BIOMIMETIC MATERIALS IN CONSERVATIVE DENTISTRY AND ENDODONTICS

Vibhuti [1], Jasleen Virk[2], Bharat Bhushan[3], Harpreet Kaur[4], Arsh Kumari[5]

Assistant Professor, Department of Conservative Dentistry and Endodontics, Desh Bhagat Dental College & Hospital, Mandi Gobindgarh.

Assistant Professor, Department of Conservative Dentistry and Endodontics, Desh Bhagat Dental College & Hospital, Mandi Gobindgarh.

PG Student, Department of Conservative Dentistry and Endodontics, Desh Bhagat Dental College & Hospital, Mandi Gobindgarh.

PG Student, Department of Conservative Dentistry and Endodontics, Desh Bhagat Dental College and Hospital, Mandi Gobindgarh.

PG Student, Department of Conservative Dentistry and Endodontics, Desh Bhagat Dental College & Hospital, Mandi Gobindgarh.

Corresponding Author: Dr. Vibhuti, Assistant Professor, Department of Conservative Dentistry and Endodontics, Desh Bhagat Dental College & Hospital, Mandi Gobindgarh.

Email id: endodontist.vibhuti@gmail.com

ABSTRACT

The paradigm of restorative dentistry has shifted from the traditional replacement of missing tooth structures to biologically oriented treatment strategies that aim to preserve and regenerate dental tissues. Biomimetic dentistry is based on the concept of restoring teeth using materials and techniques that mimic the natural structure, mechanical properties, and biological behavior of the dental tissues. Biomimetic materials interact with dentin and pulp tissues to promote remineralization, seal tooth structures, and support regenerative processes. Materials such as glass ionomer cement, resin composites, bioactive glass, mineral trioxide aggregate (MTA), Biodentine, and bioceramic sealers have significantly improved the outcomes of conservative and endodontic treatment. These materials possess properties such as biocompatibility, bioactivity, and the ability to release calcium and phosphate ions, which facilitate the formation of hydroxyapatite and reparative dentin. This review discusses the principles of biomimetic dentistry, classification of biomimetic materials, their mechanism of action, clinical applications in conservative dentistry and endodontics, advantages, limitations, and future perspectives in regenerative dental therapies.

Keywords: Biomimetic dentistry, bioactive materials, mineral trioxide aggregate, Biodentine, bioceramics, conservative dentistry, endodontics.

1. Introduction

Modern Dentistry has evolved significantly over the past few decades, with an increasing emphasis on the preservation of natural tooth structure and the biological compatibility of restorative materials. Traditional restorative approaches primarily focus on the mechanical retention and replacement of damaged tooth structures with inert materials. However, these approaches often fail to restore the natural biomechanical properties of teeth and can compromise pulp vitality.

Biomimetic dentistry is a contemporary approach that aims to restore teeth by mimicking the structure, function, and biomechanical behavior of natural dental tissues. The term "biomimetic" originates from the Greek words bio, meaning life, and mimesis, meaning imitation. Biomimetic materials are designed to replicate the physical, mechanical, and biological properties of the enamel, dentin, and pulp tissues. [1]

Biomimetic dentistry emphasizes minimally invasive procedures, adhesive bonding techniques, and the use of materials that interact with biological tissues to promote healing and regeneration. [2] These materials are particularly important in conservative dentistry and endodontics, where the preservation of pulp vitality and restoration of dentin integrity are critical objectives.

Recent advances in dental materials science have introduced several biomimetic materials, such as bioactive glass, calcium silicate cements, mineral trioxide aggregate (MTA), Biodentine, and bioceramic sealers. These materials not only restore lost tooth structure but also stimulate biological responses, such as mineralization, dentin bridge formation, and regeneration of the pulp–dentin complex. [3]

This review aims to provide a comprehensive overview of biomimetic materials used in conservative dentistry and endodontics, including their properties, mechanisms of action, clinical applications, advantages, and their limitations.

2. Concept of Biomimetic Dentistry

Biomimetic dentistry is based on the principle of restoring the tooth to its natural strength and function by replicating the structural characteristics of the enamel and dentin. Unlike conventional restorative approaches, biomimetic dentistry focuses on preserving healthy tooth structures and restoring the biomechanical integrity of the tooth.[4]

The biomimetic approach integrates the principles of adhesive dentistry, stress distribution, and tissue regeneration. The use of adhesive systems allows restorative materials to bond directly to the enamel and dentin, reducing the need for extensive tooth preparation.

Principles of Biomimetic Dentistry

The major principles include the following:

- Preservation of maximum tooth structure
- Use of adhesive bonding techniques
- Replication of the mechanical properties of dentin and enamel
- Reduction of polymerization shrinkage stresses
- Promotion of remineralization and biological repair
- Maintenance of pulp vitality

These principles aim to restore the tooth as a functional biomechanical unit capable of withstanding occlusal forces and maintaining its long-term durability.[5]

3. Natural Tooth Structure as a Model

Understanding the structure and properties of natural dental tissues is essential for developing biomimetic materials.

3.1 Enamel

Enamel is the most highly mineralized tissue in the human body, consisting of approximately 96% inorganic material in the form of hydroxyapatite crystals, 3% water, and 1% of an organic matrix.[6] Its high mineral content provides exceptional hardness and resistance to wear. However, the enamel is brittle and relies on the underlying dentin for support.

3.2 Dentin

Dentin forms the bulk of the tooth structure and consists of approximately 70% inorganic material, 20% organic matrix (primarily type I collagen), and 10% water.[7] Unlike enamel, dentin possesses a certain degree of elasticity, allowing it to absorb occlusal forces and prevent fractures.

3.3 Dental Pulp

Dental pulp is a soft connective tissue containing blood vessels, nerves, and specialized cells, such as odontoblasts. The pulp plays a vital role in dentin formation, defense against microbial invasion, and maintenance of the vitality of the tooth.[8]

Biomimetic materials aim to replicate these structural and biological characteristics to restore the natural tooth function.

4. Classification of Biomimetic Materials

Biomimetic materials used in conservative dentistry and endodontics can be broadly classified into the following categories.

4.1 Bioactive Materials

Bioactive materials interact with biological tissues and stimulate mineralization. These materials release ions, such as calcium and phosphate, which promote hydroxyapatite formation.

Examples include:

- Calcium hydroxide
- Mineral trioxide aggregate (MTA)
- Biodentine
- Bioactive glass

4.2 Regenerative Materials

Regenerative biomaterials are designed to promote tissue regeneration and healing in the body. These materials are commonly used in regenerative endodontic procedures.

Examples include:

- Platelet-rich fibrin (PRF)
- Growth factor-based scaffolds
- Stem cell-based regenerative systems

4.3 Adhesive Biomimetic Materials

These materials mimic the mechanical properties of dentin and allow adhesive bonding to the tooth structure.

Examples include:

- Resin composites
- Adhesive systems
- Resin-modified glass ionomer cement

5. Biomimetic Materials in Conservative Dentistry

5.1 Glass Ionomer Cement

Glass ionomer cement (GIC) is one of the most widely used biomimetic restorative materials in dentistry because of its chemical adhesion to tooth structure and fluoride-releasing properties.[9]

Properties

- Chemical bonding to enamel and dentin
- Fluoride release with anticariogenic effect
- Thermal expansion similar to tooth structure
- Biocompatibility

Clinical Applications

- Cervical restorations
- Atraumatic restorative treatment (ART)
- Base or liner under composite restorations
- Pediatric restorative procedures

Limitations

- Lower mechanical strength compared to composite resins
- Sensitivity to moisture during initial setting

5.2 Resin Composites

Composite resins are widely used restorative materials that mimic the optical and mechanical properties of natural tooth structures.[10]

Composition

Composite resins consist of the following:

- Resin matrix (Bis-GMA or UDMA)
- Inorganic filler particles
- Coupling agents
- Initiator–accelerator system

Advantages

- Excellent esthetics
- Adhesive bonding to tooth structure
- Conservative cavity preparation

Disadvantages

- Polymerization shrinkage
- Technique sensitivity

5.3 Bioactive Glass

Bioactive glass is a silica-based material that can bond with bone and dental tissues.[11]

Mechanism

Bioactive glass releases calcium and phosphate ions when exposed to saliva or other body fluids. These ions combine to form hydroxycarbonate apatite, which is chemically similar to the mineral phase of the enamel and dentin.

Clinical Uses

- Treatment of dentin hypersensitivity
- Remineralization of early carious lesions
- Preventive dentistry applications

5.4 Calcium Silicate-Based Materials

Calcium silicate-based materials are considered important biomimetic materials because of their ability to stimulate dentin regeneration and provide an effective seal.[12]

Examples include:

- Biodentine
- Calcium silicate cements

Clinical Applications

- Direct pulp capping
- Indirect pulp capping
- Dentin replacement under restorations

6. Biomimetic Materials in Endodontics

6.1 Calcium Hydroxide

Calcium hydroxide is widely used in endodontics because of its antimicrobial activity and ability to stimulate hard tissue formation. [13]

Properties

- High pH (approximately 12.5)
- Antibacterial action
- Induction of reparative dentin formation

Clinical Applications

- Direct pulp capping
- Apexification procedures
- Intracanal medicament

Limitations

- Weak mechanical properties
- Dissolution over time

6.2 Mineral Trioxide Aggregate (MTA)

Mineral trioxide aggregate (MTA) is considered one of the most important biomimetic materials in modern endodontics. [14]

Composition

MTA is primarily composed of:

- Tricalcium silicate
- Dicalcium silicate
- Tricalcium aluminate
- Bismuth oxide

Properties

- Excellent sealing ability
- Biocompatibility
- Bioactivity
- Ability to induce cementogenesis and dentinogenesis

Clinical Applications

- Pulp capping
- Apexification
- Root perforation repair
- Root-end filling
- Regenerative endodontic procedures

Limitations

- Long setting time
- High cost
- Handling difficulties

6.3 Biodentine

Biodentine is a calcium silicate-based material that was developed as a dentin substitute.[15]

Composition

The powder contained tricalcium silicate and zirconium oxide, while the liquid contained calcium chloride and water-reducing agents.

Properties

- High compressive strength
- Faster setting time compared to MTA
- Excellent biocompatibility
- Stimulation of dentin bridge formation

Clinical Applications

- Pulp capping
- Pulpotomy
- Root perforation repair
- Dentin replacement

6.4 Bioceramic Materials

Bioceramic materials are advanced biomimetic endodontic materials that are widely used as root canal sealers and repair materials.[16]

Examples include:

- BioRoot RCS
- EndoSequence BC sealer

Properties

- Hydrophilic nature
- Chemical bonding with dentin
- High biocompatibility
- Excellent sealing ability

7. Mechanism of Action of Biomimetic Materials

Biomimetic materials function via several biological mechanisms.

7.1 Ion Release

These materials release calcium and phosphate ions, which contribute to hydroxyapatite crystal formation and promote remineralization.

7.2 Hydroxyapatite Formation

Interaction with body fluids results in the deposition of hydroxyapatite on the material surface, creating a strong bond with the dentin.

7.3 Stimulation of Odontoblast Activity

Calcium ions stimulate odontoblast-like cells to produce reparative dentin.

7.4 Antimicrobial Effects

The alkaline pH of calcium-based materials inhibits bacterial growth in the root canal system.

8. Advantages of Biomimetic Materials

Biomimetic materials offer several advantages.

- Preservation of tooth structure
- Improved adhesion to dentin and enamel
- Promotion of remineralization
- Enhanced biocompatibility
- Support for regenerative endodontic procedures
- Long-term clinical success

9. Limitations

Despite their advantages, biomimetic materials have certain limitations.

- High cost of advanced materials
- Technique sensitivity during placement
- Long setting time for some materials
- Limited long-term clinical data for newer materials

10. Recent Advances

Recent research has focused on improving biomimetic materials using nanotechnology and regenerative medicine.

Nanotechnology

Nanofilled composites and nano-hydroxyapatite materials have improved mechanical strength and remineralization potential.

Regenerative Endodontics

The use of stem cells, scaffolds, and growth factors aims to regenerate the pulp–dentin complex rather than simply replacing the lost tissue.

Smart Materials

Smart biomaterials can respond to environmental stimuli, such as pH changes, and release ions accordingly.

11. Future Perspectives

Future research in biomimetic dentistry should focus on developing materials that can regenerate entire dental tissues. Tissue engineering approaches involving stem cells, growth factors, and biodegradable scaffolds may eventually allow for the complete regeneration of the pulp–dentin complex.

The integration of biomimetic materials with digital dentistry and minimally invasive techniques is expected to further enhance the treatment outcomes in conservative dentistry and endodontics.

12. Conclusion

Biomimetic materials have revolutionized modern dentistry by shifting the focus from simple restoration to biological repair and regeneration of dental tissues. Materials such as glass ionomer cement, bioactive glass, mineral trioxide aggregate, Biodentine, and bioceramics have demonstrated excellent clinical performance owing to their biocompatibility and bioactivity. These materials mimic the structural and biological characteristics of natural dental tissues and promote healing and remineralization of the affected tissues. Ongoing research and technological advancements are expected to further expand the applications of biomimetic materials and contribute to the development of regenerative dental therapies.

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