International Journal of Dental Sciences
www.dentaljournal.in
E-ISSN: 2663-4708, P-ISSN: 2663-4694
Received: 27-07-2024, Accepted: 26-08-2024, Published: 10-09-2024
Volume 6, Issue 2, 2024, Page No. 16-18

Bio-mimetic materials in dentistry: A review

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Abstract

The notion of biomimetics in dentistry has a lot of importance, and many studies have been conducted, either to modify the existing material or to develop new material. It is more likely to be successful, have a better prognosis, and have superior biocompatibility if the lost dental tissue is replaced rather than mild replacement with dental materials. Dentin, enamel, cementum, and pulp that have been lost could be successfully replaced through biomimetic dentistry, opening a new era of dentistry. Nonetheless, plentiful interdisciplinary research is under way to develop biomimetic materials.

Keywords: Biomimetic materials, Bio-mimetic dentistry, dentistry

Introduction

The term “Biomimetics” is derived from the Latin words “bios” which means life and “mimesis” which means to copy or mimic [1]. The phrase “biomimetic” was coined by biophysicist/biomedical engineer Otto Schmitt in the 1950s. It is the study of multi-disciplinary mechanisms and biologically produced materials to design novel products to mimic nature [2, 3]. It is an interdisciplinary field of mimicking nature’s ideal biological approaches and strategies using chemistry, physics, mathematics, and engineering concepts to develop novel synthetic materials and organs.[4] Bio-mimetic dentistry is the art and science of repairing damaged teeth with restorations that imitate the living tissues (e.g., enamel, dentin, bone, cementum, etc.) in terms of appearance, function, and strength [5, 6]. The secondary biomimetic goal is to develop restorative materials that can restore the biomechanics of the natural tooth [5, 8]. Hence, a material thus formed by biomimetic technique based on the natural process is called a biomimetic material [4].

The emerging trend of biomimetic approaches in dentistry have been employed for a range of applications, such as restoring tooth defects using bioinspired analogs to achieve remineralization, bioactive and biomimetic biomaterials, and tissue engineering for regeneration [9].

In restorative dentistry, biomimetic approaches have been applied for a range of applications, such as restoring tooth defects using bioinspired peptides to achieve remineralization, bioactive and biomimetic biomaterials, and tissue engineering for regeneration. Advancements in the modern adhesive restorative materials, understanding of biomaterial-tissue interaction at the nano and microscale further enhanced the restorative materials' properties (such as color, morphology, and strength) to mimic natural teeth. In addition, the tissue-engineering approaches resulted in regeneration of lost or damaged dental tissues mimicking their natural counterpart [9].

Unfortunately, in dentistry, there is no such biomaterial that has the same mechanical, physical, and optical properties as that of tooth structures (i.e., enamel, dentin, and cementum). In biomimetic approach of restorative dentistry, the search is for materials that will have esthetic and functional properties closer to tooth structure [4].

Biomimetic materials used in dentistry

The material used to restore the function of the tooth should exhibit properties such as modulus of elasticity, tensile strength, and compressive strength for the replaced tooth structure [10]. In this article, the properties of hydroxyapatite, glass ionomer cement, calcium hydroxide, self-healing composites, mineral trioxide aggregate, DoxaDent, Ceramir, TheraCal, bioactive glass, Emdogain, and Ceramicrete are compared to those of the natural tooth [11].

Hydroxyapatite

Hydroxyapatite is a nonrestorable calcium phosphate material. It is composed similarly to bone and has an osteoconductive characteristic. Due to its poor mechanical properties, it is not employed in areas that sustain loads. It serves as a filler in composite resin and is used in bone grafting. For endodontic therapy, hydroxyapatite has been used for perforation repair, formation of the apical barrier, pulp capping, and periapical defect repair [11].

Glass ionomer cement

Glass ionomer cements (GICs) are considered as biomimetic materials because it has properties similar to dentin, adhesiveness to tooth structures, and fluoride release.GICs are useful in deep I and II cavities to fill up the base as lining material. They are also used as restorative materials in buccal class V cavities. GIC releases fluoride, which has bactericidal properties, and stimulates sclerotic dentin. However, its tensile strength is poor and is not advocated in areas of high occlusal stress and force concentration. Biodentine, a newly developed material, may replace GIC as a liner in deep fillings in the future, but further research is needed in this field. GIC is currently being the main material for minimum invasive dentistry. It has a coefficient of thermal expansion identical to that of a natural tooth [4, 11].

Calcium hydroxide

Calcium hydroxide was introduced by Hermann in dentistry. It contains calcium ions and hydroxyl ions. Hydroxyl ions neutralize the acid produced and maintain the pH for the activity of the pyrophosphatase leading to the increasing level of calcium-dependent pyrophosphatase, which decreases the levels of inhibitory pyrophosphate and causes mineralization. It is used as a cavity liner, as an interim root canal dressing to induce hard tissue formation, in the treatment of root fracture and root resorption, and as a permanent root canal sealer. It has antibacterial properties due to the alkaline pH, and it may aid in dissolving necrotic tissue remnants, bacteria, and their byproducts. It also has the ability to induce tertiary dentin formation [5, 11].

Self-healing composites

Self-healing composites include polyurea-formaldehyde (PUF) or silica microcapsules. Silica microcapsules use water or polyacid as a healing agent. They are fabricated to repair cracks and damages, if there will be any, to restrict failure and extend the longevity of structures. In case of composite resin, if cracks are seen, the microcapsules are destroyed near the crack and the resin is released. When the catalyst placed in the epoxy composite reacts with the resin to fill the crack, the resin polymerizes and the crack is repaired [11, 12].

Mineral trioxide aggregate

Mineral trioxide aggregate (MTA) is a hydrophilic substance made of calcium silicate that was created by Torabinejad in 1990. With a pH range of 10 to 12, it crystallizes calcium hydroxide and crystals resembling hydroxyapatite when exposed to phosphate-containing solutions. Gypsum, tetra-calcium aluminoferrite, tricalcium aluminate, dicalcium silicate, and tricalcium silicate are all components of MTA. This is a preferred substance for pulp capping, root-end filling in apicoectomy procedures, vital pulp therapy, apexogenesis, and apexification. It results in cement development, dentinal bridge construction, and periodontal ligament attachment. When implanted, it stimulates the growth and development of odontoblast-like cells, which result in the production of a collagen matrix. The matrix is thus first mineralized by osteodentin and later by the development of tertiary dentin. It shows good adhesion to dentin. When employed in vital pulp therapy, it has low solubility, and no tunnel defects are seen as compared to calcium hydroxide [11-14].

DoxaDent

The calcium and aluminum present in this cement, which was first developed in 2000, react with water that contains salts of lithium to produce gibbsite and katoite. It is inorganic and non-metallic in nature. It is available as a liquid powder component. It is a tough substance with little wear resistance. It is equally potent as glass ionomer cement. Alumina, zirconium dioxide, calcium dioxide, water, and other alkaline oxides make up its constituent parts. It is employed as a long-lasting reparative material [12, 13].

Ceramir

Ceramir is used for long-term cementation and contains calcium aluminate. The calcium released reacts with alkaline pH to rebuild dentin and enamel of all zirconia, inlay, gold, and fixed partial dentures. It reacts favorably with the inorganic phosphate in saliva to form hydroxyapatite and exhibits good gingival reaction when used as a luting agent [11, 13].

TheraCal

TheraCal is made of light-cured silicate resin that has been modified with resin. It serves as a protective layer underneath base materials including cement, amalgam, and composite. Compared to Dycal and MTA, TheraCal has low calcium solubility and high calcium release [12, 13].

Bioactive glass

They have the ability to react in liquid or water. The formation of silica gel polycondensed coating on glass bulk serves as a template for the development of calcium phosphate due to its characteristics and high biocompatibility. Bioactive glasses have also been used in bioregeneration. These can be utilized for implant coating, dentin hypersensitivity treatment, and bone grafting [15, 16].

Emdogain

Emdogain is made from enamel matrix protein from the tooth germ of swine and propylene glycol alginate as a matrix. Hertwig epithelial root sheath secretes an enamel matrix-derived protein that induces the formation of periodontal tissue. Emdogain imitates these tooth-developmental mechanisms. Ameloblastin, enamelin, growth factor, tuftelin, and bone morphogenic protein are examples of non-collagen proteins that are also present in Emdogain. It has been used in the treatment of vital pulp therapy and pulpotomy because it causes reparative dentin formation. It is used to reduce external root resorption in replantation situations [11, 15].

Ceramicrete

Ceramicrete is a radiopaque filler made of cerium oxide and powdered hydroxyapatite and is a new-generation calcium-based substance. It releases calcium and phosphate ions when setting and is radio-opaque and biocompatible. When utilized as a root-end filling material, it has a greater sealing capacity when compared to Pro-Root MTA. The surface of the Ceramicrete material forms hydroxyapatite or dicalcium phosphate dihydrate (DPCD) when it is immersed in a phosphate-containing fluid (PCF). The setting time is 2.5 hours. It has an initial pH of 2.2, which increases with time [11].

Future aspects

In order to develop biomimetic restorative biomaterials, plenty of research has been conducted either modifying the existing materials or developing new materials. A variety of processing technologies including nanotechnology, fabrication methods, and functionalization of biomaterials has been explored. In the past decade, biomimetic restorative materials demonstrated considerable advancements in their properties simulating that of natural tissues. However, due to the complex structural and functional nature of dental tissues, the development of biomimetic restorative materials is still at the preliminary stage. Similarly, biomimetic tissue engineering has experienced exponential growth from developing theoretical phase to a multi-faceted fast-emerging field in recent decades; however, translating such developments to practical and clinical applications requires further research [9].

Conclusion

Considering the major challenges faced by researchers and clinicians, perhaps it may take a more than a decade for biomimetic materials to be implemented on a bigger scale to treat dental lesions. New alternative treatment modalities are likely to be available for clinical applications after innovative discoveries in genetics, molecular biology, cell biology, and materials science. Through these treatment modalities, regeneration of dentin, enamel, pulp, restorative procedures, and management of soft tissues of periodontium can possibly be carried out.

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