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Review Article

Biomimetic Dentistry: A Comprehensive Review

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ABSTRACT:
Biomimetic Dentistry is an innovative approach that aims to mimic the natural structure and function of teeth to enhance restorative outcomes. This review examines the principles of biomimetic techniques, materials, and the clinical implications of applying these methods, highlighting the advantages in preserving tooth structure, improving aesthetics, and promoting long-term health. The synthesis of biological principles with advanced dental materials provides a framework for future research and clinical practice, underscoring the importance of understanding biological systems in dentistry.
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INTRODUCTION

Biomimetic Dentistry is an innovative approach in the field of restorative dentistry that seeks to replicate the intricate structure and function of natural teeth. This paradigm shift is driven by the understanding that conventional restorative techniques often compromise the integrity of the remaining tooth structure, leading to suboptimal outcomes. By embracing principles of biomimicry, biomimetic dentistry aims to preserve as much healthy tooth material as possible while providing effective restoration solutions.[1]

The field integrates advanced dental materials that mimic the biochemical and mechanical properties of natural tooth tissue, such as enamel and dentin. These materials not only enhance aesthetic outcomes but also improve the longevity and performance of restorations. Additionally, biomimetic dentistry emphasizes minimally invasive techniques, reducing patient discomfort and recovery time.[2,3]

As research in biomaterials advances, the principles of biomimetic dentistry continue to evolve, presenting new possibilities for enhancing clinical practice. This comprehensive review will explore the underlying principles, techniques, materials, and clinical implications of biomimetic dentistry, underscoring its significance in modern dental care and its potential to revolutionize restorative practices for the future.

Objectives of Biomimetic Dentistry[2-5]

1. Mimic Natural Tooth Structure: Replicate the anatomy and function of natural teeth in restorative procedures.
2. Preserve Tooth Integrity: Minimize the removal of healthy tooth structure during restoration.
3. Enhance Aesthetic Appeal: Achieve superior cosmetic results that closely resemble natural dentin and enamel.

4. Promote Long-term Durability: Extend the lifespan of dental restorations through improved bonding and material properties.
5. Support Biological Healing: Utilize materials that foster natural repair processes in dental tissues.
6. Improve Patient Comfort: Reduce postoperative sensitivities and enhance overall patient experience.
7. Facilitate Regenerative Techniques: Incorporate methods that encourage tooth regeneration and repair.
8. Educate and Train Professionals: Provide knowledge and skills to dental practitioners on advanced biomimetic approaches.

Biomimetic Restorative Dentistry:
The primary objective of biomimetics in restorative dentistry is to restore hard tissues, such as enamel and dentin, to full functionality through a solid hard tissue bond. This enables functional stresses to be transmitted through the tooth, allowing the entire crown to act as a cohesive unit that delivers nearly normal function, along with biological and aesthetic benefits.[1,2]

However, there currently exists no biomaterial with mechanical, physical, and optical properties that perfectly match those of natural tooth structures, including enamel, dentin, and cementum. In the biomimetic approach to restorative dentistry, the focus is on identifying materials that closely resemble the aesthetic and functional properties of tooth structure.

While composites may lack strength, they offer several advantages over amalgam. Modern techniques emphasize minimal tooth preparation, reduced pulpal exposure, and a lower risk of tooth fractures.[4-6]

Glass ionomer cements (GICs) are viewed as biomimetic materials due to their similarities to dentin, strong adhesion to tooth structures, and fluoride release. GICs are particularly beneficial for filling deep Class I and II cavities as base materials. They are also employed in restorative applications for buccal Class V cavities. The fluoride released by GICs exhibits bactericidal properties and promotes the formation of sclerotic dentin. However, due to their poor tensile strength, GICs are not recommended for areas subjected to high occlusal stress and force. Biodentine, a recently developed material, may potentially serve as a replacement for GIC in deep fillings, though further research is necessary. Currently, GICs are a primary material used in minimally invasive dentistry.[4-7]

With advancements in adhesive technology, the need for bases and liners has diminished. The main reason for placing a liner beneath adhesive restorations is to protect the pulp, typically achieved through partial lining with calcium hydroxide cements.

Endodontically treated teeth are inherently fragile and more prone to fracture due to the loss of tooth structure. In case of posterior teeth, total cuspal coverage with porcelain is recommended because it will significantly strengthen the crown and increase cusp stabilization.[6]

Biomimetic Approaches for Regeneration: Various regenerative technologies have been developed based on biomimetic principles.

Regeneration of the Dentin-Pulp Complex: Recombinant human Bone Morphogenetic Proteins (BMP2 and BMP4) can stimulate new dentin formation. When these proteins are applied within a scaffold made of demineralized dentin matrix, they promote the formation of classic tubular dentin in amputated pulp tissue. Conversely, when BMPs are delivered using a type I collagen matrix, they lead to the development of osteodentin. In studies involving nonhuman primates, the application of recombinant human BMP7 in conjunction with an insoluble type I collagen matrix has successfully induced reparative dentin formation in freshly cut healthy pulp tissue. The dimensions and configuration of the inductive materials are crucial, as they influence the resultant size and shape of the reparative dentin.[4]

Stem Cell Therapy: Stem cell therapy represents an advanced technique for treating degenerated tissues. Stem cells are multipotent, allowing them to differentiate into various cell types. A straightforward application of stem cell therapy involves injecting cells with regenerative potential into a disinfected root canal system. Commonly utilized stem cells in regenerative endodontics include stem cells from human exfoliated deciduous teeth (SHED), dental pulp stem cells (DPSCs), and stem cells from the apical papilla (SCAP). DPSCs, sourced from human dental pulp, are particularly noteworthy for their ability to regenerate the dentin-pulp complex akin to that of a natural human tooth.[9,10]

Pulp Implantation: The generation of dental pulp tissue can be achieved in the laboratory through a tissue engineering process, followed by its transplantation into a cleaned and shaped root canal. Rebeca et al. developed dental pulp-like tissue using a tissue engineering triad comprising dental pulp stem cells (DPSCs), dentin matrix protein I as a growth factor, and a collagen scaffold. Upon subcutaneous transplantation in mice, the collagen served as a scaffold while the dentin matrix protein I facilitated tissue growth. The investigators demonstrated that this triadic approach can produce an organized matrix resembling pulp tissue, potentially leading to hard tissue formation.[4,12]

Root Canal Revascularization: The standard practice involves irrigation of the root canal with sodium hypochlorite and chlorhexidine, along with the placement of a mix of antibiotics (ciprofloxacin, metronidazole, and minocycline paste) to disinfect the root canal system over several weeks. The goal is to enhance the chances of revascularization in avulsed necrotic teeth, ensuring their vitality within the dental arch. This technique minimizes the risks of immune rejection and pathogen transmission since tissue regeneration utilizes the patient's own blood cells.[13]

Injectable Scaffold Theory: This method involves obtaining pulp tissue through a tissue engineering process, which is then introduced into a soft three-dimensional scaffold matrix. Among the various injectable biomaterials, hydrogels are the most advantageous in tissue engineering. Hydrogels serve as injectable scaffolds that can be easily delivered via syringe, making them noninvasive and suitable for insertion into root canal systems. Theoretically, hydrogels facilitate pulp regeneration by providing a supportive substrate for cell proliferation and helping to form an organized tissue structure.[14]

Gene Therapy: Gene therapy entails the introduction of genes using either viral or nonviral vectors. Viral vectors are genetically modified to remove their disease-causing abilities while retaining their capacity to infect cells. Common viral vectors used include adenoviruses, retroviruses, lentiviruses, and herpes simplex viruses. Nonviral delivery methods consist of plasmids, peptides, cationic liposomes, DNA-ligand complexes, gene guns, electroporation, and sonoporation. In endodontics, the goal of gene delivery systems is to introduce mineralizing genes into pulp tissue to promote mineralization.[14]

Bioengineered Tooth: Whole-tooth regeneration is an emerging field that employs a technique involving the transplantation of artificial tooth germs, allowing them to develop naturally within the oral environment.[14]

Biomimetic Mineralization: The biological mineral synthesis process produces materials with highly controlled attributes such as size, shape, texture, composition, and structure. A novel method for guided formation of an enamel-like fluoroapatite layer on a mineral substrate shows promise for remineralizing superficial enamel defects found on exposed dentin.[15]

Biomimetic Remineralization: Biomimetic remineralization of dentin can be achieved through various ion-containing solutions or silicon-based materials that leach ions. Recent studies have highlighted the use of bioactive "smart" composites containing reactive calcium silicate. Some researchers have utilized an "agarose" gel infused with sodium hypophosphate to cover acid-etched dentin surfaces.[2,4]

Biomimetic Approaches in Oral Surgery: Biomimetic techniques are being explored in oral and maxillofacial surgery for craniofacial reconstruction. Multipotent stem cells (MSCs) are employed in the tissue engineering of human-shaped temporomandibular joints. The mandibular condyles consist of both cartilaginous and bony tissues. MSCs are differentiated into chondrogenic and osteogenic cells, which are then encapsulated in a poly(ethylene glycol) diacrylate hydrogel. This hydrogel is subsequently molded to replicate an adult human mandibular condyle, featuring stratified and integrated layers of cartilage and bone.[16]

The Advantages and Limitations of Biomimetic Dentistry[1,2,4]

Advantages

1. Preservation of Tooth Structure: Minimally invasive techniques maintain more natural tooth material.
2. Aesthetic Outcomes: Restorations better mimic the appearance and translucency of natural teeth.
3. Improved Longevity: Enhanced bond strength and durability lead to longer-lasting restorations.
4. Reduced Risk of Sensitivity: Techniques can reduce postoperative sensitivity due to better adaptation to tooth structure.
5. Biocompatibility: Use of bioactive materials supports natural healing processes and promotes dentin regeneration.
6. Patient Comfort: Less invasive procedures can lead to reduced discomfort and quicker recovery times.

Limitations

1. Cost: Advanced materials and techniques may be more expensive than traditional methods.
2. Skill Requirement: Requires specialized training and expertise for effective implementation.
3. Material Limitations: Some bioactive materials may have limitations in terms of shade matching or strength under certain conditions.
4. Research Gaps: Ongoing research is needed to establish standard protocols and long-term effectiveness.
5. Limited Availability: Access to advanced biomimetic materials and technologies may be restricted in some regions.

Future Prospective: The future of Biomimetic Dentistry is promising, with potential advancements in several areas. Ongoing research into innovative materials, such as bioactive and regenerative substances, will likely yield novel restorative options that further mimic natural dentin and enamel. Advances in technology, including 3D printing and biomolecular engineering, could revolutionize how restorative treatments are approached and executed. Additionally, interdisciplinary collaboration between dental professionals and material scientists will be essential to drive this field forward, making dental care more effective and patient centered.

CONCLUSION

In conclusion, Biomimetic Dentistry represents a significant advancement in dental science, emphasizing the restoration of teeth in a manner that closely resembles natural processes. The integration of biomimetic principles into clinical practice can lead to enhanced patient outcomes, increased longevity of restorations, and greater patient satisfaction. As research continues to evolve, it is crucial for dental professionals to adapt and incorporate these emerging techniques to improve restorative practices.

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