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The development of Biomaterials in Medical Applications: A review

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ABSTRACT

Biomaterials are listed in advanced materials that have high biocompatibility which can easily adapt to the system in which they are implanted without leaving any adverse reactions and side effects. Due to their interesting properties such as biocompatibility, bioactivity, degradability, long-term stability, and many other important properties, all four main types of biomaterials (Bioceramics, Metallic biomaterials, Biopolymers, and Biocomposites) can be used in the medical field, either for medical treatment by implanting them in the human body, or the manufacturing of advanced medical devices. In this review, a comprehensive introduction to biomaterials has been mentioned. Also, the general properties of biomaterials are explained especially these interesting properties that are helpful to use in the medical field. And finally, the medical applications of each of the different types of biomaterials have been reviewed.

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1. INTRODUCTION

Material science plays an important role in the development of modern technology. In all different fields of technology, materials and the use of materials are one of the main necessities of technology. One of the fields that has an important role in human life and helps to sustain life on Earth by overcoming and treating human health issues is the medical or biomedical field. Advanced materials are types of materials that have appropriate properties that help them to be used in the field of medicine and medical inventions[1, 2]. Advanced materials are generally divided into four main groups: biomaterials, smart materials, semiconductors and nanomaterials [3]. Among all of them, biomaterials are the most widely used in the medical field due to several important properties such as biocompatibility, bioactivity, degradability, long-term stability and many other important properties that make biomaterials able to adapt to the environment and organs in which they are implanted as a medical treatment, they can also remain in place for a long time without reducing their activity[4, 5]. And, another property that distinguishes them from other types of advanced materials is that they can be designed to have a desired activation time as cells of the organs or the body that they implanted regenerate, they also deteriorate and disappear so that they do not have to be removed again [6].

Many researchers worked on biomaterials and their importance in technology, especially in biomedical fields. K. P. Valente and co-workers studied the applications of Biocomposites in living tissues [7]. M. C. Biswas, et al. reviewed the applications of biopolymers in biomedical, including drug delivery, infections, tissue engineering, and wound healing [8]. D Shekhawat et al. described the biomedical applications of bioceramics and their composites [9]. Also, HA Zaman and co-workers researched the clinical applications of metallic biomaterials [10].

In this review, a comprehensive introduction to biomaterials is given based on the existing works in the literature on biomaterials and their biomedical applications. Also, the general properties of biomaterials are explained especially these interesting properties that are helpful to use in the medical field. And finally, the medical applications of each of the different types of biomaterials are explained.

2. ADVANCE MATERIALS

Advanced materials are new or significantly improved materials that have more different and distinct advantages than conventional materials in terms of physical or functional performance [11]. Or advanced materials sometimes referred to as conventional materials, support technological development and improve the functionality and efficiency of already-existing products. All sectors are impacted by advanced materials since they not only help create newly developed products but also can improve the functionality of materials and products that already exist [12].

Based on their properties, reaction and adaptation to the environment in which they are used, advanced materials are divided into four main groups.

Biomaterials (they have high biocompatibility with living organs) [4], Semiconductors (they have intermediary properties between conductors and non-conductors) [13, 14], smart materials (modify their characteristics in response to environmental changes.) [15, 16], and Nanoengineering materials (they designed in Nano-scale (less than 100 nm)) [17-19]. This review has been focused on biomaterials (properties, types, and medical applications).

3. BIOMATERIALS

The term "biomaterials" refers to materials that may be applied to the treatment of disease and that are compatible with living tissues [20]. They have particular features such as surface improvements, biocompatibility, and degradability[21]. By offering scaffolds, encouraging tissue growth, and enhancing patient outcomes, biomaterials are essential in regenerative medicine, tissue engineering, and the creation of medical devices [22]. Also, biomaterials are either from nature or synthesized in the laboratory using metals and their alloys, polymers, ceramics, composite materials, and so on. These materials are utilized for medicinal purposes by affecting the entire or a portion of the living systems, therefore performing, augmenting, or replacing a natural function of human physiology. These materials are very complex and sensitive during their application, such as when employed for a heart valve, as hydroxy-apatite coated hip implants, and so on [4].

3.1. PROPERTIES OF BIOMATERIALS

Materials used in medical treatment must have many strong and effective properties so that during their use in the patient's body as a treatment have no side effects for the patient's body and must be able to adapt well to the environment in which they are used. Biomaterials are distinguished by having many important properties that make them very suitable for use in medical treatment as follows.

A-Biocompatibility: When materials come into touch with living organs or cells, they should not cause any toxic or adverse consequences. They should be able to assimilate into the biological environment without making harm, biomaterials have high biocompatibility [23].

B-Bioactivity: Biomaterials can be made to interact actively with cells or tissues in the body. This characteristic can be exploited to encourage the regeneration of tissue or particular biological processes, including the release of growth hormones or the attraction of cells to the area implanted [24].

C-Mechanical Stability: Biomaterials have enough mechanical stability to sustain and endure the physiological stresses and strains of the specified application. Orthopaedic implants, for instance, has mechanically strong enough to withstand the weight and stresses placed on them [25].

D- Degradation Rates: Biomaterials can be designed to degrade over time, that is, as destroyed tissues regenerate, they degrade so that they do not have to be removed from the patient's body again [26].

E-Surface properties: Biomaterials' interactions with cells, tissues, and surrounding fluids can be significantly influenced by the roughness, hydrophobicity, and charge of their surfaces while hydrophilic surfaces can encourage cell spreading and migration, surface roughness can impact cell adherence and reproduction [27].

F- Manufacturing and Processability: Biomaterials can be produced and designed to suit the user's needs. This makes biomaterials more usable and easier to use in medicine than other materials [28].

Long-term Stability: Biomaterials can remain stable for a specified period, and there are no changes in their structure and performance as long as they are specified to remain in the patient's body [29].

G-Cost-effectiveness: Biomaterials are less expensive than other medical substances that are implanted into the patient's body as a medical treatment, which makes them easier to obtain and widely used for medical treatment [30].

3.2. TYPES OF BIOMATERIALS AND THEIR MEDICAL APPLICATIONS.

Biomaterials are generally divided into two main categories natural and synthetic (Figure 3.1). Natural biomaterials including collagen, silk, hyaluronic acid, and chitosan are obtained from natural sources. They can be made from either animals or plants, and they frequently have very good biocompatibility and biological degradation.

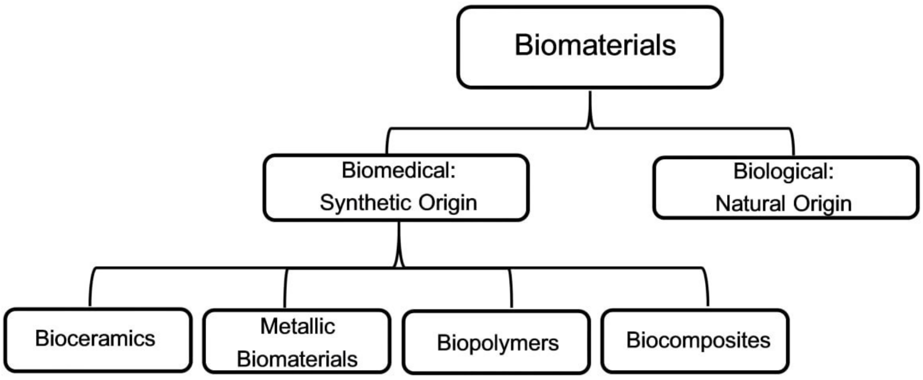

Figure 3.1. *Classification of Biomaterials [31].*

But, synthetic biomaterials could not be obtained from a natural source, they can be obtained by chemical synthesis. In this review, we will focus on the second one, which includes four main types (Bioceramics, Metallic biomaterials, Biopolymers, and Biocomposites), as each of them has its characteristics that contribute to the development of technology [4].

3.2.1. BIOCERAMICS

Bioceramics are types of ceramic materials that are meant to interact with biological systems for medical applications. These materials have received a lot of interest in the field of biomaterials because of their biocompatibility, mechanical characteristics, as well as their ability to tissue repair[32] Bioceramics are implanted in many parts of the human body as treatments in medicine (See Figure 3.2). Bioactive ceramics and bio-inert ceramics are the two primary groups of bioceramics, which serve as replacements for human hard tissues. Surface bioactive ceramics and bioabsorbable ceramics (which break down and become absorbed by cells and substituted by biological tissues) are both types of bioactive ceramics [33].

Bio-inert ceramic materials are materials that remain chemically stable after being implanted into the patient's body, meaning that there are no negative changes in their properties that can cause side effects and the bioceramics will be surrounded by human tissues rather than being ingested by tissue cells or thrown out of the body. These materials primarily consist of glassy carbon, pyrolytic carbon, and -Al2O3 [34].

A bioceramics material is said to be "bioactive ceramics" if some or all of it dissolves or is absorbed by cells in a biological environment and is then replaced by bone to establish a strong connection. These materials primarily consist of tricalcium phosphate, hydroxyapatite, and calcium phosphate glass[35].

Alumina, zirconia, hydroxyapatite, bioactive glass, and calcium phosphate ceramics are some of the most extensively used bioceramics. Because of their excellent strength and wear resistance, alumina and zirconia are ideal materials for dentistry and orthopaedic implantation. [36].

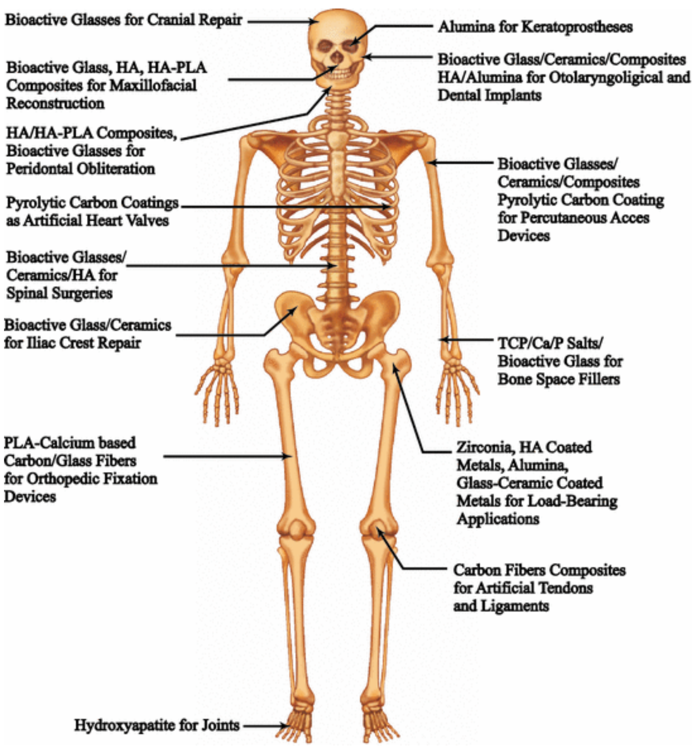

Figure 3.2. *Application of Bioceramics in the Human body [37].*

Due to its strong resemblance to the mineral component of bone and ability to facilitate osseointegration, hydroxyapatite is frequently used as an implant covering and for bone grafting. [38, 39]. Bioactive glass can capture and destroy ions that inhibit bone growth and prevent infection [40], Although biocompatible calcium phosphate ceramics support bone regrowth [41]. Also, Glass-ceramics, carbon-based bioceramics, silica-based bioceramics, and polymer-derived ceramics are other types of bioceramics that can be used in biomedical applications. Dental restorations, drug delivery systems, tissue engineering scaffolds, and biosensing are just a few of the applications for these materials. Bioceramics, due to their adaptability, are an interesting subject for future study and development in medical technology. [42].

3.2.2. METALIC BIOMATERIALS

Metallic biomaterials are types of materials with metallic characteristics that are used in biomedical applications. These materials are often utilized in orthopaedic implants, dental implants, and cardiovascular stents (Figure 3.3). Also, the mechanical strength and durability of metallic biomaterials are their primary advantages [43]. They can endure the body's strains and stresses, offering long-lasting and dependable support. Metallic biomaterials are also biocompatible, which means they are neither harmful nor damaging to live cells and organs [10].

Table 3.1. Types of metallic biomaterials and their applications (FDA is (United States Food and Drug Administration)

Type	Primary Utilizations	References
Stainless steels	Temporary devices(fracture plates,screws,hip nails,etc.) (ClassII)	[44-46]
	Total hip replacements (ClassII)	[47, 48]
Co-bassed alloys	Total joint replacements (wrought alloys)	[49, 50]
	Dentistry castings(ClassII)	[51, 52]
Ti-based alloys	Stem and cup of total hip replacements with CoCrMo or ceramic femoral heads (ClassII)	[53-55]
	Another permanent device (nails, pacemakers) (ClassIII)	[56, 57]
NiTI	Orthodontic dental archwires (ClassI)	
	Vascular stents (ClassIII)	[58-61]
	Vena cava filter (ClassII)	[62, 63]
	Intracranial aneurysm clips (ClassII)	[64, 65]
	Contractile artificial muscles for an artificial	[66]
	heart (ClassIII)	[67]
	Catheter guide wire (ClassII)	[68]
	Orthopaedic staples (ClassI)	[69-72]
Mg	Biodegradable orthopaedic implants (ClassIII)	[73]
Ta	Wire sutures for plastic surgery and neurosurgery (ClassIII)	[74]
	A radiographic marker (ClassII	[75, 76]

In addition, metallic biomaterials have a good resistance to corrosion which is an important behaviour of biomaterials that are used for long-term implant applications. Another advantage of metallic biomaterials is that they can be customized, making them easier and more useful in biomedical applications such as ceramic or polymer coatings to improve their functionality and biocompatibility[77].

In the medical field, metallic biomaterials have been used for developing implanted medical devices, such as structures or surgical implants. These materials are good for load-bearing orthopaedic and dental applications due to their superior mechanical, fatigue, wear, and corrosion features. The main types of metallic biomaterials and their primary applications in the medical field are tabulated in Table 3.1.

The most widely implemented bio-inert metals are surgical stainless steel (316L), cobalt-chromium (CoCr) alloys, and titanium (Ti) alloys (2). Due to their superior mechanical, fatigue, wear, and corrosion resistance, Ti-6Al-4 V alloy [78], 316L stainless-steel (SS) [79], Co-Cr-Mo [80], and nickel-titanium shape memory alloy (NiTi-SMA) [1, 81-92] are frequently chosen over other biomaterials like polymers and ceramics

The history of the use of substances dates back to the early 19th century but was initially only a medical idea until the 1860s when the Lister anaesthetic technique was introduced, since then, the use of substances has begun with implants to treat fractures, rib straightening, and replace total hips (Figure 3.4)[93]. And the use of substances was gradually developed, so that metallic biomaterials (such as NiTi alloy) are used for vascular stents and aneurysm clips (Figure 3.5)[94].

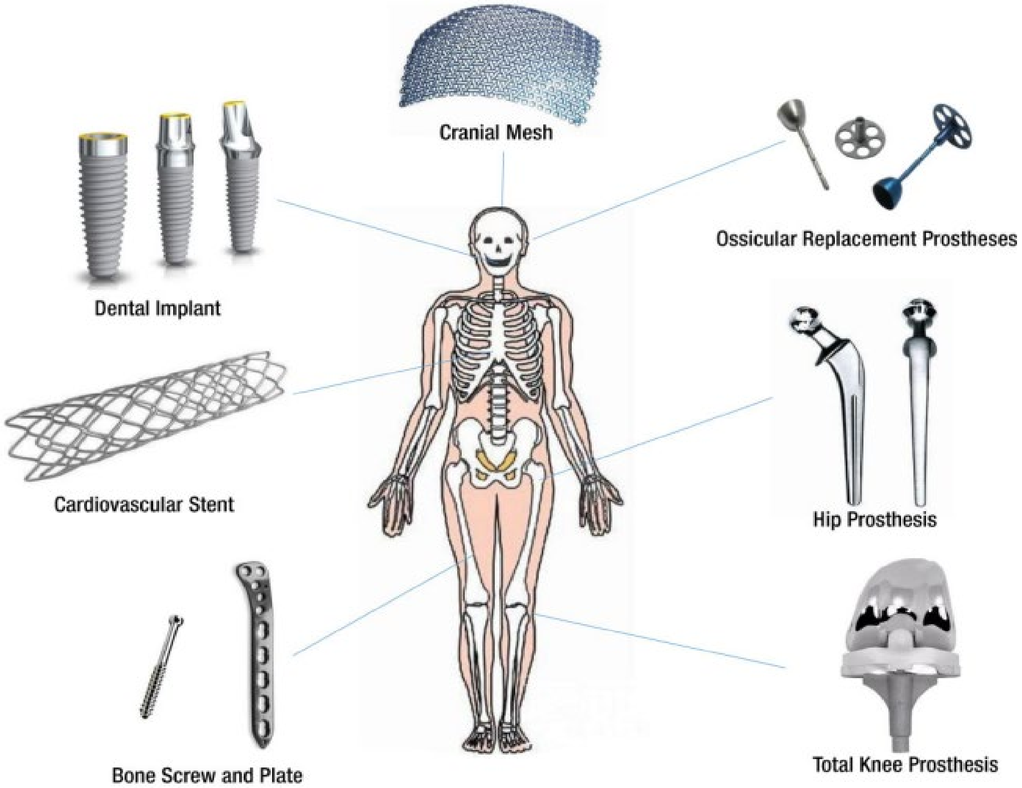

Figure 3.3. *Applications of metallic biomaterials in different positions as medical treatment in the human body [95].*

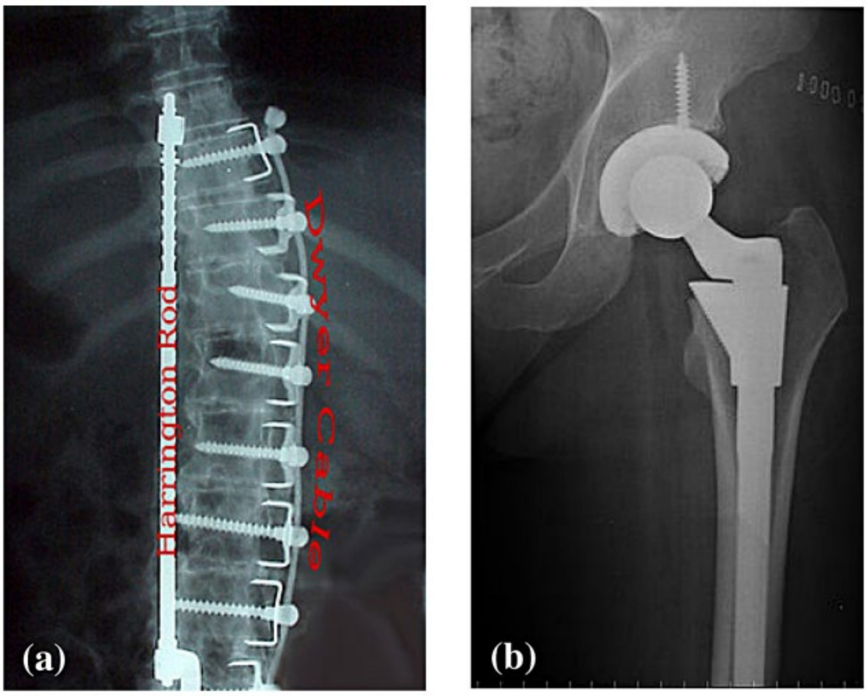

Figure 3.4. *(a) Use of stainless in the ribs straightening, and (b) total hip replacement using stainless, cobalt alloy or titanium alloy [93]*

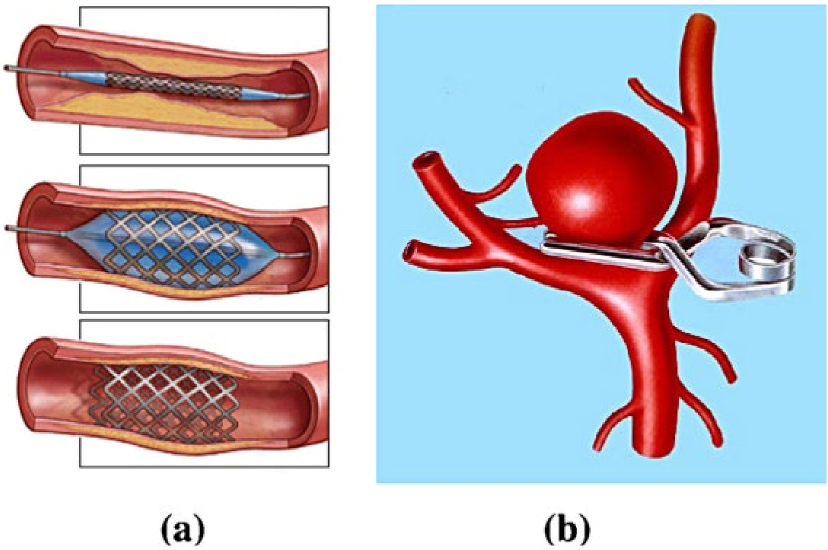

Figure 3.5. *Application of NiTi alloy in (a) vascular stent and (b) aneurysm clip [94].*

3.2.3. BIOPOLYMERS

Biopolymers are organic materials that are produced naturally and come from living things like plants, animals, or microbes. Because they are biodegradable, non-toxic, and have a smaller carbon footprint than synthetic polymers, they are seen as more ecologically friendly options. Biopolymers come in a variety of forms, each with special characteristics and uses. Examples that are often used include DNA, proteins, carbohydrates, and cellulose. These biopolymers may be used to create a variety of materials, including textiles, medical devices, packaging items, and adhesives. Biopolymers are used in a broad variety of applications. For instance, the medical industry uses biopolymers like collagen and chitosan for medication delivery and tissue engineering.

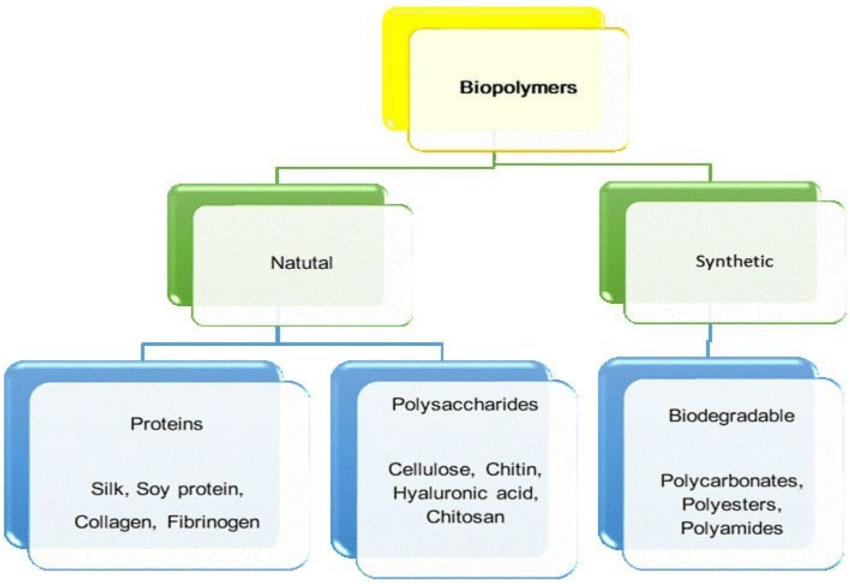

Figure 3.6. *Types of biopolymers[96].*

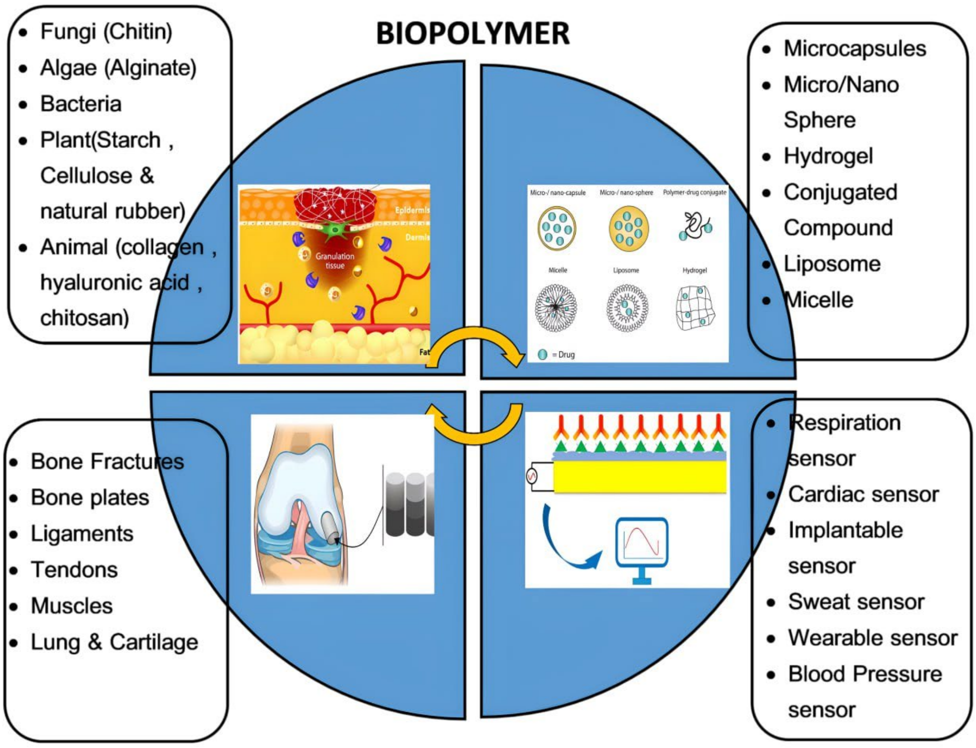

Figure 3.7. *medical applications of biopolymers [8]*

Biopolymers have three main groups (Figure 3.6). The materials that are used in medical treatment must be biocompatible to avoid any side effects on the patient's body. Most Biopolymers are biomaterials that have high biocompatibility and therefore have important and well-known uses in medicine, both as implants and in the manufacture of medical devices. In addition to biocompatibility, biopolymers have many other unique properties such as bioactivity, long-term Stability, biodegradation, non-toxicity, and so on. These behaviours make them desirable for applications in many fields, especially in medicine as shown in Figure 3.7.

Figure 3.7 demonstrates the common medical applications of biopolymers which each of them have been clarified depending on the literature including:

Tissue engineering: In tissue engineering, biopolymers are used to build scaffolds that can help the growth of cells and tissues. Artificial organs, skin, bone, and cartilage may be performed with biopolymers. [97]. Chitosan, alginate, collagen, and hyaluronic acid are biopolymers that have been utilised in tissue engineering. [98, 99]. They've been employed in a variety of tissue engineering applications, including suturing, fixing, adhesion, covering, occlusion, isolation, contact inhibition, cell proliferation, tissue guidance, and controlled drug delivery.[100].

Medical devices: The production of medical devices might use biopolymers as a component material. Molecular weight, lubricity, material chemistry, water absorption degradation, form and structure, solubility, hydrophilicity/hydrophobicity, erosion process, and surface energy are the most appropriate features for recommending these biomaterials to use in medical devices [101]. Implants, wound dressings, tissue scaffolds, and drug delivery systems are medical devices that can be manufactured based on biopolymers [102].

Wound healing: alginate, chitosan, collagen, hyaluronic acid, and silk fibroin are the most suitable types of biopolymers that can be used in wound healing, which they can be used in wound dressings, hydrogels, and scaffolds to promote wound healing [103, 104].

Drug delivery: Due to their flexibility, biocompatibility, and low toxicity, biopolymers have most applications in drug delivery such as encapsulating agents and solid monolithic matrix systems [101, 105, 106].

3.2.4. BIOCOMPOSITES

Biocomposites are composites that contain both biological and non-biological components. Natural fibres, such as plant fibres or wood fibres, are often combined with a polymer matrix to create them. The natural fibres give the composite strength and rigidity, while the polymer matrix acts as the binding material. Biocomposites have a wide range of uses, including building materials, automotive components, Bioapplications, and consumer products. They have several advantages over standard composites, including decreased weight, enhanced sustainability, and less harmful effects on the environment. Furthermore, Biocomposites have the potential to be biodegradable, giving them a more ecologically friendly option to synthetic composites [107].

Also, Biocomposites have several different types including [108]:

Basic biomaterials: Polylactic acid (PLA), polyglycolic acid (PGA), and polycaprolactone (PCL) are examples of basic biomaterials that are used to create Biocomposites. These elements are biocompatible and biodegradable, which makes them appropriate for use in medical implants.

Silk fibroin/alginate mix sponge: This type of biocomposite has applications in tissue engineering and wound healing. The silk fibroin gives mechanical strength, whereas the alginate gives a hydrophilic environment for cell development.

Biocomposites use natural fibre reinforcement: such as cellulose, chitin, and lignin. Low cost, density, and biodegradability, make them suitable for use in medical implants.

Organic/inorganic hybrid biocomposites: These biocomposites are made up of organic and inorganic components like hydroxyapatite and collagen. They might be used in bone regeneration and orthopaedic implants.

Nanocellulose composites: they are made up of cellulose nanofibers and a polymer matrix.

They may find use in wound healing and tissue engineering.

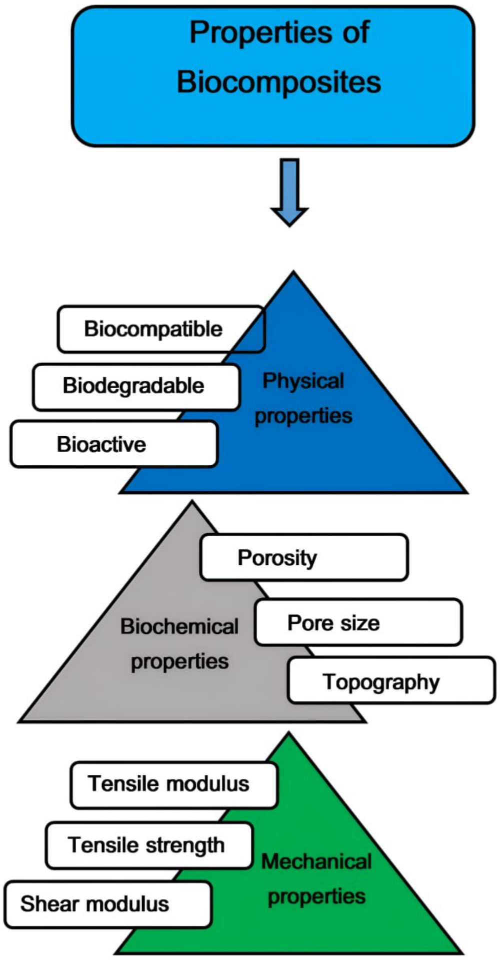

Figure 3.8. *Properties of Biocomposites.*

The main important properties of Biocomposites are demonstrated in Figure 3.8. As with other types of biomaterials, biocomposites have many important applications in medical treatment due to their suitability for use in that field based on their unique qualities explained in Figure 3.9.

The most important applications of Biocomposites are shown in Figure 3 which are their use for bone regeneration, orthopaedic, wound healing, and tissue engineering [7].

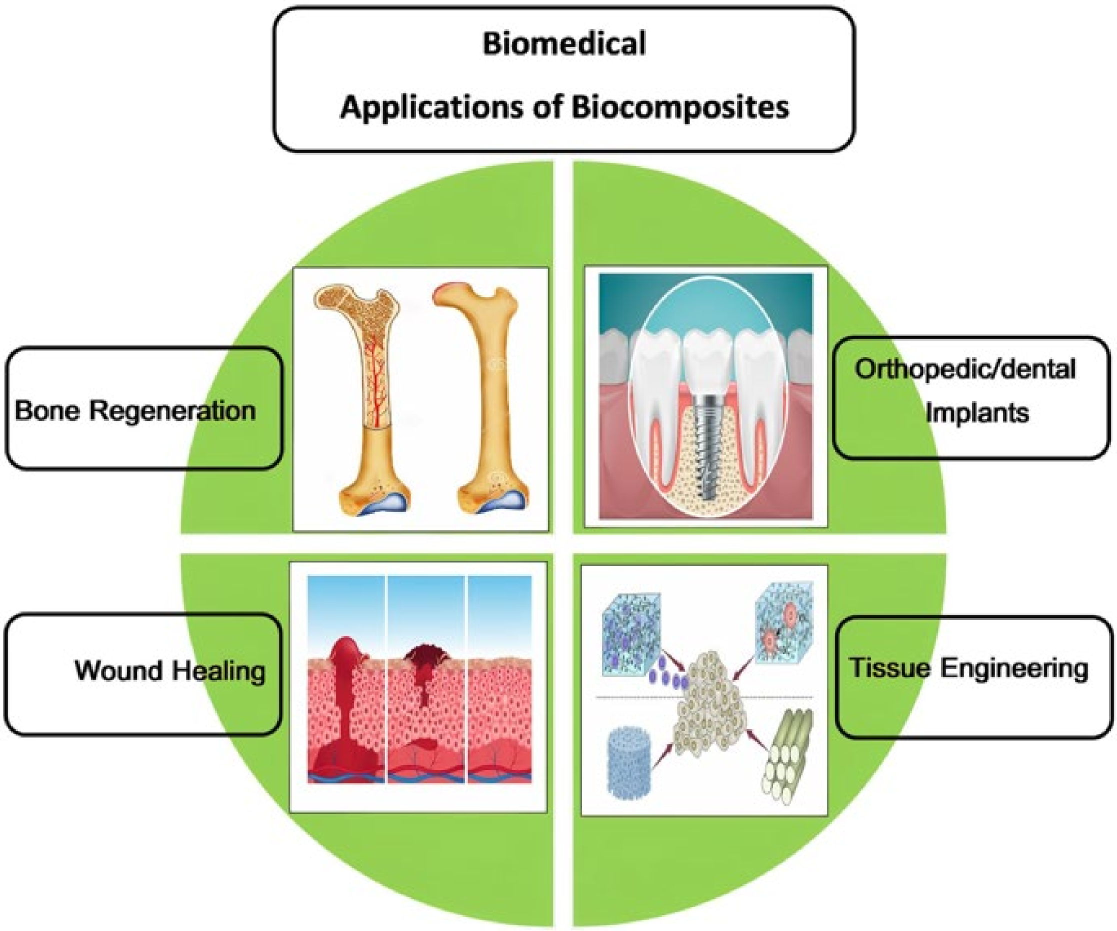

Figure 3.9. *Biomedical applications of Biocomposites [7].*

4. CONCLUSSION

Biomaterials are a group of advanced materials that have some attractive properties that are helpful to the development of biomedical technology, such as biocompatibility, bioactivity, biodegradation, long-term stability and many other important properties that make them adaptable to the environment in that they are implanted as medical treatment and can remain in place for a long time without reducing their activity and without leaving any side effects. There are four main types of biomaterials including Bioceramics, Metallic biomaterials, Biopolymers, and Biocomposites, and each of them has many important applications in the biomedical field, for example, dental restorations, drug delivery systems, tissue engineering, total hip replacements, dentistry castings, ribs straightening, wound healing, bone regeneration, and many other important applications.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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