 1960s, improved understanding of metallurgy combined with the development of superior surgical techniques, resulted in the implantation of the first total hip implant made from a stainless steel stem. The first stainless steel utilized for implant fabrication was the 18-8 (Now it is type 302 in modern classification), which is stronger and more resistant to corrosion than the vanadium steel. Later on stainless steels of grade 316 or 316L are frequently used as biomaterials. The 316 designation specifies that the alloy contains mostly iron, about 17% chromium, 10% nickel and small amounts of other metals. The addition of 17% chromium plays a vital role in making the metal corrosion resistant. In the designation 316L stainless steel ‘L’ signifies ‘low carbon’. 316L is the designation given to the most commonly used stainless steel in biomedical applications. Stainless steels are popular choice for the applications in non-permanent fracture fixation devices due to their low cost and ease of manufacturing and machining. Although stainless steels are designed to be corrosion resistant, they are not the most corrosion resistant alloys available for medical implants. Over time, stainless steel will corrode, especially at joints and crevices, so it is often only used for implants intending to stay in the body for short term (less than 1 year).

Advantages and Disadvantages:

Though the stainless steel (SS) materials have certain advantages like high strength, ductility, toughness, ease of machining and cheaper than other metals but they are also suffer from problems such as corrosion problem, much higher modulus than bone, less bone bonding than other metals, Allergy consideration with Ni, Cr and Co and may create nickel ion sensitivity.

Applications : Surgical instruments, bone plate for fracture fixation, stents, joint replacements (hip, knee, dental implant for tooth fixation, heart valve, spinal Instruments, surgical instruments, screws, dental root implant, pacer, fracture plates, hip nails, shoulder prosthesis etc.

2. Cobalt based alloys: The cobalt -chromium alloys are generally consists of 58-70% Cobalt, 26-30% chromium and a small amount of other alloying elements like molybdenum, tungsten, iron, titanium and nickel etc. There are basically two types of cobalt—chromium alloys. The castable Co-Cr-Mo alloy and the Co-Ni-Cr-Mo alloy which is usually wrought by (hot) forging. The two basic elements of the Co-Cr alloys form a solid solution of up to 65% Co. In Co-Cr-Mo alloy molybdenum up to 6 % is used. The molybdenum is added to produce finer grains which results in higher strengths after casting or forging. The chromium enhances corrosion resistance as well as solid solution strengthening of the alloy. The castable Co-Cr-Mo alloy has been used for many decades in dentistry and recently used in making artificial joints. Forged Co-Cr alloys exhibit higher wear resistance than cast Co-Cr alloys. However, the friction coefficient of the forged Co-Cr alloys has been observed to be higher than that of the cast alloys. The wear behaviour of low carbon and high carbon Co-Cr-Mo alloys depends on the surrounding environment.
The Co-Ni-Cr-Mo alloy originally contains approximately 35% Co and Ni each. The alloy is highly corrosion resistant to seawater (containing chloride ions) under stress. Cold working can increase the strength of the alloy considerably. The wrought Co-Ni-Cr-Mo alloy is relatively new, now used for making the stems of prostheses for heavily loaded joints such as the knee and hip. Ni-free Cr-Mn-Mo exhibits improved wear behaviour compared to Cr-Ni-Mo steels.
Co-Cr-Mo alloys exhibit features such as cast alloys forms have higher elastic modulus than wrought or forged forms, wrought or forged forms has the highest strength/wear resistance and cast alloy forms have lower cost than wrought or forged forms but they are hardest to fabricate and may produce cobalt or chromium ion sensitivity/toxicity.
However, there is a considerable difficulty of cold working on this alloy, especially when making large devices such as hip joint stems. Only hot-forging can be used to fabricate a large implant with the alloy. The successful biological performance of the metal implant is dependent on the mechanical and surface properties of the metals or alloys.
Advantages and Disadvantages: Co-Cr alloys are have the favourable features like high strength, high fatigue resistance high wear resistance and suitable to carry high loads and suitable for long term implantation in human body. But these alloys are very expensive and difficulty in fabrication of medical implants as per exact standards. Another limitation of these alloys has much higher modulus than bone.
Applications: Typical applications include bone and joint replacements (hip, knee), dental implants, dental restorations, heart valves bone plate for fracture fixation, screws, dental root implant, pacer, suture, dentistry, orthopaedic prosthesis, mini plates, surgical tools etc.

3. Ti and Its Alloys: Since 1930s, the use of titanium started as a biomaterial for implant fabrication. Titanium is a superior choice for medical implant applications due to similar yield strengths as stainless steel, titanium's elastic modulus is only about half that of stainless steel. It is a biomaterial with a high superficial energy and after implantation it provides a favourable body reaction that leads to direct apposition of minerals on the bone-titanium interface and titanium osseointegration. Ti forms a stable oxide (TiO_2) layer on its surface and provides it with protection against corrosion. Furthermore, Ti and its alloys are also often praise for their mechanical properties: they are very strong, but also lightweight.
Titanium is basically used in implants in two forms as commercially pure titanium (CP-Ti) and extra low interstitial Ti-6Al-4V (ELI). These materials are classified as biologically inert biomaterials. These metals do not induce allergic reactions such as has been observed with some stainless steels, which have induced nickel hypersensitivity in surrounding tissues.
The main physical properties of titanium responsible for the biocompatibility are: low level of electronic conductivity, high corrosion resistance, thermodynamic state at physiological pH values, low ion-formation tendency in aqueous environments and an iso-electric point of the oxide of 5–6. In addition, the passive-film-covered surface is only slightly negatively charged at physiological pH.
3.1 Pure Ti: Pure titanium is an allotropic material, which exists in the form of hexagonal close packed structure (HCP, α-Ti) up to 882°C and body-cantered cubic structure (BCC, ε-Ti) above that temperature. Commercially pure titanium (CP-Ti) is considered to be the best biocompatible metallic material because its surface properties result in the spontaneous build-up of a stable and inert oxide layer. It is very light with a density of 4.5 g/cm ^{3}.
The CP-Ti contains 98.9 - 99.6 % Ti, being the oxygen content and other interstitial elements such as C and N, the main element (See Table 1) influencing significantly its yield, tensile and fatigue strengths.

Table 1: Chemical composition of Ti CP (ASTM F 67) and Ti6Al4V alloy (ASTM F 136)

Element	Grade 1	Grade 2	Grade 3	Grade 4	Ti-6Al-4V^a
N max.	0.03	0.03	0.05	0.05	0.05
C max.	0.10	0.10	0.10	0.10	0.08
H max.	0.015	0.015	0.015	0.015	0.0125
Fe max.	0.20	0.30	0.30	0.50	0.25
O max.	0.18	0.25	0.35	0.40	0.13
Ti	Balance	Balance	Balance	Balance	

^{a}Aluminium= 6%, Vanadium= 4%

This data is taken from references mentioned at the end of the paper. Table 1 is from Carlos Oldani and Alejandro Dominguez(2012).

3.2 Ti-6Al-4V alloy: This alloy combining titanium with approximately 6% aluminium and 4% vanadium and appropriately designated Ti-6Al-4V ELI. The ELI represents 'extra low interstitial' and signifies that the alloy has a very low content of impurities such as iron and oxygen. The ELI designation causes the metal more ductile but slightly less strong. It also improves the alloy's fracture toughness and makes it more resistant to fatigue fracture. It is widely used to manufacture implants and its chemical requirements.
Titanium alloys are considered to be the most fascinating metallic materials for biomedical applications. Ti-6Al-4V has long been favoured for biomedical applications. Ti-6Al-4V alloy is widely used to manufacture implants and its chemical composition is given in Table 1. The addition of alloying elements to titanium enables it to have a wide range of properties because aluminium tends to stabilize the α phase and vanadium tends to stabilize the β phase, lowering the temperature of the transformation from α to β. The alpha phase promotes good weldability, excellent strength characteristics and oxidation resistance. The addition of controlled amounts of vanadium as a β stabilizer causes the higher strength of β phase to persist below the transformation temperature which results in a two-phase system. The β phase can precipitate by an ageing heat treatment. This microstructure produce local strain fields capable of absorbing deformation energy. Cracks are arrested or deterred at the particles. Titanium alloys can be strengthened and mechanical properties varied by controlled composition and thermo-mechanical processing techniques.
Titanium is very reactive at high temperature and burns readily in the presence of oxygen. Therefore, it requires an inert atmosphere for high temperature processing or is processed by vacuum melting. Oxygen diffuses readily in titanium and the dissolved oxygen embrittles the metal. As a result, any hot working or forging operation should be carried out below 925°C meanwhile machining at room temperature tends to gall or seize the cutting tools. Therefore to minimize this effect it is recommended to use very sharp tools with slow speeds and large feeds on electrochemical machining.
The Ti-6Al-4V alloy has approximately the same fatigue strength (550 MPa) of Co-Cr alloy after rotary bending fatigue tests. It should be noted that vanadium and aluminium are toxic when released into the body. However corrosion resistance afforded by the titanium oxide layer on the surface of Ti-6Al-4V, prevents the release of Al and V ions into the body avoiding issues of toxicity.
Comparative study of Titanium alloy (Ti-6Al-4V) and Titanium (Ti) metal reveals that titanium alloy is stronger than titanium metal, both have the best corrosion resistance, both have excellent bone bonding, both have relatively low elastic modulus but none of them are wear resistant as SS or Co-Cr-Mo alloys.

3.3 (α + β) Ti Alloys: Alloying of Ti is used to form a two-phase (α + β) alloy of higher strength (yield, ultimate and fatigue) than CP-Ti while maintaining excellent corrosion resistance and osseointegration tendency. The (α + β) Ti alloy with the prolonged history of use for major load-bearing applications is Ti-6Al-4V alloy with Ti-6Al-7Nb and Ti-5Al-2.5Fe being more recent alternatives that are similarly processed giving similar properties. All three alloys behave equally well in clinical use. The mechanical properties of the (α + β) Ti alloys are mainly dependent on size and distribution of α and β phase regions. Composed with their excellent corrosion resistance, high fatigue strength properties, the implants made from these alloys display superior corrosion-fatigue properties compared to other metallic biomaterials.
Though the Young's moduli of Ti and the (α + β) Ti alloys are significantly lower than those of Co-Cr-Mo or stainless steel alloys (∼110 compared to 220 and 200 GPa respectively), they however are 5–10 times greater than the modulus reported for cortical bone (10–20 GPa). The issue of stress shielding of bone next to well-fixed CP-Ti or (α + β) Ti alloy implants is a concern in the case of long-term load-bearing implant use (although less so than with the higher modulus Co-based or stainless steel alloys).

3.4 β-Ti and near β-Ti Alloys: These alloys comprises higher levels of β-stabilizing elements and presence of Mo exhibits one of the strongest effects. A number of β-Ti alloys that have been developed for use in orthopaedic implants. The structure of these alloys have Young's modulus about 64–77 GPa and subsequent annealing in the (α + β) two-phase field (500 ◦ C for 6 h – an aging heat treatment) causes the acicular α to coarsen and fine β-phase precipitates to form throughout, resulting in higher strength (because of precipitation strengthening) with an associated increase in elastic modulus to about 81 GPa. Heavy cold-working of α martensite is possible and results in the formation of a lower modulus material (∼45 GPa) with strength even greater than water-quenched and precipitation hardened material while maintaining good ductility. Surface hardening for improved wear resistance can be achieved by aging (at 500 ˚C, for example) in an oxygen-containing environment.
The β and so-called near-β Ti alloys if appropriately processed exhibit significantly lower elastic moduli (values as low as 44–51 GPa for water-quenched and cold-worked Ti-13Nb-13Zr, a near-β alloy). These alloys if appropriately processed display good formability, high hardenability, excellent corrosion resistance, and better notch sensitivity than the (α + β) Ti alloys.

3.5 Low modulus titanium alloys: The use of vanadium can cause toxicity and detrimental tissue reactions and aluminium ions from the alloy might cause prolong Alzheimer disease. The recent trend in research and development of titanium for biomedical applications is to develop alloys composed of non-toxic and non-allergenic elements with excellent mechanical properties (low modulus-high strength) and workability (Niinomi, 1999).Therefore orthopaedic alloys replacing V and Al alloys with other non toxic components such as Nb, Fe and Mo (for the V) and Ta, Hf and Zr (for the Al).
A biocompatible titanium base alloy suitable for bone implant should meet at least the following requirements (Mehta, 2008):

- Potentially toxic elements, such as vanadium, cooper and tin, should be avoided completely.

- Elements that may have potential toxicological problems, such as chromium, nickel and aluminium, should be used only in minimum and with acceptable amounts.
- The alloy should have high corrosion resistance.
- The alloy should have, at least, the following desirable mechanical properties: low modulus, high strength and good smooth and notched fatigue strength.
- The alloy should have good workability and ductility.

This has enforced the use of Ti-base alloys of low elastic modulus in an orthopaedic.

Advantages and Disadvantages: The advantages includes high biocompatibility, low Young's modulus, excellent corrosion resistance, low density but having certain disadvantages as poor tribological properties, Toxic effect of Al, and V on long term. As a mined metal, titanium is more expensive than iron and other components of stainless steel. Furthermore, the precise and clean manufacturing requirements for titanium, especially to achieve the 'ELI' required for medical implants, makes creating an implant very expensive. Titanium and titanium alloys, nevertheless, have poor shear strength, making them less desirable for bone screws, plates and similar applications. They also tend to gall or seize in sliding contact with itself or another metal.

Bulk titanium alloys used in implants present three main problems:

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

Applications: Bone and joint replacement, fracture fixation, dental implants, pacemaker encapsulation, suture, parts for orthodontic surgery, bone fixation devices like nails, screws and plates, artificial heart valves and surgical instruments etc. For permanent implant applications the alloy has a possible toxic effect resulting from re-leased vanadium and aluminum.

4. Zr-Nb Alloy: A Zr-2.5Nb alloy, developed initially for nuclear industry applications. Zirconium is a highly reactive metal. When it is annealed in an oxygen-containing atmosphere at 500°C develops a relatively thick (5 μm) monoclinic ZrO_2 layer over the alloy substrate and form a dense cohesive surface oxide layer (ZrO_2) spontaneously on exposure to an oxygen-containing environment. ZrO_2 is very hard and can be used to form a good wear resistant surface considering sufficient layer thickness. It also results in a corrosion protection layer.

Applications: Zr-Nb alloy is used for making orthopaedic components that are primarily intended for compressive loading and resisting wear (such as femoral hip implant and knee implant components).

5. Ni-Ti Alloys (Nitinol): The use of Ni-Ti for medical purposes was started since 1970s. The titanium—nickel alloys have exceptional properties that could be very useful in surgical applications. When applied in certain surgical implants, Ni-Ti is expected to provide radically new functional capabilities, improved performance and a possibility of using modestly invasive techniques. The use of Ni-Ti as a biomaterial is fascinating because of its super elasticity and shape memory effect and good damping properties, which are completely new properties compared to the conventional metal alloys. The Shape Memory Effect (SME) is the property of the material; after it is deformed the material can snap back to its previous shape following heating of the material. This property causes good corrosion resistance and elastic property (E 28–41 GPa). These features of alloys make them suitable for applications in self-locking joint replacement components.

Advantages and Disadvantages: Low Young's modulus, Ni cause allergy. Because of the high nickel content of Ni-Ti, it is theoretically possible that nickel may dissolve from the material due to corrosion and cause unfavourable effects. The biocompatibility of Ni-Ti alloys must be considered before it can be safely use as an implant material.

Applications: These alloys are used to develop the bone plates, stents, and orthodontic wires. Orthodontic wires formed from a Ni-Ti-based alloy are useful because of the wide range of working' that these wires provide during force application for tooth repositioning. SMEs are also used for cardiovascular stents where the pseudo elastic feature facilitates stent expansion/deployment following insertion into an artery. Currently, Ni-Ti seems to provoke notable interest in the medical and commercial sectors. The Ni-Ti alloy (Nitinol) is used currently in orthopaedic, dental and cardiovascular applications. It provides a possibility to make self-locking, self-expanding and self-compressing implants activating at body temperature.

6. Tantalum: From research study it is observed that metals corrosion cause unfavourable effects due to electrochemical process. Since metal corrosion contributes to the rejection of metal by the body, an extremely bio-inert metal like tantalum has been successfully implemented in medicine. Tantalum has been considered for many years to be biocompatible as a result of formation of a thin, impenetrable and stable tantalum oxide (Ta_2O_5) film on the metal surface that prohibits access of damaging substances, including acids and alkalies. Tantalum can be used as a biomaterial in two forms as porous titanium or nano particles. Therefore it is important to discuss their main features.

Porous tantalum is a biomaterial that was recently introduced in orthopaedics in order to overcome problems of the past related to implant loosening. Porous tantalum possesses some exceptional mechanical properties, mainly due to its high porosity. It has a low modulus of elasticity, close to that of subchondral and cancellous bone, leading to better load transfer and minimized stress shielding phenomenon. Its coefficient of friction is among the highest when talking about biomaterials, allowing for sufficient primary stabilization of implants, even without screw fixation. Since tantalum is very strong and ductile, it was initially employed for the production of surgical sutures (Burke 1940).

Porous tantalum foam structures are used as bone augmentation templates. Structures with compressive and tensile strengths approximately 60 and 63 MPa respectively and compressive fatigue strengths approximately 23 MPa (5 × 10 6 endurance limit) have been observed. Continuous interconnecting pores, or cells, about 550 μm in size, are formed and elastic and strength properties similar to those of cancellous bone result. They are considered sufficient to allow bone in growth and filling of the structures after which bone is expected to eventually satisfy the load-bearing requirements. These parameters are thought to contribute to the good and sometimes excellent, clinical results achieved with the use of porous tantalum Its use has led to very good results, especially in difficult cases where severe bone defect is present, as it is found to have osteoconductive and possibly, osteoinductive properties.

Advantages and Disadvantages: High corrosion resistant under extreme voltage potential and charge transfer conditions.
Applications: Tantalum is a biomaterial with a long history of applications in medicine. Due to the beneficial properties of tantalum, interest in expanding potential applications is increasing. Porous tantalum is used in domains such as hip and knee arthroplasty, hip osteonecrosis surgery and spine surgery. It consists of a carbon scaffold on which pure tantalum is deposited. Novel fabrication techniques, such as production of porous implants, introduces new qualities of these materials, including outstanding bio-compatibility and mechanical properties that are useful for tissue regeneration (Weeden and Schmidt 2007). Future applications include use of tantalum nanoparticles and hydrogel composites for targeted drug delivery purposes with the goal of treating dis-eases such as cancer and degenerative disc disease (Benz 2012).Tantalum is also used in production of electrodes. Platinum, Platinum-Iridium Electrodes used for neuromuscular stimulation require the use of materials that are corrosion resistant under extreme voltage potential and charge transfer conditions. The noble metals (Pt and Pt-Ir alloys) satisfy these conditions and are the principal materials used for making electrodes for electrical stimulation and sensing purposes. Helically coiled lead wire designs are used currently to achieve good lead flexibility and to minimize local strains during flexing thereby improving fatigue characteristics.

Table 2: Tantalum forms and applications

Form	Properties	Applications	Defects
Porous Tantalum	• Highly porous • Anti-corrosive • Cost effective • Biocompatible	• Orthopaedics • Dentistry • Tissue regeneration	Heterogeneity of pore size
Tantalum Nano-particles	• Anti corrosive • Biocompatible • Cost effective • Multi-functionality	• Contrast agents for: MR, • X-Ray CT, • Hydro-gel composite component.	Aggregation.

This data is taken from references mentioned at the end of the paper. Table 2 is from Gokhuldass Mohandas, et al,(Acta Neurobiol Exp 2014).
Porous materials have re-shaped the landscape of bone implants, as they allow for bone ingrowth and biological fixation, and eliminate implant loosening and related treatment failures. Porous tantalum is used as a material for bulk implants due to its specific bone-mimicking properties. It also facilitates the ingrowth of soft tissue and acts as strongradiopaquefor marking in orthopaedics and in endovascular medical devices. One important application which benefited from the introduction of powder (particle) metallurgy is use of tantalum as bone implants.

7. Dental Alloys: Theuse of the metals and alloys for dental implant had been in practice from an ancient period. From research finding it is observed in archaeological records of China and Egypt before the Common Era. These countries had utilised stone and ivory in earliest dental implants. Gold and Ivory dental implant were used in the 16th & 17th centuries. Research study reveals that metal implant devices of gold, lead stainless steel cobalt alloys, iridium, and tantalum, were developed in the early 20th century. Implant designs are traceable to early Egyptians and South Central American cultures and have developed the present implant designs that are now experiencing ex-plosive popularity.
In recent dentistry field, metals or alloys like Titanium, cast Ti components, Cast Ti-based alloys, Ti-6AI- 4V, CP- Ti, Ti-Cu-Ni, Ti-V, Ti-Cu, Ti-Pd and Ti-Co alloys, Co-Cr-Mo based alloy, Fe-Cr-Ni based alloys etc., are either in used in practice or in the experimental stage of development.
These metals or alloys used in dentistry for the following purposes

- Direct fillings in teeth (i.e. dental amalgams),
- Fabricating crowns and bridges (noble metal and base metal alloys),
- Partial denture frame works (base metal alloys),
- Orthodontic wires and brackets (stainless steel, Ti alloys and Ni-Ti alloys) and dental implants (CP -Ti and Ti-6A-l4V).

Necessity of acceptable characteristics in dental implant includes sufficient strength, toughness, ease of fabrication, wear resistance, corrosion resistance and biocompatibility, tissue interface characteristics, surface properties of the implant and freedom from defects etc.
Biocompatibility is again an important requirement since these materials also contact body tissues (tooth structure, soft supportive tissues) often for the remainder of a patient's lifetime although the ease of accessibility after placement relaxes the biocompatibility requirement considerably.

Advantages and Disadvantages: As in the orthopaedic applications, the major advantage of metal for these dental applications is the high intrinsic strength and fracture resistance of this class of materials.

Applications: A number of the metals and alloys already described find application in dentistry. Dental implant materials with requirements very similar to materials used for orthopaedic joint replacement implants are made almost exclusively from Ti and Ti-6Al-4V. Orthodontic wires and brackets are made of stain-less steel (types 302, 303, 304 and 305), Co-Cr-Ni-Mo alloys (Elgiloy), β-Ti, and Ni-Ti alloys (because of their low elastic moduli, high strengths and consequently large working range, a desirable characteristic for this application). Cast Ti components for crowns, partial and complete dentures, while limited because of difficulties associated with casting because of the high melting point of Ti (compared to Au-based dental alloys), its high reactivity, difficulty in surface finishing and other problems, can be made (using special vacuum melting and casting equipment) but it is not common. To satisfy aesthetic requirements for dental crowns, porcelain-fused-to-metal (PFM) restorations are made with the silicate-based porcelains being bonded to a cast metal substrate.

8. Dental Amalgams: The Chinese recorded the first use of dental amalgam to repair decayed teeth in the year 659 AD. Dental amalgams are formed by adding Hg to dental amalgam alloys i.e. alloys containing Ag, Cu and Sn plus some other minor elemental additions by amalgamation process. Dental amalgam is an alloy made of liquid mercury and other solid metal particulate alloys made of silver, tin, copper, etc. Dental amalgam alloys categorised into two forms based on the weight % of cooper. They are either low (Cu <6 wt%) or high Cu containing (Cu >6 wt%).The high Cu-ontaining dental amalgam is being favoured because it avoids the formation of an undesirable Sn-Hg phase (γ 2) that is susceptible to corrosion and results in lower strength properties of amalgams.
Dental amalgam alloys are formed as powders either by lathe cutting Ag-Cu-Sn alloy billets (resulting in irregular particles i.e., machining chips) or by atomization (to give spherical powders). The solid alloy is mixed with (liquid) mercury in a mechanical vibrating mixer and the resulting material is packed into the prepared cavity. One of the solid alloys is composed of at least 65% silver, and not more than 29% tin,6% copper. 2% zinc, and 3% mercury. The reaction during setting is thought to be in which the γ phase is Ag3Sn, the γ 1 phase is Ag 2 Hg 3 and the γ 2 phase is Sn 7 Hg.Subsequent mixing of these alloy powders with liquid mercury results in their partial dissolution, complete consumption of the liquid Hg and the subsequent formation of a number of intermetallic compounds (Ag 3 Sn, Ag 2 Hg 3 , Sn 7–8 Hg, Cu 3 Sn, Cu 6 Sn 5) due to the Hg-dental amalgam alloy reactions and the condensation of the initial 'plastic' mass to form a load-bearing filling. During the reaction, the partially reacted powder can be manipulated to fill a tooth cavity.
The final amalgam restoration exhibits reasonable mechanical properties. While susceptible to corrosion in the oral environment, build up of the corrosion product serves to limit the rate of further corrosion and to form an acceptable marginal seal at the amalgam-tooth interface Concerns related to Hg toxicity have been raised but, to date, these have not been proven to be valid although the issue remains controversial.

Advantages and Disadvantages: Hg-Ag-Sn amalgam has the advantage of formability to a desired shape susceptible to corrosion in the oral environment but concerns related to Hg toxicity.

Applications: It is used for dental restorations. Moreover dental casting alloys (i.e. Au-based, Co- and Ni-based, Ti-based) are used for making dental bridges, crowns, in-lays, on-lays and endodontics posts. Both noble and non-noble (base) metal alloys are used to form these often complex shapes. Wrought dental alloys like wrought stainless steel, Co-Cr-Ni, Nitinol β-Ti and alloys are used for making orthodontic wires where high yield strength and preferably low elastic modulus provide high 'working range' characteristics.
It is important to understand the comparison between mechanical properties of various metallic alloys with bone material so that they can be used as an implant material. Table 3 shows the comparison of metallic biomaterial with bone. The general chemical composition of metallic implant is given in Table 4.

Table 3: Comparison of mechanical properties of metallic biomaterials with bone.

Material	Young's Modulus, E (GPa)	Yield Strength, (MPa)	Tensile Strength, (MPa)	Fatigue Limit, (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	

This data is taken from references mentioned at the end of the paper. Table 3is from Nitesh R. Patel, Piyush P. Gohil, (April 2012).

Table 4: General chemical composition of some orthopaedic implant materials

Alloy	C	Ni	Ti	V	Fe	Cr	Al	Co
316L Stainless steel	0.03	13-16	…	…	Balance	17-19	…	…
Co-cast	0.35	1.0	…	…	0.75	27-30	…	Balance

Co-forged	0.35	1.0	…	…	0.75	27-30	…	Balance
Titanium	0.1	…	Balance	…	0.5	…	…	…
Ti 6Al 4V	0.1	…	Balance	3 – 4.5	0.3	…	5 - 6	…

This data is taken from references mentioned at the end of the paper. Table 4 is from Prof. K. A. Natarajan, (Lecture 37: Biomaterials And Human Implants)

V. LIMITATIONS OF CURRENT METALLIC BIOMATERIALS:

Limitations in metallic biomaterials can be summarized as follows:

[1] The presence of elements such as Ni, Cr, and Co in both stainless steel and Co-Cr alloys has toxic effects. Ni toxicity leads to dermatitis.

[2] The long-term existence of Al and V ions in Ti alloys has been found to cause Alzheimer's disease, osteomalacia and neuropathy in the long term.

[3] The presence of Co has also been reported to have carcinogenic effects. Recently, it is reported in that stainless steels and Co-Cr alloys usually contain some harmful elements, such as Ni, Co, and Cr. In addition, 6Al-4V alloy is composed of cytotoxic elements like Al and V, which may cause severe problems once released inside the human body.

[4] Mechanical failure is unacceptable for most engineered structures, it is particularly so for surgical implants where failure can result in patient pain and in certain cases, death (heart valve component fracture, for example) or the need for complicated and life-threatening revision surgery.

[5] A high friction coefficient and wear debris formation can produce an inflammatory reaction, leading to the loosening of implants due to osteolysis.

[6] A high modulus of elasticity leads to stress shielding, which causes implant failure.

VI. CONCLUSIONS:

The metal or metallic alloys as a biomaterials are formed into desired shapes using well-established and widely available fabrication techniques like casting, forging, machining. Therefore it is possible to use of metallic biomaterials in the fields of orthopaedics and dentistry. They are used in these areas for forming cardiovascular devices like artificial heart valves, blood conduits and other components of heart assist devices, vascular stents, and neurovascular implants, aneurysm clips etc.

Though some metal implants have been replaced by ceramics and polymers due to their excellent biocompatibility and bio-functionality but clinical utility of bioactive polymers and ceramics in medical science is yet not acheived. It is to be noted that for implants which require high strength, toughness and durability, they are still made of metals. With further improvement on bio-functionalities and utility of metal such as for biodegradable implants, therefore metals will continue to be used as biomaterials in the future. The future trends signify to combine the mechanically superior metals and the excellent biocompatibility and bio-functionality of ceramics and polymers to obtain the most desirable clinical performance of the implants.

Research study also indicates that the inherent mechanical properties of metallic implants are not the only a deciding factor of implant performance and success. Present implant metals and alloys have all been used in both prosperous and discomfited implant designs. The reasons for failures can include defective or improper use or the implant, surgical error and inadequate mechanical design of the implant. Therefore implant design is a multifaceted design problem in which the selection of materials is important part of the total problem. The choice of one material above another will depend on the application and the type of function that needs replacement. Unfortunately, none of the existing metallic biomaterials can meet the entire requirements. Recently developed biomaterials are design to provide biological functions by mimicking natural tissue structures.

REFERENCES:

[1] Buddy D. Ratner, Allan S. Hoffman, Frederick J. Schoen, Jack E. Lemons, "Biomaterials Science-An Introductionto Materials in Medicine", Elsevier Academic Press, Third Edition.

[2] Robert M. Pilliar," Metallic Biomaterials", Chapter 2, *Biomedical Materials,* Springer Science+Business Media, R. Narayan (ed.), LLC 2009, pp 41-79.

[3] Adopsi dari: Joseph D. Bronzino, "Metallic Biomaterials, Biomedical Engineering Fundamentals", CRC Press, third edition, 2006, Section V, CHAPTER 38 , by Joon B. Park, Young Kon Kim.

[4] Hendra Hermawan, Dadan Ramdan and Joy R. P. Djuansjah, Metals for Biomedical Applications, Faculty of Biomedical Engineering and Health Science, University Teknology, Malaysia

[5] A.Binnaz Hazar Yoruç and B. Cem Şener (2012). Biomaterials, A Roadmap of Biomedical Engineers and Milestones, Prof. Sadik Kara (Ed.), ISBN: 978-953-51-0609-8, InTech,

[6] Hendra Hermawan, Dadan Ramdan and Joy R. P. Djuansjah, "Metals for Biomedical Applications",INTECH, Biomedical Engineering – From Theory to Applications, Chapter17, pp 411-430.

[7] Mohamed A. Hussein, Abdul Samad Mohammed and Naser Al-Aqeeli, "Wear Characteristics of Metallic Biomaterials: A Review", Materials 2015, 8, pp 2749-2768.

[8] F. Barre`re , T.A. Mahmood , K. de Groot , C.A. van Blitterswijk ," Advanced iomaterials for skeletal tissue regeneration: Instructive and smart functions", Elsevier Science Direct, Materials Science and Engineering R 59 (2008) 38–71.

[9] Prof. K. A. Natarajan,"Lecture 37: Biomaterials and Human Implants", NPTEL Web Course, Course Title: Advances in Corrosion Engineering

[10] Fredrick H. Silver and David .Christiansen, Piscataway Biomaterials Science and Biocompatibility, Springer, New Jersey.

[11] Black, J., Biological Performance of Materials. 3rd ed. 1999, New York, USA: Marcel Dekker, Inc. [A comprehensive look at the issues surrounding biocompatibility and factors that influence implant success.]

[12] Langer, R. and J.P. Vacanti, Tissue engineering. Science, 1993. 260(5110): p. 920-6.

[13] Callister WD Jr. Materials Science and Engineering: An Introduction, 6th ed, Chapter 7, John Wiley & Sons, Inc, 2003.

[14] Handbook of Materials for Medical Devices, Chapter 1, "Overview of Biomaerials and Their Use in Medical Devices",pp 1-12.

[15] C.M. Agrawal, "Reconstructing the Human Body Using Biomaterials", *JOM*, Jan 1998, pp 31–35.

[16] Mehta, R. (01 Jul 2008). Powder metallurgy processing for low-cost titanium, In: Materials World Magazine, Available from: http://www.iom3.org/news/powder-metallugy-processing-low-cost-titanium

[17] Sumrita Bhat, Ashok Kumar, "Biomaterials in Regenerative Medicine" , 10.5005/ jp-journals-10028-1018

[18] Jonathan Black, Marcel Dekker, "Biological Performance of Materials: Fundamentals of Biocompatibility", Inc., New York and Basel, 1981.

[19] Yarlagadda, Prasad K. and Chandrasekharan, Margam and Shyan, John Yong Ming Recent advances and current developments in tissue scaffolding. *Bio-Medical Materials and Engineering* 15(3):pp. 159-177. (2005)

[20] Pilliar RM. Modern metal processing for improved load-bearing surgical implants. biomaterils,1991, 12: pp 95–100.

[21] Boretos JW, Eden M (1984) Contemporary Biomaterials, Material and Host Response, Clinical Applications, New Technology and Legal Aspects. Noyes Publications, Park Ridge, NJ, pp. 232–233.

[22] Angelo S. Maoa,b and David J. Mooneya," Regenerative medicine: Current therapies and future directions", PNAS, vol. 112, no. 47, November 24, 2015, pp 14452–14459.

[23] Angelo S. Mao a,b and David J. Mooney, Regenerative medicine: Current therapies and future directions, a John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138; and b Wyss Institute for Biologically Inspired Engineering at Harvard University, Cambridge, MA 02138 edited by Mark E. Davis, California Institute of Technology, Pasadena, CA.

[24] Cheryl R. Blanchard, "Biomaterials: Body parts of the future", Technology today, Fall 19195.

[25] Sumrita Bhut, Ashok Kumar," Biomaterial in Regenerative Medicine", Journal of Postgraduate Medicine, Education and Research [JPMER], April-June2012, 46(2), pp 81-89.

[26] Hwal Suh "Recent Advances in Biomaterials", Review Article, Yonsei Medical Journal, Vol.39, No. 2, pp 87-95, 1998

[27] Niinomi, M. Metallic biomaterials. J. Artif. Organs 11, pp 105–110, 2008.

[28] Prof. Bikramjit Basu,Prof. Kantesh Balani,"Introduction to Biomaterials-Introduction to basic concepts of Biomaterials Sciences; Salient properties of important material classes; overview of body environment-1", Module 1, Lecture 1.

[29] Fergal J. O'Brien," Biomaterials and scaffolds for tissue engineering", *MATERIALS TODAY, 14, 3, 2011,pp 88-95.*

[30] T. Kushibiki and Y. Tabata **"**Future Direction of Gene Therapy in Tissue Engineering", IX Gene Therapy, Chapter 13, Topics in Tissue Engineering, Volume 2, 2005. Eds. N. Ashammakhi & R.L. Reis.

[31] A.F. Mavrogenis1, R. Dimitriou, J. Parvizi, G.C. Babis, "Biology of implant osseointegration, Review Article,J Musculoskelet Neuronal Interact 2009; 9(2):61-71.

[32] Carlos Oldani and Alejandro Dominguez,"Titanium as a Biomaterial for Implants", Chapter 9, Recent Advances in Arthroplasty, Dr. Samo Fokter (Ed.)2012, ISBN: 978-953-307-990-5, In-tech, pp 149-162.

[33] Rao, S., Ushida, T.,Tateishi, T., Okazaki, Y. & Asao, S."Effect of Ti, Al, and V ions on the relative growth rate of fibroblasts (L929) and osteoblasts (MC3T3-E1) cells". Bio-Medical Materials and Engineering, Vol.6, No.2,

(1996), ISSN 09592989,pp. 79-86.

[34] Acero, J.; Calderón, J.; Salmeron, J.; Verdaguer, J. & Consejo, C.," The behaviour of titanium as a biomaterial: microscopy study of plates and surrounding tissues in facial osteosynthesis. Journal of Cranio-maxillofacial Surgery, Vol.27, No.2, (April 1999), pp. 117-123.

[35] C.N. Elias, J.H.C. Lima, R. Valiev, and M.A. Meyers,"Biomedical Applications of Titanium and its Alloys", Biological Materials Science, Overview, JOM • March 2008, pp 46-49.

[36] Dr. Poul Erik Petersen, "Future use of materials for dental restoration: report of the meeting convened at WHO HQ, Geneva, Switzerland", 16th to 17th November 2009.

[37] William J. O'Brien, "Dental Materials and Their Selection", 3rd Ed. Quintessence Publishing Co, Inc (2002).

[38] C.V. Subba Rao, P. Pranau Vanajasan, V.S. Chandana, "Scope of Biomaterials in Conservative Dentistry and Endodontics", Trends Biomater. Artif. Organs, (2011).25(2), pp 75-78.

[39] Benz K, Stippich C, Osswald C, Gaissmaier C, Lembert N,Badke A, Steck E, Aicher WK, Mollenhauer JA (2012)Rheological and biological properties of a hydrogel support for cells intended for intervertebral disc repair. BMC Musculoskelet Disord 13: 54.

[40] Burke GL (1940) The corrosion of metals in tissues; and an introduction to tantalum. Can Med Assoc J 43: pp 125–128.

[41] Weeden SH, Schmidt RH (2007) The use of tantalum porous metal implants for Paprosky 3A and 3B defects. J, Arthroplasty 22: 151–155.

[42] Nur Maizatul Shima Adzali, Shamsul Baharin Jamaludin and Mohd Nazree Derman, "Mechanical Properties, Corrosion Behavior,And Bioactivity Of Composite Metal Alloys Addedwith Ceramic For Biomedical Applications", Rev.Adv.Mater. Sci. 30 (2012) pp 262-266.