



## BIOMEDICAL CHARACTERISTICS AND EVALUATION OF CHITOSAN, BIOACTIVE GLASS AND LAPONITE®/BMP-2 AS SURFACE IMPLANT COATINGS: A SYSTEMATIC REVIEW

Nikoleta Ivanova<sup>1</sup>, Stoyan Ivanov<sup>2</sup>, Tsanka Dikova<sup>3</sup>

1) Department of Biology, Faculty of Pharmacy, Medical University of Varna, Bulgaria.

2) Department of Orthopedics and Traumatology, Faculty of Medicine, Medical University of Varna, Bulgaria.

3) Department of Dental Materials and Prosthetic Dental Medicine, Faculty of Dental Medicine, Medical University of Varna, Bulgaria.

### ABSTRACT:

**Purpose:** The surface coatings of implants primarily used in orthopedics and dentistry are developed to improve osseointegration with the body's tissues and ensure durability and functionality. In surgical practice, there is large diversity of options for grafting materials to manage bone loss, promote osteoinduction and accelerate implant integration and survival. The aim of the present study is to analyze and evaluate the biomedical characteristics of Chitosan, Bioactive glass and Laponite®/BMP-2 as potential substances for surface coatings of implants.

**Material/Methods:** A search for scientific studies was conducted in the electronic databases: Google Scholar and PubMed for a period of ten years (2014-2024) with keywords: Biomedical characteristics, Chitosan, Bioactive glass, Laponite (BMP-2), implant surface coatings.

**Results:** Results demonstrated that chitosan used as a coating for implant materials promotes osteointegration both in vitro and in vivo. Coating the implant with bioactive glasses leads to improved stability as well as the connection between the coating and the implant. The combination of Laponite®'s biocompatibility and the osteoinductive properties of BMP-2 as surface implant coating can enhance the healing of bone defects and accelerate osteointegration.

**Conclusion:** This review highlights the main characteristics of commonly used bone substitutes and provides guidance on their clinical use in orthopedic and traumatology practice and periodontal treatment in terms of improving their durability.

**Keywords:** Biomedical characteristics, Chitosan, Bioactive glass, Laponite (BMP-2), implant surface coatings,

### INTRODUCTION

In recent years, there has been significant progress in various aspects of medicine regarding the use of high-tech implants for tissue and bone regeneration. Nevertheless, implant failure remains a major challenge due to aseptic or septic reasons. The situation is even more challenging in patients with osteoporosis, diabetes, inflammatory diseases (rheumatoid arthritis, lupus, etc.) or with large bone defects. These bone defects may occur due to trauma, pseudoarthrosis, infection or bone resection in oncology. [1]

In surgical practice, there are many options for grafting materials (autografts, allografts, synthetic) to manage bone loss. Some of these materials are used as implant coatings to improve their integration and survival through the years. Thus, the ideal material is biocompatible, bioresorbable, osteoconductive, osteoinductive, porous with a comparable structure to bone and last but not least - cost effective. The third generation bone substitute substance often used as implant coatings are synthetic products: ceramic-based substitutes (calcium sulfate, tri-calcium phosphate ceramics, bioactive glasses), polymer-based bone substitutes (chitosan, Polyglycolic acid - PGA) or factor-based substitutes, which include various functional proteins having an essential role in bone repair such as BMP-2.

In recent years, the development of tissue engineering has aimed to create cell-generated and functional tissues, not just synthetic matrices to fill defects. Tissue engineering uses progenitor cells placed in 3D printed biocompatible matrices with growth factors to accelerate bone regeneration and to augment the bone-implant contact in order to reduce aseptic loosening and improve implant survival.

Among the groups of materials used for making implants (metals, polymers, ceramics and composites), titanium, due to its high corrosion resistance, minimal toxicity, biocompatibility and high mechanical strength is undoubtedly the most used material in orthopaedics and maxillofacial surgery. [2, 3]. However, metal implants have disadvan-

tages related to the fact that they are not sufficiently biologically active and that long-term exposure of the human body to metal implants can lead to the release of toxic ions due to corrosion. In order to achieve the most effective process of osseointegration and to enhance the regenerative processes in the body, surface implant coatings with specific properties are used.

Application of coatings of different texture, thickness and roughness on implant surfaces can affect their chemical inertness, cell adhesion and antibacterial characteristics. Osseointegration is essential for implant survival as it requires direct contact and interface between the adjacent tissues and the implant surface [4]. Implant material biocompatibility, implant surface characteristics and design, both macroscopically and microscopically, bone quantity and quality, unobstructed healing phase, loading circumstances, and implant coverage are important factors in achieving successful implant osseointegration [5, 6].

For implants to be clinically effective in the long term, osseointegration and contact between the implant material and the bone are essential [7], and various surface coatings [8], as well as mechanical changes to the surface [9], contribute to this.

The aim of this study is to evaluate the biomedical characteristics of chitosan, Bioactive glass and Laponite®/BMP-2 as potential substances for surface implant coatings.

## MATERIALS AND METHODS:

A search for scientific studies was conducted in the electronic databases: Google Scholar and PubMed for a period of ten years (2014-2024) with key words: Biomedical characteristics, Chitosan, Bioactive glass, Laponite (BMP-2), implant surface coatings. The following criteria were defined for including the publications in the thematic analysis: full-text publications, review articles created in English, published in refereed scientific journals, indicating the specified keywords and expressions. The exclusion criteria were as follows: case reports and abstracts; studies that did not focus on biomedical application of Chitosan, Bioactive glass and Laponite (BMP-2) as coating material; articles before 2014 and studies in languages different from English.

## RESULTS:

### 1. Biomedical characteristics of Chitosan (Cht) as surface implant coating

Chitosan (Cht) is a natural polysaccharide produced by the N-deacetylation of chitin, a structural element found in the exoskeleton of crustaceans and insects, and is the second most abundant natural polysaccharide after cellulose. The application of high power ultrasound significantly enhances the deacetylation process (removal of an acetyl group) of chitin, resulting in low molecular weight and producing high quality Cht by rapid low temperature treatment.

Chitosan is an FDA-approved copolymer that demonstrates properties such as bioactivity, biocompatibility, biodegradability, osteoconductivity and osteoinductivity, non-toxicity, drug delivery and broad-spectrum antimicrobial activity against gram-positive and gram-negative bac-

teria. Its haemostatic power is an important characteristic as it can induce platelet adhesion and aggregation and activate blood coagulation. Thus, Cht can control bleeding by adsorbing plasma and coagulating red blood cells [10].

Due to the highly pronounced biomedical characteristics of chitosan, several studies have been conducted to evaluate its action in promoting implant surface osseointegration [11, 12].

The study highlights the degree of deacetylation and molecular weight of Cht as determinants of osteoblast adhesion, growth and differentiation. Sukul et al. found in vitro that high deacetylation chitosan promotes osteoblast adhesion, secretion of bone markers and extracellular matrix production, whereas low deacetylation induces secretion of factors that stimulate osteoclastogenesis. Similarly, high molecular weight Cht induces the secretion of factors facilitating angiogenesis and bone remodelling [13].

Polo-Corrales et al. present chitosan as an excellent agent for osteoblast stimulation and, therefore, a promoter of bone formation [14]. Cht is widely used to enhance tissue regeneration, either in isolation or in combination with other biomaterials. Teixeira-Santos et al. report that the use of Cht and its derivatives to coat implant surfaces is considered a powerful alternative to prevent colonization and biofilm formation due to the antimicrobial properties of Cht [15].

Chitosan coatings can be used as drug delivery systems to release therapeutic agents directly at the site of the implant. It is a good candidate for controlled release of drugs such as antibiotics, anti-inflammatory drugs, or growth factors [16].

In a published paper, Oliveira WF, et al. report strategies by which Cht, as well as composites based on this polysaccharide, can coat the surface of implantable medical materials for possible pharmaceutical uses. They present the main methodologies in coating surfaces of implantable materials with chitosan-based compounds, namely electrophoretic deposition (EPD), dip coating, spin coating, and spray coating [17].

### 2. Biomedical characteristics of Bioactive glass surface implant coating

The general term bioactive glasses covers a number of products with variations in their composition and properties. Such as the standard silicate glass 45S5 (called 45S5 or Bioglass® and considered the progenitor), antibacterial bioactive glasses (e.g. S53P4 or BonAlive®), borate-based glasses (bioactive glass 13-93B3).

Bioactive glasses with the general formula  $45\text{SiO}_2 - 24.5\text{Na}_2\text{O} - 24.5\text{CaO} - 6.0\text{P}_2\text{O}_5$  are highly biocompatible and have a high chance of integrating with human tissue, making them a good option for improving the biocompatibility and bioactivity of metal implant surfaces. In contact with tissues, the biocompatibility of bioactive glass is determined by a series of reactions. Ions leave the glass complex on the implant surface to enter the body fluid, while hydrogen leaves the body fluids to form a network with silicon in the glass coating. This network attracts the movement of ions to the surface of the  $\text{SiO}_2$ -rich layer, resulting in the formation of an amorphous calcium phosphate (ACP) layer or

hydroxyl carbonate-apatite (HCA) layer when crystallized. This layer is very important because it provides the bond between the tissue and the glass material. The success of these reactions confirms the biocompatibility of the implant coating material. Furthermore, they can regulate or inhibit the corrosion of implant metals in a biological environment. Bioactive glass coatings are osteoconductive, meaning they support the attachment, proliferation, and differentiation of osteoblasts [18].

In a study by Chand et al., it was found that bioactive glasses, due to their specific properties, are suitable for coating and improving the functionalities of implants. They are also used in wound healing and bone formation [19]. Sola et al. studied the properties of bioactive glasses and found that compared to other materials, they are highly biocompatible, which suggests that they have a significantly greater potential for integration with human tissue than metal implants [20]. The advantages identified in the study of bioactive glasses include easier integration, the ability to replace damaged tissue or bone, and facilitating tissue regeneration. As a material, bioactive glasses facilitate better integration of implants by forming apatite at the interfaces and can also inhibit and regulate the corrosion of implant metals in a biological environment [19]. Similar findings were also found in a study by Manam et al., which established that bioactive glass has the properties to restore, replace, and promote tissue regeneration [21]. The study found that bioactive glasses have suitable biodegradability, which makes the particles extremely easy to resorb [22]. In their study, Kargozar and colleagues examine bioactive glasses, their ability to stimulate angiogenesis, and their reliability as delivery systems for ions and biomolecules. However, the possible risks of soft tissue calcification by BGs have not yet been comprehensively studied [23]. Despite the undeniable advantages of bioactive glasses in terms of implant coating, it was found that they have poorer mechanical properties compared to other materials because they are not suitable for use in load-bearing areas [24].

Oliver JN and colleagues present in their work the popular methods for coating with bioactive glass-sol-gel technique, enameling, electrophoretic deposition, thermal spraying and laser cladding [18].

### **3. Biomedical characteristics of Laponite®/BMP-2 as surface implant coating**

The studies found demonstrate the importance of bone morphogenetic protein 2 (BMP-2) for bone regeneration, fracture healing, and bone defects. One clinical study demonstrated the potential of BMP-2 as an effective agent for promoting bone growth [25]. King WJ, et al. believe that bone morphogenetic protein-2 (BMP-2) is most often applied in high concentrations to materials to induce a biological response. According to the researchers, high concentrations result in a rapid release of a potent growth factor upon implant placement [26]. A study by Cheng et al. found that to maintain bioactivity while minimizing side effects, BMP-2 should be immobilized using various methods, such as coating with fibronectin or heparin, microspheres, and hydrogels [27]. Despite the methods mentioned, it has been

established that during implantation, it is necessary to deliver the growth factors to the tissues to ensure that the growth factor is active and in the correct concentration to achieve the desired biological effect. According to Erezuma et al., laponite has the properties for injection due to the fusion of the particles and the formation of a 3D structure, which makes the laponite thixotropic. The gel formed can be modified by applying various solutions containing salt or protein. It is precisely because of its mentioned properties that laponite is defined as a tissue regenerative biomaterial [28].

In a study by Marshall K, et al., it was found that laponite is extremely easy to apply for coating, successfully covering the materials used for implants and having a beneficial effect on the adhesion of the skeleton [29]. In the mentioned study, laponite was applied to the skeleton of the implant as a coating, leaving it in appropriate conditions (dry container) to dry for 24 hours. Bone morphogenic protein 2 (BMP2) can induce ectopic bone. Nanoparticles (laponite) could bind into a gel under appropriate conditions, which is why they are widely used in clinical practice. Individual particles self-assemble based on electrostatic interactions, forming an open macroporous and thixotropic gel or glassy state, depending on the salt concentration [30]. Laponite is of great importance in the therapeutic treatment of large segments based on 3D scaffolds for engineering porous tissues due to the facilitation of the healing process. Tissue engineering technology uses 3D porous scaffolds as platforms for differentiation and adhesion of cells in bone regeneration [31]. Erezuma et al. are of the opinion that reinforced biomaterials significantly change the treatment of musculoskeletal defects, as laponite shows essential biological, mechanical, physical and chemical properties to achieve regeneration and optimal tissue integration [32].

In their study, Liu Z, and colleagues demonstrate the ability of laponite nanoclay to localize and deliver bioactive BMP-2. An ovine femoral condyle defect model confirmed PCL-TMA900 scaffolds coated with Laponite®/BMP-2 produced significant bone formation compared to the uncoated PCL-TMA 900 scaffold in vivo, assessed by micro-computed tomography ( $\mu$ CT) and histology [33].

A possible method for applying a laponite coating to an implantable surface is Layer-by-layer (LbL), LbL coating preserves the intrinsic mechanics of implants and transforms a relatively inert interface into a bio-friendly interface that attracts the adhesion of bone marrow mesenchymal stem cells (BMSCs) and therefore promotes osseointegration between the implant and surrounding tissues [34].

The combination of Laponite® synthetic clay material loaded with bone morphogenetic protein-2 (BMP-2) is recognized a strong osteoinductive factor, as a surface coating of implants, it has the potential to improve osseointegration and stimulate bone regeneration.

For a clearer systematization of the presented information, Table 1 compares the main biomedical characteristics of the three materials considered for implant surface coating – Chitosan (Cht), Bioactive Glass, and Laponite®/BMP-2 – including their advantages and disadvantages.

**Table 1.** Comparative overview of the biomedical characteristics, advantages, and disadvantages of the three implant surface coatings – Chitosan (Cht), Bioactive glass, and Laponite®/BMP-2.

Characteristic	Chitosan (Cht)	Bioactive glass	Laponite®/BMP-2
<b>Origin/Composition</b>	Polysaccharide obtained by N-deacetylation of chitin	Variations (e.g., 45S5 Bioglass®, S53P4, borate-based)	Synthetic nanoclay (Laponite®) + growth factor BMP-2
<b>Key properties</b>	Biocompatibility, bioactivity, hemostatic power, antimicrobial activity, osteoconductivity, osteoinductivity	High biocompatibility, osteoconductivity, apatite layer formation, anti-corrosion effect	Osteoinductivity (via BMP-2), 3D gel formation, bone regeneration
<b>Cellular interaction</b>	High deacetylation → osteoblast adhesion & matrix; low deacetylation → osteoclastogenesis	Ion release → HCA layer formation, supports osteoblast adhesion & differentiation	Supports BMSCs adhesion, stimulates osteogenesis
<b>Antimicrobial activity</b>	Yes – against Gram+ and Gram- bacteria; prevents biofilm	Partial (in some types such as S53P4)	None
<b>Hemostatic activity</b>	Strong – induces platelet adhesion and coagulation	None	None
<b>Drug/Growth factor delivery</b>	Suitable for controlled release of antibiotics, growth factors, anti-inflammatory agents	Can act as a carrier of ions or biomolecules	Enables localized and controlled BMP-2 delivery
<b>Coating methods</b>	Electrophoretic deposition (EPD), dip coating, spin coating, spray coating	Sol-gel, enameling, EPD, thermal spraying, laser cladding	Layer-by-layer (LbL), direct gel formation
<b>Biodegradation</b>	Biodegradable (enzymatic hydrolysis)	Yes – resorbable	Yes – degradable nanoclay
<b>Advantages</b>	Antimicrobial & hemostatic activity; biocompatible; controlled drug release	Excellent biocompatibility; promotes bone & tissue formation; corrosion protection; bioactive apatite layer	Strong osteoinductivity; localized BMP-2 delivery; suitable for 3D scaffolds; easy coating
<b>Disadvantages</b>	Properties depend on molecular weight & degree of deacetylation; possible osteoclastogenesis (low deacetylation)	Poor mechanical strength → unsuitable for load-bearing areas; possible soft tissue calcification	Requires strict BMP-2 dosage control (high dose → side effects); lacks antimicrobial activity
<b>Applications</b>	Implant coatings, tissue regeneration, hemostasis, antimicrobial systems	Bone regeneration, implant integration, anti-corrosion protection	Bone defect healing, osteogenesis stimulation, tissue engineering scaffolds

#### DISCUSSION:

The achievement of successful osseointegration depends on the following factors: biocompatibility of bone substitutes; bio material design (shape and macrotecture); surface feature (microtexture); implantation technique; recipient bed condition; mechanical loads and stability in the post-implantation period. Tissue regeneration is a biological cascade of physiologically controlled processes of induction, genesis and conduction involving specific cell types as well as extracellular

and intracellular signalling pathways.

Metal products possess high mechanical strength and fatigue resistance, but they are corrosive and toxic due to the release of active ions, which could lead to adverse tissue reactions. However, acceptable low corrosion rates have passive metals like titanium, chromium, zirconium. In medicine, metals are used because they are bio inert and can be moulded into different shapes depending on the purpose. Metals are coated with ceramics because ceramic has an outstanding elastic modulus and

can be used as scaffolds. In medicine, metals are used because they are bio inert and can be moulded into different shapes depending on the purpose. Metals are coated with ceramics because ceramic has an outstanding elastic modulus and can be used as scaffolds. Several techniques are used in practice for coating metal implants: thermal spraying, plasma spraying, biomimetic coating, sol-gel dip coating, pulsed laser deposition. Every method has advantages/disadvantages, and its application should be evaluated before biomedical application [35].

The three materials analyzed in the present study offer properties that can improve the integration of implants with bone tissue. Chitosan is known for its antimicrobial properties and biocompatibility, while bioactive glass has the ability to increase mineralization stimulate osteogenesis and bone formation. Laponit®, in combination with BMP-2 (bone growth factor), provides growth factors that significantly accelerate the processes of bone formation and regeneration, showing osteoinductive properties. The biomedical characteristics of chitosan can be further optimized through modifications in the composite design, thus ensuring a wide range of applications for both medical implant coatings and scaffolds.

Ceramics and polymers are two main bioactive materials used as implant coating materials. Although bioactive glasses are not as commonly used as polymers as coating materials, their specific properties have multiple functions [36]. As bioceramic materials, bioactive glasses have wide clinical applications. Their main properties are related to high biocompatibility as well as antimicrobial properties, making them suitable as biomaterials in medicine and dentistry [37]. Bioactive glasses have suitable body compatibility; therefore, they are similar in content to bone hydroxyapatite. In the human body, they are often used as dental implants to repair or replace damaged bones, and other applications in dentistry are related to their use in root canal treatment for periodontal disease, tooth restoration, maxillofacial surgery, etc. [38]. Bioactive glasses are used for multiple medical applications, such as non-load-bearing implants, bone cements, etc. [39]. However, due to their poor mechanical properties, these glasses cannot be used in load-bearing implants. The use of bioactive glasses has two main applications – to improve the osseointegration of implants and to protect the metal from corrosion caused by tissue fluids [40].

Bone morphogenic proteins (BMPs) are potent stimulators of osteogenesis and play a crucial role in regulating bone formation and repair. Laponite is defined as a synthetic product but on a natural basis, which occurs in calcite clay, layered magnesium lithium silicate, hectorite, etc., and when hydrated by water has the properties to disperse. Laponite disks have an affinity for binding to proteins through various mechanisms, including interlamellar and hydrophobic, as well as electrostatic interactions. These properties have utility in the therapeutic delivery of proteins on a sustained-release basis. It has been proven that the use of laponite does not cause toxicity, and it has been demonstrated that nanoclays are effective in binding and delivering growth factors for localized tissue maintenance, as well as for the formation of new blood vessels at the site of injury based on the localization of vascular endothelial growth factor [30].

## CONCLUSIONS

In summary, serious complications in orthopaedic and maxillofacial surgery are commonly associated with failure of osseointegration and peri-implant infection. Current research shows progress in bioregenerative medicine and highlights the biomedical properties of a number of materials capable of being applied as coatings for implants and tissue engineering scaffolds.

Chitosan is a promising biomaterial for use as a surface coating on medical implants due to its biocompatibility, biodegradability, and ability to promote tissue regeneration. Bioactive glass coatings offer a range of significant advantages for biomedical implants, including osteoconductivity, osteoinductivity, and the ability to stimulate tissue regeneration. Its ability to form a bone-like hydroxycarbonate apatite layer and its ion-releasing behavior make it an excellent choice for enhancing bone integration and improving healing outcomes. To increase mechanical stability, synthetic clay laponite has a significant influence as a basic material for building the individual layers for assembling a 3D scaffold.

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## REFERENCES:

1. Fernandez de Grado G, Keller L, Idoux-Gillet Y, Wagner Q, Musset AM, Benkirane-Jessel N, et al. Bone substitutes: a review of their characteristics, clinical use, and perspectives for large bone defects management. *J Tissue Eng.* 2018 Jun 4;9:2041731418776819. [[PubMed](#)]
2. Ozkan A, Çakır DA, Tezel H, Sanajou S, Yirun A, Baydar T, et al. Dental Implants and Implant Coatings: A Focus on Their Toxicity and Safety. *J Environ Pathol Toxicol Oncol.* 2023;42(2):31-48. [[PubMed](#)]
3. Peev S, Yotsova R, Parushev I. Histomorphometric Analysis of Osseointegrated Intraosseous Dental Implants Using Undecalcified Specimens: A Scoping Review. *Biomimetics (Basel).* 2024 Nov 3;9(11):672. [[PubMed](#)]
4. Hudieb M, AlKhader M, Mortaja S, Abusamak M, Wakabayashi N, Kasugai S. Impact of Bone Augmentation of Facial Bone Defect around Osseointegrated Implant: A Three Dimensional Finite Element Analysis.

- Dent J (Basel)*. 2021 Oct 3;9(10):114. [[PubMed](#)]
5. Shaikh MQ, Nath SD, Akilan AA, Khanjar S, Balla VK, Grant GT, et al. Investigation of Patient-Specific Maxillofacial Implant Prototype Development by Metal Fused Filament Fabrication (MF<sup>3</sup>) of Ti-6Al-4V. *Dent J (Basel)*. 2021 Sep 23;9(10):109. [[PubMed](#)]
  6. El-Banna A, Bissa MW, Khurshid Z, Zohaib S, Asiri FYI, Zafar MS. Surface modification techniques of dental implants. *Dental Implants*. 2020; Chapter 4, pp. 49-68. [[Crossref](#)]
  7. Jaquiéry C, Ilgenstein B, Jungo M, Rüeger K, Chenaux S, Papadimitropoulos A, et al. Clinical and radiological outcome of titanium implants in clinical practice: A 5 year, prospective, multicenter case series. *Dent J*. 2014; 2(4):106-117. [[Crossref](#)]
  8. Alghamdi HS, Cuijpers VM, Wolke JG, van den Beucken JJ, Jansen JA. Calcium-phosphate-coated oral implants promote osseointegration in osteoporosis. *J Dent Res*. 2013 Nov; 92(11):982-8. [[PubMed](#)]
  9. Stadlinger B, Korn P, Tödtmann N, Eckelt U, Range U, Bürki A. Osseointegration of biochemically modified implants in an osteoporosis rodent model. *Eur Cell Mater*. 2013 Jul 8;25:326-40; discussion 339-40. [[PubMed](#)]
  10. López-Valverde N, Aragonese J, López-Valverde A, Rodríguez C, Macedo de Sousa B, Aragonese JM. Role of chitosan in titanium coatings. trends and new generations of coatings. *Front Bioeng Biotechnol*. 2022 Jul 22;10:907589. [[PubMed](#)]
  11. Khan A, Wang B, Ni Y. Chitosan-Nanocellulose Composites for Regenerative Medicine Applications. *Curr Med Chem*. 2020; 27(28): 4584-4592. [[PubMed](#)]
  12. Aranaz I, Mengibar M, Harris R, Paños I, Miralles B, Acosta N, et al. Functional Characterization of Chitin and Chitosan. *Current Chemical Biology*, 2009, 3 (2): 203-230.
  13. Sukul M, Sahariah P, Lauzon HL, Borges J, Måsson M, Mano JF, et al. In vitro biological response of human osteoblasts in 3D chitosan sponges with controlled degree of deacetylation and molecular weight. *Carbohydr Polym*. 2021 Feb 15;254: 117434. [[PubMed](#)]
  14. Polo-Corrales L, Latorre-Esteves M, Ramirez-Vick JE. Scaffold design for bone regeneration. *J Nanosci Nanotechnol*. 2014 Jan; 14(1):15-56. [[PubMed](#)]
  15. Teixeira-Santos R, Lima M, Gomes LC, Mergulhão FJ. Antimicrobial coatings based on chitosan to prevent implant-associated infections: A systematic review. *iScience*. 2021 Nov 22;24(12):103480. [[PubMed](#)]
  16. Desai N, Rana D, Salave S, Gupta R, Patel P, Karunakaran B, et al. Chitosan: A Potential Biopolymer in Drug Delivery and Biomedical Applications. *Pharmaceutics*. 2023 Apr 21;15(4):1313. [[PubMed](#)]
  17. Oliveira WF, Albuquerque BP, Rodrigues EN, Silva MP, Kennedy JF, Correia MS, et al. Pharmaceutical applications of chitosan on medical implants: A viable alternative for construction of new biomaterials? *Carbohydr Polym Technol Appl*. 2024 Jun;7:100407. [[Crossref](#)]
  18. Oliver JN, Su Y, Lu X, Kuo PH, Du J, Zhu D. Bioactive glass coatings on metallic implants for biomedical applications. *Bioact Mater*. 2019 Oct 5;4:261-270. [[PubMed](#)]
  19. Chand P, Malik M, Prasad T. Bioactive Glass for Applications in Implants: A Review. *SchemistrySelect*. 2024, 9, 29.
  20. Sola D, Bellucci V, Cannillo A, Cattini A. Bioactive glass coatings: a review *Surf. Eng*. 27, 2011, 560-572.
  21. Manam S., Harun W, Awang N, Bin S., Kurniawan T, Ismail M, et al. Study of corrosion in biocompatible metals for implants: a review. *J. Alloys Compd*. 2017, 701, 698–715.
  22. Liang J, Lu X, Zheng X, Li YR, Geng X, Sun K, et. al. Modification of titanium orthopedic implants with bioactive glass: a systematic review of *in vivo* and *in vitro* studies. *Front Bioeng Biotechnol*. 2023 Nov 15;11:1269223. [[PubMed](#)]
  23. Kargozar S, Baino F, Hamzehlou S, Hill RG, Mozafari M. Bioactive Glasses: Sprouting Angiogenesis in Tissue Engineering. *Trends Biotechnol*. 2018 Apr;36(4):430-444. [[PubMed](#)]
  24. Yanovska A, Kuznetsov V, Stanislavov A, Danilchenko S, Sukhodub L. Synthesis and characterization of hydroxyapatite-based coatings for medical implants obtained on chemically modified Ti6Al4V substrates. *Surf. Coatings Technol*. 2011 Sep 25;205(23-24):5324–5329. [[Crossref](#)]
  25. Howard MT, Wang S, Berger AG, Martin JR, Jalili-Firoozinezhad S, Padera RF, et al. Sustained release of BMP-2 using self-assembled layer-by-layer film-coated implants enhances bone regeneration over burst release. *Biomaterials*. 2022 Sep;288:121721. [[PubMed](#)]
  26. King WJ, Krebsbach PH. Growth factor delivery: how surface interactions modulate release in vitro and in vivo. *Adv Drug Deliv Rev*. 2012 Sep;64(12):1239-56. [[PubMed](#)]
  27. Cheng CH, Lai YH, Chen YW, Yao CH, Chen KY. Immobilization of bone morphogenetic protein-2 to gelatin/avidin-modified hydroxyapatite composite scaffolds for bone regeneration. *J Biomater Appl*. 2019 Apr;33(9):1147-1156. [[PubMed](#)]
  28. Erezuma I, Eufrazio-da-Silva T, Golafshan N, Deo K, Mishra YK, Castilho M, et al. Nanoclay Reinforced Biomaterials for Mending Musculoskeletal Tissue Disorders. *Adv Healthc Mater*. 2021 Aug;10(16):e2100217. [[PubMed](#)]
  29. Marshall K, McLaren J, Wojciechowski J, Callens S, Echalié S, Kanczler J, et al. Bioactive coatings on 3D printed scaffolds for bone regeneration: Use of Laponite™ to deliver BMP-2 for bone tissue engineering – progression through in vitro, chorioallantoic membrane assay and murine subcutaneous model validation. *Biomater Adv*. 2023 Nov;164: 213959. [[PubMed](#)]
  30. Black C, Gibbs D, McEwan J, Kanczler J, Fernández MP, Tozzi G, et al. Comparison of bone formation mediated by bone morphogenetic protein delivered by nanoclay gels with clinical techniques (autograft and InductOs®) in an ovine bone model. *J Tissue Eng*. 2022 Sep 16;13: 20417314221113746. [[PubMed](#)]
  31. Zerankeshi M, Mofakhmi S, Salahinejad E. 3D porous HA/TCP composite scaffolds for bone tissue engineering. *Ceramics International*. 2022 48, 22647-22633.
  32. Erezuma I, Eufrazio-da-Silva T,

- Golafshan N, Deo K, Mishra YK, Castilho M, et al. Nanoclay Reinforced Biomaterials for Mending Musculoskeletal Tissue Disorders. *Adv Healthc Mater.* 2021 Aug;10(16): e2100217. [[PubMed](#)]
33. Liu Z, Tang Q, Liu RT, Yu MZ, Peng H, Zhang CQ, et al. Laponite intercalated biomimetic multilayer coating prevents glucocorticoids induced orthopedic implant failure. *Bioact Mater.* 2022 Sep 26;22:60-73. [[PubMed](#)]
34. Zhang X, Xu Y, Zhang X, Wu H, Shen J, Chen R, et al. Progress on the layer-by-layer assembly of multilayered polymer composites: strategy, structural control and applications. *Prog Polym Sci.* 2019 Feb;89:76-107. [[Crossref](#)]
35. Sikkema R, Baker K, Zhitomirsky I. Electrophoretic deposition of polymers and proteins for biomedical applications. *Adv Colloid Interface Sci.* 2020 Oct;284:102272. [[PubMed](#)]
36. Drevet R, Fauré J, Benhayoune H, Electrophoretic Deposition of Bioactive Glass Coatings for Bone Implant Applications: A Review. *Coatings.* 2024; 14(9):1084. [[Crossref](#)]
37. Skallevoid HE, Rokaya D, Khurshid Z, Zafar MS. Bioactive Glass Applications in Dentistry. *Int J Mol Sci.* 2019 Nov 27;20(23):5960. [[PubMed](#)]
38. Jafari N, Habashi MS, Hashemi A, Shirazi R, Tanideh N, Tamadon A. Application of bioactive glasses in various dental fields. *Biomater Res.* 2022 Jul 6;26(1):31. [[PubMed](#)]
39. Hammami I, Gavinho SR, Pádua AS, Sá-Nogueira I, Silva JC, Borges JP, et al. Bioactive Glass Modified with Zirconium Incorporation for Dental Implant Applications: Fabrication, Structural, Electrical, and Biological Analysis. *Int J Mol Sci.* 2023 Jun 24;24(13):10571. [[PubMed](#)]
40. Lopez S, Saiz E, Fujini S, Oku T, Sukanuma K, Tomsia A. Bioactive glass coatings for orthopedic metallic implants. *J Eur Ceram Soc.* 2003; 23(15):2921-2930. [[Crossref](#)]

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**Address for correspondence:**

Nikoleta Ivanova  
 Department of Biology, Faculty of Pharmacy, Medical University of Varna;  
 84, Tsar Osoboditel Str., Varna, 9000, Bulgaria.  
 E-mail: [nikoleta.ivanova@mu-varna.bg](mailto:nikoleta.ivanova@mu-varna.bg),