

Biomaterials for Various Healthcare and Biomedical Engineering: Systematic Review

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Abstract - The history of biomaterials dates back to the mists of time: human beings had always used exogenous materials to facilitate wound healing and try to restore damaged tissues and organs. Nowadays, a wide variety of materials are commercially available and many others are under investigation to both maintain and restore bodily functions. Emerging clinical needs forced the development of new biomaterials, and lately discovered biomaterials allowed for the performing of new clinical applications. The definition of biomaterials as materials specifically conceived for biomedical uses was raised when it was acknowledged that they have to possess a fundamental feature: biocompatibility. At first, biocompatibility was mainly associated with biologically inert substances; around the 1970s, bioactivity was first discovered and the definition of biomaterials was consequently extended. At present, it also includes biologically derived materials and biological tissues. The present work aims at walking across the history of biomaterials, looking towards the scientific literature published on this matter. Finally, some current applications of biomaterials are briefly depicted and their future exploitation is hypothesized.

keywords: titanium and titanium alloys, stainless steel, cobalt-chromium alloys, ceramic biomaterials, peek, bioactive glass, zirconia.

INTRODUCTION

The use of the word “biomaterials” had been largely anticipated by the practical use of materials as biomaterials. Indeed, the presence of exogenous materials in the human body can be dated back to prehistory. The spear point embedded in the hip of the Kennewick Man (around 7000 BC) and the use of carbon particles for tattooing are examples of foreign bodies that had been tolerated by the host. It is also well known that linen threads were used by Ancient Egyptians to facilitate wound healing as much as 4000 years ago; catgut was applied as suturing material by Europeans in the Middle Ages. In South Africa and India, the heads of large, biting ants were exploited to clamp wound edges together. An interesting historical review on materials for suturing was published by Muffly, Tizzano and Waters. Metallic sutures go back to Ancient Greece, when the physician, surgeon and philosopher Galen of Pergamon (II century AC) described golden wires used as ligatures. Over the centuries, other metals have been exploited: lead and silver

among others, with and without evidence of adverse reactions [1].

Cases of intended applications of non-biological materials to repair bone tissue can be attributed to Inca surgeons, who repaired cranial fractures with golden plates; moreover, ancient Mayan populations used seashells to create artificial teeth, which properly achieved osseointegration. Moreover, 4000 years ago the Chinese carved bamboo sticks in the form of natural teeth to be inserted into jaws just like current dental implants. Egyptians used precious metals for dental implants [2]. More recently, iron was utilized to produce artificial teeth in Europe (around 200 AC). A timeline illustrating the most important milestones in the history of biomaterials is depicted in lists some of the most relevant applications of biomaterials for clinical use [3].

Detailed review:

TITANIUM AND TITANIUM ALLOYS

Titanium and its alloys have been widely used as biomaterials for medical implants and prosthetics due to their excellent mechanical properties, corrosion resistance, and biocompatibility. Titanium alloys, such as Ti-6Al-4V, have been used for orthopedic implants, dental implants, and cardiovascular implants. The high strength-to-weight ratio, low modulus of elasticity, and excellent fatigue resistance of titanium alloys make them ideal for load-bearing applications. [6] Additionally, titanium alloys have been shown to be biocompatible and non-toxic, with a low risk of adverse reactions. However, the high cost of titanium alloys and the potential for corrosion in certain environments are limitations to their use.

STAINLESS STEEL

Stainless steel is another widely used biomaterial for medical implants and prosthetics. The most commonly used stainless steel alloys for biomedical applications are 316L and 304L. These alloys have excellent corrosion resistance, high strength, and good ductility. Stainless steel implants have been used for orthopedic, dental, and cardiovascular applications.

[4] However, stainless steel has a higher modulus of elasticity than titanium alloys, which can lead to stress shielding and bone resorption. Additionally, stainless steel implants can be prone to corrosion in certain environments, which can lead to the release of toxic ions.

COBALT-CHROMIUM ALLOYS

Cobalt-chromium alloys are widely used for orthopedic and dental implants due to their high strength, corrosion resistance, and biocompatibility. These alloys have a high modulus of elasticity, which can lead to stress shielding and bone resorption. However, they also have excellent wear resistance and a low risk of corrosion. [4] Cobalt-chromium alloys have been used for hip and knee replacements, as well as dental implants. However, the potential for toxicity and the high cost of these alloys are limitations to their use.

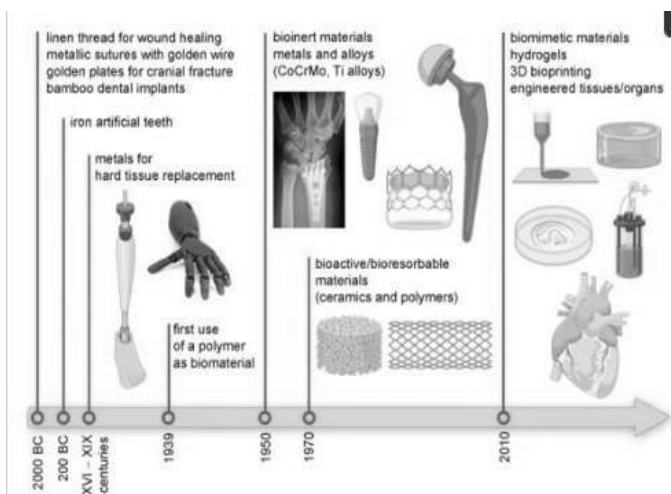


Fig: 1- Biomaterials used in various parts of body.

CERAMIC BIOMATERIALS

Ceramic biomaterials, such as alumina and zirconia, have been used for orthopedic and dental implants due to their high strength, corrosion resistance, and biocompatibility. These materials have a high modulus of elasticity, which can lead to stress shielding and bone resorption. However, they also have excellent wear resistance and a low risk of corrosion. [8] Ceramic biomaterials have been used for hip and knee replacements, as well as dental implants. However, the brittleness of these materials and the potential for fracture are limitations to their use.

POLYMERIC BIOMATERIALS

Polymeric biomaterials, such as ultra-high molecular weight polyethylene (UHMWPE) and polyetheretherketone (PEEK), have been used for orthopedic and dental implants due to their excellent mechanical properties, biocompatibility, and low cost. These materials have a low modulus of elasticity,

which can reduce the risk of stress shielding and bone restoration [9]. However, they also have a higher risk of wear and corrosion than metal biomaterials. Polymeric biomaterials have been used for hip and knee replacements, as well as dental implants. However, the potential for degradation and the limited durability of these materials are limitations to their use.

HYDROXYAPATITE AND TRICALCIUM PHOSPHATE

Hydroxyapatite and tricalcium phosphate are calcium phosphate-based biomaterials that have been used for orthopedic and dental implants due to their excellent biocompatibility and osteoconductivity. These materials have a high surface area and a porous structure, which can promote bone growth and integration. However, they also have a low mechanical strength and a high risk of degradation. [10] Hydroxyapatite and tricalcium phosphate have been used for bone grafting and tissue engineering applications. However, the limited mechanical properties and the potential for degradation are limitations to their use.

BIOACTIVE GLASS

Bioactive glass is a type of biomaterial that has been used for orthopedic and dental implants due to its excellent biocompatibility, osteoconductivity, and ability to promote bone growth. Bioactive glass has a high surface area and a porous structure, which can promote bone growth and integration [11]. Additionally, bioactive glass has been shown to have antimicrobial properties, which can reduce the risk of infection. Bioactive glass has been used for bone grafting and tissue engineering applications.

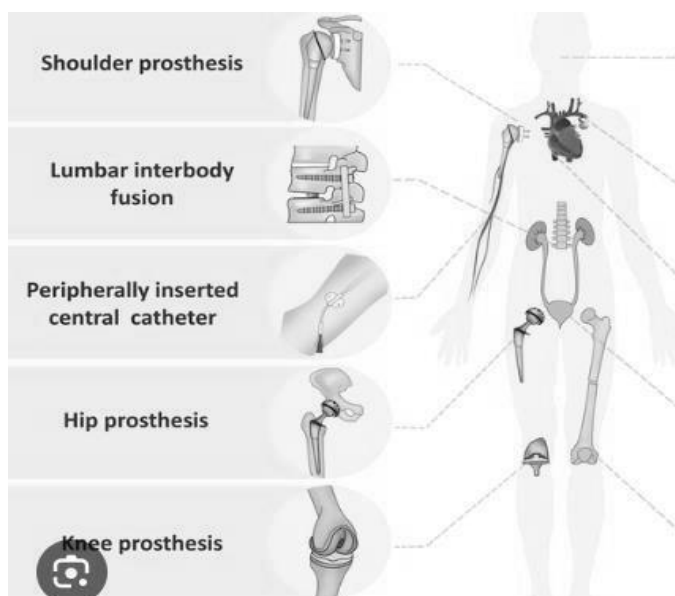


Fig: 2- Bioactive glass for orthopedic implants.

In conclusion, each biomaterial has its own unique properties and limitations, and the choice of biomaterial for a specific

application depends on the required mechanical properties, biocompatibility, and cost. The development of new biomaterials and the improvement of existing ones are ongoing

ZIRCONIA

Zirconia, composed of 95% highly sintered zirconium oxide, partially stabilized with 5% yttrium oxide, has high toughness because its microstructure is totally crystalline and it has a reinforcement mechanism called resistant transformation. Its translucency is only 30%. It has fracture toughness above 700 MPa and flexural strength between 1000 and 1500 MPa, but ceramic coating with conventional feldspathic ceramic improve its opaque appearance considerably decreases its toughness [13]. Recent studies have shown that zirconia surfaces accumulate less bacteria than pure commercial titanium, It has also been demonstrated in various studies the high tissue biocompatibility and good tolerance of ZrO₂ after subcutaneous placement for a period of six to twelve months [14]. Zirconium or zirconium (Zr) is a chemical element of atomic number 40 and atomic weight 91.22 located in group 4 of the periodic table of the elements. It is a hard, grayish-white, corrosion-resistant metal. The most important minerals in which it is found are zircon (ZrSiO₄) and baddeleyite (ZrO₂). Partially stabilized zirconia represents a high resistance to temperature changes, therefore it is an appropriate consequence for its use as a ceramic material in dental technique since high temperatures are required. Studies show that a pronounced anatomical framework design and a prolonged cooling period lead to a significant reduction in the fracture rate of single crown veneering ceramics in the posterior sector [15]. The use of fully anatomical zirconia crowns in the posterior sector is a novel option. The elimination of the possibility of a fracture produced at the junction of the veneering ceramic is a clear advantage. Zirconium is high strength, besides having a 100% biocompatible, in modern dentistry, most commonly used in what are: "interarticular posts, crowns and bridges P.P.F." adaptable for each patient.

CONCLUSION:

The significance of biomaterials in medical implants and prosthetics lies in their ability to restore function and improve quality of life for patients. Effective biomaterials can promote tissue integration, reduce inflammation, and prevent infection. They can also withstand mechanical stress and corrosion, ensuring long- term durability. The use of biomaterials has

areas of research, with the goal of creating biomaterials that can mimic the natural properties of tissues and promote optimal tissue integration and regeneration.

revolutionized the field of medicine, enabling the development of implantable devices such as pacemakers, hip replacements, and dental implants. Overall, biomaterials play a crucial role in modern medicine, enhancing patient outcomes and improving healthcare. Their effectiveness has been demonstrated through numerous clinical trials and studies. By advancing biomaterials research, we can continue to improve patient care and develop innovative medical solutions.

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