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A Review of Chitosan Biomaterials in Dental Treatment and Their Development History

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Abstract: Dental diseases are prevalent globally and seriously affect people's quality of life, and the development of dental treatment technologies is crucial to improving this situation. Chitosan biomaterials are gradually emerging in the field of dental therapy due to their unique properties. This paper reviews the application and development of chitosan biomaterials in dental therapy, reviews the development from early exploration to the present multi-faceted expansion, analyzes the current limitations and challenges. At present, chitosan biomaterials are still facing problems such as insufficient mechanical properties, the accuracy of controlled drug release needs to be improved, and the high cost and long cycle of clinical transformation. However, with the continuous development of materials science, biotechnology and other disciplines, as well as the increase of relevant policies to support the research and development and transformation of biomedical materials, chitosan biomaterials are expected to improve the performance of new modification methods, combined with cutting-edge technology to expand the application, reduce the cost and cycle of clinical transformation, so that they can promote dental treatment level to a new level, which will be the most effective way to improve the performance of chitosan biomaterials. It is expected to play a greater role in dental treatment, become an important tool for solving many difficult dental problems, promote the level of dental treatment to a new level, and make a greater contribution to the cause of oral health.

Keywords: Chitosan biomaterials, dental treatment, applications, development history

1. Introduction

The incidence of dental diseases remains high worldwide, which has an important impact on people's oral health and even general health. With the continuous development of biomaterials science, more and more new materials have been applied in the field of dental treatment, and chitosan biomaterials are one of them that have attracted much attention. Chitosan has many excellent properties, such as good biocompatibility, degradability, antibacterial properties, etc., which makes it show unique advantages in many aspects of dental treatment, and its application scope is also expanding.

However, although chitosan biomaterials have achieved certain results in dental treatment, there are still many problems that require in-depth research. For example, its mechanical properties are relatively weak, and it is easy to be deformed and broken in dental restoration scenarios with complex masticatory forces, so how to effectively improve its mechanical strength to meet the clinical needs is one of the key issues; in the controlled release of drugs, its accuracy is affected by a variety of

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factors, and it is difficult to achieve the desired sustained and stable release, so how to accurately regulate the release behavior of the drug in order to improve the reliability of the therapeutic effect is the key direction of the research; from laboratory research to clinical application, the conversion process faces high costs and high reliability. How to precisely regulate the drug release behavior to improve the reliability of therapeutic effect is the key direction of research; from laboratory research to clinical application of the transformation process, faced with the dilemma of high cost and long cycle, how to reduce the cost, shorten the cycle, and accelerate the clinical transformation is also an important challenge that needs to be solved.

Reviewing the development of chitosan biomaterials in dentistry is of great significance for the in-depth understanding and better utilization of the materials. Therefore, this paper systematically studies the application and development history of chitosan biomaterials in dental treatment, analyzes its characteristics in depth, elaborates on the specific applications in periodontal treatment, endodontic treatment, oral implantation, etc., combs through the vein of development, analyzes the current limitations and challenges, and makes a scientific and reasonable outlook on the future development of chitosan biomaterials, with the aim of providing valuable reference basis for the relevant research and clinical practice. The aim is to provide a valuable references for related research and clinical practice.

2. Properties of Chitosan

Chitosan is a naturally occurring polysaccharide derived from the deacetylation process of chitin and possesses a variety of excellent properties, among which biocompatibility is particularly prominent.

2.1. Biocompatibility

In terms of biocompatibility, chitosan shows an extremely harmonious interaction pattern with human tissue cells. When implanted into the body, it skillfully avoids the trigger of strong immune rejection and, like a gentle visitor, quietly integrates into the body environment and is readily accepted and well tolerated by the organism. This property is like a key that opens the door to a wide range of applications in biomedical fields such as dentistry. It means that in dental treatment, chitosan materials can work closely with various cells and tissues in the oral cavity, providing a stable and reliable foundation for subsequent therapeutic applications such as periodontal tissue repair and pulp regeneration. Whether it is used as a scaffold to guide cell growth or as a drug carrier to play a role locally, its good biocompatibility ensures the safety and effectiveness of the treatment process, which makes the prospect of chitosan application in the field of dental treatment brighter [1].

2.2. Degradability

In the specific physiological environment of the body, chitosan is like a dutiful "environmental guardian", which can be degraded in an orderly and gradual manner through enzymolysis and other means. Its degradation product is like a mild nutrient, non-toxic and harmless, not only will not cause any burden to the body, but also can be smoothly absorbed by the body or easily discharged from the body. This characteristic is in line with the strict criteria for the use of biomedical materials in the body, and is like a precise key that opens the door to the safe use of these materials in dental treatments in the right way. In dental treatment, for example, chitosan materials are used in periodontal tissue repair or bone defect repair processes. With the advancement of the treatment process, chitosan will be gradually degraded in accordance with the body's rhythm, not only to complete its restorative mission, but also to not remain in the body for a long time like some non-biodegradable materials, which skillfully avoids a variety of potential risks that may be triggered, such as inflammation, foreign

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body sensation, etc., providing a reliable guarantee for the patient's oral health [2]. This provides a reliable guarantee for patients' oral health [2].

2.3. Antimicrobial Properties

Chitosan has excellent antimicrobial performance in dentistry, and it can be called the loyal guardian of oral health. It acts as a precise sniper, striking at a variety of common oral pathogens, such as Streptococcus pyogenes and Porphyromonas gingivalis, and inhibiting their growth and reproduction effectively [3]. Streptococcus pyogenes plays a key role in the development of dental caries, while Porphyromonas gingivalis is an important causative agent of periodontal disease, and the emergence of chitosan has disrupted their plans.

In the oral cavity, a "battlefield" for bacteria, bacterial growth is the source of all kinds of diseases, ranging from minor gum inflammation to serious periodontal disease. Chitosan's antimicrobial action acts as a strong line of defense, reducing the chances of bacterial growth and thus reducing the risk of disease. It not only directly inhibits pathogenic bacteria, but also plays an active role by maintaining the oral microecological balance. Oral microecology is like a delicate ecosystem, the presence of chitosan helps to maintain the balance between beneficial and harmful bacteria, creating a healthy and stable oral environment, providing comprehensive protection for teeth and gums, and preventing the occurrence of many oral diseases.

2.4. Film-forming and Gelation Properties

Chitosan has unique and practical film-forming and gel-forming properties. Its molecular structure gives it the ability to be easily transformed into a film or gel under the right conditions, as if it were a material with magical transformations. This property gives it a significant advantage in dental treatments. When made into a membrane material, it is like a thin and light cling film that adheres tightly to the surface of the oral tissues, whether it is the smooth enamel of the teeth or the soft tissues of the gums; it adapts perfectly to its complex shape and fits seamlessly, providing ideal coverage and protection for localized treatments. As a gel material, it is also like a soft and elastic jelly, which can be shaped according to the shape of oral tissues and filled in periodontal pockets and other parts of the mouth. Whether it is used as a drug carrier, like a miniature spaceship for precise drug delivery, releasing drugs slowly and continuously to the lesion site, or as a periodontal restorative material, providing support for damaged tissues and promoting the healing environment, chitosan’s film-forming and gel-forming properties have demonstrated unparalleled suitability and efficacy [4,5].

3. Chitosan Biomaterials in Dental Treatment

3.1. Application in Periodontal Disease Treatment

3.1.1. Induced Tissue Regeneration

In the field of periodontal therapy, chitosan and its composites show excellent potential for tissue engineering applications. As a natural polysaccharide with good biocompatibility and degradability, chitosan is rich in amino and hydroxyl functional groups in its molecular structure, which enables it to interact with cell surface receptors and provide suitable adhesion sites for cells. When prepared as a scaffold material, this material can accurately mimic the structure and function of the extracellular matrix to construct a three-dimensional growth microenvironment for cells in the periodontal tissue, such as periodontal membrane cells and osteoblasts. In this microenvironment, cells are able to obtain sufficient physical support to initiate migration and proliferation processes. Taking Basic Fibroblast Growth Factor / Chitosan Derivative / Collagen Temperature-Sensitive Composite Hydrogel as an

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example, in the rat model study, its unique temperature-sensitive property allows the formation of a stable gel state at physiological temperature, which not only provides a temporary shelter for the cells, but also degrades gradually over time, releasing Basic Fibroblast Growth Factor. This growth factor, as an important signaling molecule, can activate a series of intracellular signaling pathways to promote cell proliferation, differentiation, and synthesis of extracellular matrix, thus effectively guiding the regeneration of periodontal tissues, significantly improving the defects and destruction of periodontal tissues due to diseases such as periodontitis, and providing a promising therapeutic strategy for the functional reconstruction of periodontal tissues [6].

3.1.2. Antimicrobial and Anti-inflammatory

The antibacterial properties of chitosan itself provide a natural defense mechanism for the treatment of periodontal disease. Its antimicrobial effect is mainly due to its positively charged amino groups, which can interact electrostatically with the negatively charged components on the surface of the bacterial cell membrane, destroying the integrity of the bacterial cell membrane, leading to the leakage of intracellular substances, and thus inhibiting the growth and reproduction of bacteria. Based on this property, chitosan can be skillfully processed into various forms of topical periodontal drug carriers, such as gels and membranes. These drug-carrying systems can effectively encapsulate and carry antimicrobial drugs to achieve localized slow release of drugs. At the site of periodontal inflammation, the drug-carrying chitosan gels or membranes can slowly but continuously release the antimicrobial drug, ensuring that the drug maintains effective therapeutic concentration at the site of action and prolonging the duration of drug action. This sustained drug release mechanism can produce a sustained inhibitory effect on periodontal pathogenic bacteria, including common porphyromonas gingivalis and porphyromonas intermedia, effectively controlling bacterial infections and reducing inflammatory responses [7].

3.2. Applications in the Treatment of Endodontics

3.2.1. Dentin Tubule Sealing

Within the therapeutic context of endodontics, dentin tubule sealing is a key strategy where chitosan derivatives play an important role. Chitosan derivatives, such as carboxymethyl chitosan, possess unique physicochemical properties that allow them to act precisely on dentin tubules [8]. Dentin tubules, as microscopic channels in dentin, play a key role in the development of dentin sensitivity, where external temperature, chemical and mechanical stimuli can be transmitted to the pulp, causing pain and discomfort. The use of carboxymethyl chitosan and other materials can penetrate deeply into the dentin tubules and adhere to them by virtue of their good biocompatibility and adhesion. For example, carboxymethyl chitosan - lysozyme nanogel forms a stable complex by synergizing with amorphous calcium phosphate. Such complexes can not only physically fill the dentin tubules and block the conduction path of external stimuli, but also chemically alter the microenvironment within the dentin tubules to further enhance the sealing effect, thus effectively alleviating the symptoms of dentin sensitivity and providing a promising therapeutic option for patients with endodontics, which shows a broad application prospect.

3.2.2. Restoration and Regeneration of Pulp Tissue

Pulp tissue repair and regeneration is a hot research topic in the field of endodontic treatment, and chitosan scaffolds provide a new direction to achieve this goal. As the core cell source of pulp tissue regeneration, pulp stem cells require a suitable microenvironment for their growth and differentiation. With its good biodegradability and structural plasticity, chitosan scaffolds can mimic the extracellular

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matrix of dental pulp tissues, providing physical support and biological signal guidance for dental pulp stem cells. In this microenvironment, pulp stem cells can maintain their self-renewal ability and differentiate into functional cells, such as dentinogenic cells, under the stimulation of specific signals, which can promote the repair and regeneration of pulp tissue. Although the field is still in the exploratory stage, a series of encouraging progress has been made [9]. In vitro experiments have shown that with the assistance of chitosan scaffolds, the proliferation, differentiation and mineralization of dental pulp stem cells have been significantly enhanced, which brings new hope for solving intractable problems, such as pulp necrosis and is expected to promote the treatment of endodontics from traditional restorative to regenerative therapy.

3.3. Applications in the Field of Oral Implants

3.3.1. Surface Coating of Implants

In the field of oral implantology, implant surface coating technology is crucial for improving implant success and long-term stability, and chitosan coating is one of the promising approaches. Chitosan coating on the implant surface, based on its natural antimicrobial properties, can effectively resist the adhesion and colonization of various bacteria in the oral cavity during the initial implant placement period, significantly reducing the risk of early peri-implant infections. This antimicrobial mechanism mainly originates from the amino group in the molecular structure of chitosan, which can interact with the negatively charged components on the surface of the bacterial cell membrane, destroying the integrity of the bacterial cell membrane and thus inhibiting bacterial growth and reproduction. At the same time, the chitosan coating can also act as a bioactive interface to promote the interaction between the implant and the surrounding bone tissue. It can regulate local cellular behaviors, such as promoting the adhesion, proliferation and differentiation of osteoblasts, accelerating the formation of bone matrix, and thus enhancing the integration of bone tissues around the implant [10].

3.3.2. Repair of Bone Defects

In the process of oral implantation, bone defects such as insufficient bone volume often pose a challenge to implant treatment, and composites made of chitosan combined with bone morphogenetic proteins provide an effective solution to this problem. As a potent osteoinductive factor, bone morphogenetic protein has the ability to promote osteoblast differentiation and new bone formation. When composited with chitosan, chitosan not only serves as a carrier for bone morphogenetic protein, realizing its slow release at the site of bone defects and prolonging its action time, but also provides a three-dimensional scaffolding structure for new bone formation. The injectable nano-chitosan bone morphogenetic protein 2 complex is a typical example. In the area of bone defects, this complex can attract and aggregate precursor cells such as mesenchymal stem cells, which gradually differentiate into osteoblasts and begin to synthesize and secrete bone matrix, ultimately realizing the formation of new bone, induced by bone morphogenetic protein 2 [11].

4. Development of Chitosan Biomaterials in Dental Treatment

4.1. Early Exploratory Phase

Initially, scientists envisioned the use of chitosan in dentistry after discovering its biocompatibility and other properties. At this stage, basic studies such as in vitro cytocompatibility experiments were conducted to simulate the cellular environment of the oral cavity, observe the effects of chitosan on cells, and determine its application potential. However, due to the technological and cognitive limitations at that time, there were few research reports, and the application conception focused on

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antibacterial aspects, such as the inhibition of common pathogens like Streptococcus pyogenes. Nevertheless, these early works laid the foundation for subsequent studies and opened the prelude to the research of chitosan application in dentistry [12,13].

4.2. Initial Application Phase

With the gradual advancement of research, scientists were no longer satisfied with in vitro studies, but initiated a journey to try chitosan for in vivo applications. Relying on evolving material preparation techniques, they processed chitosan into simple dosage forms, such as gels and membranes, which were then applied to small animal models of dental diseases. In the case of animal models of periodontal disease, for example, the researchers precisely applied the chitosan-containing gel or membrane formulations to the periodontal tissue of the diseased animals, and closely observed the repair of the periodontal tissues during the treatment process. Valuable data on the role of chitosan in vivo have been gradually accumulated through regular monitoring of the animal model, including the collection and analysis of data from various aspects such as histological examination and assessment of clinical symptoms [14].

4.3. Compounding and Expansion Phase

Recognizing the limitations of a single chitosan material, the researchers were keenly aware that there were performance limitations in a single chitosan material that would not be able to meet the increasingly diverse and complex needs of dental treatments. Thus, innovative thinking prompted them to explore the possibility of compositing chitosan with other biomaterials. Collagen, polylactic acid and other biomaterials were brought into the research field due to their unique performance advantages. Through careful design and optimization of the composite process, more excellent composites were successfully prepared. These composites not only retain the original excellent properties of chitosan, such as biocompatibility and antimicrobial properties, but also integrate the advantages of other biomaterials, such as collagen's good bioactivity and polylactic acid's adjustable degradation properties. The scope of application has also expanded rapidly, extending from the initial periodontal disease treatment field to a number of key areas of dental treatment, such as endodontics and oral implants [15,16].

4.4. Deep Optimization and Multidisciplinary Integration Phase

In this day and age, research on chitosan biomaterials has entered a more refined and cutting-edge phase. In terms of material performance optimization, researchers have started to deeply modify chitosan at the molecular level with the help of advanced chemical analysis and synthesis techniques. For example, specific functional groups are introduced into the molecular chain of chitosan by means of chemical modification, in order to achieve the goals of improving its antibacterial activity and accurately regulating the degradation rate. Meanwhile, multidisciplinary cross-fertilization has become a significant feature of this stage. Chitosan research has been closely integrated with nanotechnology, tissue engineering and other cutting-edge disciplines, giving rise to a series of innovative research results. The introduction of nanotechnology makes the particle size of chitosan-based materials smaller and the specific surface area larger, which significantly improves their drug-loading capacity and cellular uptake efficiency; the application of tissue engineering principles helps to construct more complex and biomimetic chitosan-based dental biomaterials, which can better mimic the structure and function of natural tissues [17,18].

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5. Problems and Challenges of Chitosan Biomaterials in Dental Applications

5.1. Inadequate Mechanical Properties

Although chitosan itself has a number of attractive properties and shows some potential for application in the field of dental therapy, the shortcomings in mechanical properties of chitosan materials cannot be ignored when used alone. In the complex mechanical environment of the oral cavity, teeth need to withstand the complex external forces generated by various activities such as chewing and swallowing, and their force situation is diverse and dynamic. The mechanical strength of chitosan materials is relatively low, and when applied to some dental restorative scenarios that require high support strength, such as fixed restorations in dental defect repair or dentition defect repair, they are prone to deformation, breakage, and other problems during use. This not only affects the service life and functionality of the restoration, but may also lead to restoration failure and the need for secondary restorations, bringing additional pain and economic burden to the patient. Although its mechanical properties can be improved to a certain extent by compositing with other materials and other ways, there is still a large gap compared with the actual clinical needs, and further in-depth research and optimization are urgently needed to develop chitosan-based composites with more excellent mechanical properties that can meet the needs of various dental restorations [19].

5.2. Improvement in the Precision of Controlled Release of Drugs

Chitosan has advantages as a drug carrier in dental therapy; however, it still faces challenges in terms of the precision of controlled drug release. In the in vivo environment, the rate and amount of drug release are critical for the stability of therapeutic effects. An ideal drug release system should be able to realize precise and sustained drug release according to the pathophysiological process of the disease and therapeutic needs. However, chitosan materials have not yet reached the ideal state in this regard, and their drug release behavior is affected by a variety of factors, such as the structure and composition of the material, the degradation rate, and the changes in the in vivo environment. The complexity of these factors makes it difficult for chitosan materials to accurately control the drug release process in vivo, and it is difficult to achieve stable and precise drug release over a long period of time as expected. This may lead to over- or under-concentration of the drug at the local level, which may cause toxic side effects if it is too high, or failure to achieve effective therapeutic concentration if it is too low, thus affecting the stability and reliability of the therapeutic effect, and restricting the effectiveness and popularization of the application of chitosan as a drug carrier in dental treatment.

5.3. Clinical Translation Costs and Cycle Time Issues

Chitosan biomaterials face a number of obstacles on the path from laboratory research to widespread clinical application, with the cost and lead time of clinical translation being particularly problematic. In terms of material preparation, the production process of chitosan-based materials may involve complex chemical synthesis, purification and processing techniques, which leads to higher material preparation costs. Meanwhile, in order to verify their safety and efficacy, large-scale, multi-center clinical trials are required, which not only require a large investment in patient recruitment, follow-up, data collection and analysis, but also consume a lot of time and human resources. In addition, the stringent approval process is also an important factor contributing to the long clinical translation cycle. In order to ensure the quality and safety of medical products, regulatory agencies have extremely stringent requirements for the approval of new materials, which require the submission of detailed research information, including performance tests, biocompatibility assessments, and clinical trial results of the materials. This series of factors makes the process of chitosan biomaterials moving from the laboratory to the clinic a long and difficult one, which, to a certain extent, prevents them from serving the majority of dental patients in a timely manner, delays the time when patients can benefit from this new material, and also limits its rapid development and wide application in the field of dental treatment.

6. Conclusion

The research and application of chitosan biomaterials is not only a hot spot in the field of dentistry, but also an important direction in the whole field of biomedical engineering. As a natural polymer material, chitosan has unique advantages such as a wide source, good biocompatibility, and strong degradability, which makes it have great potential for application in many fields such as tissue engineering, drug delivery, and wound repair.

With the continuous development of materials science, biotechnology and other multidisciplinary disciplines, chitosan biomaterials are expected to make more breakthroughs in the field of dental therapy. In terms of performance optimization, it is expected to further improve its mechanical properties, drug-controlled release properties, etc. through new modification methods, so that it can be better adapted to the needs of complex dental treatment. In terms of application expansion, personalized and intelligent chitosan-based dental treatment products can be developed by combining them with digital oral technology and the cutting-edge achievements of regenerative medicine [20]. At the same time, with the increasing support of relevant policies for the research and development and transformation of biomedical materials, the cost of their clinical transformation is expected to be reduced and the cycle is expected to be shortened, so that they can be applied to clinical practice more efficiently and play a greater role in improving the oral health of patients with dental diseases.

Chitosan biomaterials, with their unique biological properties, have shown a broad application prospect in the field of dental treatment, and have gone through several stages of development from the early preliminary exploration to the multifaceted application expansion nowadays. Although there are still some problems and challenges, through continuous scientific research and innovation as well as multidisciplinary cooperation, its application in future dental treatment will be improved and deepened, and it is expected to become an important tool for solving many difficult dental problems, to promote the level of dental treatment to a new level, and to make greater contributions to the cause of oral health.

References

[1] Fakhri E., Eslami H., Maroufi P., et al. Chitosan biomaterials application in dentistry [J]. International Journal of Biological Macromolecules, 2020, 162:956-974.

[2] Krishna N., Lolayekar N. Application of Chitosan Biomaterials in Dentistry-A Narrative Review [J]. Journal of Health and Allied Sciences NU, 2024, 14(2):152-156.

[3] Chenxi Z., Didi H., Colin D., et al. Preparation and application of chitosan biomaterials in dentistry [J]. International journal of biological macromolecules, 2020.

[4] Fariborz S., Samad K., Amirhossein E., et al. Advancements in Fabrication and Application of Chitosan Composites in Implants and Dentistry: a Review [J]. Biomolecules, 2022,12(2):155-155.

[5] Stolarz P.A., Mikulewicz M., Laskowska J., et al. The Importance of Chitosan Coatings in Dentistry [J]. Marine Drugs, 2023, 21(12).

[6] Zhongjuan Tan, Yuanyuan Luo, Li Yang. Study of basic fibroblast growth factor/chitosan derivative/collagen temperature-sensitive composite hydrogel for periodontal tissue regeneration in rats [J]. West China Journal of Stomatology, 2023, 41(01):21-28.

[7] Xingyue Wen, Junyu Zhao, Chongjun Zhao, et al. Research progress of chitosan in the treatment of periodontal disease [J]. International Journal of Stomatology, 2024, 51(04):416-424.

[8] Song J.H. Carboxymethyl chitosan-lysozyme nanogel stabilized amorphous calcium phosphate to seal dentin tubules [D]. Tianjin Medical University, 2018.

DOI: 10.54254/2753-8818/89/2025.21449

[9] Chen L.H., Lei C.M., Wang L.L. In vitro experiments of basic fibroblast growth factor/chitosan/polylactic acid scaffolds for periodontal tissue regeneration engineering [J]. Chinese Tissue Engineering Research, 2017, 21(26):4106-4112.

[10] Bagna, H.R. Chen, T. Li, et al. Regeneration of periodontal tissues induced by injectable nano-chitosan bone morphogenetic protein 2 complex [J]. Chinese Tissue Engineering Research, 2015, 19(38):6184-6189.

[11] Xiaofei Du. Research progress of chitosan in biomedical polymer materials [J]. Henan Chemical Industry, 2021, 38(12):5-6.

[12] Mingkai Jiang, Wenshuai Cao, Quanchen Xu. Research progress of carboxymethyl chitosan application in periodontology [J]. Guangdong Dental Disease Control, 2014, 22(05):275-278.

[13] Ling Deng, Ling Zou, Wei Li. Research on the application of chitosan and its derivatives in the treatment of oral caries [C]// Proceedings of the Twelfth National Academic Conference on Dental Materials, the Fifth Specialized Committee on Dental Materials Changeover Conference, 2017:1.

[14] Zhenhang Tang, Zhuo Chen. Research progress on chitosan-promoted enamel biomimetic mineralization restoration [J]. Stomatology, 2022, 42(03):256-260

[15] Xiaoxia Feng, Weiwei Hou, Xiaoting Jin, et al. Construction of polylactic acid-hydroxyacetic acid electrospun silk-chitosan electrosprayed microsphere periodontal bionic membrane [J]. Chinese Tissue Engineering Research, 2020, 24(04):511-516.

[16] Denise D.O., A. A C., A. J.M., et al. Chitosan-Hydroxycinnamic Acids Conjugates: Emerging Biomaterials with Rising Applications in Biomedicine [J]. International Journal of Molecular Sciences, 2022, 23(20):12473-12473.

[17] Aguilar A., Zein N., Harmouch E., et al. Application of Chitosan in Bone and Dental Engineering [J]. Molecules, 2019, 24(16):3009-3009.

[18] Luca S., Gaetano M., Anastasia F., et al. Critical Overview on Pure Chitosan-based Scaffolds for Bone Tissue Engineering: clinical insights in Dentistry [J]. International journal of medical sciences, 2023, 20(12):1527-1534.

[19] Espinoza F.I.A., Contreras G.R., Rocha G.A.D., et al. Gelatin-Chitosan Hydrogel Biological, Antimicrobial and Mechanical Properties for Dental Applications [J]. Biomimetics, 2023,8(8).

[20] Cedryck V., P.S.P., Mark P.B., et al. Tissue Engineered Constructs for Periodontal Regeneration: Current Status and Future Perspectives [J]. Advanced healthcare materials, 2018,7(21):e1800457.