

Biosmart Materials: A Review

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Abstract: *The quest for an ideal restorative materials in dentistry leads to the discovery of newer generation of material which aims at improving the efficiency and reliability. These materials can alter its properties in a controlled manner at various stimuli such as stress, temperature, moisture, pH and electric or magnetic field. These materials returns to its original state on removal of the stimulus, thus referred as smart material. These properties of smart materials have a beneficial application in various fields of dentistry. This recent inovation in the material science marked an era of biosmart dentistry.*

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I. Introduction

With the advent of new technology numerous changes have been made in the field of restorative dentistry.¹ Dental profession continues to develop ideal restorative dental materials that may replace enamel & dentin.² Traditionally, materials are designed for long-term use with little or no interaction with body tissues and fluid. No single material in dentistry are ideal in nature and fulfill all the requirements of an ideal material.³ Material science has evolved from the use of inert materials to materials with specific functions and finally to smart materials. Biomaterials are developed with properties to repair and replace the natural hard and soft tissues in the human body.⁴ It can be classified as bioinert (passive), bioactive & bioresponsive/ smart materials based on their interaction with the environment.⁵ A newer generation of materials were developed which may be altered in a controlled fashion when stimulus are applied. These materials are known as smart materials.⁶ McCabe Zrinyi defined smart materials as "Materials that are able to be altered by stimuli and transform back into the original state after removing the stimuli". Stimulus can be in form of stress, temperature, moisture, pH, electric or magnetic fields.⁷ Its application has demonstrated a promising results in the field of dentistry. These materials are also known as "Biomimetic" as their properties mimic the natural tooth structure. They are highly responsive and have greater capacity to sense and respond to any environmental changes.⁶

Smart Glass Ionomer Cement

Wide range of temperature fluctuation occurs in the oral cavity due to intake of hot or cold foods and fluids. Thus ,the restorative materials placed in the oral cavity may show thermal expansion or contraction.⁸ Presence of difference in the thermal expansion and contraction between a restoration and the tooth structure may cause stresses at the interface, and finally lead to microleakage.⁹ Glass Ionomer Cement (GIC) with the potential of thermoresponsive smart behavior were developed. This behavioral properties was first observed by Davidson.⁷ They have CTE close to that of dental hard tissues.⁷ Minimal or no dimensional changes occurs on heating and cooling between 20° and 50°C in wet conditions, but the materials demonstrated a marked contraction when heated at 50°C in dry conditions due to movement of water in or out of the gel structure.⁸ These properties mimic the behavior of human dentin and makes GIC a smart dental material.⁷ Another smart behavior of GIC is the fluoride release and recharge capacity. Resin-modified GIC, compomer or giomer exhibit properties of smart cement. e.g., GC Fuji IX GP EXTRA (Zahnfabrik Bad Säckingen, Germany).⁹

Smart Composites

A unique biologically active restorative material containing amorphous calcium phosphate as filler encapsulated in a polymer binder was developed by Skrtic. This material can stimulate the repair of tooth structure since it releases significant amounts of calcium and phosphate ions.^{10,11}

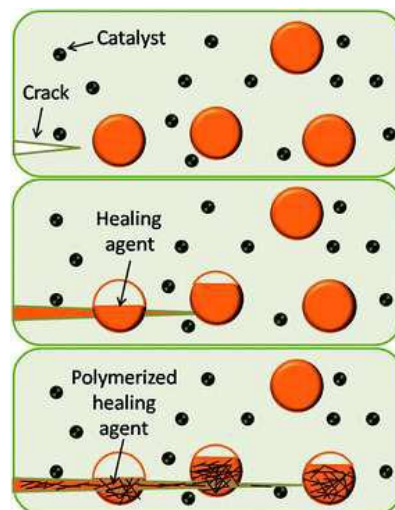
At low pH values, i.e., at or below 5.8, during a carious attack, ACP converts to hydroxyapatite (HAP) and precipitates, thus replacing the lost HAP. Thus, these ions merge within seconds to form a gel. This gel becomes amorphous crystals, resulting in calcium and phosphate ions in less than 2 minutes.³

Ariston pHc Alkaline Glass Restorative Material

They are light-activated alkaline, nano-filled glass restorative material. They are indicated for the restoration of class I and II lesions in both deciduous and permanent teeth to a depth of 4mm.¹¹ It releases calcium, fluoride and hydroxyl ions when intraoral pH values drop below 5.5. Thus, it counteracts the demineralization and promotes remineralization.^{7,11}

Self-Healing Composites

White *et al.* develop a self-healing polymer. These are epoxy system which contain resin filled microcapsules Dicyclopentadiene (DCPD). It is a highly stable monomer with excellent shelf life, encapsulated in thin shell made of urea formaldehyde.⁷ Occurrence of crack in such epoxy composites ruptures the microcapsules and release resin near the crack. This resin fills the crack by reacting with Grubbs catalyst present in the epoxy composite. Thus, polymerization reaction takes place and repairs the crack.³ It shows better repair than those repaired with macroscopic repair methods.⁶ Main problems may occur from the potential toxicity of the resins in the microcapsules and from the catalyst.³



Mechanism of Self-Healing Composites

Smart Prep-burs (Smart Preparation burs)

Smart prep-burs are developed in an attempt to selective caries-removal. These burs are made of polyamide/imide (PAI) polymer. It possess mechanical properties slightly lower than sound dentin with hardness of 50 KHN but higher than the hardness of a carious dentin (0 to 30 KHN).⁹ Thus it removes only the infected dentin and the affected dentin which has the ability to remineralise is left intact. The time required for caries removal may be slightly longer. Ex: SS White Smart Bur II.^{7,9}



Smart Prep-Burs

Shape Memory Alloys:-

They are the metals with the ability to recover its original shape/length when subjected to the thermo-mechanical load. Such alloys have properties like super elasticity, shape memory, good resistance to fatigue and wear and relatively good biocompatibility. Ex: Nickel –Titanium.⁹

In endodontics. In 1988, Walia et al. introduced Ni- Ti to Endodontics. 55wt% Ni and 45 wt% Ti are commonly used.^{3,9} NiTi rotary endodontic instruments can access to the curved root canals due to its superelastic properties during the chemomechanical preparation. It reduce the incidence of canal transportation and aberrations.³ It shows stress-induced thermoelastic transformation from austenitic crystalline phase to a martensitic structure on stressing at a constant temperature. In martensitic phase, only a light force is sufficient for bending. On relieving the stress, it regain its original shape.⁷

Smartseal Obturation System

Different canal filling materials and techniques are currently available to achieve three dimensional filling of the instrumented canal, accessory canals and irregularly shaped canals with minimum voids.¹ The C Point system (EndoTechnologies, LLC, Shrewsbury, MA, USA), a smart seal obturation system is a point-and-paste root canal filling technique. It consists of hydrophilic endodontic points and an accompanying sealer.¹² They are available in different tip sizes and tapers. This sealer are designed to expand laterally without expanding axially, by absorbing residual water from the instrumented canal space and naturally occurring intra radicular moisture.³

It consists of a mix of two proprietary nylon polymers: Trogamid T and Trogamid CX.⁹ The lateral expansion of C Point occurs non-uniformly, depending on the extent to which the hydrophilic polymer is pre-stressed (i.e., contact with a canal wall will reduce the rate or extent of polymer expansion). Thus it enhances the sealing ability of the root canal filling, thereby reducing the possibility of reinfection.⁷

Amorphous Calcium Phosphate (ACP)

Amorphous calcium phosphate (ACP) was first described by Aaron S. Posner in 1963. At neutral or high pH, it remains in its original form. But at or below 5.8 (critical pH), where demineralisation of tooth surface occurs, it gets converted to crystalline Hydroxyapatite (HAP) and replaces the lost crystals.¹¹ It forms a gel-like structure within seconds and releases calcium and phosphate ions, thus neutralizes and buffers the pH. It is used as bone repair materials, smart coated implants, dental varnish (Enamel Pro varnish), chewing gums, dentifrices, mouth washes, dental cements, orthodontic adhesive (Aegis Ortho), pit and fissure sealants, composites and dental adhesives.⁹

Casein Phosphopeptide (CPP)

They are milk derivatives in combination with ACP (CPP-ACP complex), used for the remineralisation of incipient white spot lesions. Available in some dentifrices under the name ReCaldent. It is marketed as GC tooth mousse plus- (The University of Melbourne, Victoria, Australia) and a new GIC containing 3%(w/w)CPP-ACP (Fuji VII EP).⁷

Smart Antimicrobial Peptide

Smart Antimicrobial Peptide are pheromone-guided smart peptide, which are targeted against *Streptococcus mutans*, causative microorganism of dental caries.^{9,12} These Antimicrobial peptides vary in their peptide sequence and posttranslational modifications. It is an amphipathic mixtures of α -helical and β -sheet structures with a cationic charge. It binds to the negatively charged functional groups of microbial membranes (e.g. lipopolysaccharides) and create a disruption into the membranes.¹³ Specifically targeted antimicrobial peptides (STAMP's) could be delivered as current oral care products like mouthwash, toothpaste or dental floss which could help with suppression of cariogenic bacteria.^{7,9}

Smart Fibres For Laser Dentistry

Hollow core photonic crystal fibers (PCFs) which deliver radiation of high-fluency and capable of ablating tooth enamel have been developed. Sequences of picosecond pulses of Nd: YAG laser radiation is transmitted through a hollow-core photonic crystal fiber with a core diameter of approximately 14 micrometers and is focused on a tooth surface to ablate dental tissue.⁸ It supports the single fundamental mode regime for 1.06-micrometer laser radiation. It can also be used to transmit emission from plasma on the tooth surface in the backward direction for detection and optical diagnostics.⁶

Calcium Hydroxide

Calcium Hydroxide was introduced by Hermann in dentistry in 1920. It is used as a mineralizing agent and antimicrobial agent.⁴ It causes release of extracellular matrix molecules and raises expression of biomolecules like BMP, FGF etc., has antimicrobial and anti-inflammatory action.¹

To improve its biological performance, Controlled-release Calcium hydroxide loaded microcapsules based on polylactic acid (PLA) and ethyl cellulose (EC) have been developed. These microcapsules prolonged the release of ions.¹ It is controlled by regulating the ratio of PLA/EC. When more EC was used as the shell material, the release was much slower.¹⁴ Drugs which are encapsulated with microcapsules, releases either by diffusion through the polymer barrier, by erosion of the polymer material or by a combination of both diffusion and erosion mechanisms.

Mineral Trioxide Aggregate (MTA)

MTA was developed by Mahmood Torabinejad at Loma Linda University. It consists of 50-75 % (wt.) calcium oxide and 15-25 % silicon dioxide. Due to its high pH (12.5), it causes regeneration of the periodontal ligament (PDL), dentinal bridge formation, biomineralisation and stimulation of cell differentiation and has antimicrobial activity. Difficulty in manipulation and longer setting time are its limitations.^{1,4}

- i). MTA angelus (Aangelus, Londrina, PR, Brazil): It composed of 80% Portland cement and 20% bismuth oxide and has setting time of 14 minutes .⁴
- ii). MTA fillapex (angelus solutions odontological, Londrina, PR, Brazil):- A calcium silicate-based bio ceramic sealer was created with an attempt to incorporate physical and chemical properties of a resin-based root canal sealer and the biological properties of MTA .¹
- iii). MTA plus (Avalon biomed Inc., Bradenton, FL, USA) :- A fine powder root canal sealer with composition similar to ProRoot MTA .¹
- iv). Pozzolan cement (Endocem) (Maruchi, Wonju, Korea) :- It is a fast setting MTA derived material which does not contain any chemical accelerator.¹

Biodentin

It was introduced in 2011 (Septodont, Saint-Maur-des-Fossés, France) and is composed of calcium carbonate, tricalcium silicate and zirconium oxide and a water based liquid containing calcium chloride as the setting accelerator.¹ It is hydrophilic powder composed of modified composition of MTA by addition of setting accelerators and softeners and a new predosed capsule formulation for use in a mixing device.¹⁶ When it comes in contact with dentine it results into formation of the tag-like structures next to an interfacial layer and is called “Mineral Infiltration Zone,” which may contribute to adhesive properties. It has improved physical properties, reduced setting time (12 min) and induces odontoblast-like cell differentiation and mineralization.¹ Because of its high alkalinity it has inhibitory effects on microorganism. It preserves pulp vitality and promotes its healing process. Due to its dentine like mechanical properties it can be used as an dentine substitute for posterior restoration.¹⁶

Bioaggregate (BA) (Innovative Bioceramix Inc., Vancouver, BC, Canada)

Introduced in 2006, delivered as powder form of nanoparticles containing tricalcium silicate, dicalcium silicate, calcium phosphate monobasic, amorphous silicon dioxide, tantalum pentoxide (radio pacifier) and it's liquid contains deionized water.¹

On reaction with water it produces a biocompatible and aluminum-free ceramic biomaterials that stimulates the proliferation of human PDL fibroblasts and aids in periodontal regeneration and promotes cementogenesis ,thus forms a hermetic seal inside the root canal.^{1,17} It has excellent handling characteristics with working time of at least 5 minutes. It is indicated for repair of root perforation, repair of root resorption, root end filling, apexification, and pulp capping.¹⁷

Endosequence Root Repair Material (ERRM) putty, ERRM paste RRM putty fast set (FS) and iroot FS

Endosequence root repair material (ERRM) are delivered as a premixed mouldable putty (iRoot BP Plus) or as a preloaded paste in a syringe with delivery tips for intracanal placement. It contains calcium phosphate monobasic, calcium silicates, zirconium oxide and tantalum oxide. Inside the dentinal tubules, ERRM forms tag-like structures.¹

RRMs are premixed, single component materials which is ready to use from the syringe or a tiny screw-cap box and does not requires mixing, thus differentiating it from MTA, bioaggregate and biodentin. It has the initial setting time of 20 min. iRoot FS (Brasseler USA, Savannah, GA) are iRoot series material with improved handling properties and shorter setting time.¹

Smart Sutures:

Smart sutures are made up of thermoplastic polymers which have both shape memory and biodegradable properties. Plastic or silk threads are covered with temperature sensors and micro-heaters that can detect infections.⁷ Sutures are loosely tied so that when temperature is increased above the thermal transition temperature near the body temperature, the sutures shrink & gets tightened. Ex: Novel MIT Polymer (Aachen, Germany)⁹

II. Conclusion

Recent innovation in the material science have revolutionized and marked the beginning of an era of 'biosmart dentistry'. These biosmart materials are designed to stimulate physical and mechanical properties of the lost tissues. They have multiple application in many areas of dentistry and posses properties which may change according to the environment, hence the term smart material is applicable.

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