Biomimetic Materials in Restorative Dentistry and Endodontics – A Review

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Abstract

In 1950, while researching the nerves in a squid, Otto Schmitt coined the word "Biomimetics" It means imitating life, literally. To seek to mimic or reproduce it artificially to preserve the same esthetics or work is the study of natural structural processes. Since tooth structure has no natural means for restoration, biomimetic methods can be implied to restore the teeth mechanically to its normal function and esthetics. There are two things of biomimetic dentistry. First, the damaged or absent dental tissue is replaced, leading to complete restoration to the tooth of function and aesthetics. And the substance used will regenerate the damaged dental tissue, replicate and imitate it. The bio-compliant and Physico-chemical products of biomimetic material have the benefits of improved biocompatibility, sealing ability, high strength, antibacterial properties and are used to preserve long term esthetic and restoring techniques. Recent biomimetic technologies have established the potential to transcend various considerable drawbacks of technologies of a previous age. This study would seek to provide a clearer explanation for biomimetic materials 'relative role in the sense of past and current dental materials.

***Keywords**: Biomimetic Materials, Restorative Dentistry, Endodontics*

Introduction

"Biomimetics is characterized as the study of the structure, creation and function of substances and materials, as well as biological processes and mechanisms, particularly for the synthesis of similar products with artificial mechanisms that mimic them".[1] Biomimetic material is a substance created by biomimetic processes based on natural processes occurring in biological systems. The main concept of Biomimetics is to restore all ready tissues to completion via a strong fabric attachment, which can help the crown achieve its ultimate biological and esthetic functional outcome by providing for functional stresses.[2]

There is no biomaterial in dentistry that has the same mechanical, electrical and optical properties as the structure of the tooth and has the functional features of preserved teeth in operation. Employing biomimetic therapeutic methods, dental practitioners could develop and get closer to normal biological systems and their operation. There are two main perspectives to which the phrase "*Biomimetic* is applied: a purist viewpoint that focuses on recreating biological tissues and a descriptive perception that focuses on using materials that effect in a mimicked biological effect".

A biomimetic material can suit the portion of the tooth that it substitutes in a variety of respects, including the modulus of elasticity and the structure of the corresponding areas (e.g., enamel, dentin, dentoenamel, pulp). So this analysis would aim to present a clearer explanation of the biomimetic materials 'relative role in the sense of past and present dental material. Figure 1

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below shows the generation of biomaterials.

GENERATION OF BIOMATERIALS

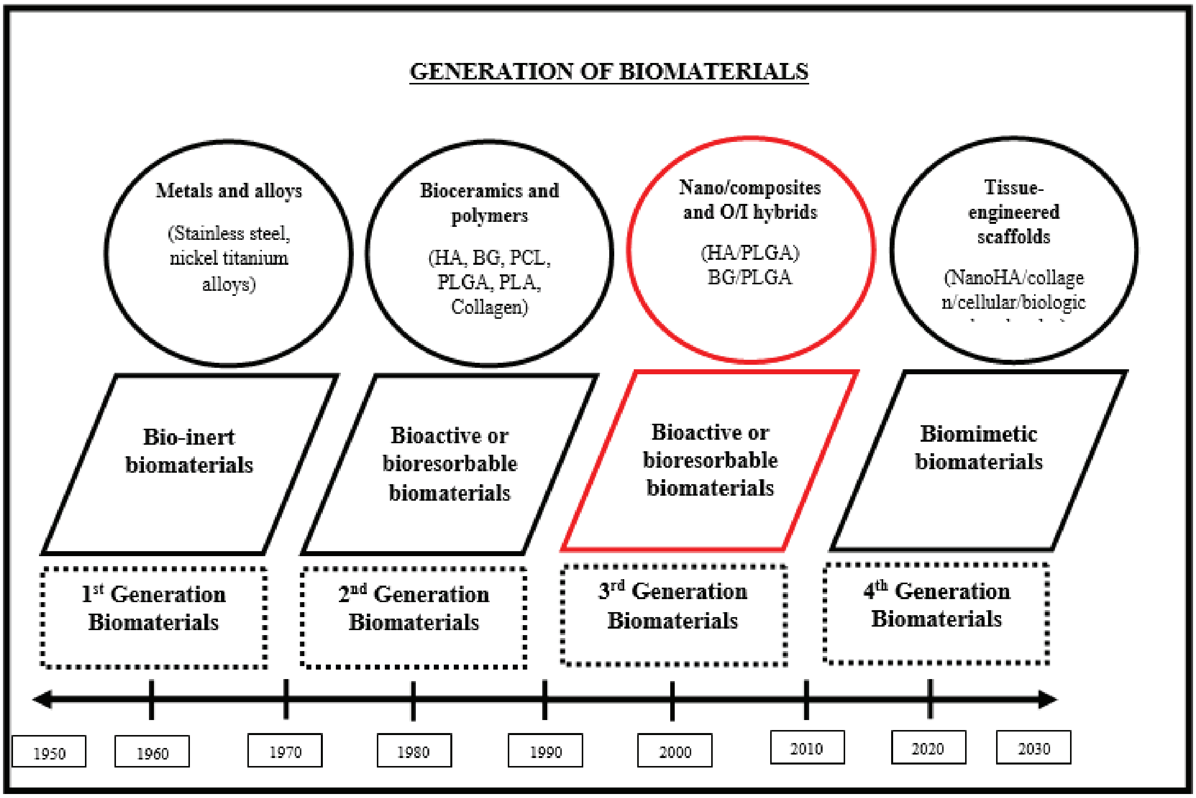

Figure 1. Generation of biomaterials

BIOMIMETICS IN RESTORATIVE DENTISTRY:

A biomimetic strategy in restorative dentistry should signify similar aesthetic and practical restorative materials to the natural tooth and its enamel and dentine layers. In 2006 Magne stated "The objective of Biomimetics in restorative dentistry is to reestablish all of the prepared dental tissues to full function by the creation of a hard tissue bond that permits functional stresses to pass through the tooth, making the entire crown into the final functional biologic and esthetic unit. The intact tooth in its ideal hues and shades, and more importantly in its intracoronal anatomy, location and mechanics in the arch, is the guide to reconstruction that governs success".[3]

Table.1 Features the resemblance of natural tooth substance to existing artificial materials.

	Elastic modulus (Gpa)	Thermal expansion coefficient (x 10-6 o/C)	Ultimate tensile strength (Mpa)		Corresponding material	Elastic modulus (Gpa)	Thermal expansion coefficient (x 10-6 o/C)	Ultimate tensile strength (Mpa)
ENAMEL	82	17	10		Feldspathic ceramics	60-70	13-16	25-40

***Cont...* Table.1 Features the resemblance of natural tooth substance to existing artificial materials.**

DENTIN	14	11	40-105		Hybrid composites	10-20	20-40	40-60
					Glass-ionomer cements	4-10	35	4-5

GLASS IONOMER CEMENT:

Invented by Wilson and Kent in 1969, consisting of glass powder of fluoroaluminosilicate along with water-soluble polymers (acids). Once liquid and powder are combined, this results in a hardening reaction involving neutralization of the acidic group along with considerable fluoride release. It is labelled as biomimetic substance because it is synthetic, chemically adheres to the surface of the tooth, minimum shrinkage, less microleakage, high humidity structural stability, release fluoride, bactericidal nature, stimulate sclerotic dentin and also has similar properties to dentin. Nonetheless, due to their low tensile strength, they are not recommended in the use of high occlusal force and stress.

Modifications of Glass-Ionomer were Water settable GIC, Metal modified GIC and Resin modified GIC. Metal-based GIC has been improved by adding filler particles to maximize fracture resilience & wear resistance but esthetic properties have been compromised. Resin modified GIC was auto-cured, Light-cured, dual-cured depending on activator initiator system resulting in improvement of Optical properties as better translucency was achieved, diametral tensile strength was much higher but compressive strength and hardness are lesser, adhesion with dentin was higher than that of conventional GIC but microleakage was increased due to polymerization shrinkage of resin. Fibre-reinforced GIC involves the incorporation of a continuous network/scaffold of alumina and SiO2 ceramic fibres. Flexural strength is increased(15.6 Mpa) and Compressive strength is increased (200Mpa) and Fracture Toughness— 0.22 Mpam0.5. This proficiency is called the “Polymeric Rigid Inorganic Matrix Material” or PRIMM Alumina and SiO2 ceramic fibres

A recent advance in GIC modification is nano-hydroxyapatite/yttria-stabilized ZIRCONIA (HA/YSZ) containing GIC which defines a new class of restorative glass ionomer that promises the strength and durability ideal for permanent posterior restoration maintaining aesthetics.

GIC as Biomimetic Material in Endodontics – Glass-ionomer based sealer: used in obturation because of their dentin bonding property, enables adhesion between the material and canal wall but has minimum anti-bacterial property and removal is difficult in case of retreatment. “KT-308 (GC Corporation Company, Tokyo, Japan)” a GIC based sealer, offers improved zinc oxide-eugenol-based sealer which is resistant to coronal penetration of bacterial agents into the root canals.[4] “ZUT (University of Toronto, Ontario, Canada)” is an amalgamation of GIC and an antimicrobial silver-containing zeolite that is effective against E.faecalis and can therefore treat teeth with chronic apical periodontitis more effectively.[5] “Active Gutta-Percha (Brasseler USA, Savannah, GA, USA)” are Glass ionomer infused Gutta-Percha cones that bonds to GIC sealer and remarks to present adhesive bonding of the active Gutta-percha to intra-radicular dentin.[6,7]

Composite:

Bowen introduced composite in 1962 which offers colour stability, wear resistance, radioopacity and enhanced physical properties.[8]

Composition: Resin matrix–BIS-GMA or Urethane Dimethacrylate (UDMA) + Dimethacrylate monomers (TEGDMA), Inorganic Fillers: Quartz/Glass Particles (0.1 to 100µm) Colloidal Silica (0.02 to 0.04

µm), Coupling Agents: organosilanes, Pigments: oxides of titanium, Activator: Tertiary amines, Photo-initiator: Camphorquinoneand Chemical-initiator: Benzoyl Peroxide

Table 2. **Modifications of different biomimetic materials**

MODIFICATIONS	MATERIALS USED
REINFORCED FILLERS	· Electrospun nylon nanofibres containing highly aligned silicate single crystals · Nanofibres and e-glass fibres with SiO2 in the semi-interpenetrating polymer network(IBN) matrix · TiO2 Nanocomposites modified with Allytriethoxysilane(ATES)
CARIES PREVENTION FILLERS	· Nano-DCPA whiskers · TTCO-Whiskers · CaF2 nanoparticles with reinforcing whisker fillers · Polymer-kaolinite Nanocomposite
RESINS	· Epoxy-polyol matrix · Epoxy functionalized cyclic siloxane · Bioactive poly i.e methyl methacrylate/SiO2-CaO nanocomposite · Epoxy resin ERL-4221(3,4-Epoxycyclohexylmethyl-(3,4-epoxy cyclohexane carboxylate · Silsesquioxane(SSQ)
NANOPARTICLES SURFACE MODIFICATION WITH DIFFERENT SILANES	· 3-methacryloxypropyltrimehoxysilane(MPTS) · N-octyltrimethoxysilane(OTMS) · Equal masses of MPTS ad MPTS · Y glcidoxypropyl trimethoxysilane (GPS) · Allytriethoxysilane(ATES)

***"Smart Dentin Replacement" (SDR)* - is the first** kind of flowable composite resin material with properties modified with lower polymerisation stress and decreased polymerisation; higher depth of cure and bulk-filling content that can be used in Class I and Class II cavities up to 4 mm in increments [9,10,11]

CERAMICS:

By firing at a high temperature, ceramic is classified as a substance made from non-metallic material. Ceramic applications are promising because they are strongly esthetic, have lengthy-term consistency in colour, tough compressive strength and hardness, outstanding biocompatibility and chemical inertness. Dental ceramics includes a phase of crystal and a phase of silica-based glass. Leucite crystal and lithium disilicate crystals are similar to porcelain dental prism rods. The enamel rod is 4-8um in diameter. It is a compact, systematized agglomerate of hydroxyapatite crystals. The cross-section has keyhole form characteristics.

"Ceramics are studied for the manufacturing of bone tissue and other dental applications too. Hydroxyapatite (HA), an essential inorganic part of the bone, is a ceramic dependent on calcium phosphate. New bone formation happens first on the scaffold surface in Novel ceramic bone replacement material called Ceraball. Ceraballs can act as a transporter for pluripotent mesenchymal stem cells, stromal cells and bone marrow".[12]

BIOMIMETICS IN ENDODONTICS

Calcium hydroxide:

Hermann introduced calcium hydroxide to dentistry at the turn of the 20th century and has been widely used in endodontics. It is a solid alkaline material with a pH of about 12.5 and has numerous biological properties that have impelled it to be used in many clinical contexts. Its dental use primarily relates to its antibacterial properties and the ability to promote repair and encourage the regeneration of hard tissues. The greatest advantage of calcium hydroxide is the bacterial effects deliberated by its elevated pH because certain endodontic micro-organisms are incompetent to live in the extremely alkaline atmosphere created by calcium hydroxide, as an intracanal treatment.

It was frequently used as a mineralising and antimicrobial agent. Based on whether the threat is succumbing to or subsisting with current odontoblasts, two forms of dentin may be produced. Reactionary dentinogenesis in which tertiary dentin matrix is covered by oriented controlled pre-existing odontoblasts and reparative dentinogenesis in which the secretion of tertiary dentin matrix occurs after the death of primary odontoblasts by an entirely new generation of secreting cells. Calcium hydroxide enhances the production of biomolecules (such as FGP, BMP, etc.), induces the release of extracellular matrix molecules (such as dentin sialoproteins, dentin phosphoproteins), has anti-inflammatory and antimicrobial activity.[13] “Controlled-release Calcium hydroxide charged microcapsules” based on ethyl cellulose (EC) and polylactic acid (PLA) has been developed to advance its biological efficiency.[14] Those formulas delayed the release of ions. Disadvantages of $Ca(OH)_2$: inconsistent treatment time, apical closing unpredictability, patient follow-up challenge, prolonged treatment, canal susceptibility to fracture during treatment, $Ca(OH)_2$ does not conform to dentine and lacks sealing capacity. Tunnel defects can act as microleakage pathways in dentine bridges.

Calcium Sulfate

It has been shown that calcium sulfate (CS) is fully bioabsorbable, osteoconductive, doesn’t induce an inflammatory response, makes fibroblast migration and doesn’t raise serum calcium levels either. It had been seen recently that Calcium Sulfate can be turned into a granular blend with poly-lactic acid to reduce the degradation rate.[15]

“Calcium Phosphate”

“Calcium phosphates” play a significant function in the mineralisation of biological and pathological compounds. Also commonly found in paste, cement, ceramics, and scaffolding.[16] The various calcium phosphate products described below in Table 2.

Table 3. Calcium phosphate materials

CALCIUM PHOSPHATE MATERIALS	EXAMPLES
Calcium phosphate ceramics	· Calcium hydroxyapatite [calcitite (calcite,Inc)] · Beta-tricalcium phosphate [synthograf, augment (miter,Inc.] · Biphasic calcium phosphates [triosit(zimmer)]
Calcium materials material from natural products	· Coralline HA[inerpore 200(interpore)] · Bio-oss(from sintered bovine bone)
Glass-ceramics	· Bioglass (American biomaterial corporation)

“Calcium Enriched Mixture (CEM)”

“It consists of calcium oxide, phosphorous pentoxide, sulfur trioxide, and silicon dioxide. It may promote stem cell differentiation and cementogenesis”.

Mineral Trioxide Aggregate

MTA is a novel advanced technology for endodontics and appears to be important over other technologies. It has been used in both surgical and nonchirurgical applications since its invention by Torabinejad and colleagues in 1993. This is the first restorative material that makes cementum overgrowth gradually and may help the periodontal ligament to be regenerated. This should also be called 'Biomimetic Material.' MTA's capacity to cause dentine bridge formation may be attributed to its excellent sealing efficiency or biocompatibility. MTA can stimulate cytokine release from bone cells and enable osteoblasts to be attached in monolayer form.[17]

MTA can activate cementoblasts to generate a matrix for the formation of cementum. Studies indicate that MTA enables cementoblast attachment and growth, and building a mineralized matrix gene and protein expression. Irrespective of its origin, cementoblasts are the cells accountable for cementum production and regeneration, concluding that MTA is semiconductive materials.

Advantages: Resistance to marginal leakage reduces bacterial migration, Least toxicity of all the filling materials, Excellent biocompatibility, Hydrophilic sets in the presence of moisture. Moisture contamination is not an issue, Negligible Solubility**,** Super Sealing ability**,** Sufficient compressive strength to allow condensation of amalgam when it is used as a pulp capping agent, Reasonably radio-opaque and Non-resorbable.

Disadvantages: Difficult to manipulate, Prolonged setting time and Dissolves in acidic pH.

Calcium-Aluminate Cement (Binderware, São Carlos, Brazil),

This had been built by São Carlos Federal University. This consists of aluminium oxides (Al_2O_3), silicon (SiO_2), calcium (CaO), iron (Fe_2O_3) and magnesium. It enables the regulation of impurities like Fe_2O_3 (which promotes tooth darkening) and is free of CaO and MgO which prevents unnecessary expansion of the substance after contact with moisture.[18,19]

Biodentine™ (Septodont, France):

"In 2011, it was introduced which composed of tricalcium silicate, calcium carbonate and zirconium oxide and a water-based liquid containing calcium chloride as the setting accelerator.[20,21] Once biodentine makes contact with dentine, it contributes to the formation of tag- structures next to an interface layer which is called "Mineral Infiltration Area" and may contribute to adhesive properties".[22] It has shortened setting time (12 min), enhanced physical properties and induces mineralization and cell differentiation.[20]

"Bioaggregate (Innovative Bioceramix Inc., Vancouver, Canada)"

"Introduced in 2006, it is available as powder consisting of nanoparticles comprising dicalcium silicate, tricalcium silicate, amorphous silicon dioxide, calcium phosphate monobasic, tantalum pentoxide (radio pacifier) and liquid form has deionized water. As it is an aluminium free formulation, so it aids in periodontal regeneration and human PDL fibroblasts proliferation" .[21-25]

Bioactive glass:

The bioactive glass was first introduced by Hench et al, are surface-active glasses that bond chemically to bone materials. They are non-bone graft materials. These bioactive glasses contain different ratios of Sodium dioxide (24.5%), Calcium oxide (24.5%), silicon oxide and phosphorus (45%). "Bonding of BAGs to the living bones is accomplished by a bone-like apatite coating formed on their surface in the body environment due to their close bond with living bone, BAGs have been used as bone replacement products in different clinical conditions". Currently, there are two widely available glasses for use at bone locations, Bioglass with a partial size of 300-355μm. These are 100% organic bone restorative or regenerative materials. "Mohn et al' combined BAG particles with 50% bismuth oxide and used as the root canal filling substitute. BAG has an antibacterial influence, directly and indirectly, linked to pH".[26]

Conclusion

It is a biomaterial scheme that mimics the mechanical and physical properties of the affected tissue and thus provides a framework for the disease to adapt and alter therapeutic methods. Biomimetic dentistry is a collaborative approach that can change everyday dental practice. This uses the strength of advanced molecular, environmental, and physical research to solve real clinical challenges. Biomimetic products serve as cement, filling materials, root canal sealer, and root-crown repair material and possess features such as root-reinforcing after obturation, strong sealing capacity, improved antibacterial properties and biocompatibility. Nevertheless, in terms of requirements for classifying them as ideal products, there are drawbacks. Multiple in vitro and in vivo experiments have shown good results, but long-term success requires more randomised and double-blind trials with biomimetic materials.

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