AJMB
eISSN: 2600-8173

https://doi.org/10.37231/ajmb.2023.7.2.617
https://journal.unisza.edu.my/ajmb

PENERBIT
Universiti Sultan Zainal Abidin

Asian Journal of Medicine and Biomedicine

Biomimetic Materials in Pediatric Dentistry: From Past to Future

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Received: 23rd March 2023 **Accepted: 27th June 2023** **Published: 20th October 2023**

Abstract

"Biomimetics" is the field of science that uses the natural system of synthesizing materials through biomimicry. This method can be widely used in dentistry for regeneration of dental structures and replacement of lost dental tissues. This is a review paper that states its scope, history, different fields of biomimetic dentistry, and its future conditions in India. With Biomimetic dentistry, only the damage and decay are removed from the teeth, and the final restoration is bonded to the remaining healthy natural tooth structure. The scope of biomimetic dentistry in India is enormous in the near future. It is the designing of biomaterials that simulates physical and mechanical properties of the lost tissue, thus providing an opportunity to introduce and change treatment modalities for the disease. Biomimetic dentistry is an interdisciplinary approach and has potential for transforming everyday dental practice. It brings the power of modern biological, chemical, and physical science to solve real clinical problems. Biomimetics provides a new strategy that translates our knowledge of biological structures and functions and creates new synthetic pathways to mimic biological processes.

Keywords

Biomimetic, dentistry, pediatric, physical property, mechanical property

Introduction

The advancement of dental materials is closely related to the evolution of dentistry. Nanotechnology has aided in the processing of a wide range of nanostructured materials with complex arrangements of organic or inorganic molecular level constituents, simulating living tooth structure and allowing for novel dental applications.[1] As a result of the application of nanotechnology to dental materials, the terms bioactive, bioinduction, and biomimetics are frequently defined separately. The word "biomimetic" is a combination of the phrases "biology," which is the study of life or living matter in all of its forms, and "mimic," which refers to imitation or copying. Over the past few decades, adhesive "bonding" technologies have advanced in dentistry, allowing for the removal of almost no healthy tooth structure followed by the adhering of tooth-colored material onto, or within, the decay removal area that strengthens and closely resembles the form and colour of the remaining healthy tooth. [2]

Hench proposed some criteria for assessing a material's bioactivity. As a result, a new classification of bioactive materials was proposed in 1994, with two groups:

- **Class A:** This category includes materials that cause both intracellular and extracellular responses. They have the ability to bind to both bone and soft tissues. 45S5 Bioglass, for example.
- **Class B:** These materials are osteoconductive and only cause extracellular reactions. Synthetic hydroxyapatite implants, for example. [3]

The use of the biomimetics idea in dentistry is known as "biomimetic dentistry." The main objective of biomimetics is to imitate organic oral processes, including the calcification of a soft tissue precursor. The secondary meaning relates to the imitating or restoration of the biomechanics of the original tooth. 3 The goal of biomimetics is to synthesise similar products using artificial mechanisms that resemble natural structures by studying the formation, structure, and function of biologically produced substances and materials (such as silk or conch shells), as well as biological mechanisms and processes (such as protein synthesis or mineralization). [4]

Natural teeth exhibit an unrivalled balance of stiffness, strength, and resilience due to the optimal combination of Enamel and Dentin. Ideally, the restorative materials should have mechanical, biological, and optical properties that are similar to the tissue being replaced. Biomimetics enables the repair of damaged dentition by mimicking the biological, aesthetic, biomechanical, and functional properties of natural teeth. Due to their excellent biocompatibility, biomimicry, bioactivity, and remineralisation potentials, a variety of bioactive formulations such as micro and nanohydroxyapatite (HA), tricalcium phosphate, mineral trioxide, caseinphosphate, and bioactive glasses have recently been introduced.

By utilising biomimetic therapy strategies, dental practitioners can enhance and come closer to the natural biological structures and their activities. Two approaches are used to define the word "biomimetic": a purist approach that emphasises the replication of biological tissues and a descriptive approach that emphasises the use of materials that provide an imitated biological function [9]. Despite their differences, both aim to restore ecosystems by replicating biological. The function and modulus of elasticity of a biomimetic material should be comparable to those of the tooth structure it is replacing (such as pulp, dentin, enamel, and the dentinoenamel junction).[6]

History of Biomimetic Materials

The term "biomimetics" was first used by Ottoschmit in the 1950s. Jack Steele coined the term "bionics" in 1960. Although the concept is not new, its practical application has only recently become possible due to extensive research in the fields of biochemistry and molecular biology. It is thought that attempts to replace body parts began at least 2500 years ago, when artificial teeth were carved from oxen bones. [7]

In the first and second centuries AD, crude dental implants were attempted in the Roman population as well as in pre-Columbian cultures of Central and South America. The use of dental amalgam to repair decayed teeth was documented in Chinese literature as early as 659 AD. The sophisticated inventions of the cardiac pacemaker, artificial heart valves, and knee joint replacement made the mid-twentieth century significant in the history of biomimetic medicine. Accidental organ and tissue loss has been treated surgically, and the use of mechanical devices such as kidney dialyzers, as well as organ transplantation from one person to another, has increased in recent years. [8]

Biomimetic Dentistry

Bio-mimetic dentistry is the art and science of restoring damaged teeth with restorations that look, function, and feel like natural teeth. [9] It is conservative in that it only replaces what is damaged and strong in that it replicates nature's original design. This approach's two guiding principles are: Teeth should be treated early and with proper techniques. Early treatment of weakened teeth allows us to preserve healthy enamel, providing a better foundation for Biomimetic bonding. The importance of early intervention in less invasive treatment cannot be overstated. Using proper biomimetic bonding techniques, you can save your tooth by removing old bacteria and infection, sealing out new infection and bacteria, eliminating sensitivity, and restoring natural strength and function.

By creating a firm tissue connection that permits functional stresses to travel through the tooth and incorporates the entire crown into the final functional biologic and aesthetic outcomes, biomimetics in restorative dentistry aims to restore complete function to all prepared dental tissues. Less dental work is better than more dental work, or even no dental work is preferable, according to biomimetic dentistry. For the riskiest situations (non-vital or damaged teeth), bonding porcelain restorations is advised rather than using intraradicular portions or full coverage crowns. [10]

Principles and Mechanism of Action

Through a hard tissue link, biomimetics in restorative dentistry aims to fully functionally repair the hard tissues (enamel and dentin). As a result, the entire crown becomes a unit that gives almost normal function as well as biologic and aesthetic benefits. This enables functional stresses to travel through the tooth. [11] There is sadly no dental biomaterial with the same mechanical, physical, and visual characteristics as tooth structures (i.e., enamel, dentin, and cementum). Finding materials with aesthetic and functional qualities akin to tooth structure is the aim of the biomimetic approach to restorative dentistry. Despite being weaker than amalgam, composites offer several advantages. Less pulpal involvement, less tooth breakage, and little preparation are all advantages of the most recent procedures. [12]

The use and indications for bases and liners have decreased due to the development of improved adhesives. The indication for using an adhesive liner is primarily for pulp protection in the form of partial lining with Ca (OH)2 cements. Endodontically treated teeth are fragile and prone to fracture due to the removal of tooth structure and the loss of cushioning effect caused by the removal of pulp. Total cuspal coverage with porcelain is recommended for posterior teeth because it significantly strengthens the crown and increases cusp stabilization.[13]

The ability of bioactive materials to spontaneously produce an appetite layer when in contact with phosphate-containing physiological fluids is largely responsible for their performance. [14] Apatite formation is aided by the interaction of $Ca2+$ released from the material with phosphates, and it is thought to be the foundation of several inorganic biomaterials such as glass ceramics. In vital pulp therapy, bioactive materials induce cytological and functional changes within pulpal cells, resulting in the formation of reparative dentin at the surface of exposed dental pulp. It promotes the proliferation, migration, and differentiation of odontoblast-like cells that produce a collagen matrix when it is applied. This unmineralized matrix is then mineralized, first by osteodentin and then by tertiary dentin formation. [15]

A bioactive restorative material demonstrates at least one of the following actions: [16]

- Remineralizes and strengthens tooth structure by releasing fluoride and/or other minerals.
- When immersed in body fluid or simulated body fluid (SBF), it forms an apatite-like material on its surface.
- Tissue repair and regeneration are aided by promoting the body's natural healing mechanism.

Thus, bioactive materials can be divided into three major categories, as summarised below: [17]

Table1: Mechanism of action of Bioactive materials [16]

	MECHANISM OF ACTION	DENTAL MATERIALS	COMMERCIAL EXAMPLES
BIOACTIVE MATERIALS	REMINERALISATION ONLY	G.I CEMENTS AND THEIR DERIVATIVES	RIVA SELF CURE, EQUIA FORTE AND ACTIVA bioactive RESTORATIVE (pulpdent)
	DEPOSITION OF HYDROXYAPATITE	CALCIUM ALUMINIUM CEMENTS	CERAMIR
	TISSUE REGENERATION	CALCIUM SILICATE CEMENTS (MTA AND OTHER RELATED PORTLAND CEMENTS	BIODENTINE, I ROOT SP, Bio ROOT, ENDOSEAL MTA AND THERACAL
		CALCIUM PHOSPHATE CEMENTS	HYDROSET
		CALCIUM SILICATE/ CALCIUM PHOSPHATE COMBINATION CEMENTS	Endo SEQUENCE BC SEALER

Recent Advances

- Compomer
- Condensable/self-hardening GIC:
- Low viscosity/flowable GIC
- Bioactive glass:
- Fiber-reinforced GIC
- Proline-containing GIC
- Calcium aluminate GIC
- Nanotechnology in GIC [18]

Glass ionomer cement (GIC) is a biomimetic material because it has dentin-like properties, is adhesive to tooth structures, and is anticariogenic due to fluoride release. GICs can be used as a lining material in deep class I and class II cavities. [19] They are also used in the restoration of buccal class V cavities. GIC produces fluoride, which has bactericidal properties, stimulates sclerotic dentin, and has properties that are similar to dentin. GIC is currently the primary material used in minimally invasive dentistry, which falls under the category of Biomimetic Restorative Dentistry. [20]

Clinical Applications

1. Preservation of pulp vitality High biocompatibility reduces the risk of pulp or tissue reaction. Bioactive: dentine remineralization for unique pulp healing properties.

2. Prevention of clinical failures Mineral tags in dentine tubules combined with high dimensional stability over time provide long-lasting sealing properties. Outstanding microleakage resistance reduces the risk of bacterial percolation.

3. Ultimate dentinal substitute Simple handling for optimal clinical use. Superior radiopacity for both short and long-term monitoring. [21]

Biomimetics in Pedodontics

A biomimetic strategy in restorative dentistry should use materials that are similar in appearance and function to the natural tooth and its enamel and dentine layers. "The goal of Biomimetics in restorative dentistry is to reestablish all of the prepared dental tissues to full function by creating a hard tissue bond that allows functional stresses to pass through the tooth, making the entire crown into the final functional biologic and aesthetic unit," Magne stated in 2006. The intact tooth, in its ideal hues and shades, as well as its intracoronal anatomy, location, and mechanics in the arch, is the guide to reconstruction that governs success". [22]

Glass Ionomer Cement

Increased compressive strength (200 Mpa), fracture toughness, and flexural strength (15.6 Mpa) (0.22 Mpam0.5). Alumina and SiO2 ceramic fibres are called as "Polymeric Rigid Inorganic Matrix Material," or PRIMM, for having this property. The nanocrystalline hydroxyapatite/yttria-stabilized zirconium (HA/YSZ) A new class of restorative glass ionomers, defined by GIC, which is a recent development in GIC modification, offers the strength and durability needed for permanent posterior repair while keeping aesthetics. [23] Glassionomer-based sealers are employed in obturation because of their dentin bonding characteristic, which allows them to act as biomimetic materials in pedodontics. adhesion between the material and the canal wall but has little anti-bacterial property and is difficult to remove in the event of retreatment. "KT-308 (GC Corporation Company, Tokyo, Japan)," a GIC-based sealer, provides improved zinc oxide-eugenol sealer that is resistant to coronal penetration of bacterial agents into root canals. [24]

Bioactive Materials

New bioactive glass compositions have been developed to promote and improve bioactivity, the addition of calcium oxide is essential in the first step of the formation of hydroxyapatite due to an exchange of hydrogen ions, bioactive glass compositions created with calcium and silica oxide were shown to improve mechanical resistance and better mineralization ability and lower surface roughness. [25] Commercial examples includes Riva self-cure, equia forte, pulpdent.

ACTIVA BioACTIVE Restorative (Pulpdent Corporation)

A resin-modified glass ionomer cement (RMGIC) that has been improved using "rubberized" resin, according to the maker. Some of this material's intriguing features have been studied in earlier research: Flexural strength was reported to be much higher than that of other RMGIC and comparable to that of flowable and bulk-fill resin composites[26]. When compared to compomers and RMGIC, high fracture toughness was found. [27]

MTA

It is a hydrophilic substance created by Torabinejad that is based on calcium silicate. Its pH ranges from 10 to 12.5 and when it sets in a phosphate-containing solution, it crystallises calcium hydroxide and hydroxy-apetite-like substances. Cementum growth, dentinal bridge formation, and attachment of the periodontal ligament are all results of it. It has strong adherence to dentin. When employed in vital pulp treatment, it has a lower solubility than calcium hydroxide and no tunnel flaws are seen. [28]

Hydroxyapatite

It is a calcium phosphate substance that cannot be repaired. It is composed similarly like bone and has an osteoconductive characteristic. It adheres to bone. Due to its poor mechanical qualities, it is rarely employed in areas that sustain loads. It serves as a filler in composite resins and is utilised in bone grafting. For endodontic therapy, hydroxyapatite has been used for pulp capping, perforation repair, apical barrier construction, and periapical defect repair. According to Jean et al., tricalcium-phosphate hydroxyapatite created reparative dentin that mineralized to a greater extent and thicker than calcium hydroxide-derived dentin. [29]

Bioactive glass

Hench created it for the first time in 1969. These eyewear items have the capacity to attach to bone and tissue and trigger osteogenesis. These come from several families and are made up differently. [30] These can be utilised for implant coating, dentin hypersensitivity treatment, and bone grafting. Eg: 45S5.

Hydroset

The compressive strength, biaxial flexural strength, Young's modulus, working time, setting time, and injectability of these innovative formulations were then compared to those of conventional self-setting calcium phosphate cement. Since bone void fillers are not intended to support loads, HydrosetTM is employed in these applications because of its injectability, biocompatibility, and osteoconductive qualities. [31]

Biomimetic Approaches for Regeneration

Different regenerative technologies are invented based on biomimetic approaches.

Regeneration of Dentin-Pulp Complex

Recombinant human BMP2 and BMP4 can stimulate the formation of new dentin. Recombinant BMP induces classic tubular dentin in amputated pulp when delivered in a scaffold of demineralized dentin matrix. BMP, on the other hand, induces osteodentin formation when delivered via type I collagen matrix. The combination of recombinant human BMP7 and an insoluble type I collagen matrix induces reparative dentin formation in freshly cut healthy pulp tissue in nonhuman primates. The inductive material's size and shape are important because they control the size and shape of the reparative dentin.[32]

Pulp Implantation

By using tissue engineering, pulp tissue may be created in a lab and then transplanted into a cleansed and formed root canal system. Using the tissue engineering trio of DPSCs, dentin matrix protein I, and a collagen scaffold, Rebeca et al. produced tissue that resembled dental pulp. A scaffold is provided by collagen, while a growth factor is provided by dentin matrix protein I. A tissue engineering trio consisting of DPSCs, dentin matrix protein I, and a collagen scaffold was shown by the researchers to be able to create an organised matrix comparable to pulp tissue, which may lead to the creation of hard tissue. [33]

Root Canal Revascularization

And the current practise is to disinfect the root canal system by irrigating it with sodium hypochlorite and chlorhexidine and placing antibiotics (a mixture of ciprofloxacin, metronidazole, and minocycline paste) for several weeks. Our goal should be to improve the chances of revascularization of an avulsed necrotic tooth. The success of the revascularization process ensures that the tooth in the arch will live. Because the tissue is regenerated by the patient's own blood cells, the chances of immune rejection and pathogen transmission are reduced. [34]

Injectable Scaffold Theory

Pulp tissue is obtained through a tissue engineering process and then administered in a soft threedimensional scaffold matrix in this procedure. Hydrogels outperform all other injectable biomaterials in the field of tissue engineering. Hydrogels are injectable scaffolds that can be delivered with a syringe, are noninvasive, and are simple to place in root canal systems. Hydrogel, in theory, promotes pulp regeneration by acting as a substrate for cell proliferation and differentiation into an organised tissue structure. [35]

Gene Treatment

It is a method for transferring genes that can make use of viral or nonviral vectors. Genetically altered viral vectors can still infect cells but lose their capacity to cause illness. Viral vectors include Herpes simplex virus, lentivirus, retrovirus, and adenovirus. Nonviral delivery mechanisms include plasmids, peptides, cationic liposomes, DNAligand complexes, gene guns, electroporation, and sonoporation. Systematic introduction of mineralizing genes into pulp tissue is the goal of endodontic gene therapy. [36]

Bioengineered Tooth

Whole tooth regeneration is a rapidly developing field that employs the strategy of implanting artificial tooth germs and allowing them to develop in the oral environment. [30]

Conclusion

The notion of biomimetics in dentistry is extremely beneficial, and more and better interdisciplinary scientific and technical study is needed in this area. Regrowing missing dental tissue offers a better prognosis, superior biocompatibility, and a high success rate compared to moderate replacement with dental materials. The use of biomimetic dentistry in India will soon be quite broad. Dentin, enamel, cementum, and pulp that had been lost may be successfully replaced thanks to biomimetic dentistry, ushering in a new era of dentistry. Biomimetics is the study of the synthesis, organisation, or operation of biologically generated substances and materials, as well as biological systems and processes. It is done to create comparable items using synthetic processes that resemble natural ones. A biomimetic substance is one that was produced utilising a biomimetic technology that was inspired by biological systems' inherent processes. The field of dentistry has expanded dramatically in recent years.

Biomimetic dentistry would replace lost dentin, enamel, cementum, and pulp with success, ushering in a new era of dentistry. Biomimetic materials are used as root canal sealers, filling materials, cements, and root and crown repair materials, and they have properties such as root strengthening after obturation, good sealing ability, enhanced biocompatibility, and antibacterial properties. Modern biomaterials have demonstrated the ability to overcome the limitations of traditional materials.

Biomimetic materials are used as root canal sealers, filling materials, cements, and root and crown repair materials, and they have properties such as root strengthening after obturation, good sealing ability, enhanced biocompatibility, and antibacterial properties. Modern biomaterials have demonstrated the ability to overcome the limitations of traditional materials. When determining the standards for identifying them as optimal materials, there are limitations. The illness is given the ability to adapt and modify treatment options thanks to a biomaterial system that replicates the mechanical and physical characteristics of the damaged tissue. A collaborative method called "biomimetic dentistry" has the power to revolutionise standard dental procedures. This uses cutting-edge molecular, environmental, and physical research to solve actual clinical issues. Future materials will ideally foster circumstances for enhanced tooth-like qualities because of adhesion, remineralization, and integration capabilities even if these materials are still in their infancy and their long-term usefulness is dependent on mechanical and physical property advancements.

Future Recommendations

Biomimetic materials hold great potential in pediatric dentistry by mimicking the natural properties of teeth and promoting their regeneration. Their use can enhance the longevity of dental restorations, reduce the need for invasive procedures, and provide a more biocompatible and aesthetic solution for children's dental care. Biomimetic materials have a promising future in pediatric dentistry, offering a range of benefits for children's oral health. These materials imitate the natural structure and properties of teeth, promoting regeneration and repair. By using biomimetic restorative materials, such as bioactive composites and demineralizing agents, dentists can provide more conservative and minimally invasive treatments for young patients. These materials offer improved bond strength, durability, and aesthetics, enhancing the longevity of dental restorations. Furthermore, they provide a biocompatible environment, reducing the risk of adverse reactions or sensitivity. With their ability to mimic nature's design, biomimetic materials have the potential to revolutionize pediatric dentistry and improve oral health outcomes for children.

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