Biomedical Products and the Importance of Research in Biotechnology

Remus Marcel Farcas[1], Ioan Peț[1*], Gabi Dumitrescu[1], Petculescu-Ciochina Liliana[1], Dorel Dronca[1*], Daniela Moț[1], Mirela Ahmadi[1]

[1]Department of Biotechnlogy, Faculty of Bioengineering of Animal Resources, University of Life Sciences "King Mihai I" from Timișoara, Timișoara – 300645, Calea Aradului 119, Romania

Abstract

Biomedical products, such as orthopaedic prostheses/implants, represent one of the most innovative outcomes of biotechnology research, combining engineering, material science, and biological knowledge to improve patients' quality of life. This paper aims to highlight the importance of research in the development of biomedical devices, with a particular emphasis on orthopaedic implants. Advances in biomaterials, surface functionalization, and tissue integration underscore the crucial role of biotechnology in developing safe, durable, and biocompatible products. The discussion also focuses on how ongoing research is vital for addressing challenges such as infection resistance, mechanical durability, and patient-specific customization, highlighting examples from Stryker – a global leader in medical device manufacturing.

Keywords: biomedical products, orthopaedic prosthesis, biomaterials.

1. Introduction

The global demand for biomedical products has increased significantly in recent decades, driven by the rising prevalence of degenerative diseases, traumatic injuries, and an aging population. According to the World Health Organization, musculoskeletal disorders are among the leading causes of disability worldwide, creating an urgent need for efficient and safe orthopaedic solutions [1]. In this context, orthopaedic prostheses – artificial devices designed to replace damaged or missing bones and joints – play a central role in restoring patient mobility, independence, and overall quality of life. Traditionally, prostheses were conceived mainly as mechanical substitutes, focused on strength and durability. However, advances in biotechnology have shifted the paradigm toward devices that not only replace but also integrate with living tissues. This integration requires careful consideration of material properties, cellular responses, and biomechanical compatibility. Biotechnology provides the tools to investigate how cells interact with implant surfaces, how bioactive coatings enhance osseointegration, and how patient-specific implants can be designed using 3D imaging and additive manufacturing.

At the industrial level, biomedical companies translate biotechnology research into clinical practice. Stryker, one of the world's leaders in medical device manufacturing, has pioneered several orthopaedic innovations, including hip and knee replacement systems, porous titanium implants (Tritanium® technology), and robotic-assisted surgery platforms such as the Mako system. These technologies illustrate how interdisciplinary collaboration between biotechnology, engineering, and clinical sciences can generate products that improve both surgical outcomes and patient recovery. Therefore, the study of biomedical products and the continuous research in biotechnology are not only scientific

* Corresponding author: Ioan Peț, ioanpet@usvt.ro; Dorel Dronca, doreldronca@usvt.ro

priorities but also societal necessities. The following sections analyze how biotechnology contributes to material development, biocompatibility, customization, and the future challenges of orthopaedic prostheses.

2. Materials and methods

This paper is conceived as a review based on a synthesis of scientific literature, industrial reports, and case studies related to biomedical products, with a focus on orthopaedic prostheses/implants. A systematic search of peer-reviewed journals, biotechnology databases, and clinical reports was conducted, emphasizing articles published in the last two decades.

Data were synthesized to illustrate the direct link between biotechnology research and practical outcomes in biomedical product innovation, highlighting clinical benefits, technological challenges, and future perspectives. The selection included peer-reviewed papers from the last 20 years, with a focus on:

- ***Materials used in prosthesis manufacturing*** (metals, ceramics, polymers, composites).
- ***Biotechnological approaches*** (surface biofunctionalization, antimicrobial coatings, stem cell-based strategies).
- ***Clinical perspectives*** (patient outcomes, durability, rejection rates).
- ***Industrial applications from companies*** such as Stryker, which integrate biotechnology research into product development.
- ***Technological innovations*** such as additive manufacturing and nanotechnology.

The methodology involved grouping the data by thematic categories (materials, tissue integration, personalization, and challenges) and synthesizing results to highlight the contribution of biotechnology.

3. Biomedical products and biotechnology

Biomedical products represent one of the most significant achievements of modern biotechnology, as they combine biological knowledge with engineering and material sciences to provide innovative healthcare solutions. Among them, orthopaedic prostheses and implants, cardiovascular stents, dental implants, and tissue scaffolds are widely used to restore or enhance human functions affected by disease, trauma, or degeneration.

Biotechnology contributes to the development of these products by improving material biocompatibility, enhancing tissue integration, and reducing risks such as infection or rejection. For instance, advances in nanotechnology and biofunctional coatings have enabled the design of implant surfaces that stimulate osteoblast proliferation and vascularization [2,3]. Similarly, additive manufacturing techniques informed by biotechnology allow the customization of implants, improving patient comfort and outcomes [4,5].

The integration of living cells, growth factors, and biodegradable polymers demonstrates the potential of biotechnology to create hybrid products that actively participate in tissue regeneration [6]. Industrial leaders such as Stryker have successfully applied these principles in orthopaedic implants and robotic-assisted systems, highlighting how biotechnological research translates into clinical innovation [7].

Overall, biotechnology is not only a scientific driver but also a practical enabler of safer, more durable, and patient-specific biomedical products.

3.1. Advances in biomaterials

One of the most decisive aspects in the design of biomedical products is the choice of materials. The traditional use of stainless steel and cobalt-chromium alloys provided adequate strength and corrosion resistance, yet these materials are associated with ion release and inflammatory responses in some patients [3]. Titanium alloys, particularly Ti-6Al-4V, have become the preferred option because they combine mechanical reliability with excellent biocompatibility. Recent biotechnological research has focused on modifying titanium surfaces at the micro- and nanoscale to improve cellular adhesion and bone regeneration [4].

Ceramics, including alumina and zirconia, are also valuable due to their hardness and wear resistance. They are frequently used in articulating surfaces of hip prostheses, reducing friction and prolonging implant life. Polymers, such as ultra-high molecular weight polyethylene (UHMWPE), are widely employed in joint replacements; recent advances involve cross-linking UHMWPE to

improve resistance to wear particles that can induce osteolysis.
Industrial leaders like Stryker have integrated these findings into their product portfolio. For example, the Accolade II Hip Stem and Triathlon Knee System employ optimized alloys and coatings that support rapid osseointegration while ensuring long-term stability.

3.2. Biocompatibility and tissue integration

Biocompatibility remains a central challenge in orthopaedic product development. An implant must not only withstand physiological loads but also create a favorable environment for bone and soft tissue integration. Biotechnology research has demonstrated that surface chemistry and topography significantly influence protein adsorption and subsequent cell attachment [8].
The development of Tritanium® porous metal technology by Stryker exemplifies this principle. Its highly porous structure mimics the trabecular architecture of natural bone, enhancing vascularization and osteoblast activity [9]. Laboratory studies confirm that such bioinspired designs reduce healing time and improve implant fixation compared to smooth metallic surfaces.
In parallel, advances in biotechnology have introduced biofunctional coatings incorporating growth factors, antimicrobial peptides, or extracellular matrix proteins. These coatings not only accelerate osseointegration but also help mitigate risks of infection, a frequent complication in orthopaedic surgery [10-12].
Biocompatibility and tissue integration are critical determinants of the long-term success of biomedical implants, particularly in orthopaedics. Clinically, a prosthesis/implants must not only provide mechanical stability, but also establish a functional interface with surrounding bone and soft tissue. Poor integration may lead to implant loosening, pain, and revision surgery, which is associated with higher costs and morbidity.
Challenges include the variability of patient responses, as immune activation or chronic inflammation can compromise healing [13]. Surface modifications, such as porous structures or bioactive coatings, have improved outcomes by enhancing osteointegration and reducing fibrous encapsulation [3,7]. Nevertheless, implant-associated infections remain a major complication, requiring innovative antimicrobial strategies [14]. Continuous research in biotechnology is essential to address these challenges and ensure safer, longer-lasting implants.

3.3. Customization and 3D printing

Personalization has become a driving force in biomedical innovation. Additive manufacturing (3D printing) enables the production of implants tailored to individual anatomy, derived from CT or MRI scans [15]. Such customized implants offer superior fit and function, reducing surgical time and improving patient outcomes [6].
Stryker is among the pioneers of medical 3D printing, producing spinal cages and knee replacement components with porous titanium structures that balance strength with biological integration [16,17]. Biotechnology contributes by developing printable biomaterials that combine mechanical performance with bioactivity. Emerging research on bioprinting suggests the possibility of fabricating scaffolds seeded with living cells, opening avenues for hybrid implants that integrate biological and mechanical functionalities [18].

3.4. Challenges and future perspectives

Despite major advances, challenges remain in the development of biomedical products:

- ***Infection risk:*** Prosthesis/implant-related infections occur in up to 2% of hip and knee replacements [7, 19-21]. Research focuses on antimicrobial coatings with silver nanoparticles, chitosan, or antibiotics incorporated directly into implant surfaces.
- ***Durability and wear:*** Mechanical wear releases microscopic particles that can induce inflammation and osteolysis. Biotechnology explores nanostructured coatings and new composite materials to minimize wear [22].
- ***Immune response and rejection:*** Even biocompatible materials can cause chronic immune activation. Genetic and molecular studies help design biomaterials that minimize immune system activation [23].
- ***Cost and accessibility:*** Advanced prostheses and implants remain expensive. Research in biotechnology aims to identify cost-effective biomaterials and simplified manufacturing processes studies help design biomaterials that minimize immune system activation.

Future perspectives include the integration of smart implants equipped with biosensors that can monitor load, healing, or infection, sending data in real time to physicians. Such developments rely heavily on biotechnology research in biosensing and bioinformatics, and companies such as Stryker are already exploring robotic and digital health technologies to enhance clinical outcomes [24].

3.5. Biotechnological impacts on composite orthopaedic implants

Biotechnological research has significantly enhanced the development of composite orthopaedic implants, enabling the integration of advanced materials with diagnostic technologies. Novel composites—such as UHMWPE reinforced with nanoparticles (n-TiO_2, carbon fibers)—have demonstrated improved cell compatibility, antibacterial activity, and structural stability, fostering better implant integration in bone repair [25]. Additionally, the advent of MRI-compatible biodegradable alloys (e.g., Fe–30Mn–6Cu produced by selective laser melting) has ushered in a new era of implants that allow postoperative imaging without safety concerns, while also providing antibacterial function and mechanical performance [26]. Furthermore, Ti–6Al–4V implants doped or coated with bioactive glass composites, fabricated via additive manufacturing, show accelerated early-stage osseointegration, as evidenced in in vivo animal models [27]. Such advances underscore how biotechnology drives the design of smart, safer, and more detectable composite implants.

4. Conclusions

Orthopaedic prostheses and implants exemplify the potential of biotechnology to transform medical practice. Through the combination of material science, biology, and engineering, biomedical products have evolved from simple mechanical devices to highly sophisticated systems that interact with living tissues.

Biotechnology research remains fundamental for improving biocompatibility, ensuring durability, and developing innovative solutions such as personalized implants and biofunctional coatings. Continuous interdisciplinary efforts are necessary to overcome challenges such as infection, immune rejection, and costs.

The future of biomedical products lies in the integration of biotechnology with digital technologies, ensuring that prostheses not only replace but also restore and enhance human function.

Acknowledgements

The authors would like to thank the scientific community in biotechnology and biomedical engineering for the continuous contributions that inspired this review. Special recognition is given to Stryker, whose innovative biomedical products and research initiatives in orthopaedic implants and robotic-assisted systems serve as benchmarks for applied biotechnology.

References

1. * * WHO, Global Burden of Disease Study, World Health Organization Report, 2019.
2. Liu, X., Chu, P.K., Ding, C., Surface modification of titanium, titanium alloys, and related materials for biomedical applications, Materials Science and Engineering: R, 2004, 47, 49–121.
3. Le Guéhennec, L., Soueidan, A., Layrolle, P., Amouriq, Y., Surface treatments of titanium dental implants for rapid osseointegration, Dental Materials, 2007, 23, 844–854.
4. Bartolo, P.J., Kruth, J.P., Silva, J., Levy, G., Malshe, A., Rajurkar, K., Leu, M., Biomedical production of implants by additive manufacturing, CIRP Annals, 2012, 61(2), 635–655.
5. Mota C, Puppi D, Chiellini F, Chiellini E. Additive manufacturing techniques for the production of tissue engineering constructs. Biotechnol Adv. 2020;42:107579.
6. O'Brien FJ. Biomaterials & scaffolds for tissue engineering. Mater Today. 2011;14(3):88–95.
7. Geetha, M., Singh, A.K., Asokamani, R., Gogia, A.K., Ti based biomaterials, the ultimate choice for orthopaedic implants – A review, Progress in Materials Science, 2009, 54, 397–425.
8. Mutlu N, Kurtuldu F, Nowicka A, Liverani L, Galusek D, Boccaccini AR. Morphology and topography of chitosan-Zn complex/PEO fiber mats influence cell viability and attachment. International Journal of Biological Macromolecules. 2025 Jun 1;311:143394.
9. Zhao R, Guo S, Zhang F, Zhang W, Yang D, Yue X, et al. Enhanced energy absorption and low anisotropy of additively manufactured porous Ti-6Al-4V alloy with disordered trapezo-rhombic dodecahedron structures. Additive Manufacturing. 2024 Sep 5;95:104557.
10. Gao TJ, Lindholm TS, Kommonen B, Ragni P, Paronzini A, Lindholm TC. Microscopic evaluation of bone-implant contact between hydroxyapatite, bioactive glass and tricalcium phosphate implanted in sheep

diaphyseal defects. Biomaterials. 1995 Oct 1;16(15):1175–9.
11. Makkar P, Kang HJ, Padalhin AR, Faruq O, Lee B. In-vitro and in-vivo evaluation of strontium doped calcium phosphate coatings on biodegradable magnesium alloy for bone applications. Applied Surface Science. 2020 Apr 30;510:145333.
12. Błoniarz A, Marchewka J, Sitarz M, Drożdż K, Gosiewski T, Brzychczy-Włoch M, et al. Effect of adding selected carboxylic acids to the solution on electrophoretic deposition, adhesion strength, morphology and antibacterial properties of chitosan coatings on titanium. Progress in Organic Coatings. 2024 Apr 1;189:108258.
13. Dada M, Popoola P. Chapter 12 - The design of hybrid polymeric materials for tissue engineering: 3D bioprinting, polymeric protheses, smart polymers, and shape memory polymeric biomaterials. In: Sadiku ER, Aderibigbe BA, editors. Hybrid Polymeric Systems for Biomedical Applications [Internet]. Woodhead Publishing; 2025. p. 499–528.
14. Tande, A.J., Patel, R., Prosthetic joint infection, Clinical Microbiology Reviews, 2014, 27(2), 302–345.
15. von Witzleben M, Liu S, Sembdner P, Holtzhausen S, Blum SFU, Lützner J, et al. Additive manufacturing of patient-specific, biphasic implants with zonal design for regeneration of osteochondral defects–critical evaluation of the work flow from clinical MRI data to implantation. Materials Today Bio. 2025 Jun 1;32:101858.
16. Simcox T, Tarazona D, Becker J, Ayres E, Gould J. Improved Implant Positioning of Cephalomedullary Nail for Trochanteric Fractures Using the Stryker ADAPT Navigation System. Injury. 2021 Nov 1;52(11):3404–7.
17. Filardi V. Biomechanical behavior of fibula fracture fixation using the Stryker VariAx 2 system: A finite element analysis of lower limb load distribution. Journal of Orthopaedics. 2025 Nov 1;69:53–60.
18. Ajji Z, Jafari A, Mousavi A, Ajji A, Heuzey MC, Savoji H. 3D bioprinting of thick core–shell vascularized scaffolds for potential tissue engineering applications. European Polymer Journal. 2025 Jan 6;222:113564.
19. Bordure P, Hubert L, Marc C, Rony L. La conservation des implants ostéo-intégrés lors de la prise en charge chirurgicale des infections chroniques de prothèses totales d'épaule inversées (PTEI) influence-t-elle les résultats fonctionnels sans affecter l'efficacité du traitement de l'infection ? Revue de Chirurgie Orthopédique et Traumatologique. 2021 Jun 1;107(4):430–5.
20. Barthel A, Boyer P, Jenny J, Gaudias J, Boeri C, Niglis L, et al. Apport de la sonication des implants au diagnostic microbiologique des infections chroniques de prothèse articulaire de hanche et de genou. Médecine et Maladies Infectieuses Formation. 2024 Jun 1;3(2, Supplement):S27–8.
21. Dumaine V. Complications mécaniques des prothèses massives du fémur distal. Revue de Chirurgie Orthopédique et Traumatologique. 2025.08.18; https://www.sciencedirect.com/science/article/pii/S1877051725001704
22. Abbas B, Weng HC, Syed J, Gosvami NN, Huang EW, Mishra S, et al. Development of tribo-efficient novel nanostructured silica coatings on additively manufactured Ti-6Al-4V via PMMA degradation. Tribology International. 2025 Dec 1;212:110962.
23. Liu B, Li Y, Chen H, Li S, Dan X, Xue P, et al. From molecular mechanisms to clinical translation: Silk fibroin-based biomaterials for next-generation wound healing. International Journal of Biological Macromolecules. 2025 Jun 1;313:144266.
24. Khadeeja Thanha KP, Ayisha Sana P, Ajesh JS, Naseef PP, Tharayil H, Lubaib P, et al. Advanced smart bioelectronics for wound healing: biosensing, drug delivery, and artificial intelligence. International Journal of Pharmaceutics. 2025 Nov 10; 684: 126098
25. Kadhim TR, Oleiwi JK, Hamad QA. Improving the biological properties of UHMWPE biocomposite for orthopedic applications. Int J Biomaterials. 2023;2023:4219841.
26. Yang X, Yin X, He Y, Cheng J, Li X, Chen G, et al. Selective laser melted Fe–30Mn–6Cu alloy: A multifunctional candidate for MRI-compatible, biodegradable, antibacterial, and biocompatible orthopedic implants. AccScience (Open Access). 2025.
27. Lee CY, Kung PC, Huang CC, Shih SJ, Huang EW, Chen SY, et al. In vivo study of bone growth around additively manufactured implants with Ti-6Al-4V and bioactive glass powder composites. arXiv. 2025 Jan;2501.11098.