



PEDIATRIC DENTAL SMART MATERIALS: A REVIEW

Dental Science

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ABSTRACT

With the focus shifting to minimal intervention dentistry, there is a constant need to introduce newer dental materials which bio-mimics the properties of the tooth. There is not a single material in dentistry that fulfils all the requirements of ideal material. Therefore, the quest for ideal restorative material continues and the concept is now shifted towards smart materials. Some of the application of smart materials in pediatric dentistry includes glass ionomer cement, smart composites with amorphous calcium phosphate stimulating repair of defective teeth, smart prep burs, shape memory alloys, zirconia crowns, and smart fibres with hollow-core photonic-crystal for the delivery of laser radiation. These offer natural esthetics coupled with excellent durability and biocompatibility. These materials allow new dental therapies with significantly enhanced clinical outcomes of treatments. The future will involve harvesting the current knowledge into designing of materials to incorporate smartness in them.

KEYWORDS

Calcium phosphates, dental materials, fluorides, shape memory alloys, smart materials, zirconium

INTRODUCTION

In the early half of the 20th century, dental materials were inert and passive so that they don't interact with the oral environment. In 1960s, bioactive materials were manufactured. With the advent of minimal intervention dentistry, the search for new materials that mimicked the properties of teeth continued. Takagi in the year 1990 explained materials that are intelligent as they respond to environmental changes at the most optimum conditions and reveal their functions according to the environment.^{1,2} Smart materials can be defined as "Materials that are able to be altered by stimuli and transform back into the original state after removing the stimuli". The stimuli can be derived from temperature, pH, moisture, stress, electricity, chemical or biomedical agents, and magnetic fields.³ When they are embedded in host materials and are activated, they can compensate for faults or cracks produced, a phenomenon called the called self-repairing effect and helps to keep the material in safe condition.⁴

DESIGNING

Various factors that determine smart behaviour includes:³

1. The role of water:

The smart behaviour of certain materials may be related to the ability of a gel structure to absorb or release solvent rapidly in response to a stimulus such as temperature. In the oral environment, the key solvent is water as well as it is strongly or loosely bound to gels and salts present in structures. This can be absorbed or released at different rates. Also, fluoride ions may be dissolved in water which can undergo reversible interactions with the gel, salt, or oral structures.

2. Smart thermal behaviour:

One of the most common problems with dental materials is their tendency to expand and contract to a greater extent than the natural tooth tissue when subjected to hot or cold stimuli. Hence it is necessary to match the coefficient of thermal expansion with tooth structure.

3. The role of porosity:

It creates a reservoir for water.

4. Expansion and radial pressure:

Some materials combine a special interactive characteristic with acceptable durability. Therefore they have to combine salt or gel with resin to impart stability. But compatibility becomes a problem. Such a problem can be solved by incorporating species having hydrophilic and hydrophobic groups.

5. Ion release and recharging:

Most materials with fluoride releasing properties tend to rapidly lose fluoride. However, some smart materials containing GIC salt phases offer long term solutions to this problem. There is evidence that the fluoride released from salt phases can be replaced when the material is

bathed in a high concentration of fluoride as may occur in toothpaste or mouth rinse.^{5,8}

6. Biofilms and smart behaviour:

Biofilms formed on the surface of materials in the mouth has shown to enhance the behaviour of smart materials containing fluoride-releasing salt phases.⁹

PROPERTIES

Dental materials are identified as smart materials for how they react to the oral environment.

Thus they should have one of the following properties:

A. Colour-changing materials:

- 1. Photochromic materials:** These change colour reversibly with changes in light intensity i.e. these materials change color in response to changes in light conditions.¹⁰
- 2. Thermochromic materials:** These change colour reversibly with changes in temperature.¹⁰
- 3. Electrochromic materials:** These change their colour or opacity on the application of a voltage.¹

B. Light-emitting materials:

- 1. Electroluminescent materials:** These produce a brilliant light of different colours when stimulated electronically.
- 2. Fluorescent materials:** These produce visible or invisible light on the application of light having shorter wavelengths.
- 3. Phosphorescent materials:** These produce visible or invisible light on the application of light having a shorter wavelength, detectable only after the source of the excitement has been removed.

C. Moving materials:

- 1. Conducting polymers:** They are conjugated polymers or organic compounds in which electron can move from one end to the other end as they have extended p-orbital system.
- 2. Dielectric elastomers:** They exhibit mechanical strain when subjected to an electric field.
- 3. Piezoelectric materials:** These produce an electric field when exposed to a change in dimension caused by an imposed mechanical force.¹¹
- 4. Polymer gels or pH-sensitive:** They can reversibly swell or shrink due to changes in their environment.¹⁰
- 5. Shape memory alloys (SMA):** They can adopt different shapes at different temperatures because of its marked and controlled changes in structure.¹²

D. Thickness changing materials:

- 1. Magnetostrictive materials:** Material that changes its length when

subjected to an electro-magnetic field.^{4,13}

- 2. Electrostrictive materials:** Similar to piezoelectric, but they strain proportionally to the square of the applied voltage of the applied electric field and produce displacement in the same direction.¹³

E. Temperature changing materials:

Thermoelectric materials: Special types of semiconductors that, when coupled, function as a "heat pump".

F. Rheological materials:

- 1. Electrorheological materials:** Fluid materials that experience dramatic changes in viscosity on the application of electricity.⁴
- 2. Magnetorheological systems:** Fluid materials that become solid when placed in a magnetic field.¹⁰

G. Biofilm formation: Presence of biofilm on the surface of material alters the interaction of the surface with the environment.¹⁴

APPLICATIONS IN PEDIATRIC DENTISTRY

The concept of smart materials has changed from a conventional passive system to an active, multifunctional, structural and electronic system.⁴

Dental Smart Materials can be classified as:

Passive Smart Restorative Materials

These materials sense the external change and react to it without external control. They also have self-repairing characteristics.¹⁵ Passive smart materials are those which esthetically restore the teeth and tend to release fluoride ions.

Active Smart Restorative Materials

These materials sense change in the environment and respond to them¹⁵. They esthetically restore the teeth and tend to release fluoride ions as the pH of oral fluids decreases below 5.5 but will terminate the release of diagnostic or preventive agents like fluoride when the pH rises above 5.5.

Various smart materials used in pediatric dentistry are:

GLASS IONOMER CEMENT

Wilson and Kent introduced glass ionomer cement in the year 1972.¹⁶ It has the characteristics of both, the translucency and fluoride release of silicate cement and the ability to chemically bond to tooth structure of the polycarboxylate cement. The smart behaviour of glass ionomer cement was first introduced in the field of dentistry by Davidson.¹⁷ It has the ability of gel structure to absorb or release solvent rapidly in response to a stimulus. It proves to be a better dentin replacement and has fluoride release capabilities. The application includes usage in high caries risk patients due to the ability to release fluorides.

SMART COMPOSITES

Smart composites may be useful with various applications including the release on-command remineralising elements or antimicrobial products and fluorides to fight microorganisms or secondary caries.^{18,19} They have the advantages of excellent sustained release of calcium and phosphate ions into the stimulated saliva and excellent biocompatibility. Thus they have high prophylactic value in preventing caries by reducing demineralization and promoting remineralisation of tooth.²⁰

AMORPHOUS CALCIUM PHOSPHATE (ACP)

Aaron S. Posner has described ACP for the first time in 1963.²¹ It is one of the most precursors, required for the formation of hydroxyapatite. ACP, when incorporated in composite material, has an extended time release and acts as a source for calcium and phosphate, useful for preventing caries.^{22,23} ACP is referred to as a smart material because it only releases calcium and phosphate ions when the surrounding pH drops to a level where it can start to dissolve the tooth.

CASEIN PHOSPHOPEPTIDE (CPP)

It is a milk derivative which is used in combination with ACP is used for the remineralisation of incipient white spot lesions. It has been shown to stabilize calcium and phosphate as nanoclusters together with fluoride ions, preserving them in an amorphous or soluble form.

These can be combined with restorative materials to provide benefits of remineralisation as well as restoration in pediatric dentistry.

SELF-HEALING COMPOSITES

It is a resin-based material that has an epoxy system containing a resin-filled microcapsule of Dicyclopentadiene (DCPD), a highly stable monomer with excellent shelf life, encapsulated in a thin shell made of urea-formaldehyde. If a crack occurs in epoxy composite material, these microcapsules rupture and release resin resulting in repair of crack.

SHAPE MEMORY ALLOYS

The term smart material in the field of dentistry was probably first used with Nickel-Titanium (NiTi) alloys commonly known as Shape memory alloys. Nickel-titanium (NiTi) alloys have two unique features such as super-elasticity and shape memory and hence categorized as smart materials. This smart property is the result of the substance's ability to undergo a phase change from Martensite which occurs at low temperatures and high stresses to austenite which occurs at high temperatures and low stresses. Thus the lattice organization can be altered either by stress or temperature.¹⁴ NiTi alloys are commonly used to make orthodontic wires as well as NiTi rotary files which can be used in tortuous pediatric canals.

ZIRCONIA

Zirconia is a highly stable polycrystalline ceramic oxide. It is unique among dental ceramics in that it exhibits a physical property called **transformation toughening**. At different temperatures zirconia can have three different patterns: monoclinic, cubic, and tetragonal. Monoclinic crystal structure occurs between room temperature and 950°C. Above 950°C, it gets converted to the tetragonal crystal structure having 1% shrinkage during heating and equivalent expansion during cooling. It changes into a cubic structure at a higher temperature. Normally, during cooling, the tetragonal material transforms into monoclinic form again, but the process is accompanied by expansion. So the structure is stabilized using Yttrium oxide which forms Yttrium stabilized zirconia or tetragonal zirconia polycrystal. When there is a crack, the tetragonal structure precipitates into its monoclinic form and thus stabilizes the crack.²⁴ The common application involves the use of zirconia crowns in pediatric dentistry which provides aesthetics as well as greater resistance to the formation and progression of crack through it when compared to other forms of ceramics.

SMART PREPBURS

Smart Prep Burs are polymer burs that can cut only infected dentin, leaving the affected dentin to remineralise.²⁵ They have shovel-like straight cutting edges.²⁵ The cutting blades deflect and deform upon encountering normal or partially decalcified dentin, thereby enabling the reduction of cutting efficiency. As the hardness is less than intact dentin, it removes only the carious part of the dentin and is worn off when it comes in contact with healthy dentin. It is self-limiting and will not cut sound dentin unless applied with great force; it wears away rather than cut healthy dentin, thus making it ideal for minimal intervention dentistry. The time required for caries removal may be slightly longer, but when considered against the benefits they are awesome. They are available in three ISO sizes 010, 014, and 018, and are meant for single-use only (self-limiting action). They should be used with light pressure and excavation should be done from the centre to the periphery to avoid contact with the harder dentin.

SMART FIBRE FOR LASER DENTISTRY

Hollow-core photonic-crystal fibres (PCFs) are used for the delivery of high-fluence laser radiation capable of ablating tooth enamel. These fibres are known as Smart Fibres.²⁶ It can be used for detection and optical diagnosis through transmit plasma emission and also provide laser pulses with total energy up to 2mJ which improves the quality of lasers. Sequences of pulses of Nd: YAG-laser radiation is passed through a hollow-core photonic-crystal fibre having a core diameter of approximately 14 micrometres which is then focused on a tooth surface to ablate dental tissue. The laser breakdown was visualized as the optical characterization of the ablated enamel surface. One of the disadvantages is that this fibre should be used carefully because in some cases the fibre walls fail and the laser light may escape and harm the healthy tissue.²⁷

SMART IMPRESSION MATERIAL

Smart impression materials exhibit various advantageous properties like increased hydrophilicity to get void-free impressions and shape memory during elastic recovery. Its snap set behaviour results in the impression which has no distortion and low viscosity ensuring a better flow of the material.²⁸ One of the examples includes smart wetting impression material which is monophase, vinyl polysiloxane material.

SMART ANTIMICROBIAL PEPTIDE

These are pheromone-guided —smart antimicrobial peptide, which is targeted against *Streptococcus mutans* causative microorganism of dental caries.²⁹ The concept of tissue regeneration wherein the tissues can be regrown in the oral cavity is an emerging new technology.³⁰ The BRAX-I gene has been isolated along these lines is thought to be responsible for the control of micro-organisms on enamel growth.³¹ Antimicrobial peptides vary in their peptide sequence and post-translational modifications, but the majority of AMPs are amphipathic mixtures of α -helical and β -sheet structures with a cationic charge. The actions of AMPs involve binding to the negatively charged functional groups of microbial membranes (example lipopolysaccharides) and disrupts by inserting into the membranes, although it has been suggested that several AMPs translocate intracellularly and are lethal via a different mechanism.¹⁵ They can help in the suppression of cariogenic bacteria when delivered in various products like mouthwash, toothpaste, or dental floss.

CONCLUSION

Smart materials respond to stimuli and activate their functions according to these changes. These materials have numerous applications and are doing wonders in the field of dentistry. Advances in form of these smart materials are paving the future of dentistry. It should also be noted that these materials are in their developing phase. Information on critical properties such as post-polymerization shrinkage which can cause microleakage, improvement in fracture toughness for durability, and the ease of dentinal bond to restorative materials requires further studies.

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