An Overview on Biomaterials and Its Applications in Medical Science

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Abstract- Biomaterials have been used tremendously in medical science over last many decades. In human body a number of body tissues like teeth, ligament, bones tendons and others have been successfully replaced by these biomaterials. In present scenario the various applications of these biomaterials are still awaited. The most important challenge in using these biomaterials is immune rejection because in current situation the lifetime implants and bone replacement must required biocompatibility along with the biological and mechanical characteristics of the biomaterial used. Till now a number of biomaterials have been discovered and due to their biocompatibility and biodegradability, these are biomaterials are employed significantly in biotherapy and medical science. On the basis of the source, these biomaterials can be grouped into two categories namely natural or synthetic polymers, henceforth they have paid much consideration. An ideal biomaterial must have the following characteristics like they fulfill the various chemical and physical requirements along with the mechanical vigor and biocompatibility e.g. stainless steel, zirconia, alumina, Co-Cr alloys, polythene (high molecular weight), poly methyl methacrylate etc. In present scenario, considerable efforts has been done in improving the utility of artificial joints, but now the current focus has been committed for reducing the wear and to amplify the duration of implants or prosthesis inside the human body. In the present review an efforts has been made to provide awareness and importance of these biomaterials in the medical science along with fulfilling all the challenges.

Key words: Biomaterials, Biocompatibility, Biological and Mechanical characteristics.

1. Introduction
From early 19th century, the utility and importance of metallic materials and their composites has become evident. From last 2-3 centuries, a significant development has been done in the area of synthetic material to know about the interaction between biomaterials and human body and their effective use [1, 2]. Henceforth, biomaterials are manmade, used extensively to replace/repair the various biological activities of the human tissue and these materials get in contact with the body fluids continuously and therefore help in improving the normal human activities [3]. Through engineering designing, the designed material should be checked for identical/unique characteristics needed for its exact application. In this process one
important factor i.e. biocompatibility should be kept in consideration during the designing of biomaterials coupled with its chemical, physical and mechanical characteristics, whether the material is bioactive, bio inert or biodegradable [4].

During past few years, biotherapy using these biomaterials has become more evident in the prophylaxis of a number of lethal diseases like AIDS, cancer, cardiac infections etc. [5-8]. Biotherapy is the amalgamation of fundamental science and clinical functions that can be a potent tool for the treatment of lethal and incurable diseases [9-11]. Normally, biotherapy primarily associated with the prophylaxis of lethal diseases by involving biotechnology or bio based drugs, including the detection of therapeutic targets by pathological examination and the expansion of biotechnology associated with gene therapy, immunotherapy, stem-cell therapy and tissue engineering (bone, heart, liver etc.) [12,13]. In gene therapy technique a deliberate modulation in gene expression is created in a particular tissue for the prophylaxis of pathological conditions, whereas immunotherapy may be defined as the prophylaxis of disease by using vaccines and antibodies [14, 15]. Treatment through stem cell therapy primarily includes cancers, hematological disorders and cardiovascular disorders etc by using stem cells to treat them [16-19]. Moreover, now a day’s bone marrow transplantation is the extensively available stem-cell therapy. Recently tissue engineering is a growing field in biomedical technology that facilitates the repair and regeneration of damaged tissues.

On the basis of their origin, biomaterials can be categorized into two major classes namely natural and synthetic (manmade). Natural biomaterials have been employed since last many years e.g. gelatin, hyaluronic acid, heparin and alginate etc. [20-23]. Moreover, due to their requirement in high quantities, synthetic biodegradable polymers are now in consideration due to ease in manipulation and large-scale production [24].

2. Classification of biomaterials:

In nature, a number of materials are available in industry along with its alloy but only few of them show biocompatibility, henceforth they exhibit excellent bio-functionality and have potential to employ as future implantation materials [25]. Metals, polymers, ceramics and composites are some of the major classes of biomaterials that are extensively employed in biomedical applications. Some significant characteristics and utility of various biomaterials are explained in Table-1 and Fig-1.

| S. No. | Materials | Advantages | Limitations | Applications |
|-------|-----------|------------|-------------|--------------|
| 1.    | Metals (Ti and its alloy, Ag, Au, Stainless steel etc.) | • Enough vigor  
• Enough stiffness,  
• Outstanding tiredness resistance  
• Enough tensile strain and compressive stress etc. | • Enough elasticity  
• May destroyed by rust,  
• Enough density,  
• complex in preparation | Weight tolerating implants such as bone plates and pins, screws, dental root implants, joint replacements, wires etc. |
| 2.    | Ceramics (Alumina, Zirconia, Hydroxyapatite etc.) | • Ecofriendly to living tissue  
• Enough vigor and firmness  
• Enough resistance to rust and wear  
• Less density | • Hard  
• Not flexible  
• Less tiredness resistance  
• Variable mechanical vigor | Covering for load bearing implants, medical sensors, dental and orthopedic implants etc. |
3. Polymers (Nylon, silicon, polyester etc.)
   - Ecofriendly to living tissue
   - Enough resilience
   - Less load
   - Simple to construct
   - High resistance to rust
   - Less vigor
   - Variation in shape
   - Chance of degradation
   - Contact lenses socket, heart valves, blood vessels, artificial hearts, hip joint etc.

4. Composites / Bio composites
   - Physically powerful
   - Enough resistance to rust and wear
   - Ecofriendly to living tissue
   - Required steadiness/homogeneity
   - Not easy to construct
   - Joint replacements, bone cement, Dental implants.

Table-1: Biomaterials Classification: Their Properties and usefulness

3. Characteristics of biomaterials:
The requirement of designing and selection criteria of biomaterial depends upon the type of medical application. The biomaterial must have some unique characteristics that can have potent application in biomedical field for longer duration without immune rejection (Fig-1). Some of these characteristics are described here [26,27]-
1. Outstanding biocompatibility
2. Sufficient mechanical properties
3. High quality physical and chemical properties
4. Enough resistance to wear
5. Enough resistance to rust
6. Osseo-integration (For bone implants)

4. Applications of biomaterials:
Biomaterials play an important role in diverse fields like in medicines, food manufacturing units, pharmaceutical companies, fashion designing and other household appliances. In the area of medical
In sciences, biomaterials are significantly applied in dental fixture fabrication, implants, prosthesis and tissue scaffolds. In pharmaceutical sector, in addition to the production of tablets and capsules these biomaterials are employed in the designing of customized implants for drug delivery [28]. Henceforth, these biomaterials are applied as per the application and requirement of the impaired/injured tissue e.g. biomaterials applied for the dental and orthopedic purpose must have extended shelf life in addition to having potent mechanical vigor. While on the other hand, the biomaterials required for skin and visceral organ should posse’s flexibility with higher rates of degradation. Various applications of some biomaterials are given in the table-2.

| S. No. | Problem area                      | Examples                                      |
|-------|----------------------------------|-----------------------------------------------|
| 1     | Substitution of damaged part     | Kidney dialysis machine and hip joint         |
| 2     | Support in healing               | Bone plates, screws and sutures.              |
| 3     | Helps in prophylaxis             | Catheters, drains                             |
| 4     | Helps in analysis                | Catheters and Probes                          |
| 5     | Accurate cosmetic problem        | Augmentation mammoplasty, chin augmentation   |
| 6     | Accurate functional defect       | Harrington spinal rod                         |
| 7     | Improve function                | Cardiac pacemaker, contact lens               |

Table-2: Applications of Biomaterial [29]

4.1 Cardiovascular biomaterials-
There are certain cardiac disorders that drastically influence the quality of human life and such disorders are not able to treat by using medicines alone. Therefore, there is an urgent need for some supportive therapy which helps in improving the condition of the patient. Such an emerging therapy is the use of ‘biomaterials’. In cardiac disorders, these biomaterials can be helpful in successfully constructing and implanting heart valves and vascular grafts. Such materials that are being applied as implant in such cardiac disorders and effectively cooperate with biological machinery are called cardiovascular biomaterials (CB).

Due to the success of these cardiovascular biomaterials, these are in great demand now days. These cardiovascular biomaterials can be classified into following three categories namely metals, polymers and biological materials. The characteristics of the cardiovascular biomaterial used, depends upon the type of impairment/injury e.g. during cardiac damage, polymers have been the choice of treatment but blood compatibility may cause problem. Hence, some new technologies like surface modifications are now implemented and explored to overcome this problem.

4.2 Blood vessel prostheses/vascular grafts-
For the treatment of impaired/injured blood vessels, most common technology employed is blood vessel prosthesis. In addition to this, vascular bypass, commonly known as vascular graft technology is a surgical procedure in which the impact of blockage minimized by rejoining the blood vessels, so as blood can flow freely from one area to another. It’s a typical process in which the blood flow should be maintained normal between two healthy areas through bypassing the blocked blood vessel(s). For this vascular bypass surgery, the most ideal material used is individual’s own vein (autograft) or donor vein (allograft). In
addition to them polyethylene terephthalate (dacron) and polytetrafluoroethylene, viz., PTFE (teflon) also used frequently.

4.3 Heart valves-
Patients suffering from valvular heart disease are now treated by implanting a machine i.e. artificial heart valve. This condition has occurred when any one heart valve out of four impaired in its functioning. On the basis of their function, these artificial heart valves have been classified into two types namely biological and mechanical. Biological valves are made up of either from the elements of biological origin or from the synthetic materials like PTFE, Dacron etc. While on the other hand mechanical heart valves are manufactured from polymers, metals and ceramics e.g. stainless steel, titanium, silicone and pyrolytic carbon. Recently transcatheter aortic valve implantation achieved by fabrication from metals, ceramics, and polymers (titanium, stainless steel, Dacron) and biological material (pig heart valve) [30].

4.4 Stents-
A stent is used to open/bypass the blocked blood vessels carrying the oxygenated blood to the heart. These stents are inserted into the lumen of the blood vessels and may be metallic or plastic in nature. On the basis of the requirements, stents are of different types like urethral stents, coronary stents, prostatic stents, vascular stents, esophageal stents, and biliary stents [31]. On the basis of physical and functional uniqueness, these stents may be grouped into three categories like bare-metal stents (BMS), drug-eluting stent (DES), and bioabsorbable stents [31].

4.5 Cochlear replacements-
The individuals suffering from sensorineural loss of hearing may be treated by using cochlear replacement therapy. Actually this cochlear implant is a neuroprosthetic appliance that switches sound into electrical signals that excite the auditory nerve. This cochlear appliance is implanted in the individuals with sensorineural loss of hearing through surgery. Cochlear appliance can be divided into two parts; one is sound processor that is the external portion helps in conveying signals from the skin to the implant that contains microphones, electronics including DSP chips, battery, and a coil. Another part is inner component that collect signals and contains a series of electrodes positioned inside the cochlea that excites the cochlear nerve. Some important factor like biocompatibility, sterility and structural damage to tissues must be kept in mind during the cochlear implantation process [32].

4.6 Dental implants for tooth fixation-
Individuals suffering from dental problems like bridge, crown, denture, and facial prosthesis or functions as an orthodontic anchor etc. may undergo dental implantation process as a treatment therapy. This dental implant technology also known as endosseous implant/fixture is very successful and unique therapy that interfaces with the bone of the jaw or skull to support a dental prosthesis.

In the current scenario, Osseointegration process is widely used advance technology for dental implants in which there is a bond formation takes place in between metal and the bone. In this process initially the implant fixture is permitted to osseointegrate and then we add the dental prosthetic to it. In this process the time required for healing process may be variable as attachment of the dental prosthetic to the implant or positioning of an abutment to hold the prosthetic [33]. Biomaterials that are frequently employed for this function contains ceramics (aluminum, titanium and zirconium oxide, bioactive and biodegradable ceramics), metals and alloys (titanium and titanium-6 aluminum-4 vanadium [Ti-6Al-4V], cobalt-chromium-molybdenum-based alloy, iron-chromiumnickel-based alloys) and polymers and composites (PMMA, PE, PTFE, silicone rubber, polysulfone) [33].

4.7 Drug delivery systems-
For making effective formulation of a drug, it should be kept in mind that the active constituent is present at the target site in maximum amount inside the human body. It has been observed in the previous study that in pharma sector the drug delivery system depend on several factors like the delivery device or dosage form, and the active component at the requisite site of action. The consumption of tablets and capsules as conventional dosage is restricted by the requirement of elevated doses that coupled with higher toxicity profiles. To remove this obstacle a novel drug therapy has been developed. In novel drug therapy the active ingredient is modulated in such a way that it confers maximum advantage to the target site and side effects get minimized. Some examples based on this therapy comprises of nanoformulations, liposomes, microspheres and osmotic drug delivery systems. These can be applied as oral administration or parenteral use. Mucoadhesive drug delivery system is another example that based on transdermal applications [34].

4.8 Artificial ligaments and tendons-
There are certain connective tissues like tendons and ligaments that provide firmness and support to the musculoskeletal system. When these tendons and ligaments get damaged due to some accident or injury in sports, there is an urgent requirement of implanting with artificial tendons and ligaments. But during this implantation process it should be keep in mind that these artificial tendons and ligaments must have similar structural, functional and biochemical characteristics as the native ones. The biomaterial used in the formation of these artificial tendons and ligaments must have adequate mechanical vigor to tolerate the body weight instant after implantation [35].

4.9 Bone cement-
Bone cement is a biomaterial that is used for filling the gap between the bone and the prosthesis. Basically this bone cement consist of two components namely a powder (pre-polymerized PMMA/PMMA copolymer beads) that acts as an initiator and a liquid (MMA monomer) as an inhibitor. During incorporation of initiator to the accelerator, process of Free radical polymerization is initiated as a result of which the viscosity of the cement changes and it turned into a hard material [36]. Biomaterial that is to be used for filling the gaps must essentially made up of bioresorbable material that also helps in the development of new bone into the damaged area. For bone regeneration, bioceramics that are made up of CaP are most commonly used biomaterial having the characteristics like excellent biocompatibility, osseointegration and osteoconduction [37]. The most common example of CaP is hip implants.

4.10 Joint replacements-
Arthroplasty is the term basically used for Joint replacement surgery in which the dysfunctional joint is replaced with an prosthetic orthopedic. This surgical procedure has applied on hips, fingers, shoulders, knees and ankles. In certain diseases like rheumatoid arthritis and osteoarthritis, this therapy is only available and show good results. Metal and their alloys, composites and ceramics are the some commonly employed biomaterials for such purpose [38]. Metal alloys like titanium alloys, Co-Cr alloys and stainless steel are the best material used for this purpose. The preference is given to cobalt-chromiummolybdenum (CoCr or CoCrMo) and Titanium-6 aluminum-4 vanadium (Ti6Al4V) followed by titanium-aluminum-niobium (Ti6Al7Nb), iron-chromiumnickel (stainless steel, AISI 316 L) and commercially pure titanium (cpTi). Biomaterial that are least frequently used are ceramics (alumina and zirconia) [39].

4.11 Intraocular lenses (iols) for eye surgery-
Usually patients during cataract surgery must be implanted with artificial intraocular lenses [40]. In this surgical process opacified contents in the capsular bag of the cataractous lens are removed and intraocular are incorporated inside the capsular bag for re-establishing the normal refractive power [40]. In this process biocompatibility should be keep in consideration. These lenses are made up of either acrylic or silicone material. On the basis of elasticity, acrylic lenses may be foldable or nonfoldable, while silicon
lenses are foldable. Due to this flexibility, these lenses can be inserted inside the eye through small cut/opening [40].

4.12 Skin tissue substitutes-
Skin is the outermost surface and the largest organ of the human body that helps in defending from the external environment. In certain cases like trauma, self recovery or healing is offered by the stem cells present inside epidermis layer. On the other hand if the damage/injury is deep then regeneration does not take place and some other therapy like skin grafting is needed for its treatment [41]. Most commonly required synthetic skin substitutes are Biobrane®, Alloderm™, Integra® and TransCyte™. However, biological substitutes, also known as tissue engineered skin are cultured cell suspensions/sheets that either used alone or in combination with dermal matrix. Most common example of biological substitutes with allogeneic cells are Dermagraft™, OrCel™, Apligraft™ and with autologous cells is Epicel™ [41].

5. Conclusion-
It has been observed from last few years, that due to biocompatibility and biodegradability, these biodegradable polymers have been frequently applied in biotherapy. Though, after the advancement in newly emerging branches like biotechnology and medical technology have fixed the higher benchmark for these biomaterials. Ideal biodegradable polymers with unique characteristics are of immense value. On comparing natural biodegradable polymers with synthetic biodegradable polymers, it has been observed that synthetic biodegradable polymers have reduced immunogenicity and can be very easy to alter chemically, so, they can be found as a new opportunity for future also. Furthermore, the development and rapid transformation of modern experimental biomaterials into clinical trials also assist in the promotion as well as development of novel biomaterials that may contribute enough in developing competent therapy in the treatment of related infections/diseases.

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