ECRONICON OPEN ACCESS

EC DENTAL SCIENCE
Review Article

Biosmart Material in Operative Dentistry

Mohamed Hany Ahmad Fouad[1]* and Sawsan Badr Jaber Ishaq[2]

[1]Cairo University, Giza, Egypt

[2]Batterjee Medical College, Jeddah, Saudi Arabia

***Corresponding Author:** Mohamed Hany Ahmad Fouad, Professor of Restorative Dentistry, Registered in Saudi Commission for Health Specialties as Consultant, Saudi Arabia. Email: abdelghanymohamedhany@gmail.com, Number: 05JD0323

Received: December 06, 2022; **Published:** December 12, 2022

DOI: 10.31080/ecde.2023.22.01947

Abstract

Introduction: Materials science has changed over a period of time, and it is not what it used to be. The conventional materials used in dentistry were passive and inert and had little to no interaction with body fluids and tissues. Materials used in the oral cavity are selected on the basis of their to survive oral environment without adversely interacting with oral tissues. At present, the scenario has changed. Many of the materials have become advanced in terms of function and biologically interact with body tissues. They are designed to perform and interact with tissues and are termed "Bio-smart" material. The structural modification in materials and devices allows them to actively participate and work in a better way for the desired outcome of planned treatment. Therefore, the concept of an "active" rather than "passive" material can be useful in dentistry. This first came into consideration with the introduction of fluoride-releasing materials and led to advancement in many more of them over a period of time. This permits and reflects a change in material philosophy. The same concept holds true in many other areas of engineering, such as automotive engineering, biomedicine, aerospace, and robotics.

Aim of the Study: The aim of the review is to understand the concept of various biosmart materials used in restorative dentistry over a period of time.

Methodology: The review is a comprehensive research of PUBMED since the year to 1988 to 2014.

Conclusion: The advent of these smart materials has drastically changed the treatment outcome. There are numerous applications of smart materials ranging from their fluoride-releasing properties to high mechanical aesthetic results, working as wonders in the field of dentistry. Advances in the form of these biosmart dental materials would be even better for the future.

Keywords: *Bio-Smart Materials; Smart Burs; Self-Healing Composites*

"Smart" material is a material that possesses a great capacity to sense and respond to any environmental change they are subjected to. Hence, these materials can also be called "responsive materials". Smart materials are defined as materials that exhibit one or more properties that can be altered in a controlled fashion by external stimuli such as temperature, pH, stress, moisture, and electric or magnetic fields in a significant way [1].

Nature of smart materials

A most important key feature of smart behavior in smart materials used in dentistry is their capacity to go back to the original state even after the stimulus has been withdrawn. The properties of smart materials are as follow [2-5]:

1. Piezoelectric materials: These are the materials that produce a voltage when stress is applied or vice versa.
2. Thermoresponsive materials: These are the materials that adopt different shapes at different temperatures due to remarkable and controlled changes in the structure, such as shape memory alloys (SMAs) or shape memory polymers.

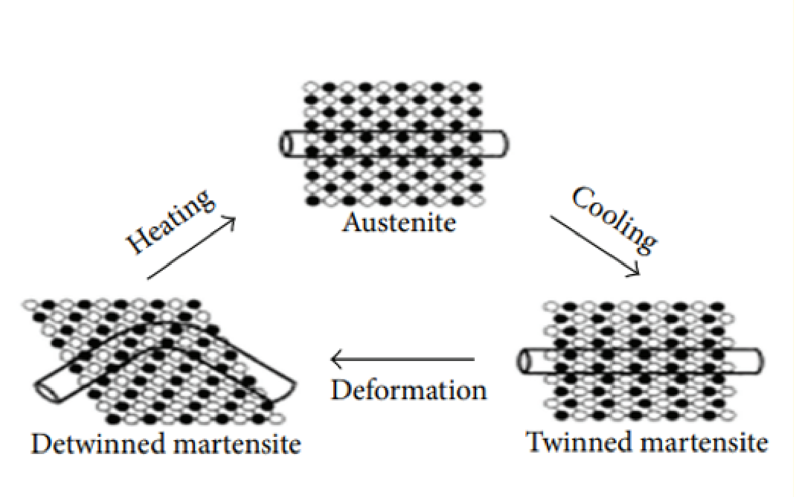

Figure 1: *Shows a diagrammatic representation of the shape memory effect of NiTi alloy [5].*

3. Thermochromic materials are materials that exhibit a change in color in response to temperature change.
4. Photochromic materials change color in response to changes in light conditions.
5. Magnetorheological materials are fluid in state and become solid when placed in a magnetic field.
6. pH-sensitive materials are the materials that either swell or collapse when there is a change in the pH of the surrounding media.
7. In biofilm formation, in such materials, the presence of biofilm on the surface may alter the interaction of the surface with the environment and exert a positive response [5].

Classification of smart materials in dentistry

Smart materials in dentistry can be classified as [6]:

I. Passive smart restorative materials: These are the materials that respond to external change without external control. E.g.
   a. Glass ionomer cement (GIC)
   b. Resin-modified GIC
   c. Compomer

d. Dental composites.

II. Active smart restorative materials: These are the materials that utilize a feedback loop that enable them to function as a cognitive response.

The following table elaborates on various types of smart materials used in various fields of dentistry [6].

Restorative dentistry	• Smart GIC • Smart composites - Ariston pHc - Aluminium composite panel (ACP) composites • Smart prep burs
Prosthetic dentistry	• Smart ceramics • Smart impression materials
Orthodontics	• Shape memory alloys (SMAs)
Pediatric and preventive dentistry	• Fluoride-releasing pit and fissure sealants • ACP-releasing pits and fissure sealants
Endodontics	• Nickel-titanium (NiTi) rotary instruments
Oral surgery	• Smart suture
Smart fibers for laser dentistry	
Smart antimicrobial peptide	

Glass ionomer cement as a smart material

The oral cavity is subjected to a wide variety of temperatures; variations may occur in the oral cavity due to the consumption of hot or cold drink and food. Therefore, any restorative materials placed in this environment show thermal contraction or expansion in response to temperature change. The term coefficient of thermal expansion (CTE) is generally used to describe the dimensional changes of a substance or material in response to thermal change. The CTE is an inherent property of each material at a specific temperature and dealing with such thermally-induced volumetric changes in materials, a comparison of CTE values of the restorative material and the tooth becomes more important than the CTE value of the material itself. The CTE value of materials should match that of the tooth or should be as close as possible since two materials are in contact; when they expand or contract at a similar rate, gap formation at the interface is negligible, and so is the microleakage. The discrepancy of thermal expansion and contraction between the tooth and a restoration structure tends to develop stresses at their interface and have unfavorable effects on the margins, which ultimately leads to microleakage [7-10].

Glass-ionomers exhibit very little to no change in dimension upon heating or cooling between 20◦C and 50◦C in wet conditions, while in dry conditions, the materials showed a significant contraction above 50◦C because the expected expansion on heating is compensated by fluid flow to the surface of the material and vice-versa upon cooling. In dry conditions, the contraction of material is also owned by the fact that there is a rapid loss of water on heating. This dimensional change is akin to that of human dentine, which exhibits little dimensional change upon heating in wet conditions, and significant contraction is noted in dry conditions owing to the flow of fluids in the dentinal tubules. Therefore, glass-ionomer materials are able to mimic the behavior of human dentine through a type of smart behavior and hence, can be considered a smart material. The reaction of Glass ionomer cement to their environment is active and is considered to have “smart” behavior [7,10,11].

Another inherent property of GICs is porosity, and the fluid contained in these porosities contributes majorly to the water content. The porosity of a material is affected by the method of mixing and the viscosity of the cement. As in the low viscosity material, hand mixing reduces the porosity in comparison to mechanical mixing. For them, the materials that are already viscous in nature, the levels of porosity are low and are not affected by mixing. Therefore, this aspect of the smart behavior of dental cement can be controlled by the clinician, and in terms of this, GICs are described as "smart materials" with respect to their thermal behavior and volumetric changes close to that of tooth substance [8,11].

The other aspect of GIC which makes them smart materials is their ability to release and recharge fluoride release. Resin-modified GIC, compomer, or giomer are some other materials that exhibit these smart characteristics, e.g. GC Fuji IX GP EXTRA [13].

Figure 2: *Showing GC Fuji IX GP EXTRA - fastest setting glass ionomer, which provides improved stability against water, an important smart feature in challenging oral environments [6].*

Smart composites

Boskey and Aaron S. Posner first described amorphous calcium phosphate (ACP) in the 1960s. It was obtained as an accident by mixing high concentrations of calcium chloride and sodium acid phosphate in a buffer as amorphous precipitates. A number of materials have been developed based on ACP with different applications, such as bases/liners, endodontic sealers, orthodontic adhesives, and pit and fissure sealants. Amorphous calcium phosphate has also been tested as a filler phase in bioactive polymeric composites. A unique biologically active restorative material containing ACP as filler encapsulated in a polymer binder was developed by Skrtic. This material is known to stimulate the repair of tooth structure because of the sustained release of significant amounts of calcium and phosphate ions. Apart from being excellently biocompatibility, the ACP-containing composites release calcium and phosphate ions into saliva, especially in the oral environment caused by bacterial plaque or acidic foods [14,15].

Mechanism: The calcium and phosphate ions released can be deposited into tooth structures as an apatitic mineral. This apatite mineral is similar to hydroxyapatite (HAP), found naturally in teeth and bones. ACP at high pH or neutral pH remains as ACP, but when the pH value drops at or below 5.8, as that usually occurs during a carious attack, ACP converts into HAP and precipitates over the tooth;

thus, they replace the lost HAP during an acid attack. When the pH level in the mouth drops below 5.8, the calcium and phosphate ions merge within seconds to form a gel-like substance, and in less than 2 minutes, the gel becomes amorphous crystals. This response of ACP-containing composites to pH can be described as smart, and hence they are called smart restorative materials [15,16].

Ariston pHc alkaline glass restorative material

Ariston pHc (pHc means pH control) is alkaline glass restorative material, a light-activated alkaline, nano-filled glass restorative material indicated for restoration of class I and II lesions in primary and permanent teeth. It is identified as a "smart" restorative material because it releases calcium, fluoride, and hydroxyl ions into the oral cavity, similar to ACP material when intraoral pH values drop below the critical pH of 5.5. This release of ions counteracts the demineralization of teeth and aids in remineralization. The material can also be placed in bulk cured at thicknesses of up to 4 mm [17].

Figure 3: *Showing Ariston pH control - introduced by Ivoclar - Vivadent (Liechtenstein) Company and the ACP-releasing smart composite used as pit and fissure sealant [6].*

Self-healing composites

Most restorative materials have a limited lifetime and degrade over a period of time due to different physical, chemical, and biological causes. These factors include external static (creep) or dynamic (fatigue) forces, corrosion, dissolution, erosion, internal stress states, or biodegradation. All the factors combined or alone gradually lead to a deterioration of the materials and, finally, failure of the restorative material. This has led scientists and researchers to create new materials that have self-repair capabilities [18].

One of the first self-repairing or self-healing synthetic materials shows many similarities to resin-based dental materials since it is resin-based. This resin-based system was an epoxy system that contained resin-filled microcapsules. If epoxy composite material cracks due to external factors, a few microcapsules are smashed near the crack and release the resin. The released resin subsequently fills the crack and further reacts with a Grubbs catalyst dispersed in the epoxy composite system. This results in polymerization of the resin and a repair of the crack [19].

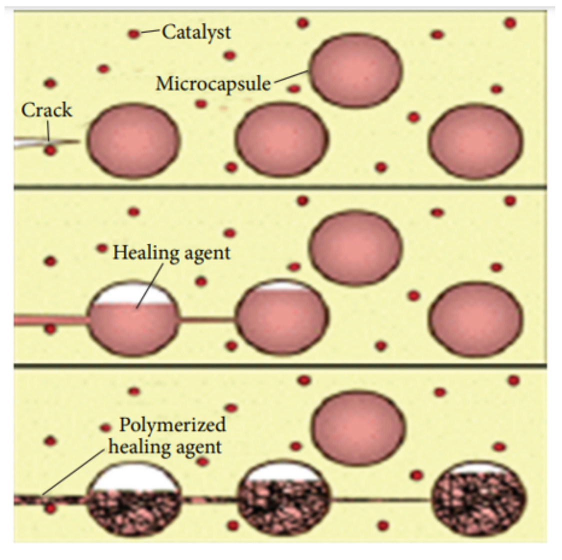

Figure 4: *Shows a basic method of the microcapsule approach [19].*

A major disadvantage of this system is the potential toxicity of the resins in the microcapsules and the catalyst, which needs to be present in the composite. The amounts of these agents are essential to repair microcracks in the dental composite. The self-repairing mechanism based on microcapsules is promising, and composites repaired in such a manner perform better than those repaired with macroscopic approaches, which led to poor mechanical properties of the repaired composite but yet an aesthetically pleasing outcome [20].

Smart ceramics

Esthetics is one of the major concerns in dentistry. Ceramic material has a long track in dentistry to fabricate crowns, but it is often used with metal substructure as porcelain fused metal (PFM) crowns which reduce the aesthetic quality of the restoration. In recent times high-tech ceramic zirconia is available that has proven to exhibit good mechanical properties and thrive in extreme situations such as heat shields in a space shuttle, spherical heads of artificial hip joints, and brake discs of sports cars. They are polycrystalline ceramics that do not contain glass. All the atoms in this material are packed into regular crystalline arrays in which crack development and propagation are difficult through atoms in the less dense and irregular network found in glasses. Therefore, they are much tougher and stronger than glass-based ceramics [21].

When compared to other ceramics and alumina, the fracture toughness and flexural strength of zirconia are significantly higher; although they are opaque and copings need to be veneered for high aesthetics, zirconia can appear quite lifelike. A transformation toughened zirconia included an additional mechanism that is not found in other polycrystalline ceramics [21].

Zirconium oxide is transformed from one crystalline state to another during firing, unlike alumina. During firing temperature, zirconia is tetragonal, while at room temperature, it is monoclinic. Each unit cell of monoclinic occupy 4.4% more volume than when tetragonal. This transformation was a bit disadvantageous since it would lead to the crumbling of the material upon cooling [21].

Later in the 1980s, ceramic engineers learned to stabilize the tetragonal form at room temperature by the addition of small amounts of calcium 3 - 8 mass% and later yttrium or cerium [16]. Even though the tetragonal form was stable at room temperature, it was also “metastable,” that is, the trapped energy still exists within the material to drive it back to the monoclinic state. It was found that the highly localized stress ahead of a propagating crack is sufficient enough to trigger grains of ceramic to transform in the vicinity of that crack tip. Therefore, the 4.4% volume increase becomes beneficial by altering material conditions around the crack tip and shielding it from the outside stress [17]. As a result of this, the compressive or crack closure stress is produced, which either stops the crack or slows it down. This crystallographic transformation of zirconia material in response to stress makes it a smart material [21].

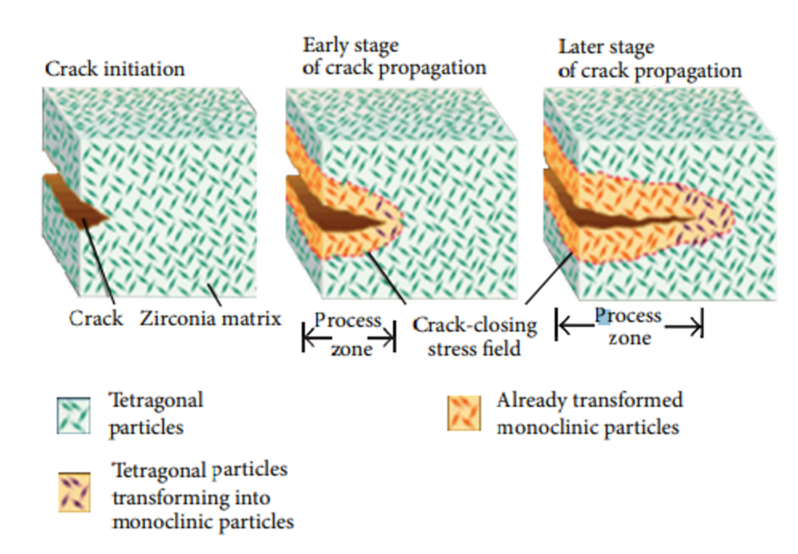

Figure 5: *Showing phase transformation in zirconia [22].*

Smart prep burs

Smart prep burs are polymer burs made of polyamide resin. Their hardness is found to be less than healthy dentin and more than carious dentin. Therefore, these burs only remove soft carious dentin easily, but when it comes in contact with the hard dentin, they burn out; as a result, they avoid unnecessary cutting of tooth structure. Commercially, two burs are available as smart bur: Smartbur (available in three different sizes of 004, 006, and 008, and recommended speed to use is 500 to 800 pm.) and polybur-1 [23].

Polybur-1 is also available in various sizes (014, 018, and 023) and is used at speeds higher than smart bur (2000 to 8000 rpm). Both burs are round in shape with spade-like cutting edges [23].

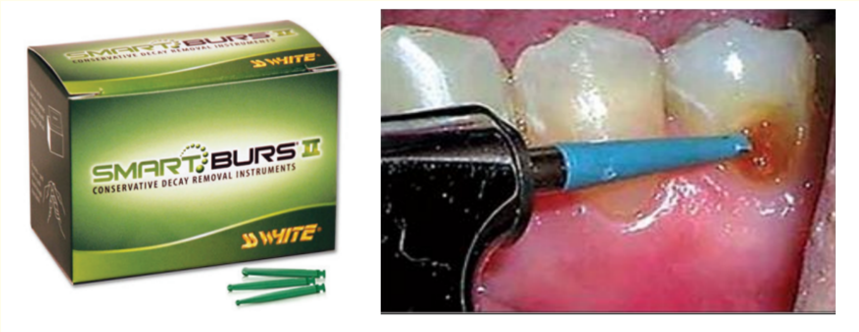

Figure 6: *Showing smart Prep Bur [23].*

Conclusion

There is great scope for progress and further development of such smart materials used in dentistry. The most sophisticated advancement yet to happen in smart materials is the advent of materials in the future that can emulate biological systems. These multifunctional materials will have the property to select and execute specific functions intelligently in order to respond to external stress changes in the local environment. Therefore, such smart materials will benefit the patient, and the quality of dental therapy will undergo a major improvement.

Bibliography

1. McCABE JF., *et al*. “Smart materials in dentistry-Future prospects”. *Dental Materials Journal* 28.1 (2009): 37-43.
2. Allameh SM., *et al*. “Piezoelectric generators for biomedical and dental applications: Effects of cyclic loading”. *Journal of Materials Science: Materials in Medicine* 18.1 (2007): 39-45.
3. Gil FJ and Planell JA. “Shape memory alloys for medical applications”. *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine* 212.6 (1998): 473-488.
4. Stayton PS., *et al*. “Smart’ delivery systems for biomolecular therapeutics”. *Orthodontics and Craniofacial Research* 8.3 (2005): 219-225.
5. Thompson SA. “An overview of nickel–titanium alloys used in dentistry”. *International Endodontic Journal* 33.4 (2000): 297-310.
6. Dhull KS., *et al*. “Biosmart Materials in Dentistry: An Update”. *International Journal of Oral Care and Research* 5.2 (2017): 143-148.
7. Yan Z., *et al*. “Response to thermal stimuli of glass ionomer cements”. *Dental Materials* 23.5 (2007): 597-600.
8. Versluis A., *et al*. “Thermal expansion coefficient of dental composites measured with strain gauges”. *Dental Materials* 12.5-6 (1996): 290-294.
9. Bullard RH., *et al*. “Effect of coefficient of thermal expansion on microleakage”. *Journal of the American Dental Association* 116.7 (1988): 871-874.
10. Yan Z., *et al*. “Response to thermal stimuli of glass ionomer cements”. *Dental Materials* 23.5 (2007): 597-600.
11. JF McCabe., *et al*. “Smart materials in dentistry”. *Australian Dental Journal* 56.1 (2011): 3-10.
12. Nomoto R., *et al*. “Effect of mixing method on the porosity of encapsulated glass ionomer cement”. *Dental Materials* 20.10 (2004): 972-978.
13. Yan Z., *et al*. “Effects of temperature on the fluoride release and recharging ability of glass ionomers”. *Operative Dentistry* 32.2 (2007): 138-143.
14. Boskey AL. “Amorphous calcium phosphate: the contention of bone”. *Journal of Dental Research* 76.8 (1997): 1433-1436.
15. Skrtic D and Antonucci JM. “Bioactive polymeric composites for tooth mineral regeneration: physicochemical and cellular aspects”. *Journal of Functional Biomaterials* 2.3 (2011): 271-307.
16. Skrtic D., *et al*. “Amorphous calcium phosphate-based bioactive polymeric composites for mineralized tissue regeneration”. *Journal of research of the National Institute of Standards and Technology* 108.3 (2003): 167.

17. Xu HH., *et al*. "Effects of calcium phosphate nanoparticles on Ca-PO4 composite". *Journal of Dental Research* 86.4 (2007): 378-383.
18. Jandt KD and Sigusch BW. "Future perspectives of resin-based dental materials". *Dental Materials* 25.8 (2009): 1001-1006.
19. RS Trask., *et al*. "Self-healing polymer composites: mimicking nature to enhance performance". *Bioinspiration and Biomimetics* 2.1 (2007): P1-P9.
20. Teixeira EC., *et al*. "Shear bond strength of self-etching bonding systems in combination with various composites used for repairing aged composites". *Journal of Adhesive Dentistry* 7.2 (2005).
21. Little DA. "A smart ceramics system for expanded indications". *Inside Dent* 8.12 (2012): 1-4.
22. Badami V and Ahuja B. "Biosmart materials: Breaking new ground in dentistry". *The Scientific World Journal* (2014).
23. Dammaschke T., *et al*. "Efficiency of the polymer bur Smart Prep compared with conventional tungsten carbide bud bur in dentin caries excavation". *Operative Dentistry* 31.2 (2006): 256-260.

Volume 22 Issue 1 January 2023