An Overview on Recent progresses and future perspective of biomaterials

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Abstract. Over the past many decades, tremendous advances in the field of bio materials have been made. Many of the human tissues, such as bones, teeth, tendons, ligaments and other load bearing implants replacement in the human body are carried out successfully with the help of biomaterials. At present, essential concerns in the field of biomaterials are still to be met. The present demand for lifelong implants and bone replacement is characterized by biocompatibility, bioactivity, and mechanical properties of biomaterials, without the immune rejection shows a great challenge. Presently stainless steel, titanium alloys, Co-Cr alloys, zirconia, alumina, ultra-high molecular weight polyethylene, Poly methyl methacrylate etc. are some of the biomaterials that satisfy the requirements of physical and chemical properties, mechanical strength, and biocompatibility for biomedical applications. Significant progress has been made to improve the function of artificial joints, but currently the major efforts has been devoted to minimizing the wear and to increase the lifespan of the implants or prosthesis during its functionality in the human body. In this review, the evolution of different metals/ceramics and polymers that are most commonly used in biomedical applications has been discussed along with the different approaches used to fulfil the challenges faced by medical field.

Key words: Biomaterials; Biocompatibility; Metals/Ceramics; Polymers; Composites etc.

1. INTRODUCTION
An important and challenging use of metallic materials and their composites can be traced back to 19th century. Over the centuries, considerable advancement in the field of synthetic materials has been made in understanding the interaction between materials and living body for effective use of biomaterials in many ways [1,2]. Biomaterials are the synthetic materials that widely used to substituting/recondition the biological functions of body tissue and constantly or periodically remain in contact with body fluid and thus enhance the quality of life of human being [3]. In engineering design, materials designed by matching the properties required for specific application. Biocompatibility is the one of most important parameter that need to be considered while designing the materials for biomedical applications along with the mechanical, physical and chemical properties, whether the material is bioactive, bio inert or biodegradable [4].

In ancient time many natural materials like wood, rubber and glue and other synthesized materials such as iron, gold, zinc and glasses were used for biomedical applications. Metals and their alloys, ceramics and polymers are extensively used as biomaterials. All these materials have different atomic arrangement that provides distinct atomic structure and physical, mechanical and chemical properties. These properties of metallic biomaterials are greatly governed by their composition, microstructure and phases and on the basis of different properties existing in the materials they provide alternative applications for different body parts. Due to attractive mechanical properties of metals such as strength, stiffness, fatigue life these are efficiently used for most of the load bearing applications of the biomedical system [5]. Although Many metals and its alloys have been manufactured in the industry, only some of them are biocompatible which provide good bio functionality and capable to use as distant future implantation materials such as stainless steel, cobalt chromium alloys, Nickel, pure titanium and its alloys (Ti-6Al-4V and Ti-6Al-7Nb), magnesium etc.
To endorse prosthetics stabilization and bone ingrowth highly porous ceramics has been developed. However, due to its porous nature (low mechanical strength) they are used for low loaded or unloaded bearing applications. Recently, Ceramics have become important for biomedical application considering three basic types bioactive, bioinert and bioresorbable ceramics [2].

According to Hench’s classification the first generation (1960s and 1970s) ceramics biomaterials were ‘inert’ (alumina and zirconia), they minimize the foreign body response and also immune response. The replacement of conventional metallic femoral heads, acetabular cups of hip joint by high density and highly pure alumina (α-Al₂O₃) was one of the outstanding uses of ceramics because of its excellent wear and corrosion resistance along with high strength and good biocompatibility [4,6,7].

Afterward, second generation (1980 and 2000) ceramics were ‘bio-active’ (Hydroxyapatite, glass ceramics) as well as bioresorbable (calcium phosphate ceramics). Bioactive materials form chemical bond with soft tissues or promote them to particular responses and behavior. These ceramics are effectively used for bone repair and fixation applications. Bioresorbable materials undergo a progressive degradation in the body while regenerating new tissues and degrading materials are ingest and liberated by metabolic action of body. And for new generation ceramics both the concept of bio activity and biodegradability are united and material properties are combined with their capability to signal and activate specific cellular activity and behavior [2,6].

Natural and synthetic polymers are also the choice for the biomedical application because of its outstanding properties. Collagen and fibronectin, silk fibroin, fibrin, chitosan etc. are the natural polymers which possess good bioactivity and cytocompatibility, whereas synthetic polymers are those which allow precise manipulation of the physicochemical properties i.e. microstructure, degradation rate, mechanical properties, porosity etc. [6,8] and widely used in various tissue engineering applications. Many of the synthetic polyester have been developed that possess structural tunability and good mechanical strength such as polycaprolactone (PCL), poly lactico-glycolic acid (PLGA), poly-lactic acid (PLA), polyvinyl acetate (PVA) and these are the polymeric implant biomaterials that are expected to degrade over a period of time [9,10]. This paper briefly reviews the various metals/ceramics and polymeric biomaterials that have potential to face the challenges of the biomedical engineering.

2. ESSENTIAL CONSIDERATION IN DESIGN OF ARTIFICIAL BIOMATERIALS

The specific medical application decides the design and selection parameters for biomaterials. A material designed for biomedical application should acquire some conspicuous properties (shown in figure 1) for successful and distant future use of biomaterial inside/outside usage in the body without immune rejection, that described as; [11,12].

1. Excellent biocompatibility
2. Adequate mechanical properties
3. Good physical and chemical properties
4. High wear resistance
5. High corrosion resistance
6. Osseo-integration (For bone implants)

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**Figure 1.** Schematic representation of material design requirements of biomaterials
3. CLASSES OF BIOMATERIALS

Although many of the materials and their alloys are available in the industry, only some of them are biocompatible which provide good bio functionality and capable to use as distant future implantation materials [13]. The important classes of the biomaterials that is widely used for biomedical application are, metals, ceramics, polymers and composites. Few of the important properties and applications of different materials are summarized in Table 1 and Table 2.

**Table 1.** Important properties for different classes of biomaterials [14,15,16]

| S.No. | Materials | Advantages | Limitations | Applications |
|-------|-----------|------------|-------------|--------------|
| 1.    | Metals (Ti and its alloy, Ag, Au, Stainless steel etc.) | • Good strength  
  • High Toughness,  
  • Excellent fatigue resistance  
  • High Ductility and malleability etc. | • High modulus  
  • May corrode,  
  • High density,  
  • Difficult to prepare etc. | Load bearing implants such as Joint replacements, bone plates and pins, wires, screws, dental root implants etc. |
| 2.    | Ceramics (Alumina, Zirconia, Hydroxyapatite etc.) | • Biocompatible  
  • Great strength and stiffness  
  • Good corrosion and wear resistance  
  • Low density | • Brittle  
  • Not resilience  
  • Low fatigue resistance  
  • Anisotropic mechanical properties under different loading conditions | Dental and orthopedic implants, coating for load bearing implants, medical sensors etc. |
| 3.    | Polymers (Nylon, silicon, polyester etc.) | • Biocompatible  
  • Good resilience  
  • Light weight  
  • Easy to fabricate  
  • Good corrosion resistance | • Low strength  
  • deforming with time  
  • May degrade | Hip joint socket, blood vessels, contact lenses, heart valves, artificial hearts, etc. |
| 4.    | Composites /Bio composites | • Strong  
  • Tailor made  
  • Good corrosion and wear resistance  
  • High Biocompatibility | • Lack of consistency/homogeneity  
  • Difficult to prepare | Bone cement, joint replacements, Dentistry, bone plates, rods, screws etc. |

**Table 2.** Specific Applications of monolithic materials for biomedical application [17-22]

| S.No. | Biomedical Applications | Materials |
|-------|------------------------|-----------|
|       |                        | Metals    | Ceramics | Polymers |
| 1.    | Orthopedic: Joint substitutes, Screws, Pins and wires, hip | Stainless steels, Cobalt, | Alumina, Zirconia, porous and dense | Poly methyl methacrylate (PMMA), ultra-high molecular |
|       |                        | chromium  | Hydroxyapatite , | |

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prosthesis, rods and fracture plates for bone fixation, etc.

alloys, magnesium and its alloys, Titanium and its alloys

Tri-calcium Phosphate, Calcium Phosphate and its salts etc.

weight polyethylene (UHMWPE), Poly lactic acid (PLA), Poly hydroxyl butyrate (PHB), Poly-D,L-lactide-co-glycolic acid (PLGA), Poly-L-lactate (PLA), etc.

2. Orthodontic: Dental implants (filling and posts), screws, staples, Orthodontic arch wires,

Cobalt chromium alloys, Titanium and Ti-based alloys (Ni-Ti and Ti6Al4V), stainless steel, platinum, silver etc.

Alumina, Zirconia, Glass, Hydroxyapatite, Tri-calcium Phosphate, Calcium Phosphate and its salts etc.

Poly methyl methacrylate (PMMA), ultra-high molecular weight polyethylene (UHMWPE), poly tetra fluoro ethylene (PTFE), poly-sulfone(PS), polyethylene terephthalate (PET) etc.

3. Cardiovascular: Stents, valves, Aneurysm clip, Metal coils etc.

Stainless steel, cobalt and its alloys, chromium and its alloys, Nitinol, Titanium alloy (NiTi), magnesium-based alloys

Hydroxyapatite, Tri-calcium Phosphate, Calcium Phosphate etc.

Polyamides, poly tetra fluoro ethylene (PTFE), polyolefin, polyester, polyurethane etc.

4. Instrumental and Supplies: Needles, Scissors, Clamps, Equipment etc.

Stainless steel

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Ti-6Al-4V alloy has been borrowed from aerospace industry and very effectively used in biomedical application due to its superior mechanical properties (high strength weight ratio, relatively low elastic modulus, corrosion resistance and high fatigue strength etc.) along with good biocompatibility. However, the main drawback of using the titanium alloy is its incapability to bond with neighboring hard tissues in in-vivo (inside the body) environment [23]. These metallic materials are widely used for orthopedics surgery and other load bearing implants ranges from simple wires, pins, fracture fixation plates, to artificial joints for knees, ankles, hips, shoulders etc. Simultaneously, metals are also used for dental and orthodontic practice as tooth filling and roots. Metallic materials have tendency to degrade by the reaction with environment (corrosion process) and these corrosion reactions releases some toxic byproducts from biomaterials such as insoluble chemical compounds and ions that may leads to adverse effect (reactions, irritations, toxicity etc.) in the body [24]. The dominant reason in failure of metallic prosthetics is friction and wear of surfaces due to relative motion between loosened parts that causes inflammatory response to the body and makes the patient uncomfortable. It can be avoided by ceramics coating/ bioactive materials, that provides biocompatibility, wear and corrosion resistance toughness etc. [25]. Both natural and synthetic polymers are widely utilized for biomedical application. Polymers are relevant materials as compared to metals and ceramics for biomedical applications because of its outstanding properties such as low density, controlled degradability, environmental friendly and ease of fabrication [26].

4. CONCLUSION

It has been observed that, only one material (i.e. biomaterial) can not suffice all the requirement of a bio implant. For the specific application we need to choose the specific material to fulfil all the requirements of particular biomedical application. These requirements of biomaterials can be fulfilled by having mixture of materials, i.e. composite material. metal/ polymer based composites are extensively used in biomedical application because of its superior combination of properties such as
high strength and stiffness, better wear and corrosion resistance compared to unreinforced metal (i.e. also a requirement for the successful use of biomaterial). Alumina, zirconia, Hydroxyapatite, niobium pentoxide etc. are the biocompatible ceramics. The proper selection of matrix system and reinforcing materials along with volume fraction shape and size of reinforcing phases play crucial role for getting the combination of properties such as high strength, wear and corrosion resistance and biocompatibility.

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