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BIOMIMETIC MATERIALS IN DENTISTRY: A COMPREHENSIVE REVIEW

Dental Science

Dr Kirti Rathee* *Corresponding Author

Dr Anjum Zia

Dr Ankita Sundan

Dr Tuba Siddiqui

ABSTRACT

Biomimetic materials are the materials fabricated by Biomimetics techniques, i.e., based on natural processes found in biological systems. These materials are said to produce results that replicate the form, function, and other characteristics of natural teeth and oral tissues— in terms of biologic process, strength, physical characteristics etc.

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, Form, Function, Strength

INTRODUCTION:

Biomimetic refers to human- made processes, substances, devices or systems that imitate nature. The art and science of designing and building biomimetic apparatus is called as Biomimetics. It is the study of biological structures, their functions and synthetic pathways emerging at the intersection between cellular biology, molecular biology, material sciences, dentistry and medicine. 'Bio' meaning 'life' and 'Memesis' meaning 'imitation' are derived from Greek words.[1]

Biomimetic materials are the materials fabricated by Biomimetics techniques, i.e., based on natural processes found in biological systems. These materials are said to produce results that replicate the form, function, and other characteristics of natural teeth and oral tissues— in terms of biologic process, strength, physical characte ristics etc.[2]

Biomimetics provides a new strategy that translates our knowledge of biological structures and functions and creates new synthetic pathways to mimic biological processes.

Teeth are made mostly of a natural ceramic and a natural composite: enamel and dentin, respectively. The thin surface layer of enamel consists mainly of a calcium-based mineral called hydroxyapatite. Underneath, the bulk of the tooth is made of dentin--a mix of hydroxyapatite, collagen, water, and salts. A third type of tissue, cementum, lines the dentin under the gum line.[6] Today we have amazing materials and techniques that help reproduce the esthetics and functions that these specific layers provide. Biomimetic dentistry is a philosophy that teeth needing restoration should be rebuilt if possible to mimic clearly the function and form of the original design.[3]

GLASS IONOMER CEMENT:

A technique or material is considered biomimetic if it is able to re-establish and/or recreate the functional ability of the element that was lost due to disease, trauma, or aging-related problems. An example of dental biomimetics in this sense is the replacement of tooth structure destroyed due to carious disease, and one of the biomimetic or artificial replacements of dentin is glassionomer.[4]

Glass-ionomers, made of calcium or strontium alumino-fluoro-silicate glass powder (base) are combined with a water-soluble polymer (acid). Glass-ionomers were invented in 1969 and reported by Wilson and Kent in the early 1970s. Glass-ionomer cement components, when blended together, undergo a hardening reaction that involves neutralization of the acid groups by the powdered glass base. Significant amounts of fluoride ions are released during this reaction. Two variations of true glass-ionomer materials that were developed in the 1980s and 1990s are those modified by inclusion of metal and those with a light-polymerized liquid resin component that renders the cement photocurable as part of the overall hardening reaction. The latter are referred to as resin- modified glass-ionomer cements.[5]

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 appreciated, 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 SUBSITUTE"**. As a biomimetic dentin substitute, glass ionomers when used as a base prior to the placement of composite resin (direct sandwich technique) facilitates a reduction in the amount of shrinkage stress that occurs between the direct resin restoration and the cavity preparation walls by approximately 20% to 50%.

RESIN BASED COMPOSITES:

The goal of adhesive restorative dentistry is to return all of the lost dental tissues to full form and function. It can be achieved by means of restorative materials that recover the strength and protect the remaining tooth structure when effectively bonded to both enamel and dentin. These adhesive techniques protect the pulp and maximize preservation of tooth structure with minimal preparation and allow the long-term maintenance of their vitality and naturalappearance.[6]

Resin based composites are one such kind of restorative material. Composite (componere = to combine) is the universally used tooth-coloured direct restorative material. Composites were developed in 1962 by combining dimethacrylates (epoxy resin and methacrylic acid) with silanized quartz powder (Bowen 1963). Thanks to their properties (aesthetics, and advantages of adhesive technology) composites have taken over the place that was occupied by amalgam.
The material consists of three components: resin matrix (organic content), fillers (inorganic part) and coupling agents. The resin matrix consists mostly of Bis-GMA (bisphenol A-glycidyldim ethac rylate).Since Bis-GMA is highly viscous alone, it is mixed in different combinations with short-chaine monomers such as TEGDMA (triethylenglycol-dimethacrylate).[7]

The fillers are made of quartz, ceramic and or silica. With increasing filler content the polymerisation shrinkage, the linear expansion coefficient and water absorption are reduced.

SMART COMPOSITES:

A new approach in restorative dentistry was the introduction of an ion releasing composite material in 1998. Ariston is an "intelligent" restorative material, it is a light- cured filling material indicated for posterior restorations. Its monomer matrix consists of a mixture of dimethylmetacrylates and inorganic fillers include alkaline glass, Ba-Al fluorosilicate glass, Ytterbium trifluoride and highly dispersed silicon dioxide. It also contains a catalyst and stabilizers. Its colour is white so that, for aesthetic reasons, it is more acceptable than amalgam.[8]

According to the first research reports, Ariston releases three different types of ions (fluoride, calcium and hydroxyl). The release of these ions depends on the pH value. When the pH value in the oral cavity is low due to active plaque, Ariston releases a significantly higher amount of ions than it does with neutral pH values.

CERAMICS:

Ceramic materials are the most biologically acceptable of all materials. Ceramics are fully oxidized or chemically stable compounds. Because of their chemistry, ceramics are much less likely to produce any adverse effects, compared with metals and polymers, which are not as chemically stable.[6]

EVOLUTION OF BIOMIMETIC GLASS CERAMICS:

As early as in the seventies, Mc Lean and O'Brian described the use of leucite- based sintering ceramics (crystal phase: $KAlSi_2O_6$) for the veneering of metal frameworks.

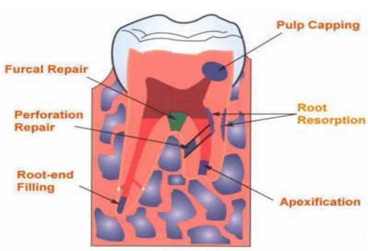
These materials already provided a glimpse of the unique aesthetic properties of ceramic restorations, compared with the non-veneered metal restorations in use at the time. It is certainly safe to say that this period of time marked the beginning of the ceramic age in restorative dentistry. Replacing metal in dental applications became a particular focus of research following these developments. Dicor was the first glass-ceramic that allowed the manufacture of inlays and crowns. The major crystalline phase present in this glass ceramic was mica. Further development of this material resulted in the introduction of DICOR MGC, a machinable glass ceramic. Applying the advantage of the viscous flow mechanism of glass-ceramics, leucite glass-ceramics can be processed in various shapes and, consequently, allow the manufacture of inlays and crowns. The translucency, colour and wear behaviour of the leucite glass- ceramic restorations are adjusted to those of the natural tooth.[9]

MINERAL TRIOXIDE AGGREGATE:

MTA is a powder consisting of fine hydrophilic particles of tricalcium silicate, tricalcium aluminate, tricalcium oxide and silicate oxide. It also contains small amounts of other mineral oxides, which modify its chemical and physical properties. Hydration of the powder results in a colloidal gel that solidifies in approximately three hours. Bismuth oxide powder has been added to make the aggregate radiopaque. Electron probe microanalysis of MTA powder showed that calcium and phosphorus are the main ions present.[10]

PROPERTIES:

1. MTA has a pH of 10.2 initially and has a pH of 12.5, 3 hours after mixing. This may impart some antimicrobialproperties.
2. The material has lowsolubility.
3. It has a radio-opacity slightly greater than that ofdentin.
4. Biocompatibility: nonmutagenic, shown to be less cytotoxic than SuperEBA and IRM. In animal studies, MTA was the only material studied that allowed cementum overgrowth. In vitro studies of human osteoblasts showed that MTA stimulated cytokine release and interleukin production. These studies suggest that MTA is not just an inert material but may actively promote hard tissueformation.



BIODENTINE:

A new experimental Ca_3SiO_5-based restorative cement has been developed, put on the market under the name of BIODENTINE™ (Septodont, Saint Maur des Fosses, France).

The main component of the powder is a tricalcium silicate, with the addition to the powderof$CaCO_3$and ZrO_2. Theliquidisasolution of$CaCl_2$withawaterreducingagent. As every cement, the setting reaction leads to a gel structure, which allows possible ionic exchanges. The reaction of the powder with the liquid led to the setting and hardening of the cement.The hydration of the tricalcium silicate ($3CaO.SiO_2$) leads to the formation of a hydrated calcium silicate gel (CSH gel) and calcium hydroxide ($Ca(OH)_2$). The cement located in inter- grain areas has a high level of calcite ($CaCO_3$) content

Compared to others Ca based cements, this material presents two advantages: Faster setting time of about 12minutes and higher mechanicalproperties.[11]

DIAROOTBIOAGGREGATE/I-ROOT BIOAGGREGATE;

BioAggregate Root Canal Repair Material is a biocompatible pure white powder composed of ceramic nano-particles. Upon mixing powder with BioA Liquid, the hydrophilic BioAggregate powder promotes cementogenesis and forms a hermetic seal inside the root canal. Its effectiveness to clinically block off bacterial infection, ease of material manipulation and superior quality make BioAggregate the most innovative and unique root canal repair material.

COMPOSITION:

Powder: Tricalcium silicate, Dicalcium silicate, Tantalum pentoxide, Calcium phosphate monobasic, Amorphous silicon oxide

Liquid: Deionized water

DiarootBioaggregate vs MTA

Compound	Compound Present		Function & Properties
	DiaRoot	MTA	
Gel-like calcium silicate hydrate	Yes	Yes	Main structural component; provides strength, hardness and sealing properties of set cement.
Gel-like calcium Aluminate hydrate	No	Yes	Fast setting. Aluminum ion in soluble form is toxic.
Calcium hydroxide	Yes (less than MTA)	Yes	Hydration product of calcium silicates. Structurally weak.
Hydroxyapatite (HAP)*	Yes	No	Reactively removes part of Ca(OH)2 from setting (hydrating) calcium silicates. In highly dispersed in-situ precipitated form strengthens the calcium silicate hydrogel.
Calcium sulfate	No	Yes	Adjusts the setting time.
Bismuth oxide	No	Yes	Provides radiopacity.
Tantalum oxide	Yes	No	Provides radiopacity.
Amorphous silicon oxide	Yes	No	Reactively removes part of Ca(OH)2 from setting (hydrating) calcium silicates.

AMORPHOUS CALCIUM PHOSPHATE (ACP):

It is the initial solid phase that precipitates from a highly supersaturated calcium phosphate solution, and can convert readily to stable crystalline phases such as octacalcium phosphate or apatitic products. Its morphological form, structural model and X-ray diffraction patterns are typical for noncrystalline substances with short-range periodic regularity. ACP has been demonstrated to have better in vivo osteoconductivity than hydroxyapatite (HAP), better biodegradability than tricalcium phosphate, good bioactivity but no cytotoxicity. These excellent biological properties make ACP widely used in dentistry, orthopaedics and medicine.[12]

BIOACTIVE GLASS:

The material Bioactive glass was invented by American Professor **Larry Hench** during the Vietnam War. Tasked by the US Government to develop a material which could be used to repair large bone injuries suffered by Servicemen during the war, Professor Hench used silica (glass) as a carried or host material which could be combined with other ingredients such as calcium in a powdered form to pack between bone fragments to fuse shattered bones.[6]

Bioactive glasses (BAGs), as opposed to most technical glasses, are characterized by the materials reactivity in water and in aqueous liquids. The bioactivity of BAGs is derived from their reactions with tissue fluids, resulting in the formation of a hydroxycarbonate apatite (HCA) layer on the glass.[13]

The Bioactive Glass formulas given by Clark et al. in 1996 were:

A58: 58% SiO_2 38% CaO, 4% P_2O_5

A68: 68% SiO_2 28% CaO, 4% P_2O_5

BONE REPLACEMENT GRAFT:

Bone replacement grafts can promote tissue/bone regeneration thr ough a variety of mechanisms. Some grafts actually contain cells that lay down bone matrix, ultimately resulting in new bone formation. These grafts are referred to as having osteogenic properties. Other grafts release growth factors and other mediators that signal the host to produce native bone. These grafts are considered osteoinductive. Furthermore, other graft materials might simply act as a scaffold on which host bone might grow. This property is referred to as osteoconductive. In general, grafts can be categorized into autogenous, allograft, alloplast, and xenograft sources.[3]

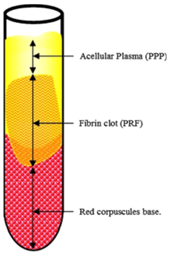
PLATELET RICH PLASMA:

The use of autologous products with high platelet concentrations such as Platelet rich plasma (PRP), Platelet concentrates (PC) and platelet gels developed to combine the fibrin sealant properties with growth factor effects of platelets- providing an ideal growth factor delivery system at the site of injury. The scientific rationale behind the use of these preparations lies in the fact that growth factors (GFs) are known to play a crucial role in hard and soft tissue repair mechanisms. These GFs exhibit chemotactic and mitogenic properties that promote and modulate cellular functions involved in tissue healing, regeneration and cell proliferation.

PLATELET RICH FIBRIN:

Platelet rich fibrin (PRF) was first developed in France by Choukroun et al in 2001. This second generation platelet concentrate eliminates the risk associated with the use of bovine thrombin

The PRF protocol is very simple: A blood sample is taken without anticoagulant in 10-ml tube which is immediately centrifuged in a table centrifuge at 3000 rpm (approximately 400g) for10minutes.



PROPERTIES OF PRF:

1. The biochemical analysis of the PRF composition indicates that this biomaterial consists of an intimate assembly of cytokines, glycanic chains, structural glycoproteins enmeshed within a slowly polymerized fibrin network. These biochemical components have well known synergetic effects on healingprocesses.
2. PRF is not only a platelet concentrate but also an immune node able to stimulate defense mechanisms. It is likely that the significant inflammatory regulation noted on surgical sites treated with PRF is the outcome of retro control effects from cytokines trapped in the fibrin network and released during the remodeling of this initialmatrix
3. Role of fibrin matrix ofPRF: Fibrin is the natural guide of angiogenesis, Fibrin constitutes a natural support toimmunity, Fibrin and wound coverage: Fibrin matrix guides the coverage of injured tissues, affecting the metabolism of epithelial cells and fibroblasts.[14]

CONCLUSION:

Biomimetic dentistry remains a very active area of research. By its nature, it is interdisciplinary, and it has tremendous potential for transforming everyday dental practice. “The future of biomimetics in dentistry is indeed very promising, but we are not there yet”**Tay** emphasizes. “Only tight collaborations between engineers, chemists, tissue engineers, material scientists, and biologists will make these 'next-generation' materials become a reality.”

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