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Review Article **Conservative Dentistry and Endodontics**

Emerging Trends in Biomimetic Dentistry: Materials and Clinical Applications

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Abstract

Biomimetic restorative dentistry (BRD), a paradigm change from conventional dental techniques, aims to restore damaged teeth by mimicking their natural appearance, functionality, and structure. This multidisciplinary discipline uses biological processes as inspiration to develop cutting-edge dental treatments that blend in perfectly with the natural tissues of teeth. In contrast to conventional techniques, which frequently entail significant tooth reduction and the use of inflexible, incompatible materials, BRD places a higher priority on maintaining healthy tooth structure, which improves the endurance, durability, and aesthetics of restorations. This review examines the basic concepts, range of materials, state-of-the-art clinical techniques, and creative applications of biomimetics in dentistry.
Keywords: Biomimetic dentistry, Biomimetic materials, Caries Management, Aesthetic Dentistry, Smart Materials, Evidence-Based Practice.

INTRODUCTION

Nature has long served as a foundation for human innovation and technological advancement. Biomimicry, derived from the Greek meaning "to imitate life," builds upon this idea by examining effective natural designs and applying those principles to develop advanced materials and technologies.[1] It is an interdisciplinary area that uses concepts from chemistry, physics, mathematics, and engineering to replicate natural biological systems in the development of advanced materials and structures.[2] Biomimetic dentistry focuses on the restoration of damaged teeth using materials that emulate the structural, functional, and aesthetic characteristics of natural dental tissues such as enamel, dentin, bone, and cementum.[3,4] A key aim of this approach is to recreate the natural biomechanical behavior of the tooth through appropriate material selection and techniques. Materials developed by mimicking natural biological processes are known as biomimetic materials. [2,5] By utilizing biomimetic principles, dental practitioners can design treatment strategies that closely replicate the structure and function of natural tissues. This review highlights the potential of biomimetic dentistry and its promising role in transforming modern dental care.[1]

PROTOCOL OF BIOMIMETIC DENTISTRY

Preservation of Tooth Structure:

Traditional "extension for prevention" techniques involve removing both decayed and healthy tooth structure and replacing it with rigid restorative materials, which can compromise tooth strength and longevity (Fig-1). In contrast, biomimetic dentistry emphasizes a conservative approach that preserves natural tissue and restores teeth by closely replicating their functional behavior using adhesive systems and stress-minimizing strategies(fig-2).[5]

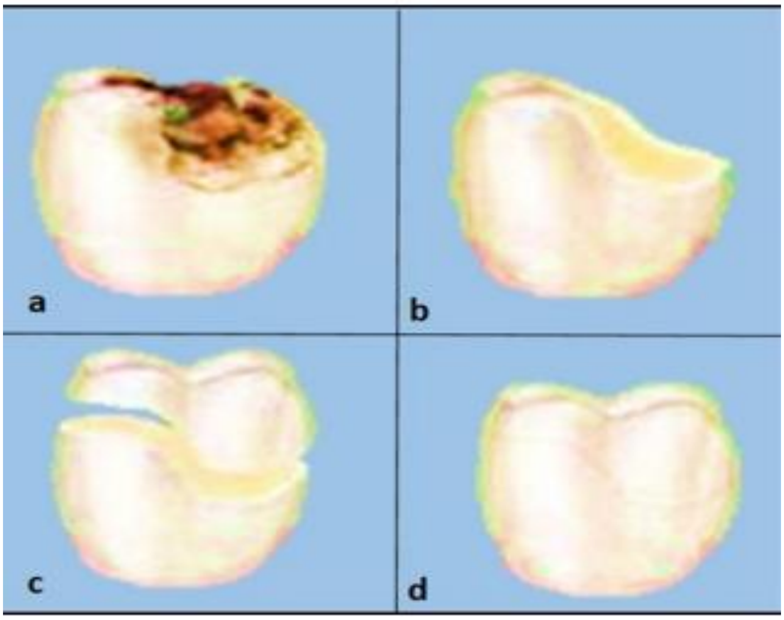

Fig. 1: (a) Decayed tooth, (b) the decay is completely removed, (c) more tooth structure is removed to allow space for the placement of rigid restoration, (d) restoration is placed over the weakened tooth structure

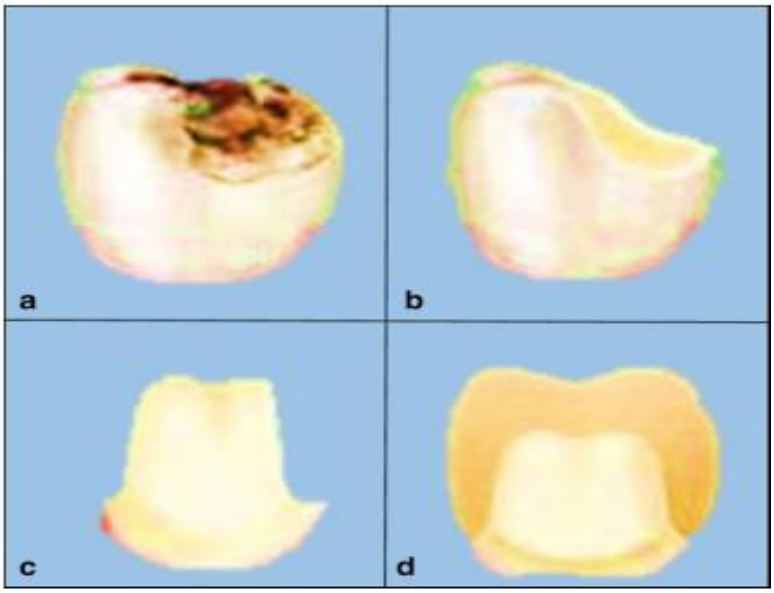

Fig. 2: (a) Decayed tooth, (b) the decay is removed completely, (c) limited tooth structure is removed to maintain tooth strength, (d) restoration is bonded to the tooth restoring the structural integrity and strength

STRESS-REDUCING PROTOCOLS IN BIOMIMETIC DENTISTRY [6]

Indirect/Semi-direct restorations: Reduce polymerization shrinkage and distribute stress due to composites having an elastic modulus similar to dentin.

Decoupling with Time (DWT): Allows proper maturation of dentin bond by delaying composite placement, minimizing shrinkage stress.

Incremental layering: Placement of thin composite layers (<1 mm) reduces C-factor stress and improves adaptation.

Fiber reinforcement: Use of fiber inserts (e.g., Ribbond) helps absorb stress and mimic dentin properties.
Controlled polymerization: Slow-start or pulse curing techniques decrease shrinkage stress.
Material selection: Use composites with low shrinkage (<3%) and elastic modulus close to dentin.
Dual-cure composites: Provide gradual setting, allowing better bond development in deep areas.
Removal of cracked dentin: Ensures integrity of the peripheral seal zone and prevents crack propagation.
Cusp reduction: Reducing cusp thickness helps convert tensile forces into compressive forces.
Occlusal adjustment: Proper guidance reduces tensile stress on restorations and tooth structure.

BOND-MAXIMIZING PROTOCOLS IN BIOMIMETIC DENTISTRY [6]

Peripheral seal zone (PSZ): Maintain a 2–3 mm caries-free margin without pulp exposure to ensure a durable seal.
Surface modification: Techniques like air abrasion and silane application improve adhesion and reduce bond failure.
Enamel beveling: Enhances bonding by increasing surface area across enamel rods.
MMP inhibition: Use of agents like chlorhexidine helps preserve long-term bond strength.
Dentin bonding systems: Advanced bonding techniques (total-etch/self-etch) provide strong and reliable adhesion.
Immediate dentin sealing (IDS): Improves bond strength and protects dentin.
Resin coating: Application of flowable resin creates a stable, well-polymerized bonding interface.
Deep margin elevation: Converts subgingival margins to supragingival, improving bonding and forming a stable "bio-base."

MATERIALS UTILISED IN BIOMIMETIC DENTISTRY

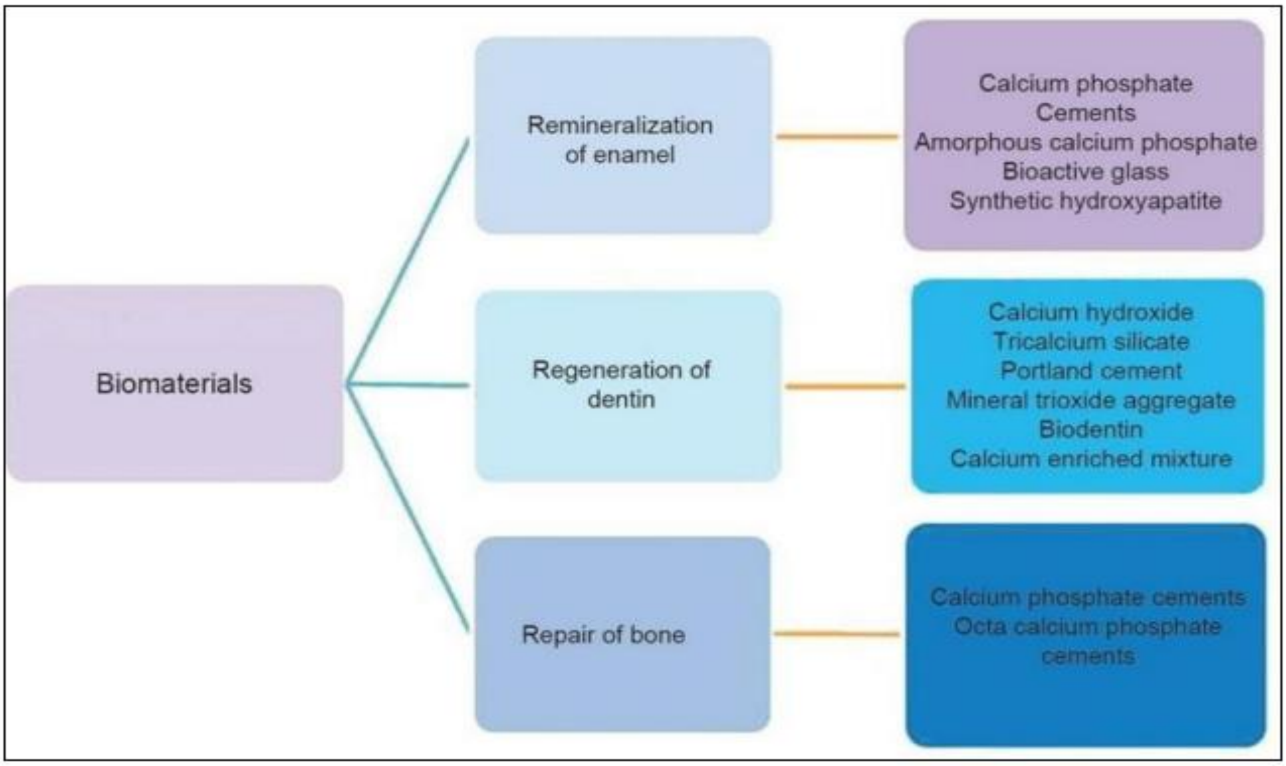

Fig. 3: Based on biomineralization

Glass Ionomer Cements (GICs): These materials form a chemical bond with tooth structure, release fluoride ions that aid in caries prevention, and exhibit a thermal expansion behavior comparable to natural dental tissues.[7]
Calcium Hydroxide ($Ca(OH)_2$): This material possesses antimicrobial properties and encourages the deposition of tertiary dentin, thereby protecting the underlying pulp.[1]
Self-healing composites: These novel restorative materials incorporate resin-filled microcapsules that rupture when cracks develop, enabling automatic repair of the damaged area.[1]

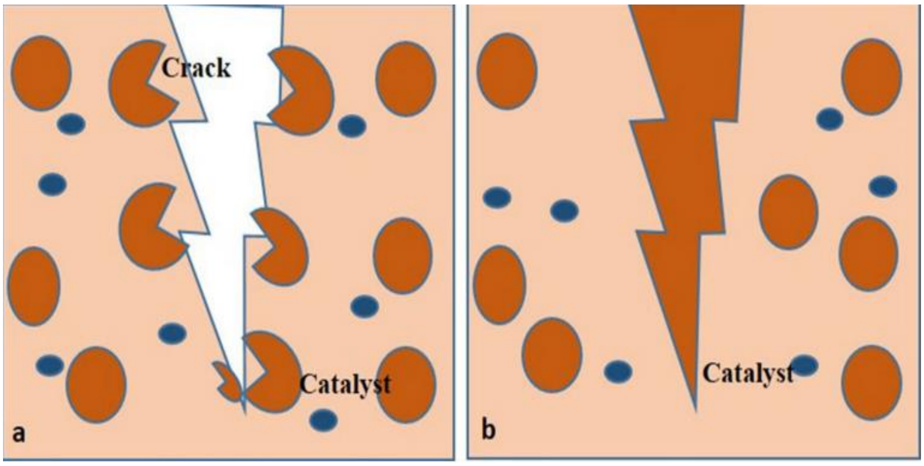

Fig. 4: (a)Self-healing composite resin a microcapsules rupture and release of healing agents, (b) healing of the crack after polymerization of the healing agent by the catalyst

Mineral Trioxide Aggregate (MTA): A biocompatible material known for its excellent sealing ability, strong adhesion to dentin, and capacity to induce dentin bridge formation, outperforming calcium hydroxide in many aspects.
TheraCal: A light-cured resin-modified material containing calcium silicate fillers, known for its ability to release calcium ions.[8]
Generex A & B: Calcium silicate–based materials commonly used for root-end fillings, offering good handling characteristics and resistance to washout.[9]
Doxadent: A calcium aluminate–based cement with favorable biocompatibility, though it demonstrates lower wear resistance compared to composite materials.[8]
Ceramir: A calcium aluminate–based material primarily used for the permanent cementation of dental restorations.[10]
Hydroxyapatite (HA): A biocompatible material similar in composition to natural bone, promoting strong bonding with hard tissues; however, its limited mechanical strength restricts its use in high load-bearing areas.
Calcium Phosphate Cement (CPC): A moldable material that converts into hydroxyapatite upon setting and provides good handling properties.
Amorphous Calcium Phosphate (ACP) Technology: This system contains calcium and phosphate ions that help in the remineralization of demineralized tooth structure by restoring lost minerals.
Tricalcium Phosphate (TCP): TCP is a bioactive, osteoconductive material that facilitates bone formation and plays a supportive role in the remineralization of dental hard tissues.
Bioactive Glass: Bioactive glass is a specialized dental material designed to replicate the properties of natural tooth structure. It releases ions such as fluoride, calcium, and phosphate, which enhance enamel strength and help prevent early carious lesions. Additionally, it aids in occluding dentinal tubules, thereby reducing hypersensitivity, and provides a smoother tooth surface that limits bacterial adhesion. Its ability to bond with bone and stimulate regeneration makes it valuable in bone grafting procedures as well.[1]
Emdogain: Emdogain is an enamel matrix derivative that simulates natural tooth development, promoting the regeneration of periodontal tissues including cementum, periodontal ligament, and alveolar bone.
Platelet-Rich Fibrin (PRF) Membrane: PRF is a biocompatible autologous membrane rich in platelets, growth factors, and fibrin. It accelerates wound healing, enhances tissue regeneration, and supports both soft and hard tissue repair.[8]
Ceramicrete: It is a novel calcium – based material composed of cerium oxide and powdered hydroxyapatite, providing inherent radiopacity. When used as a root-end filling material,it demonstrates superior sealing compared to ProRoot MTA.[11]

CLINICAL APPLICATION

The choice of restorative technique depends on the severity of tooth destruction and the desired esthetic outcome. Materials such as dental ceramics and hybrid resin-based composites (RBCs) are designed to simulate the characteristics of enamel and dentin, respectively. RBCs are typically indicated for teeth with moderate structural loss, as they involve conservative tooth preparation, reduce the likelihood of pulpal damage and fractures, and help strengthen the remaining tooth structure, particularly in cavities with a low configuration factor.

In situations of extensive tooth damage, including significant wear or fractures, bonded ceramic restorations are preferred due to their enhanced mechanical strength and long-term durability. Among these, alumina-based ceramics demonstrate excellent compressive strength, wear resistance, and fracture resistance.[12]

Glass ionomer cements (GICs), known for their antibacterial effects and biomimetic properties, are commonly used in pediatric dentistry for managing deep Class I and II lesions as well as Class V restorations.

However, because of their comparatively low tensile strength, their use is generally avoided in areas subjected to high occlusal forces, such as posterior load-bearing regions**.** [13]

Calcium hydroxide is involved in many dental applications such as pulp capping, pulpotomy, apexification and root canal disinfection as well as in treatment of root resorption, root or furcation perforations, and horizontal tooth fracture. [14-16]

MTA is advocated for several dental applications such as pulp capping, retrograde filling, apexification, and management of furcation and root perforations.[17]

CPP-ACP contained toothpastes, sugar-free chewing gums, mouth rinses, and biomaterials (composite resin, glass ionomer, etc.) showed efficacy in triggering hydroxyapatite precipitation and tissue repair. [14-16]

LIMITATIONS AND CHALLENGES IN BIOMIMETIC DENTISTRY:

Biomimetic dentistry is often expensive due to the use of advanced materials and techniques, limiting its affordability. It requires specialized training and high clinical skill, making it technique-sensitive. Limited exposure during dental education also affects its adoption among practitioners. Additionally, access to modern technologies is restricted in rural or low-resource settings, hindering its widespread use.[18]

FUTURE ASPECTS:

Advances in biomimetic dentistry are driven by innovations in nanotechnology and improved material engineering aimed at closely replicating natural tooth structure. Although notable progress has been achieved, the intricate nature of dental tissues means these materials are still in early stages of development. Biomimetic tissue engineering has expanded rapidly, but its routine clinical use is yet to be fully realized. Continued research is essential to bridge the gap between laboratory developments and everyday clinical practice.[15]

CONCLUSION

Biomimetic dentistry emphasizes conservative, tissue-preserving approaches using advanced materials that mimic natural tooth structure. It enhances strength, function, and aesthetics of restorations. Despite challenges, it represents a promising future direction in modern dental care.

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