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Review Article

Biomimetic materials: A comprehensive review

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ABSTRACT:
Biomimetics in dentistry is a very useful concept and further and firmer multidisciplinary scientific and technical research is needed in this field. Regeneration of the lost dental tissue rather than mild replacement with dental materials ensures better prognosis, excellent biocompatibility, and high success rate. 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.
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INTRODUCTION

The term "bio" means life and "mimesis" in Greek means imitate.[1] Biomimetics is defined as the study of the formation, structure, or function of biologically produced substances and materials and biological mechanisms and processes especially for the purpose of synthesizing similar products by artificial mechanisms which mimic natural ones. A material fabricated by Biomimetic technique based on natural process found in biological systems is called a Biomimetic material.[2]

Biomimetics is an emerging inter disciplinary field that combines information from the study of biological structures and their function with physics, mathematics, chemistry and engineering in the development of principles that are important for the generation of novel synthetic materials and organs.[3]

The main principle of Biomimetic Dentistry is to replace the lost dental tissues by artificial and naturally available materials to restore full function and bear with all functional stresses along with the maintenance of aesthetic results. The subject matter of Biomimetics is known by several names Bionics, Biognosis etc. The concept is very old but the implementation is gathering momentum only recently because the science base can cope with the advanced techniques and our civilization is in ever increasing need of sympathetic technology.[3]

BIOMIMETIC PRINCIPLES IN RESTORATIVE DENTISTRY

Due to the development of improved adhesives, the use and indications for bases and liners have decreased. The indication for placing a liner under adhesive restoration is mainly for pulp protection in the form of partial lining using $Ca(OH)_2$ cements.

Endodontically treated teeth are fragile and susceptible to fracture because of tooth structure removal and loss of cushioning effect due to the removal of pulp. In case of posterior teeth, total cuspal coverage with porcelain is recommended because it will significantly strengthen the crown and increase cusp stabilization.[4]

GLASS IONOMER CEMENT (GIC)

Glass ionomer cement (GIC) is considered as biomimetic material because it has properties similar to dentin, adhesiveness to tooth structures, and it is anticariogenic because of fluoride release. GICs are useful in deep class I and class 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 and also has properties similar to dentin. GIC is currently being the main material for minimal invasive dentistry which is under the umbrella of Biomimetic Restorative Dentistry.[2]

In dentin replacement, glass ionomer not only recreates the functional strength of dentin, but it also rejuvenates the remaining affected dentin through remineralization. Glass-ionomer cement has similar mechanical properties to dentine. This, together with the important benefits of adhesion and release of fluoride, render it an ideal material in many restorative situations. However, it„s relatively poor mechanical properties must be considered, and therefore it should only be used as a final restorative material in low stress areas, and it must be protected by resin composite or amalgam in areas of high stress. Because of the extensive use of this cement as a dentin replacement material it has been referred to as "MAN MADE DENTIN" and "DENTIN SUBSTITUTE". As a biomimetic dentin substitute, glass ionomers when used as a base prior to the placement of composite resin (Direct Sandwich Technique) facilitates reduction in the amount of shrinkage stresses that occurs between the direct resin restoration and the cavity preparation walls by approximately 20% to 50%.[4-6]

FLUORIDE RELEASE

Fluoride release is considered one of the important advantages of glass-ionomer cements. It can be sustained for very long period of time, and shows a pattern of an initial rapid release ("early burst"), followed by a sustained, lower level diffusion-based release.[6]

It has been shown that glass ionomer materials are able to release fluoride at a sustained rate for long periods of time (at least 5 years). Also, being water-based systems, they act as continuing fluoride ion reservoirs in the mouth by taking in salivary fluoride from dentifrices, mouthwashes and topical fluoride solutions at the dental office. Fluoride ion release and uptake associated with all the glass ionomer systems, while useful for all young patients, are particularly advantageous for those with high susceptibility to dental caries.[7]

ADHESION & BONDING TO DENTAL TISSUES

Adhesions of glass-ionomer cements can be attributed to two inter- related phenomena, namely:

1. Micromechanical interlocking, caused by glass-ionomer being self-etching due to the polyacid component.
2. True chemical bonding: This involves ionic bonds being formed between the carboxylate groups on the polyacid molecules and calcium ions in the tooth surface. This has been observed experimentally on hydroxyapatite and also on enamel and dentin using X-ray photoelectron spectroscopy, though experimental conditions for these studies involve high vacuum, so requiring that the surfaces must be more strongly desiccated than under clinical conditions.[6]

THEORIES OF ADHESION:[7-9]

b. Electrostatic (Electronic) Theory:
c. Diffusion Theory:
d. Acid – Base Theory:

RECENT ADVANCES[10-12]

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

RESIN BASED COMPOSITES

The goal of Biomimetics in Restorative Dentistry is to return all of the prepared dental tissues to full function by the creation of a hard-tissue bond that allows functional stresses to pass through the tooth, drawing the entire crown into the final functional biologic and aesthetic results. Composites resins are now displaying favourable properties and longevity on par to amalgam. The technique involves minimal preparation decreasing pulpal involvement and decreasing the prognosis of fractures. Therefore, it preserves tooth vitality and substance. The bonded composite can prevent fracture of unsupported cusps in primary and permanent molars that were restored with amalgam, and the use of preformed metal crowns was avoided.

Modern dental composite restorative materials began in the early 1960s, with the discovery of Bowen" s Bis-GMA (2,2-bis[4-(2-hydroxy-3 methacryloxypropoxy) phenyl]- propane) with inorganic particle formulations. Dental composites are composed of synthetic polymers, inorganic fillers, initiators, and activators that promote light-activated polymerization of the organic matrix to form cross-linked polymer networks, and silane coupling agents which bond the reinforcing fillers to the polymer matrix.[8-14]

RECENT ADVANCES: [12-17]

1. Self-Repairing Materials
2. Antimicrobial Composite

3. ORMOCER
4. Stimuli Responsive Composite:
5. Giomer

CERAMICS

For a long time, ceramic materials have been defined as compounds of metallic and non- metallic elements consisting of oxides, nitrides, carbides, and silicates. Most of the ceramics used in dentistry were primarily based on silicon that usually occurs in the form of silica (silicon dioxide), due to the silicon‟ s high oxygen affinity or as silicates compounds.

The increasing use of polycrystalline ceramics (with no silicon in their composition), and the introduction of so-called „hybrid‟ ceramics imposed the need for a new classification system. According to this classification system, all-ceramic and ceramic-like restorative materials can be categorized into three groups:

(1) Glass-matrix ceramics,
(2) Polycrystalline ceramics, and
(3) Resin-matrix ceramics.

All restorations can be shaped so naturally that they cannot be distinguished from your real teeth.

Cercon – material: A high-tech ceramic, Zirconium Oxide, is used and has already been proven in many extreme situations such as heat shields in the Space Shuttle, brake disks for sports cars and the spherical heads of artificial hip joints. This high-tech ceramic has the potential to give prosthetic care a whole new image, because thanks to Cercon smart ceramics it can now be used in dentistry.

- Cercon- technology
- Cercon-compatibility
- Cercon-esthetics

With the additional advantage of having maximum stability thanks to its strength in thin sections, Cercon restorations can be well integrated to follow the natural contours of the mouth. Together with the natural teeth, a harmonious overall appearance can be achieved that makes as good an impression as your own teeth.[18- 25]

MINERAL TRIOXIDE AGGREGATE (MTA)

Mineral Trioxide Aggregate (MTA) is a unique material with several exciting clinical applications. MTA is potential and one of the most versatile materials of this century in the field of dentistry. During endodontic treatment of primary and permanent tooth MTA can be used in many ways. MTA materials have been shown to have a biocompatible nature and have excellent potential in endodontic use. MTA materials provide better microleakage protection than traditional endodontic repair materials using dye, fluid filtration, and bacterial penetration leakage models. In both animal and human studies, MTA materials have been shown to have excellent potential as pulp capping and pulpotomy medicaments. MTA material can be used as apical and furcation restorative materials as well as medicaments for apexogenesis and apexification treatments.[21]

CLINICAL APPLICATION OF MTA: [20-25]

1. IN PRIMARY TEETH

i. Pulp capping
ii. Pulpotomy
iii. Root canal filling
iv. Furcation perforation repair
v. Resorption repair

2. IN PERMANENT TEETH

i. Pulp capping
ii. Partial pulpotomy
iii. Perforation repair - Apical, lateral, furcation
iv. Resorption repair - External and internal
v. Repair of fracture - Horizontal and Vertical
vi. Root end filling
vii. Apical barrier for tooth with necrotic pulps and open apex
viii. Coronal barrier for regenerative endodontics
ix. Root canal sealer

BIODENTINE

Biodentine is a calcium-silicate based material that has drawn attention in recent years and has been advocated to be used in various clinical applications, such as root perforations, apexifications, resorptions, retrograde fillings, pulp capping procedures, and dentin replacement. Calcium silicate-based materials have gained popularity in recent years due to their resemblance to mineral trioxide aggregate (MTA) and their applicability in cases where MTA is indicated. Although various calcium silicate-based products have been launched to the market recently, one of these has especially been the focus of attention and the topic of a variety of investigations. This material is the “Biodentine” calcium silicate-based product which became commercially available in 2009 (Septodont) and that was specifically designed as a “Dentine Replacement” material.[26- 30]

BIODENTINE AS BIOMIMETIC MATERIAL

Biocompatibility of a dental material is a major factor that should be taken into consideration specifically when it is used in pulp capping, perforation repair or as a retrograde filling. During the aforementioned procedures, the material is in direct contact with the connective tissue and has the potential to affect the viability of periradicular and pulpal cells. Cell death under these circumstances occurs due to apoptosis or necrosis.

In a study performed by Zhou et al., where Biodentine was compared with white MTA (ProRoot) and glass ionomer cement (FujiIX) using human fibroblasts, both white MTA and Biodentine were found to be less toxic compared to glass ionomer during the 1- and 7-day observation period.[28- 33]

BIO- AGGREGATE

BioAggregate (BA) also referred to as DiaRoot (DiaDent) BioAggregate (Innovative Bioceramix, Vancouver, BC, Canada) (De-Deus et al. 2009; Hashem & Wanees Amin 2012) is a material that was introduced for perforation repair, root-end filling, as well as pulp capping.[33- 35] BA is a material with fine particle size, bioactivity, certain antibacterial properties, and no reported toxicity. However, so far, all investigations on BA have been laboratory studies. One will need to see in vivo and evidence-based investigations to determine the material‟ s efficacy in clinical applications.

BIO ACTIVE GLASS (BAG)

A material is reputed to be bioactive when the engineered substance produces a physiologically active response when it interacts with the biological system by forming a strong material tissue bond. The biocompatibility of a material is gauzed by its ability to exhibit harmony in vivo. The development of bioactive glasses (BAGs) is a milestone in the development of biocompatible material because of its properties, such as mechanical biocompatibility.

The chemistry of BAG is mimicking the natural hard tissues composition, and has a bioactive role in the regeneration. BAGs are usually composed of 40–52% SiO_2, 10–50% CaO, 10–35% Na_2O, the glass composition may contain 2–8% P_2O_5, 0–25% CaF_2, or 0–10% B_2O_3. Na-free BAG prevented the disruption of the glass network and showed equal bioactivity. In addition, various elements such as Si, P, Sr, Cu, F, Ag, Zn, and F are added to enhance the bioactivity and antimicrobial properties. Generally, the BAGs are prepared by either quenching or sol-gel technique. The bioactivity is influenced by the structure and composition of the glass, manufacturing techniques, and the rate of ionic dissolution. The most bioactive glasses have superior surface area with higher dissolution rate and thus faster apatite formation. The FDA has approved Bioglass® 45S5 and S53P4 for clinical applications due to desired antimicrobial properties. There is increasing use of bioactive glasses in various aspects of dentistry including dental restorative materials, toothpaste, mineralizing agents, desensitizing agents, pulp capping, root canal treatment, and air abrasion. Resin composites with BAG and fluoride enhanced dentin remineralization and eliminated enzymatic degradation at the dentin interface. PerioGlas® has been extensively used in periodontal surgical procedures to stimulate bone regeneration, especially in interproximal bone defects due to its haemostatic effect on trabecular bone.[32- 35]

CONCLUSION

Biomimetic dentistry would successfully replace lost dentin, enamel, cementum, and pulp and open a new era of dentistry. Biomimetic materials functions as root canal sealer, filling materials, cements and root and crown repair material and possesses features as like strengthening the root following obturation, good sealing ability, enhanced biocompatibility and antibacterial properties. Contemporary biomaterials have shown ability to overcome the limitations of traditional materials. However, there exists limitations when considering criteria for categorizing them as ideal materials. Several in vitro and in vivo studies have demonstrated good results, however randomized and double-blind studies of sufficient duration with biomimetic materials have been needed to confirm long term success.

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