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APPLICATION OF BIOMATERIAL IN REGENERATION IN DENTISTRY

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ABSTRACT

Biomaterials have revolutionized regenerative dentistry, providing innovative tissue restoration and repair solutions. This review discusses the latest advancements in biomaterials and their applications in dental regeneration, including bone, periodontal, and soft tissue regeneration. Biomaterials such as bioactive ceramics, polymers, and composites offer significant advantages due to their biocompatibility, biodegradability, and ability to promote cellular response, leading to enhanced tissue repair. Recent developments in bioengineered scaffolds, growth factors, and stem cell technology have opened new avenues for regenerating complex dental structures with improved functional and aesthetic outcomes. Key challenges in biomaterial application, such as integration with native tissues, potential immunogenicity, and clinical efficacy, are explored, alongside strategies to overcome these limitations. This review underscores the potential of biomaterials in advancing regenerative dentistry and highlights future directions for optimizing biomaterial design to improve clinical outcomes in dental tissue engineering.

KEYWORDS: Biomaterials, Regenerative dentistry, Tissue restoration, Dental regeneration.

INTRODUCTION

The field of regenerative dentistry is undergoing a profound transformation with the introduction and rapid advancement of biomaterials, reshaping the possibilities for dental tissue repair and regeneration. These cutting-edge materials are engineered to interact harmoniously with biological systems, opening new avenues for restoring essential dental structures such as bone, periodontal tissues, and soft tissues. These structures are critical for maintaining oral health, functionality, and aesthetics, making their effective regeneration a core priority in modern dentistry.[1-4] Biomaterials used in regenerative dentistry span a diverse range, including bioactive ceramics, polymers, and composite materials, each uniquely suited to address different aspects of tissue repair.[5-9] These materials' high biocompatibility and biodegradability enable them to interact seamlessly with the body's natural processes. Their ability to support and stimulate cellular responses such as proliferation, migration, and differentiation also enables enhanced tissue regeneration. Bioactive ceramics, for instance, can induce osteogenesis (bone formation) by providing a conducive environment for bone tissue growth, while biodegradable polymers allow precise control over degradation rates to match tissue healing timelines.[10-11] Composite biomaterials, which combine properties of different materials, offer versatile solutions tailored to meet complex regenerative requirements. Recent developments have also seen the integration of bioengineered scaffolds, growth factors, and stem cell technology into biomaterial-based therapies, resulting in more robust approaches to dental tissue engineering.[13-17] Scaffolds designed to mimic the native extracellular matrix (ECM) provide essential structural support, facilitating cell attachment, proliferation, and differentiation. These scaffolds are often combined with bioactive growth factors that stimulate tissue-specific cellular responses, accelerating the healing process.[18-22] Stem cells further amplify the regenerative potential, as they can differentiate into various types of dental cells needed for complex tissue structures, such as enamel, dentin, and periodontal ligaments. Together, these technologies not only improve functional outcomes but also allow for aesthetically pleasing restorations, which are increasingly in demand.[23-27] Despite significant strides, several challenges impede the full clinical integration of biomaterials in dental regeneration. Effective integration with native tissues remains a considerable hurdle; biomaterials must not only support healing but also form robust, long-lasting bonds with surrounding tissues. Additionally, some biomaterials may evoke immunogenic responses, triggering an immune reaction that can compromise the effectiveness of the regenerative process.[28-31] The long-term clinical efficacy of biomaterials is another critical concern, especially given the demanding environment of the oral cavity, where restorative materials must withstand continuous mechanical forces, fluctuating pH levels, and exposure to bacteria.[32-35] To overcome these limitations, researchers are employing a variety of strategies to enhance biomaterial performance. Surface modifications, such as incorporating biomimetic coatings or modifying surface topography, improve tissue attachment and reduce immunogenicity. Embedding bioactive molecules or peptides into the biomaterial can further promote tissue healing and integration by encouraging cell recruitment and differentiation.[30,36-39] Personalized approaches are also gaining momentum, where patient-specific scaffolds are fabricated using 3D printing and other precision engineering techniques, creating structures that better replicate the individual's dental anatomy and align with their unique biological responses.[40-43]

This review provides a comprehensive exploration of current advancements in biomaterials for regenerative dentistry, discussing the innovative designs and strategies that are pushing the field forward. It highlights both the transformative potential and the challenges that lie ahead, focusing on solutions to improve the functionality, longevity, and compatibility of biomaterials for dental applications. The future of regenerative dentistry will be driven by optimizing biomaterial properties and leveraging new technologies to deliver highly personalized, effective treatments that restore not only the structure but also the function and aesthetics of dental tissues. This continual evolution in biomaterial science holds the promise of greatly improving clinical outcomes and patient quality of life in dental regenerative therapies.

Types of Biomaterials in Dental Regeneration

In regenerative dentistry, biomaterials play a vital role in the repair and regeneration of dental tissues (Table. 1, Figure 1).

1. Ceramic Biomaterials

Ceramic biomaterials are among the most commonly used due to their bioactivity, biocompatibility, and mechanical strength, making them ideal for applications that require durability and aesthetics. Examples include hydroxyapatite (HA), which closely resembles the mineral component of bone and is often used in bone grafts and dental implants. Calcium phosphate cements (CPC) are another example, used for their bioactivity and osteoconductivity in bone tissue engineering. Zirconia, known for its high strength and aesthetic appeal, is frequently used in dental crowns and implants.[44-48]

2. Polymeric Biomaterials

Polymeric biomaterials are favored for their flexibility, processability, and adaptability to various functions, making them well-suited for applications requiring a softer material. Examples include polylactic acid (PLA) and polyglycolic acid (PGA), both commonly used in scaffolds for tissue regeneration as they naturally degrade in the body. Poly(methyl methacrylate) (PMMA) is utilized in dental prosthetics and as a bone cement in implants, while chitosan, a natural polymer, is used in periodontal treatments for its antimicrobial properties and biocompatibility.[49-52]

3. Metallic Biomaterials

Metallic biomaterials are essential in dentistry for load-bearing applications due to their strength and durability. Titanium and its alloys are highly biocompatible and corrosion-resistant, making them ideal for dental implants. Cobalt-chromium alloys are valued for their durability and are used in partial dentures and frameworks. Stainless steel is commonly used in orthodontic wires and brackets due to its strength and resistance to wear.[53-56]

4. Composite Biomaterials

Composite biomaterials combine two or more material types to harness the advantages of each, offering strength, bioactivity, and aesthetic appeal. Resin-based composites are widely used for tooth-colored fillings due to their strength and visual appeal. Glass ionomer cements, known for their fluoride-releasing properties, are used in dental restorations to aid in tooth adhesion. Fiber-reinforced composites, employed in bridges and prosthetic frameworks, offer improved mechanical properties for structural applications.[57-61]

5. Biodegradable Biomaterials

Biodegradable biomaterials are designed to break down in the body over time, making them ideal for temporary structures that support tissue regeneration and healing. Collagen, for example, is frequently used as a scaffold in periodontal regeneration to support cell growth and tissue repair. Gelatin is applied in dental surgeries as a hemostatic agent and in scaffolds within tissue engineering applications. Polydioxanone (PDO) is used in suture materials and scaffolds due to its predictable degradation rate.[62-66]

6. Bioactive Glasses

Bioactive glasses encourage bone regeneration by releasing ions that stimulate bone formation and integrate well with bone tissue. An example is 45S5 Bioglass, which is often used as a bone graft substitute, forming a bond with natural bone to promote growth. Silicate-based glasses are used in dental fillers and coatings to enhance bone adhesion, improving implant success.[67-71]

7. Natural Biomaterials

Natural biomaterials, derived from biological sources, are used in applications requiring high biocompatibility and bioactivity. Alginate, extracted from seaweed, is used as a scaffold in dental and periodontal regeneration. Silk fibroin is employed in tissue engineering, especially for guided tissue regeneration, due to its excellent biocompatibility. Hyaluronic acid, known for its wound-healing properties, is used in periodontal therapy and as a filler material. Each of these biomaterials plays a distinct role in supporting regenerative processes in dentistry, facilitating the repair, replacement, and regeneration of damaged tissues.[7,52,72-74]

Table 1: Types of Biomaterials in Dental Regeneration.

Type of Biomaterial	Applications	Examples	Properties	References
Ceramic	Dental implants, bone grafts	Hydroxyapatite (HA), Calcium Phosphate Cement (CPC), Zirconia	Bioactivity, biocompatibility, mechanical strength	[44-48]
Polymeric	Dental prosthetics, tissue regeneration scaffolds	Polylactic Acid (PLA), Polyglycolic Acid (PGA), Poly(methyl methacrylate) (PMMA), Chitosan	Flexibility, processability, biodegradability	[49-52]
Metallic	Dental implants, prosthetic frameworks, orthodontic wires	Titanium, Cobalt-Chromium Alloys, Stainless Steel	Strength, durability, corrosion resistance	[53-56]
Composite	Dental fillings, structural scaffolds, bridges and prosthetics	Resin-based composites, Glass ionomer cements, Fiber-reinforced composites	Strength, bioactivity, adhesion, fluoride release	[57-61]
Biodegradable	Tissue regeneration scaffolds, periodontal repair	Collagen, Gelatin, Polydioxanone (PDO)	Biodegradability, cell growth support, tissue repair	[62-66]
Bioactive Glasses	Bone grafts, dental fillers	45S5 Bioglass, Silicate-based glasses	Bone growth stimulation, improved bone adhesion	[67-71]

Natural	Dental and periodontal tissue regeneration	Alginate, Silk Fibroin, Hyaluronic Acid	High biocompatibility, wound healing properties	[7, 52, 72-74]

Figure 1: Types of Biomaterials.

Traditional Challenges in Dental Regeneration

The application of biomaterials in dental regeneration has provided solutions to traditional challenges in tissue regeneration within dentistry. In the past, efforts to regenerate dental and bone tissues faced limitations and complexities, which presented specific challenges.

1. Lack of Proper Biocompatibility and Scaffolding

Traditional materials often lacked compatibility with dental tissues, leading to inflammation and immune responses that reduced the success of treatments. Many traditional materials were unable to provide a scaffold or framework that allowed for effective cell growth and proliferation, making tissue regeneration difficult.[75-76]

2. Insufficient Resistance to Infection

Due to the high bacterial presence in the mouth, traditional materials could not fully prevent bacterial growth, which led to infections and compromised the regenerated tissue.[77]

3. Lack of Stem Cell Activation

Older methods could not stimulate stem cells and promote cellular differentiation to form new tissue, which is essential for targeted and precise regeneration.[78-79]

How Biomaterials Address These Challenges

1. High Biocompatibility

Modern biomaterials, such as hydroxyapatite and bioactive glass, exhibit high biocompatibility, which prevents immune reactions and facilitates better acceptance in dental and bone tissues. This high biocompatibility enables regeneration to proceed without adverse reactions.[80-84]

2. Providing Structural Framework for Tissue Growth

Biomaterials like bioceramics and collagen provide a structure similar to the extracellular matrix, allowing cells to easily attach, proliferate, and ultimately create new tissue. This supports the growth and regeneration of dental and bone structures.[85-87]

3. Antibacterial Properties

Some modern biomaterials include nanoparticles of metals like silver and zinc, which have antibacterial properties. This helps prevent infections at the repair site and inhibits bacterial growth, preserving the newly formed tissue.[88-90]

4. Stimulating Stem Cells and Cellular Differentiation

Certain modern biomaterials can stimulate stem cells to differentiate into specialized dental cells, such as odontoblasts and osteoblasts. This capability helps in the creation of healthy new dental tissues, which is essential for effective and precise regeneration.[91-93]

CONCLUSION

The application of biomaterials in dental regeneration has significantly transformed approaches to oral health and dental treatment. Biomaterials, through their biocompatibility and regenerative capabilities, support the natural healing of dental tissues and reduce the reliance on traditional restorative methods. These materials, especially bioactive ceramics, polymers, and nanocomposites, have shown promising results in facilitating tissue regeneration, enhancing cellular growth, and supporting the restoration of both hard and soft dental tissues. The integration of advanced biomaterials in dental applications continues to address challenges like infection control, biocompatibility, and long-term durability, contributing to more effective, minimally invasive, and patient-centered treatment modalities.

Future Perspectives

In the future, research and development in biomaterial applications in dental regeneration will likely emphasize personalized, patient-specific treatment options. The use of smart biomaterials that respond dynamically to the oral environment holds immense potential. Additionally, advancements in nanotechnology, bioengineering, and 3D printing are expected to enable the creation of highly precise, customized implants and scaffolds that closely mimic the natural dental tissue structure. Incorporating bioactive molecules such as growth factors, peptides, and gene therapy into biomaterial scaffolds could further enhance regenerative outcomes. The ongoing exploration of sustainable and biodegradable materials will also play a key role in reducing environmental impacts. Ultimately, the future of dental biomaterials lies in interdisciplinary collaboration, where innovations in materials science, biology, and clinical practice converge to advance regenerative dentistry and improve patient outcomes.

Author Contributions

Conceptualization, Adriána Petrášová and Elham Saberian; methodology, Andrej Jenča and Janka Jenčová; validation, Andrej Jenča and Adriána Petrášová; formal analysis, Elham Saberian; investigation and resources, Adriána Petrášová; data curation, Andrej Jenča and Adriána Petrášová; writing—original draft preparation, Elham Saberian; writing—review and editing, Andrej Jenča and Janka Jenčová; visualization, Adriána Petrášová; supervision, Andrej Jenča; project administration, Adriána Petrášová. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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