Biomaterial Based Nanostructured Orthopaedic Implants for Medical Applications

Aakansha Soy[1], Sutar Manisha Balkrishna[2]

[1]*Assistant Professor, Department of CS & IT, Kalinga University, Raipur, India.*
[2]*Research Scholar, Department of CS & IT, Kalinga University, Raipur, India.*

Biomaterials are non-viable materials that have been designed to interact with biological systems for a therapeutic (to treat, augment, repair, or replace a tissue function of the body) or diagnostic (to improve human health) purpose. Biomaterials are materials, either synthetic or natural, inorganic or organic, that prolong the useful life of vital bodily components. In order to prevent negative effects on the physiological body, a biomaterial used in biomedical applications must be chemically inert, nonimmunogenic, and able to operate safely and dependably in the tissue environment. A biomaterial should also not be poisonous and exhibit the proper host reaction for the intended use. Therefore, orthopaedic biomaterials are made to be implanted in the human body as parts of devices intended to carry out specific biological tasks by replacing or mending various tissues, including bone, cartilage, ligaments, and tendons, as well as by directing bone repair when required.

Keywords: Biomaterial, nanotechnology, Health, orthopaedic.

1. Introduction

Biomaterial is any material (not food or medication) or mixture of materials, synthetic or natural, that is engineered to take a form that can be used alone or in conjunction with other elements of a complex system to control interactions with biological systems in order to direct the course of any therapeutic (treat, augment, repair, or replace a tissue function of the body) or diagnostic procedure in human or veterinary medicine [1]. Devices designed to cure malformed human body parts with biomaterials as its component may either strengthen or replace missing or deformed bones, cartilages, ligaments, or tendons [4]. Biomaterials also include biological materials like bone allografts. Prostheses or implants are the terms used to describe the biomaterial devices used in orthopaedics [5]. Because humans are born with diseases like congenital heart disease and suffer from illnesses that last until death, biomaterials have remained essential to humankind [9][3]. Chronic arthritis mostly affects the elderly, while it can sometimes strike younger individuals; in spite of its widespread occurrence and significant scientific progress, the aetiology of arthritis is still unknown [13].

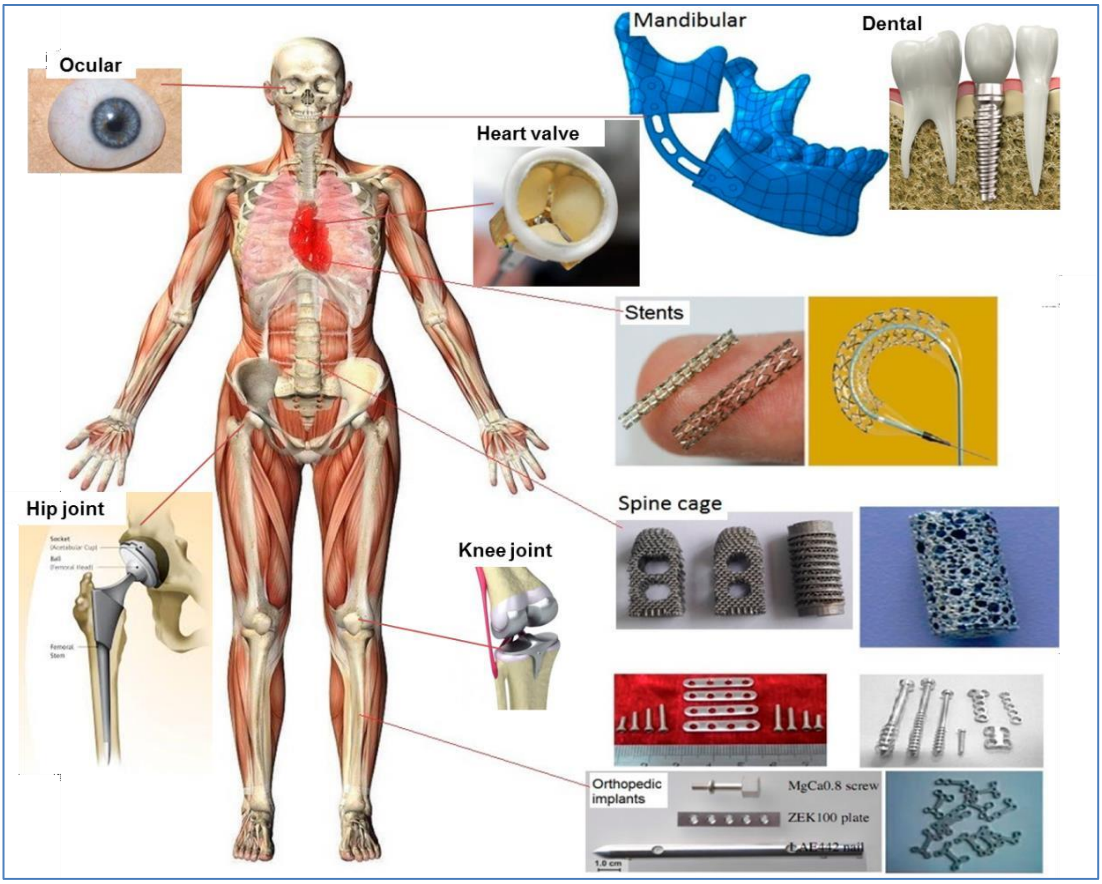

Figure 1: Implants used in different places of human body

Because this condition shortens the lives of individuals affected, many choose replacements in order to alleviate excruciating pain and immobility [2]. In addition to the sick, young, active individuals like athletes and those who use large machinery or drive cars frequently require implants because the incidence of accidents is rising quickly [6]. Improved biomaterials were desperately needed, particularly in the wake of the world wars and in light of the recent worldwide terrorism incident, which suggests that the biomaterials sector will receive much more attention [11].

In this instance, section 1 of the article examines the introduction, while section 2 examines the relevant literature. The purpose of the right to health is explained in Sections 3, and 4, the challenge of the proposed work is discussed in Section 5, and the project is concluded in Section 6.

2. Literature Review

Revision surgery has drawbacks such as a longer recovery period, a lower quality of life and functional outcome, a weaker fixation, and a shorter lifespan [7]. Revision procedures are exceedingly expensive in addition to having an impact on the patients' emotional and physical well-being [12]. As a result of humanity's growing need for implants, research into durable biomaterial implants is rising.

3. Orthopeadic Implants

Millions of people worldwide suffer from degenerative and inflammatory issues related to their bones and joints. In fact, half of all chronic diseases in older adults over 50 in affluent nations are caused by these issues. By 2020, it is expected that the number of people over 50 with bone illnesses will have doubled [8]. Surgery is frequently necessary for certain bone conditions, and in cases of spontaneous joint degradation, total joint replacements may be necessary. In addition, a variety of chronic, transient, or biodegradable illnesses must be treated to address musculoskeletal issues such as low back pain, scoliosis, osteoporosis, and multiple fractures caused by accidents. Thus, it is anticipated that orthopaedic biomaterials would be inserted into the human body as components of devices meant to carry out specific biological tasks by taking the place of or replacing various tissues, including bone, ligaments, cartilage, and tendons, as well as mending bone when needed.

Figure 2: Orthopaedic Implants

Orthopaedic implants include both permanent implants, such as disc, joint, and plate replacements, and temporary implants, such as bone plates and screws. A vast range of widely used materials, including metals and their alloys, ceramics, resorbable and non-resorbable polymers and composites, different types of hydroxyapatites (HAp), resorbable bioglass, and bone allografts, are utilised in the production of orthopaedic implants. The most often utilised metallic materials in orthopaedic applications are alloys such as Mg, Ta, 316L SS, Co-Cr, Ti, and its alloys, Ni-Ti shape memory alloy, and others.

4. Importance of Orthopedic Implants

Materials for the development of medical devices were as readily available in the 20th century as they were for other industrial uses. Indeed, early surgeons used materials that have a successful track record of industrial use, such as those found in chemical, energy, mechanical, and aerospace, to create their implants. Every day, the prosthetics sector faces more and more demands. According to a recent estimate, the global market for hip and knee implants reached US$14 billion in 2011, and it was predicted to grow by an additional 7% as of right now. The number of hip, knee, and spinal replacements performed is incredibly high among all mechanical prostheses, and it has significantly increased globally over the past 20 years. Based on the statistics gathered, it is estimated that about 1 million hip replacements and 2,50,000 knee replacements are performed year; by 2025, the numbers are predicted to have doubled. According to Nasab et al. (2010), there will be a 174% increase in total hip replacements and a 673% increase in total knee arthroplasties by the year 2030 compared to the current rate. The increasing average life expectancy globally and the reliance of a significant segment of the elderly population on bioimplants for body part replacement or restoration of lost functions are the causes of the orthopaedic industry's expansion. Currently biomaterials have been used successfully to save lives and to restore quality of many people’s life [14].

5. Challenges in Selecting Suitable Implant Materials

The human body's dynamic physiological and biochemical conditions must coexist with the design and selection of appropriate implant materials. The goals of implant material selection should include biocompatibility, device performance, patient comfort, minimising hospitalisation time—that is, the interval between implantation and dentition restoration—and procedure adaptability, which enables patients to lead as normal a life as possible. Because of the intricacies of the human body and the extremely corrosive environment that an implant must endure following implantation, the selection of biomaterials involves extremely strict requirements based on characteristics. Materials are typically chosen based on their biocompatibility, which implies that they should not be irritating, thrombogenic, immunogenic, carcinogenic, or poisonous. Individual variability, including age, sex, general health, co-existing disorders, physical mobility, and lifestyle traits, can significantly influence the implantable medical devices. These factors also determine the patient, for whom the devices will be placed.

The design of the implant, the minimal amount of contact between the implant and the body, the implant's long-term endurance in the musculoskeletal system, the existence or lack of endotoxins and microorganisms, the material's capacity to reduce the rate of bone opposition, roughness and porosity, etc. are all significant considerations that must be made when choosing an implant material [10]. By combining a series of in-vivo and in-vitro tests with standardised tests for biocompatibility, bioactivity, stress shielding, minimising material deterioration (including corrosion, wear resistance, and degradation), and mechanical properties (including fatigue strength, toughness, and wear resistance), it is possible to evaluate the biological behaviour of synthetic implantable materials. While many metals and alloys were generated by the industry, only a small number of them are biocompatible and have the potential to be successful long-term implant materials. The vast majority of orthopaedic medical devices that are sold commercially are made up of these parts. Based on their primary alloying components, these orthopaedic materials can be broadly divided into four groups: stainless steels, cobalt-based alloys, titanium-based alloys, and other miscellaneous alloys such NiTi, Mg, and Ta alloys, etc. The United States Food and Drug Administration (FDA) approved a number of medical devices made of the metallic materials in the first three groups mentioned above in 2011, and orthopaedic practitioners commonly utilise these devices. Due to their distinctive material qualities (such as shape memory NiTi and degradability Mg alloys), which may be able to satisfy possibly more specialised tissue requirements, the materials in the last group mentioned above have just lately been produced. However, a number of medical implants manufactured with these recently created alloys have not yet received FDA approval because of serious fundamental concerns related to biocompatibility.

6. Conclusion

Permanent implants used to replace hip, knee, spinal, shoulder, toe, finger, etc. are classified as orthopaedic implants. Temporary implants like plates and screws are also included in this category. The two types of corrosion that affect temporary implants are pitting corrosion on stainless steel implants and crevice corrosion at protected areas in screws and plates. Orthopaedic implant failure is mostly caused by wear, which is also known to hasten corrosion. Therefore, it is advisable to use wear-resistant ceramics for fabricating orthopaedic implants. Only the femoral component of hip implants is made of Ti-based alloys; the head is composed of strong ceramic or Co-Cr alloy, and in some cases, cement is applied to provide a good fix. The distribution of corrosion products from these orthopaedic implants into the body is still a significant concern. The orthopaedic implants' mechanical working environments within the human body are quite intricate. The fatigue strength of skeletal bone implants, such as prosthetic knee and hip joints and spinal plate and wire fixation, is a problem. Compared to the patient's body weight, the loading stress level in artificial hip joints is many times higher.

References

1. Maher, Shaheer, Gagandeep Kaur, Luis Lima-Marques, Andreas Evdokiou, and Dusan Losic. "Engineering of micro-to nanostructured 3D-printed drug-releasing titanium implants for enhanced osseointegration and localized delivery of anticancer drugs." ACS Applied Materials & Interfaces 9, no. 35 (2017): 29562-29570.
2. Wang, Quan, Yixing Huang, and Zhiyong Qian. "Nanostructured surface modification to bone implants for bone regeneration." Journal of biomedical nanotechnology 14, no. 4 (2018): 628-648.
3. S. Neelima, Manoj Govindaraj, Dr.K. Subramani, Ahmed ALkhayyat, & Dr. Chippy Mohan. (2024). Factors Influencing Data Utilization and Performance of Health Management Information Systems: A Case Study. Indian Journal of Information Sources and Services, 14(2), 146–152. https://doi.org/10.51983/ijiss-2024.14.2.21
4. and osteogenic titanium implants." Coatings 10, no. 8 (2020): 756. Ishak, Mohd I., Xiayi Liu, Joshua Jenkins, Angela H. Nobbs, and Bo Su. "Protruding nanostructured surfaces for antimicrobial

5. Frank, H., Lueger, M., & Korunka, C. (2007). The significance of personality in business start-up intentions, start-up realization and business success. Entrepreneurship & Regional Development, 19(3), 227–251. https://doi.org/10.1080/08985620701218387.
6. Chen, Ming-qi. "Recent advances and perspective of nanotechnology-based implants for orthopedic applications." Frontiers in Bioengineering and Biotechnology 10 (2022): 878257.
7. Alamer, L., Alqahtani, I. M., & Shadadi, E. (2023). Intelligent Health Risk and Disease Prediction Using Optimized Naive Bayes Classifier. Journal of Internet Services and Information Security, 13(1), 01-10.
8. Limongi, Tania, Luca Tirinato, Francesca Pagliari, Andrea Giugni, Marco Allione, Gerardo Perozziello, Patrizio Candeloro, and Enzo Di Fabrizio. "Fabrication and applications of micro/nanostructured devices for tissue engineering." Nano-micro letters 9 (2017): 1-13.
9. Jaggessar, Alka, Hesam Shahali, Asha Mathew, and Prasad KDV Yarlagadda. "Bio-mimicking nano and micro-structured surface fabrication for antibacterial properties in medical implants." Journal of nanobiotechnology 15 (2017): 1-20.
10. Lomotey, R.K., & Deters, R. (2013). Facilitating Multi-Device Usage in mHealth. Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications, 4(2), 77-96.
11. Kumar, Sandeep, Monika Nehra, Deepak Kedia, Neeraj Dilbaghi, Kumar Tankeshwar, and Ki-Hyun Kim. "Nanotechnology-based biomaterials for orthopaedic applications: Recent advances and future prospects." Materials science and engineering: C 106 (2020): 110154.
12. Li, Tao, Karan Gulati, Na Wang, Zhenting Zhang, and Sašo Ivanovski. "Bridging the gap: Optimized fabrication of robust titania nanostructures on complex implant geometries towards clinical translation." Journal of colloid and interface science 529 (2018): 452-463.
13. Jäger, Marcus, Herbert P. Jennissen, Florian Dittrich, Alfons Fischer, and Hedda Luise Köhling. "Antimicrobial and osseointegration properties of nanostructured titanium orthopaedic implants." Materials 10, no. 11 (2017): 1302.
14. Bobir, A.O., Askariy, M., Otabek, Y.Y., Nodir, R.K., Rakhima, A., Zukhra, Z.Y., Sherzod, A.A. (2024). Utilizing Deep Learning and the Internet of Things to Monitor the Health of Aquatic Ecosystems to Conserve Biodiversity. Natural and Engineering Sciences, 9(1), 72-83.
15. Valiev, Ruslan Z., Evgeny V. Parfenov, and Lyudmila V. Parfenova. "Developing nanostructured metals for manufacturing of medical implants with improved design and biofunctionality." Materials transactions 60, no. 7 (2019): 1356-1366.