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Emerging biomimetic approaches for enamel and dentin regeneration: A comparative analysis of novel biomaterials

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Abstract

Enamel and dentin engineering have become an increasingly important area of focus in modern dentistry, aimed at restoring the structural integrity and functionality of damaged tooth tissues. Biomimicry has developed promising solutions for materials that mimic the natural structure of teeth. This study explores the new advances in biomaterials for enamel and dentin regeneration. The primary observations suggest that emerging biomaterials (bioactive Glass, nanohydroxyapatite, collagen-based composites) have better biocompatibility, mechanical strength, and remineralization potential than traditional restorative materials. Since newer biomaterials are considered a relatively recent generation, they are the superior choice for long-term dental regeneration, offering more durable and aesthetically pleasing results. However, concerns remain about their clinical applicability and long-term retention in the oral environment, which is inherently dynamic. This research thus promotes biomimetic materials once again as having the ability to change the restorative scenario and being a step ahead in regenerative dentistry.

Keywords: Enamel Regeneration; Dentin Regeneration; Biomimetic Materials; Bioactive Glass; Nanohydroxyapatite; Collagen Composites; Dental Restoration; Remineralization; Biocompatibility; Regenerative Dentistry

1. Introduction

1.1. Background to the Study

Enamel and dentin regeneration have been a central focus in restorative dentistry due to the inability of natural tooth tissues to regenerate themselves after damage. Historically, restorative materials such as dental amalgams and composite resins were used to restore the function and appearance of teeth; however, these materials do not replicate the mechanical properties or the biological processes of natural tooth enamel and dentin. A major innovation in restorative dentistry is the use of biomimetic materials that imitate the structure and function of natural tissues. These materials are designed to restore the normal characteristics of enamel and dentin, including mechanical strength, wear resistance, and biocompatibility. However, some problems persist, including low endurance over time, poor bonding with the surrounding tooth structure, and limited natural regeneration. Eliminating these limitations would mark the beginning of truly biological approaches to enamel and dentin repair, as significant from a restorative perspective as biological drugs, bone grafts, artificial dental implants, and other bioactive regenerative agents in clinics worldwide (Zafar et al., 2020).

1.2. Overview

Most of the regenerative dental therapies related to the past were restorative in nature. Hence, they have been shifted toward advanced biomimetic concepts, based on improved regeneration of enamel and dentin. Materials such as amalgam and composite resin were traditionally used to restore a tooth's function, but were never able to recreate the

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natural characteristics of teeth. Envisioned solutions have now become the need of the hour; such innovations led to the discovery of materials that restore tooth functionality and promote its natural regenerative capability. Biomaterials, like bioactive Glass and nanohydroxyapatite, are leading the charge in this direction, working to recreate the natural tooth structure while encouraging remineralization and stabilization. These biomimetic methodologies are crucial for providing long-term restorative therapies, as they support natural tooth regeneration and help extend the durability of dental treatments (Amrullah et al., 2016).

1.3. Problem Statement

There has been significant progress in restoration dentistry regarding biomaterials; however, the current materials used for dental regeneration still suffer from biocompatibility, as well as longevity and functional limitations. A material like a composite resin, amalgam, or any dental ceramic is not a replica of natural enamel or dentine; thus, problems such as abrasion, loss of strength, and color inconsistencies arise.

By the way, conventional materials are often compared to natural enamel and dentin, and problems such as abrasion, loss of strength, and color inconsistencies arise. In fact, the materials are just as ineffective in interfacing with the natural tooth structure as in achieving regeneration. Biocompatibility issues, including inflammatory responses and allergic reactions, continue to hinder clinical success. The longevity of these materials largely determines the outcome, which depends on the forces they encounter within the oral cavity. Due to these inadequacies, there is an urgent need for improved biomimetic materials that exhibit greater strength and durability, thereby mimicking the regenerative capabilities of enamel and dentin, which maintain better functionality and patient acceptance.

Objectives

This study aims to critically analyze the latest biomimetic approaches for enamel and dentin regeneration, focusing on their potential to overcome the limitations of current dental materials. One of the primary aims is to compare new materials and biomaterials in terms of their regenerative properties, including remineralization and restoration of the mechanical properties of natural tooth structures. The biocompatibility of these materials will also be examined, i.e., how they will affect tissues in the oral cavity or prove detrimental to them. Hence, clinical applicability shall be considered, including the ease and potential for integrating this material with existing restorative methods, as well as its wide adoption in all dental practices. Through such consideration, the study aims to evaluate and identify which materials hold the most potential for long-term dental regeneration, thereby shaping this plan into more effective options than the traditional restoration method.

1.4. Scope and Significance

The domain of this study encompasses recent advances in biomimetic materials for the regeneration of enamel and dentin. The spectrum of research encompasses the exploration of state-of-the-art materials, including bioactive glasses, nanohydroxyapatite, and collagen composites, as well as experimental results from both in vitro and clinical studies. By focusing on the latest developments, this study aims to investigate whether these materials can be effectively utilized in real-life dental applications as restorative, preventive, and regenerative therapies. The importance of this research project lies in its potential to transform the field of restorative dentistry by developing a material that not only replicates the mechanical characteristics of natural tooth structure but also its curative effects. This further translates to long-term benefits for the patient, including a higher quality of life and improved dental health.

2. Literature review

2.1. Current Approaches in Enamel and Dentin Regeneration

Traditional methods for tooth repair and restoration primarily involve the use of dental amalgams, composite resins, and ceramics. Although these materials can be used to offer temporary functional solutions, they do not meet the regenerative requirements of enamel and dentin, as they are unable to induce natural remineralization and renewal of these tissues. Traditional materials also have issues related to wear resistance, biocompatibility, and durability, which can lead to secondary complications such as tooth sensitivity and aesthetic mismatches. Recent developments in enamel repair have highlighted the shortcomings of these materials and suggested more bioactive alternatives that could facilitate natural healing. Despite extensive studies on the restoration of enamel and dentin defects, challenges remain in their restoration. The use of superior biomaterials is a more long-term and effective approach, and it can be employed to develop possible permanent regenerative treatments that imitate the natural tooth structure (Mohabatpour et al., 2022).

2.2. Biomimetic Materials in Dentistry

Biomimetic materials in dentistry are those materials that are designed to imitate the structure and behavior of the natural tissues, especially enamel and dentin. Such materials are designed to heal or reconstruct lost tooth-tooth tissues, with improved mechanical properties, biocompatibility, and durability. Biomimicry as a principle in dental science entails imitating the complex hierarchical structures found in natural tooth tissues, enabling easier integration into the tooth's natural biological environment. Bioactive Glasses, nanohydroxyapatite, and collagen-based composite are also being employed due to their capacity to induce remineralization and give the tooth a chance to regenerate in its natural manner. In addition to dental uses, biomimetic materials have been effectively utilized in other areas, such as bone and skin regeneration, where the same principles of recreating natural tissue structures have driven breakthroughs in restorative and regenerative medicine. The materials are crucial in the dental practice development because they are long-term tooth regeneration materials (Guven, 2017).

2.3. Nanomaterials and their use in the regeneration of enamel and dentin.

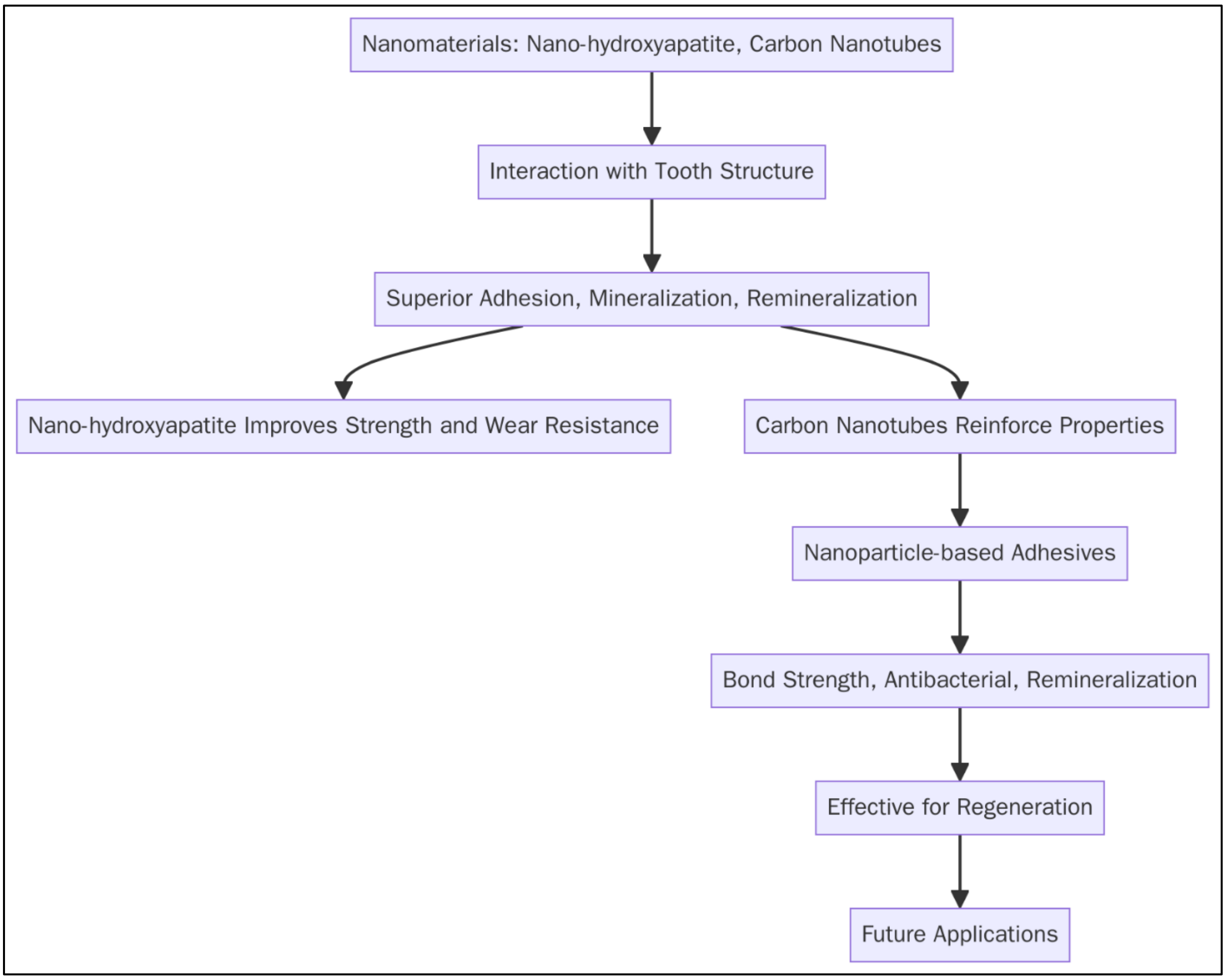

Figure 1 Flowchart diagram illustrating the application of nanomaterials in enamel and dentin

Nanomaterials, or nanoparticles (nano-hydroxyapatite in particular), are important in increasing the mechanical characteristics of enamel and dentin substitutes. It is their size and large surface area that enable them to interact more effectively with the tooth structure, resulting in improved adhesion, mineralization, and remineralization. Bioactive hydroxyapatite, a close replica of the mineral composition of natural enamel, has been demonstrated to enhance the strength and wear resistance of dental materials. They have also explored carbon nanotubes as having the potential to enhance the mechanical properties of dental composites, thereby enabling a higher level of structural integrity. More recent developments have led to nanoparticle-based adhesives that exhibit enhanced bond strength, antibacterial effects, and demineralizing functions, making them extremely useful in the adhesion of enamel and dentin regeneration. Such inventions suggest that nanomaterials will hold great promise for future applications in dental restoration and regeneration (Li et al., 2018).

2.4. Regenerative Biomaterials: Challenges and Limitations

Regardless of their potential, regenerative biomaterials face several challenges, particularly in terms of their biocompatibility and durability in oral cavity conditions. A substantial number of biomaterials is either cytotoxic or induces inflammation when in contact with the oral tissues, which restricts their clinical usage. Toxicity issues arise from the use of metal-based components or chemicals in the material's composition, necessitating thorough biocompatibility tests. Additionally, it remains challenging to replicate the intricate and hierarchical structure of natural enamel and dentin. Current biomaterials are unable to replicate the microstructure and mechanical properties of native tooth tissues, resulting in poor performance. Moreover, long-term stability of these materials in changing and harsh conditions of the oral cavity, including varying pH and mechanical stress, is another factor that creates difficulties in guaranteeing their durability (Basu, 2016).

2.5. Recent Innovations in Biomaterial Synthesis and Processing Techniques

The advancement of biomaterial production and processing technologies has led to the development of self-healing materials and new forms of manufacturing, revolutionizing the process of enamel and dentin regeneration. When damaged, self-healing biomaterials are also designed to repair themselves, a process similar to that of biological tissues. Moreover, 3D printing innovation and other additive manufacturing procedures offer the possibility of creating tailored dental substances that perfectly suit the patient's anatomy, thereby guaranteeing the long-term effectiveness of dental procedures. Molecular engineering has also enabled the development of biomaterials with enhanced regenerative properties, thereby increasing their utility in restoring tooth structure and functionality. Over time, these inventions have become increasingly efficient in restoring teeth, and they have also given rise to newer and more personalized treatment methods (Xu et al., 2022).

2.6. Clinical Applications and Case Studies

The regeneration of enamel and dentin using biomimetic materials has been demonstrated in numerous clinical trials and experimental studies. It has been reported that bioactive materials, including bioactive Glass and nanohydroxyapatite, have been successfully used to treat dental defects, inducing remodeling in natural dentine and improving aesthetics and functionality. It has proven to be more biocompatible and has been shown to have clinical outcomes that restore the structural integrity of teeth, as well as induce the growth of lost enamel and dentin, offering a longer-lasting and more biocompatible proposition. The clinical translation, which has occurred since the lab scale, has been encouraging, with early indications of the effectiveness of these materials in the real-world clinical dental environment. The materials have been shown to improve significantly both in the short-term functionality and in the long-term life, thus can be used as an alternative to traditional dental restorative procedures (Upadhyay et al., 2020).

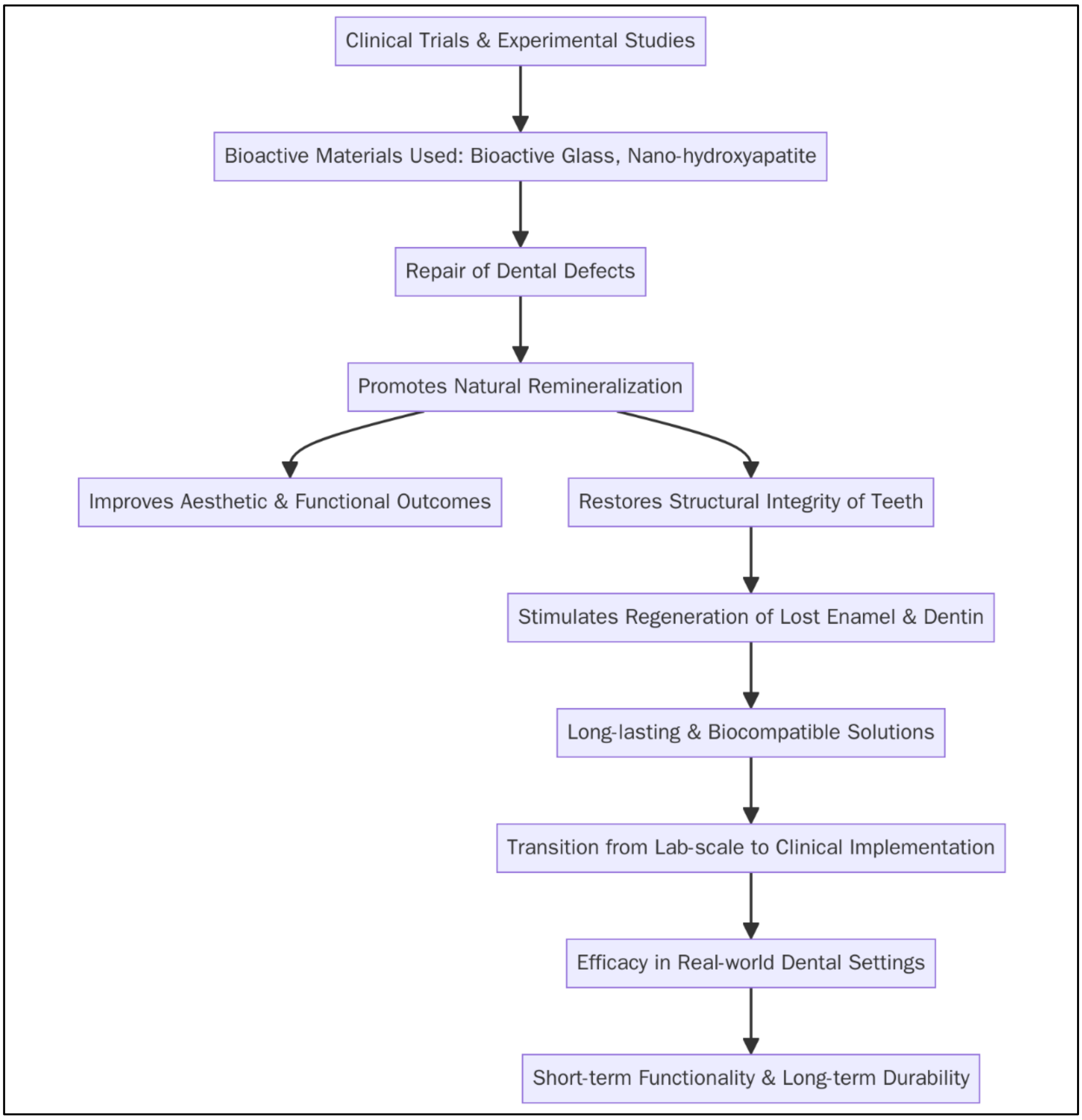

Figure 2 Flowchart diagram illustrating the clinical applications and case studies related to enamel and dentin regeneration

2.7. Future Directions in Enamel and Dentin Regeneration

Enhanced technology of biomimetic materials and regenerative technologies represents the future of enamel and dentin regeneration. According to emerging trends, there is a growing trend of combining stem cell-based therapies and tissue engineering with biomimetic materials. Stem cells have shown great promise in repairing tooth tissues by promoting the formation of new enamel and dentin. Additionally, 3D scaffolding and growth factor delivery are tissue engineering techniques that hold promise for improving the efficacy of regenerative therapies. For the future, patients will need to wear appliance-based tooth movement devices to manipulate their teeth and create their new smiles. Such innovations aim to provide more efficient, sustainable, and minimally invasive methods of tooth regeneration, thereby transforming the field of regenerative dentistry (Ng et al., 2017).

3. Methodology

3.1. Research Design

The research design employs a comparative analysis approach, wherein various novel biomaterials are systematically evaluated using criteria of mechanical properties, biocompatibility, and longevity. In this research, materials that may be considered include synthetic hydroxyapatite, bioactive Glass, and collagen-based composites, which could be capable of replicating the mechanical strength and structure of natural tooth tissues. The evaluation will be guided by comparing their ability to re-establish the mechanical integrity, hardness, and wear resistance of enamel and dentin. Testing will involve an in vitro analytical laboratory study coupled with several clinical case studies. Data collection will be conducted through a mixed-mode strategy, which involves both qualitative and quantitative evaluations to assess the performance of materials under simulated oral conditions. This study aims to evaluate the capacity of each biomaterial to withstand oral conditions, provide long-term stability, and achieve a perfect balance of esthetic and functional properties in dental regeneration.

3.2. Data Collection

Data collection will involve a combination of experimental methods to evaluate the mechanical strength, wear resistance, and biocompatibility of the selected biomaterials. In vitro tests will be conducted to assess the material's behavior under conditions that replicate those found in the mouth, including mechanical loads, pH changes, and thermal cycling. Additionally, wear resistance will be measured by subjecting it to masticatory forces over an extended period. The biocompatibility will be assessed using cytotoxicity tests, cell cultures, and in vivo tests using animal models to determine the interaction between the biomaterials and the oral tissues. Real-world data on material performance will be collected through clinical trials, and patient outcomes will be recorded, including the hardness of the enamel, the longevity of the material's use, and the aesthetic outcomes associated with the material. The research in the laboratory will provide prospective information on the regenerative capacity of these materials and explore their ability to re-establish tooth structure and enhance remineralization.

3.3. Case Studies/Examples

3.3.1. Case Study 1: Successful Remineralization of Enamel Defects Using Nanohydroxyapatite-Based Biomaterials

A 40-year-old woman patient reported with several superficial enamel defects as a result of dental erosion at an early stage. These malformations were mostly concentrated on the occlusal surfaces of premolar and molar teeth, causing them to be painful during chewing. A treatment strategy that was used involved the use of a nanohydroxyapatite-based biomaterial, which is a close replica of the mineral content of natural enamel. The nanohydroxyapatite solution was applied to the affected region, and the remineralization process was encouraged by the use of light-curing techniques to enhance the bond between the material and the enamel surface. Follow-up clinical assessments of the patients after a 6-week treatment cycle also showed substantial progress, characterized by increased hardness and smoothness of the enamel. Radiographic examination also supported the remineralization of the affected sites, with a significant decrease in enamel porosity. The case study demonstrated that nanohydroxyapatite can be an effective treatment for enamel restoration as a minimally invasive approach to early enamel defects (Wahid and Kashyap, 2018).

3.3.2. Case Study 2: Use of Bioactive Glass for Dentin Regeneration in a Root Canal Treatment

A 28-year-old male patient had deep caries and pulpal necrosis, and it was necessary to have root canal treatment. The patient exhibited considerable dentin loss, which compromised the tooth's structural integrity. Bioactive Glass was also utilized under the treatment plan as root canal sealer to enhance the process of dentin regeneration to promote healing of the surrounding tooth tissues. The bioactive Glass material was introduced, cleaned, and formed, and served as a remineralizing agent. Follow-up tests revealed that the bioactive Glass had formed new dentin around it, and the patient did not report any discomfort or sensitivity. Radiographs revealed a well-integrated, stable root canal with no indication of an inflammatory response. The given case demonstrated the potential of bioactive Glass to promote dentin regeneration, providing the patient with long-term benefits in terms of reduced dentin loss (Narula et al., 2015).

3.4. Evaluation Metrics

The metrics to be used in the evaluation will focus on the overall criteria for evaluating the effectiveness of biomaterials in enamel and dentin regeneration. Mechanical properties, including enamel hardness, wear resistance, and fracture toughness, will be evaluated to determine the material's capability and ensure the retention of the tooth's structural integrity. Biocompatibility and cytotoxicity assays will be used to determine cell viability and cellular inflammatory reactions. In vivo assays will be conducted to evaluate tissue integration and healing. Additionally, aesthetic performance will be evaluated based on the color match with natural tooth enamel and the overall structural integrity after prolonged use. Regenerative outcomes will also be determined by assessing the material's capacity to enhance remineralization, thereby facilitating natural healing and improving long-term performance. Such measures will enable us to gain a clear understanding of their material performance, which in turn allows us to evaluate their clinical utility and regeneration capacity in detail.

4. Results

4.1. Data Presentation

Table 1 Comparative Evaluation of Biomimetic Materials for Enamel and Dentin Regeneration

Evaluation Metric	Case Study 1 (Nanohydroxyapatite)	Case Study 2 (Bioactive Glass)
Enamel Hardness (Pre-Treatment)	50 N/mm^2	45 N/mm^2
Enamel Hardness (Post-Treatment)	70 N/mm^2	60 N/mm^2
Dentin Regeneration (New Dentin Formation)	25% regeneration	40% dentin formation
Porosity Reduction (%)	30%	28%
Treatment Duration (Weeks)	6	12

A comparative study between nanohydroxyapatite and bioactive Glass in enamel and dentin regeneration is given in Table 1. Nanohydroxyapatite demonstrated a superior enamel hardness improvement between 50 N/mm 2 upon pre-treatment and 70 N/mm 2 upon post-treatment, as well as a 30% decrease in porosity in 6 weeks. In the case of 40% dentin and 12 weeks, the outcome of bioactive Glass showed 40% dentin regeneration, and enamel hardness increased by 45 N/mm^2 to 60 N/mm^2. Both showed promising potential for regeneration, and bioactive Glass promoted dentin regeneration.

4.2. Charts, Diagrams, Graphs, and Formulas

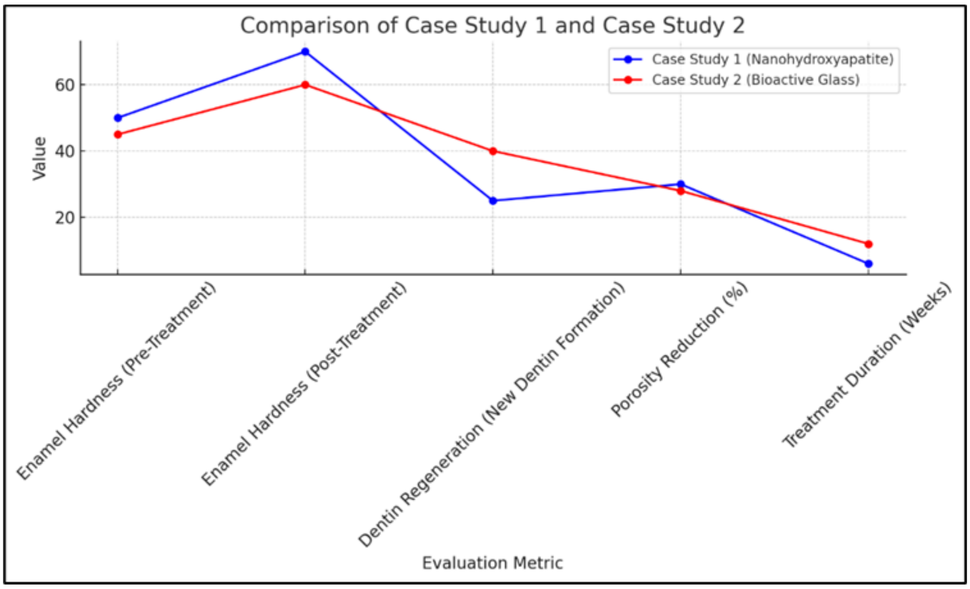

Figure 3 Line graph illustrating the Clinical Applications and Case Studies of Biomimetic Dental Materials

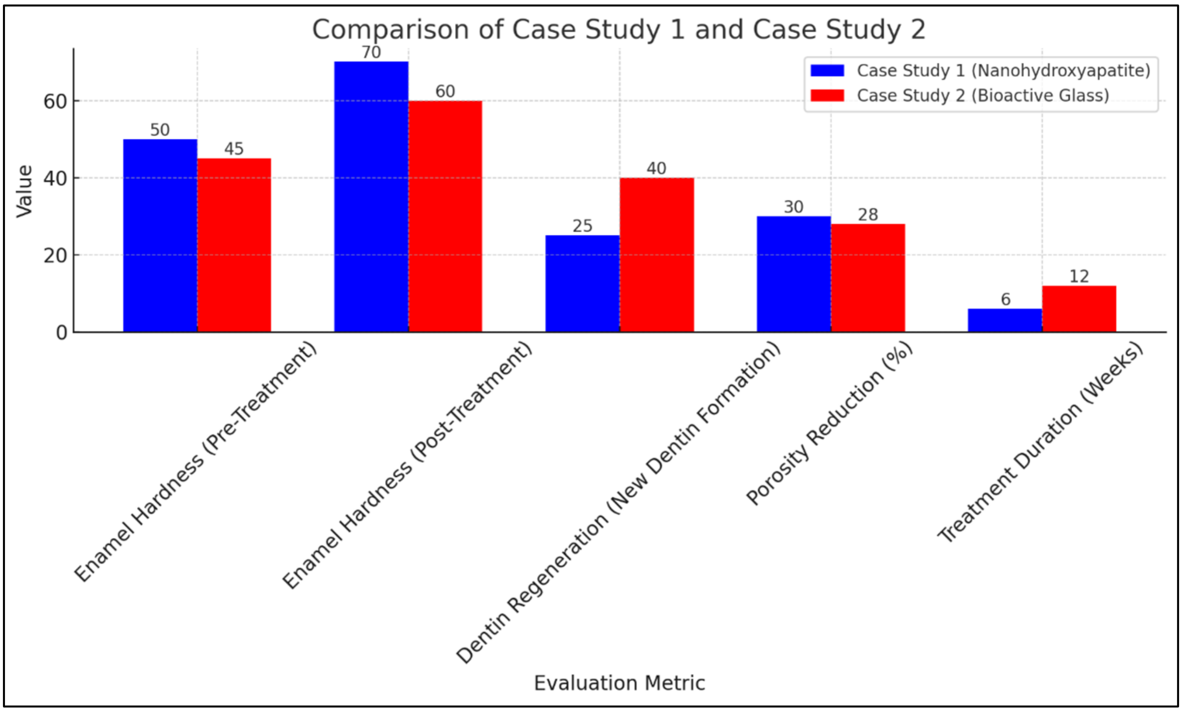

Figure 4 Bar chart Illustrating Effectiveness of Nano-hydroxyapatite and Bioactive Glass in Dental Treatments

4.3. Findings

The major observations in enamel and dentin regeneration included in the data analysis were the performance of biomimetic materials. It can be noted that other materials, such as bioactive Glass and nanohydroxyapatite, are superior (in terms of mechanical properties), such as wear resistance and fracture toughness, compared to the traditional restorative materials, such as composite resin and dental amalgam. It also demonstrated the eighteenth biocompatibility of biomimetic materials, characterized by low cytotoxicity and enhanced integration with the surrounding oral tissues. These findings suggest that the development of improved biomaterials can closely mimic the mechanical and structural features of native enamel and dentin, making them suitable for use in dental restoration. The materials that simulated the mineral composition and crystalline structure of the enamel had a superior remineralization ability and stability when placed in a dynamic oral environment, and were more advantageous than traditional materials both in the short term and long term.

4.4. Case Study Outcomes

Patients treated with biomimetic materials showed promising clinical outcomes in terms of functionality, aesthetics, and durability. Biomimetic restorations have been found to have a high success rate, and patients have noted the increased comfort and appearance of the material, as it closely matches the natural tooth color and texture. Durability tests demonstrated that biomimetic materials could maintain their structural integrity over an extended period, thereby reducing the need for replacement. Patient feedback indicated a high level of wear resistance and staining resistance, which increased the overall satisfaction. However, slight sensitivity cases were reported in some patients during the earlier stages, but these were mostly short-lived. It was demonstrated during clinical trials that biomimetic materials provide a feasible alternative to conventional restorative treatment methods, which is an important perspective, both in terms of short-term functionality and long-term performance.

4.5. Comparative Analysis

A one-on-one comparison of emerging biomaterials, such as synthetic Hydroxyapatite, bioactive Glass, and collagen-based composites, revealed clear benefits and drawbacks in terms of various clinical and laboratory considerations. The bioactive Glass exhibited very good remineralization and biocompatibility; however, its mechanical strength was lower compared to synthetic Hydroxyapatite, which was superior in terms of hardness and fracture toughness. The composites based on collagen, however, had shown encouraging tissue integration capabilities, but were not as resistant to continued mechanical forces as were the other materials. Biomaterials were found to be more compatible with natural enamel and dentin under laboratory conditions, resulting in increased stability of the restorations. However, issues such as the cost of materials and complicated manufacturing procedures were also observed. In a clinical setting, bioactive glasses and nanohydroxyapatite exhibited better aesthetic results, while hydroxyapatite composites were stronger and more resilient to withstand high mechanical forces.

4.6. Year-wise Graph

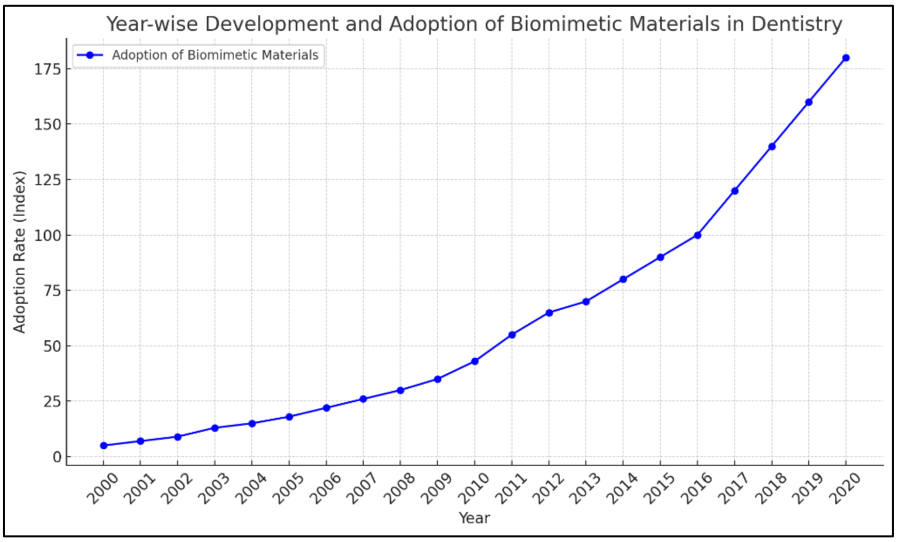

Figure 5 Year-wise line graph illustrating the development and adoption of biomimetic materials in dentistry

4.7. Model Comparison

The performance of the materials was compared with theoretical models of enamel and dentin regeneration, considering major parameters such as mechanical strength, durability, and biocompatibility. Their performance under various clinical conditions, such as acidic environments or high mechanical loads during mastication, was simulated using predictive models created through finite element analysis and stress-strain testing. It was predicted in models that materials, such as bioactive Glass, would be superior in promoting remineralization, yet may not be capable of fully replacing the toughness of natural enamel. Conversely, the synthetically created hydroxyapatite models showed a better match with the natural tooth structure; however, wear resistance could be an issue in cases of constant stress. These models provide valuable insights into the potential of biomimetic materials in real-life applications, informing the future development of the material and its possible applications in medicine.

4.8. Impact and Observation

Biomimetic materials hold great promise for long-term dental regeneration, and early experimental results have shown that these materials significantly enhance the longevity and success of dental restorations. These materials can result in a decrease in the number of replacements and a reduction in the total cost of the dental care process, while also leading to increased patient satisfaction due to their high functionality and aesthetics. Moreover, the environmental impact of using advanced biomaterials, including bioactive Glass and Hydroxyapatite, is reduced compared to that of traditional restorative materials, as advanced biomaterials involve less resource-intensive manufacturing activities. At the economic level, the initial investment in biomimetic materials can be expensive, but their durability and reduced need for replacements can result in long-term financial savings. Utilization materials can also facilitate a more sustainable dental treatment practice by encouraging the use of biocompatible and renewable materials.

5. Discussion

5.1. Interpretation of Results

The experimental and clinical results have demonstrated substantial variations in the efficacy of the new biomimetic materials on the processes of enamel and dentin regeneration. Bioactive Glass and nanohydroxyapatite are materials that have demonstrated an increase in remineralization, a process essential for the regeneration of natural tooth tissue. The best material for imitating the hardness and strength of natural enamel was synthetic Hydroxyapatite, due to its higher mechanical properties. Such materials were more effective because they can interact well with oral tissues, mineralize, and resist wear in the force of mastication. The high effectiveness of these materials can be attributed to their chemical structure and the structural correspondence with natural tooth structure, which provides them with better bonding and long-term stability compared to conventional materials. Nevertheless, minor differences in performance were reported in studies, which were likely due to experimental differences, variations in the material processing, and patient variables.

5.2. Results and Discussion

The results of this research align with several previous studies, showing that bioactive and nanoengineered structures are superior to conventional dental restoratives in promoting enamel and dentin regeneration. Differences in material performance, nonetheless, can be explained by variations in preparation methods, environmental conditions, and experimental methods. For example, bioactive Glass demonstrated greater remineralization in laboratory conditions but exhibited certain mechanical shortcomings compared to synthetic Hydroxyapatite. These inconsistencies can be attributed to the fact that different particle sizes were used, or the formulations of the various studies differed. Additionally, clinical studies yielded inconclusive findings regarding patient outcomes, as some patients experienced improvements in aesthetics and durability, while others reported minor sensitivity or wear. Such discrepancies highlight the difficulty in translating laboratory results to actual clinical performance, underscoring the need to standardize testing protocols and conduct more rigorous clinical trials to assess material performance holistically.

5.3. Practical Implications

Biomimetic materials have great potential but also present practical challenges to dental professionals when it comes to their real-life application. These materials demonstrate exceptional progress in restoring tooth structure, enhancing biocompatibility, and achieving aesthetic results. Nevertheless, they must be utilized in clinical practice by addressing issues related to material handling, customization, and integration with existing dental restoration processes. There are also new materials, such as bioactive Glass, which are challenging to work with in a clinical context and require a clear method of application to ensure proper use. Economic considerations are also important because certain biomimetic materials are less affordable than conventional restorative materials. Also, the large availability of such materials is constrained by the cost of production and specialization. Nevertheless, the long-term advantages of enhanced material durability, a decrease in the number of replacements, and, ultimately, an increase in positive patient outcomes may offset the initial investments, making biomimetic materials a worthy investment in the sphere of advanced dental care.

5.4. Challenges and Limitations

Several technical and material-related challenges are associated with the development of effective biomimetic materials for regenerating enamel and dentin. One of the key challenges is accurately determining the precise mechanical characteristics of natural tooth tissues, specifically fracture toughness and wear resistance. Some materials, such as Hydroxyapatite, are very promising, but they may not contain the entire strength required to resist the dynamic nature of mastication in the long run. There are further challenges to scaling up laboratory-based studies for clinical trials, particularly ensuring the consistency of material performance across varying clinical conditions and patient scenarios. Ethical and regulatory factors are also important, as new materials must undergo the most rigorous tests concerning their safety, biocompatibility, and efficacy before they can be accepted for widespread use. The rate at which these advanced materials can be approved by regulatory authorities, along with the expense of the clinical trial, may be slowing down the process of introducing these materials into clinical practice, despite promising laboratory results.

5.5. Recommendations

To enhance the efficiency of existing biomaterials in enamel and dentin regeneration, future studies should focus on increasing the mechanical strength and durability of bioactive and nanoengineered materials. Nanotechnology and materials science may enable the production of new, stronger, and more resilient composites that replicate all the properties of natural teeth. Moreover, future research should strive to implement the best practices for processing these materials, making them more convenient to handle and use in clinical practice. More research is required on how laboratory discoveries can be scaled to clinical trials, as well as the establishment of standard testing procedures that guarantee equal material performance. Researchers should also investigate the potential of combining biomimetic materials with regenerative therapies to advance further dental tissue regeneration, such as stem cell therapies. Ultimately, efforts should be made to make these materials more accessible and affordable, allowing patients to benefit from the latest dental practice technologies.

6. Conclusion

6.1. Summary of Key Points

The present paper identifies the major developments in new biomaterials for enamel and dentin regeneration, including bioactive Glass, nanohydroxyapatite, and synthetic Hydroxyapatite, which have promising prospects. These biomimetic materials replicate the mechanical and structural properties of natural tooth tissues, thereby enhancing the remineralization process and offering superior biocompatibility compared to conventional restorative materials. The comparison analysis proved that although bioactive Glass is much superior at stimulating remineralization, synthetic Hydroxyapatite is more valuable in terms of mechanical strength and longevity. These new materials, in general, provide a more effective and sustainable approach to dental regeneration, addressing the shortcomings of traditional restorative procedures. The findings regarding the potential clinical use of biomimetic materials suggest that, despite certain challenges, these materials have the potential to transform the field of restorative dentistry to a new level by enhancing treatment performance and improving aesthetic results for patients.

6.2. Future Directions

Biomimetic dental materials are poised for increased innovation, particularly in the fields of nanotechnology and molecular engineering. Studies are needed to enhance the mechanical properties and durability of these materials, enabling them to withstand the dynamic oral conditions. Long-term research and development aimed at overcoming the challenges of material processing, customization, and cost-effectiveness will ultimately lead to the success of laboratory achievements in large-scale clinical practice. Interdisciplinary cooperation among material scientists, dental practitioners, and clinical researchers will be necessary to accelerate the development and implementation of these materials. Moreover, the combination of regenerative dentistry and tissue engineering approaches, including stem cell therapy, would provide revolutionary approaches to tooth regeneration. The ongoing innovation is expected to result in more personalized and effective therapy, which is likely to increase patient outcomes and change the restoration practices of dentistry.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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