

Biosmart Materials in Dentistry: An Update

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ABSTRACT

In dentistry, there is no single material, i.e., ideal in nature and fulfills all the requirements of an ideal material. So, the quest for an “ideal restorative material” continues, leading to introduction of newer generation of materials. These are termed as “smart” as these materials support the remaining tooth structure to the extent that more conservative cavity preparation can be carried out. These materials can be altered in a controlled fashion by stimulus, such as stress, temperature, moisture, pH, and electric or magnetic field. Some of these are “biomimetic” in nature, as their properties mimic natural tooth substance, such as enamel or dentin. The current dental materials were improvised in order to make them smarter. The use of smart materials has revolutionized dentistry, which includes the use of restorative materials, such as smart composites, smart ceramics, compomers, resin-modified glass ionomer, amorphous calcium phosphate-releasing pit and fissure sealants, etc., and other materials, such as orthodontic shape memory alloys, smart impression material, smart suture, smart burs, etc. This article aims to highlight the use of “smart materials” to achieve maximum advantage by conventional restorative techniques in dentistry.

Keywords: Biomimetic, Dentistry, Smart materials.

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INTRODUCTION

Since ages, materials used in dentistry were designed to be passive and inert, i.e., to exhibit little or no interaction with body tissues and fluids. Materials, such as amalgams, composites, and cements were often judged based on their ability to survive without interacting with the oral environment.

The present scenario has changed. Many of the advanced materials used at the forefront of materials science are functional: They are required to perform things and undergo purposeful change and play an active

part in the way the structure or device works. Today, the most promising technologies for lifetime efficiency and improved reliability include the use of “bioresponsive or smart materials.”

A material is said to be “smart” if it possesses great capacity to sense and respond to any environmental change. Hence, these materials are also known as “responsive materials.” Smart materials can be defined as designed materials that have one or more properties that can be significantly changed in a controlled fashion by external stimuli, such as stress, temperature, moisture, pH, and electric or magnetic fields.¹

NATURE OF SMART MATERIALS

A key feature of smart behavior includes its ability to return to the original state even after the stimulus has been removed. Table 1 shows the classification of smart material in dentistry. Existing smart materials include:

- Piezoelectric materials, which produce a voltage when stress is applied or vice versa.²

Table 1: Classification of smart materials in dentistry

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|---|
| I. Passive smart restorative materials: Respond to external change without external control. |
| • Glass ionomer cement (GIC) |
| • Resin-modified GIC |
| • Compomer |
| • Dental composites |
| II. Active smart restorative materials: Utilize a feedback loop to enable them to function like a cognitive response through an actuator circuit. |
| 1 Restorative dentistry |
| • Smart GIC |
| • Smart composites |
| – Ariston pHc |
| – Aluminium composite panel (ACP) composites |
| • Smart prep burs |
| 2 Prosthetic dentistry |
| • Smart ceramics |
| • Smart impression materials |
| 3 Orthodontics |
| • Shape memory alloys (SMAs) |
| 4 Pediatric and preventive dentistry |
| • Fluoride-releasing pit and fissure sealants |
| • ACP-releasing pits and fissure sealants |
| 5 Endodontics |
| • Nickel-titanium (NiTi) rotary instruments |
| 6 Oral surgery |
| • Smart suture |
| 7 Smart fibers for laser dentistry |
| 8 Smart antimicrobial peptide |

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- Thermoresponsive materials, such as shape memory alloys (SMAs)³ or shape memory polymers, adopt different shapes at different temperatures due to remarkable and controlled changes in structure.
- Thermochromic materials change color in response to changes in temperature.
- Photochromic – these materials change color in response to changes in light conditions.
- Magnetorheological – these are fluid materials that become solid when placed in a magnetic field.
- pH sensitive – materials that swell/collapse when the pH of the surrounding media changes.⁴
- Biofilm formation⁵ – presence of biofilm on the surface of material alters the interaction of the surface with the environment.

RESTORATIVE DENTISTRY

Smart Glass Ionomer Cement

Wide temperature fluctuations may occur in the oral cavity due to the intake of hot or cold food and fluids. Hence, the restorative materials placed in this environment may show thermal expansion or contraction in response to thermal stimuli. The coefficient of thermal expansion (CTE) is normally used to describe the dimensional changes of a substance in response to thermal change.⁶

When dealing with thermally induced volumetric changes, comparison of CTE values of the restorative material and the tooth substance is more important than the CTE value of the material itself. The mismatch of thermal expansion and contraction between a restoration and the tooth structure may cause stresses to develop at the interface, and this may finally lead to microleakage.⁶ An interesting observation was made in few studies to determine the values of CTE of various restorative materials, and it was shown that Glass Ionomer Cement (GIC) has potential thermoresponsive smart behavior.

The GICs have a CTE close to that of dental hard tissues. Through observation, there were minimal or no dimensional changes in GICs in terms of heating (expansions) and cooling (contractions) between 20° and 50°C in wet conditions, but the materials demonstrated a marked contraction when heated at 50°C in dry conditions. This action was due to the movement of water in or out of the gel structure, which mimics the behavior of human dentin and indirectly shows the behavior of smart features.⁷ The other aspect of the smart behavior of these materials is the fluoride release and recharge capacity.⁸ Resin-modified GIC, compomer, or giomer also exhibits these smart characteristics, e.g., GC Fuji IX GP EXTRA (Zahnfabrik Bad Säckingen, Germany) (Fig. 1).

Smart Composites

Skrtic developed unique biologically active restorative materials containing aluminium composite panel (ACP) as filler encapsulated in a polymer binder, which may stimulate the repair of tooth structure because it releases significant amounts of calcium and phosphate ions in a sustained manner.

Mechanism of action: ACP at neutral or high pH remains as ACP. When low pH values, i.e., at or below 5.8, occur during a carious attack, ACP converts to hydroxyapatite (HAP) and precipitates, thus replacing the HAP lost to the acid. So, when the pH level in the mouth drops below 5.8, these ions merge within seconds to form a gel. In less than 2 minutes, the gel becomes amorphous crystals, resulting in calcium and phosphate ions.

Ariston pHc Alkaline Glass Restorative Material

It is a light-activated alkaline, nano-filled glass restorative material (Fig. 2) recommended for the restoration of class I and II lesions in deciduous and permanent teeth. It is



Fig. 1: GC Fuji IX GP EXTRA – fastest setting glass ionomer, which provides improved stability against water, an important feature in challenging oral environments



Fig. 2: Ariston pH control – introduced by Ivoclar – Vivadent (Liechtenstein) Company



Fig. 3: Smart burs



Fig. 4: The ACP-releasing smart composite used as pit and fissure sealant

an “intelligent” restorative material because it releases calcium, fluoride, and hydroxyl ions when intraoral pH values drop below the critical pH of 5.5; it counteracts the demineralization and promotes remineralization.⁹ The material can be adequately cured in bulk thicknesses of up to 4 mm.

Smart Prep Burs

These are polymer burs made of polyamide resin. Their hardness is less than healthy dentin and greater than carious dentin. Thus, these burs are capable of removing soft carious dentin, but when it comes in contact with the hard dentin, they burn out, avoiding unnecessary cutting of tooth structure.¹⁰

Commercially, two burs are available: Smart bur (Fig. 3) and polybur-1. Smart burs are available in three different sizes of 004, 006, and 008, and recommended speed to use is 500 to 800 rpm. Polybur-1 is also available in 014, 018, and 023 sizes and used at a speed higher than smart bur, at around 2000 to 8000 rpm. Both burs are round shaped with spade-like cutting edges. One study showed that significantly less sound dentin was removed with the smart prep bur when compared with stainless steel round bur.¹¹

PEDIATRIC AND PREVENTIVE DENTISTRY

ACP-releasing Pit and Fissure Sealants

The ACP was first described by Aaron S. Posner in 1963. It is a vital antecedent in biological formation of HAP. It has two properties: Preventive and restorative, justifying its use in dental cements, adhesives, pit and fissure sealant, and composite (Fig. 4).¹²

Mechanism of Action

At neutral or high pH, ACP remains in its original form in the oral environment. But, when the surrounding

pH drops to a level where it can demineralize the tooth surface, i.e., at or below 5.8 (critical pH), ACP converts into crystalline HAP, thus replacing the HAP crystal lost to the acid. These released ions will merge within seconds and form a gel. In less than 2 minutes, this gel becomes amorphous crystals, resulting in calcium and phosphate ions.¹³ Crystalline HAP is the final stable product in the precipitation of calcium and phosphate ions from neutral or basic and it neutralizes the acid and buffers the pH.

It is considered as a “smart material” because:

- It acts as a reinforcement of the natural defense mechanism of the tooth only when needed.
- It has long life and there is no wash-out.
- Patient compliance is not required.

Examples include Aegis Pit and Fissure Sealant produced by Bosworth.

Fluoride-releasing Pit and Fissure Sealants

Considering the fact that occlusal surfaces constitute only 12% of the tooth surface, they are eight times as vulnerable as smooth surfaces to caries.¹⁴ So, prevention of occlusal caries assumes paramount importance in the preservation of tooth structure.

There are two common methods of fluoride incorporation into fissure sealant materials: (a) The anion exchange system (organic fluoride compound chemically bound to the resin) and (b) addition of fluoride salt to the unpolymerized resin.

The mechanism of fluoride release from the fluoride fissure sealant remains speculative. Fluoride release might occur from the insoluble sealant material as a result of porosity. It might also occur because the fluoride ion or the fluoride glass is not tightly bound to the polymerized resin molecules. Examples are Fluoroshield and Deltonplus (Fig. 5).



Fig. 5: FluroShield

PROSTHETIC DENTISTRY

Smart Impression Materials

Aquasil Ultra Smart Wetting® Impression Material

This new formula of Aquasil (Fig. 6) is an addition to the silicone impression material designed with a reduced contact angle, an increase in tear strength, and maintenance of a low viscosity during the working time. The material is available as a regular- and fast-set rigid (light green), heavy (light green), monophasic (maroon), low (teal), and extra-low (orange) viscosities.

SMART CERAMICS

In 1995, the first “all-ceramic teeth bridge” was invented at ETH Zurich based on a process that enabled the direct machining of ceramic teeth and bridges. Since then, the process and the materials were tested and introduced in the market as Cercon – smart ceramics.

Cercon is a zirconia-based all-ceramic material created from one unit with no metal substructure that allows them to blend well with the surrounding natural dentition.¹⁵

Advantages

- Metal free, biocompatible;
- Delivers outstanding esthetics without reservations or compromise;
- Has properties of fracture toughness, flexural strength, reliability, and crystallographic transformation of zirconium oxide.

ORTHODONTICS

SMA – Nickel–Titanium Alloy

The SMAs constitute a group of metallic materials with the ability to recover a previously defined length or a shape when subjected to an appropriate thermomechanical load.



Fig. 6: Aquasil

The shape memory effect was first observed in copper–zinc and copper–tin alloys by Greniger and Mooradian in 1938, but it was only in the early 1960s that Buehler et al created and patented Nitinol, a nickel–titanium (NiTi) alloy in the Naval Ordnance Laboratory in Silver Springs, Maryland, USA. The SMA alloys have exceptional properties, such as super elasticity, shape memory, good resistance to fatigue and wear, and relatively good biocompatibility.¹⁶

The most commercially important use of SMAs lies in the orthodontic applications. The arch wires made of stainless steel have been employed as a corrective measure for misaligned teeth for many years. Due to the limited flexibility and tensile character of these wires, considerable forces are applied to teeth, which cause a great deal of discomfort. Retensioning of these wires for every 3 or 4 weeks in the initial stages of treatment is necessary for which the patient has to visit the orthodontist very often. Superelastic wires are now used for these corrective measures. Owing to their elastic properties and extendibility, the level of discomfort can be reduced significantly as the SMA applies continuous, gentle forces, which are in physiological range, over a longer period. Visits to the orthodontist are also reduced significantly. Example is NiTi arch wires and brackets.

ENDODONTICS

NiTi Rotary Instruments

The introduction of NiTi files in rotary endodontics has made instrumentation easier and faster than conventional hand instrumentation during biomechanical preparation of root canal treatment. Nitinol endodontic files for root canal procedures offer superior flexibility, durability, and torqueability as compared with stainless steel files.

This shape memory effect and superelasticity of rotary NiTi¹⁷ files offer the following advantages:

- Less chances of file breakage within the canal during instrumentation;



Fig. 7: Tightening of smart suture after raise preparation in thermal temperature

- Less fatigue to the operator;
- Less transportation and decreased incidence of canal aberration;and
- Minimal postoperative pain to the patient.

ORAL SURGERY

Smart Suture

These sutures are made up of biodegradable shape memory polymers.¹⁸ They are applied loosely in their temporary shape and the ends are fixed. When the temperature is raised above the thermal transition temperature, the suture would shrink and tighten the knot, applying optimum force. This thermal transition temperature, which is close to the human body temperature, and the biodegradable ability of polymer promote biocompatible application by tying a knot with proper stress in surgery. Smart sutures also made of plastic or silk threads covered with temperature sensors and microheaters can detect infections (Figs 7 and 8).¹⁹ Example is Novel MIT Polymer (Aachen, Germany).

SMART FIBERS FOR LASER DENTISTRY

Transmission of high-energy laser pulses capable of ablating dental tissues is a crucial issue in laser dentistry (Wigdor et al; Fried; Strassl et al). Hollow-core photonic fibers for the delivery of high-fluence laser radiation capable of ablating tooth enamel have been developed. These photonic fibers are known as smart fibers.²⁰ The 40 ps of neodymium-doped yttrium aluminum garnet pulses with a total energy up to 2 mJ are transmitted into a hollow core of a photonic crystal fiber with a core diameter of approximately 14 μm and are focused on a tooth surface to ablate dental tissue. The same fibers are not only to transport the high-power laser pulse to a tooth surface, but also to transmit emission from plasmas produced by



Fig. 8: Smart sutures use ultrathin silicon sensors to measure temperature at wound site

the laser pulses on the tooth surface in backward direction for detection and optical diagnosis.

SMART ANTIMICROBIAL PEPTIDE

Repertoire of antibiotics affects a broad range of microorganisms, including the normal flora. The ecological disruption resulting from antibiotic treatment frequently results in secondary infections or other negative clinical consequences. To address this problem, a new class of pathogen-selective molecules, called specifically (or selectively) targeted antimicrobial peptides (STAMPs), based on the fusion of a species-specific targeting peptide domain with a wide-spectrum antimicrobial peptide domain has recently been developed.²¹ A natural bacterial pheromone [competence-stimulating peptide (CSP)] serves as the targeting peptide domain in a STAMP against an oral bacterial pathogen, *Streptococcus mutans*, which is the principal microorganism responsible for the cause of dental caries. Further studies showed that an 8-amino-acid region within the CSP sequence is sufficient for targeted delivery of the antimicrobial peptide domain to *S. mutans*. These STAMPs are capable of eliminating *S. mutans* from multispecies biofilms without affecting closely related noncariogenic oral streptococci, indicating the potential of these molecules to be developed into "probiotic" antibiotics, which could selectively eliminate pathogens while preserving the protective benefits of a healthy normal flora.

CONCLUSION

In the 21st century, science and technology relies heavily on the development of new materials that are expected to respond to the environmental changes and manifest their own functions according to the optimum conditions. Smart materials are an answer to this requirement of environment-friendly and responsive materials, which alter their properties to perform specific functions. Due to a rapid progress in this area of science, smart materials hold a good promise for the future and in the field of biosmart dentistry. Dental practitioners should be aware of these

innovative materials to enable their use and utilize their optimal properties in day-to-day practice to provide quality and effective solutions to dental problems.

REFERENCES

1. McCabe JF, Yan Z, Al Naimi OT, Mahmoud G, Rolland SL. Smart materials in dentistry – future prospects. *Dent Mater J* 2009 Jan;28(1):37-43.
2. Allameh SM, Akogwu O, Collinson M, Thomas J, Soboyejo WO. Piezoelectric generators for biomedical and dental applications: effects of cyclic loading. *J Mater Sci Mater Med* 2007 Jan;18(1):39-45.
3. Gil FJ, Planell JA. Shape memory alloys for medical applications. *Proceedings of the Institution of Mechanical Engineers Part H. J Eng Med* 1998 Jun;212(6):473-488.
4. Stayton PS, El-Sayed ME, Murthy N, Bulmus V, Lackey C, Cheung C, Hoffman AS. "Smart" delivery systems for biomolecular therapeutics. *Orthod Craniofac Res* 2005 Aug;8(3):219-225.
5. Rolland SL, McCabe JF, Robinson C, Walls AW. In vitro biofilm formation on the surface of resin-based dentine adhesives. *Eur J Oral Sci* 2006 Jun;114(3):243-249.
6. Yan Z, Sidhu SK, Carrick TE, McCabe JF. Response to thermal stimuli of glass ionomer cements. *Dent Mater* 2007 May;23(5):597-600.
7. McCabe JF, Yan Z, Al Naimi OT, Mahmoud G, Rolland SL. Smart materials in dentistry. *Aust Dent J* 2011 Jun;56(1):3-10.
8. Yan Z, Sidhu SK, Mahmoud GA, Carrick TE, McCabe JF. Effects of temperature on the fluoride release and recharging ability of glass ionomers. *Oper Dent* 2007 Mar-Apr;32(2):138-143.
9. Xu HH, Weir MD, Sun L, S Takagi, Chow LC. Effects of calcium phosphate nanoparticles on Ca-PO₄ composite. *J Dent Res* 2007 Apr;86(4):378-383.
10. Dammaschke T, Rodenberg TN, Schfer E, Ott K. Efficiency of the polymer bur SmartPrep compared with conventional tungsten carbide bud bur in dentin caries excavation. *Oper Dent* 2006 Mar-Apr;31(2):256-260.
11. Hauman CH, Kuzmanovic DV. An evaluation of polymer rotary instruments' ability to remove healthy non-carious dentine. *Eur J Prosthodont Restor Dent* 2007 Jun;15(2):77-80.
12. Dube M, Ponnappa KC. Smart ART! *J Int Oral Health* 2009;1:52-57.
13. Skrtic D, Antonucci JM, Eanes ED. Amorphous calcium phosphate-based bioactive polymeric composites for mineralized tissue regeneration. *J Res Natl Inst Stand Technol* 2003 Jun;108(3):167-182.
14. Charbeneau GT, Dennison J. Clinical success and potential failure after single application of a pit and fissure sealant: four-year report. *J Am Dent Assoc* 1979 Apr;98(4):559-564.
15. Little DA. A smart ceramics system for expanded indications. *Inside Dent* 2012 Dec;8(12):1-4.
16. Fukuizumi M, Kakigawa H, Kozono Y. Utility of Ni-Ti shape memory orthodontic wire. *Dent Mater J* 1999 Oct;18(4):413-424.
17. Brent L, Crumpton J, S. Mcclanahan S. Endodontic rotary nickel-titanium instrument systems. *Clin Update* 2003 Aug;25:15-16.
18. Yuan P. Biodegradable shape-memory polymers. *Literature Seminar*, 2010 September.
19. Patel P. Smart sutures that detect infections. *Bio Med News* 2012.
20. Konorov SO. Hollow-core photonic-crystal fibres for laser dentistry. *Phys Med Biol* 2004 Apr;49(7):1359-1368.
21. Eckert R, He J, Yarbrough DK, Qi F, Anderson MH, Shi W. Targeted killing of *Streptococcus mutans* by a pheromone-guided "smart" antimicrobial peptide. *Antimicrob Agents Chemother* 2006 Nov;50(11):3651-3657.