

**To Be Smart in Future Dentistry: The Smart Materials**Dr. Savitha Sathyaprasad<sup>1</sup>, Dr. Krishnamoorthy SH<sup>2</sup>, Dr. Musaffar T<sup>3\*</sup>, Dr. Dhanya KB<sup>4</sup><sup>1</sup>Senior Professor and HOD, Dept of Pedodontics, KVG Dental College and Hospital, Sullia India<sup>2</sup>Professor, Dept of Pedodontics, KVG Dental College and Hospital, Sullia India<sup>3</sup>PG Student, Dept of Pedodontics, KVG Dental College and Hospital, Sullia India<sup>4</sup>PG Student, Dept of Pedodontics, KVG Dental College and Hospital, Sullia India**Review Article****\*Corresponding author**

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**Abstract:** As of now, there has been no single material in dentistry that fulfills all the requirements of an ideal material. As the quest for an "ideal restorative material" continues, a newer generation of materials was introduced. 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 may be altered in a controlled fashion by stimulus such as stress, temperature, moisture, pH, electric or magnetic field. 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 paper attempts to highlight some of the currently available "smart materials" in paediatric dentistry to achieve maximum advantage by conventional restorative techniques.

**Keywords:** shape memory alloys, smart composites, smart ceramics, smart glass ionomer, smart impression materials.

**INTRODUCTION**

Traditionally materials used in dentistry were designed to be passive and inert, and they were often judged on their ability to survive without interacting with the oral environment for example materials like amalgams, composites and cements. A change in the scenario was noticed by the beginning of 1960's. Currently materials used in dentistry based on their interactions with the environment and the most promising technologies for life time efficiency and improved reliability include the use of "bio-active" smart materials can be grouped as bio inert (passive), bioactive, and bio responsive or smart materials.

There is no single material in dentistry that is ideal in nature and fulfills all the requirements of an ideal material. As the quest for an "ideal restorative material" continues, a newer generation of materials was introduced. 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. 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,

**Nature of Smart Materials**

Smart materials have an inherent capability to sense and react according to the changes in the environment. They can respond to the stimuli and environmental changes by activating their functions accordingly and hence they are called as 'responsive

materials'. These materials have properties that can be altered in a controlled fashion by stimuli such as stress, temperature, moisture, pH, electric, or magnetic fields, the ability of these materials to return to the original state after the stimulus has been removed [1]. Thermo-responsive materials such as shape memory alloys or shape memory polymers, adopt different shapes at different temperatures due to changes in structure.

**Smart alloys – the first smart dental materials**

The term 'smart material' or 'smart behavior' defined as 'dental materials science', was probably first used in connection with nickel-titanium alloys, or shape memory alloys which are used as orthodontic wires. The smart behavior is related to the ability of the alloy to initially undergo strain in response to stress in the normal way, but at the point identified as the yield stress there is a further increase in strain which in 'normal' alloys would be identified as irreversible

yielding'. In the SMA alloys, however, this 'yielding' is related to a reversible change in the crystal structure. The phase changes involved in the crystal transitions involve a small exothermic / endothermic response which can be used to monitor or measure the extent of the change. The amount of energy involved is very small and very sensitive recording equipment is required (e.g. temperature modulated differential scanning calorimetry).

### **The role of water**

Many types of smart behavior are 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 and the structures may be gels or salts which contain water which may be bound either strongly or loosely and therefore may be absorbed or released at different rates. Depending upon the nature of the water and how strongly it is bound, the observed changes may be dependent upon the dimensions of the structures [2].

### **Smart thermal behavior**

The vast majority of materials respond to a temperature change in a predictable manner. This involves a dimensional change characterized by the coefficient of thermal expansion. One problem with dental filling materials is their tendency to expand and contract to a greater extent than the natural tooth tissue when subjected to hot or cold stimuli.

### **The role of porosity**

The smart behavior of GIC and related materials is closely linked to their water content and the way in which this can react to changes in the environment. One important feature which may provide a location for the formation of reservoirs within the material is porosity. The number and size of pores within cement can be controlled by method of mixing [3]. In the low viscosity material, handmixing reduces the porosity significantly, either by shaking or rotation. For the viscous material the levels of porosity are low and not significantly affected by mixing. These differences in porosity are reflected in differences in water absorption.

### **Ion release and recharging**

In the case of GICs, the fluoride release rate can become negligible within a week. However, the smart behavior of materials containing GIC salt phases offers some 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 a toothpaste or mouth rinse [4]. In the long term, the fluoride re-released after recharging may be much more important than the initial 'burst' which is sustained only for a short time. The levels of fluoride release maintained can be increased by beginning the recharging process as soon as possible after setting. Another area where

'smart' fluoride interactions can have a significant benefit is in the prevention of demineralization around orthodontic brackets. Another aspect of smart behaviour is easy debonding of brackets at the end of treatment. Some resin based materials have a potential to release fluoride and neutralize acids. Other resin based materials have been designed to release calcium, fluoride and hydroxyl ions at low pH, Taking this a stage further, smart composite materials have been developed [5] which contain amorphous calcium phosphate particles or whiskers which at low pH provide a source of calcium and phosphate ions which may act to prevent demineralization of tooth structure and reportedly maintain acceptable mechanical properties in the process.

### **Biofilms and smart behavior**

Formed on the surface of materials in the mouth may enhance the smart behaviour of materials containing fluoride releasing salt phases. Recent work with saliva, using live / dead staining techniques, fluoride release from materials does not prevent biofilm formation or growth. The presence of a biofilm on the surface of a material alters the interaction of the surface with the environment and in the case of a restorative material; the biofilm may act as a lubricant which prevents abrasive wear [6]. The formation of biofilms and the way in which this changes the interaction of the materials with the environment represents a clear example of smart behavior for these materials

Smart materials sense changes in the environment around them and respond in a predictable manner. In general, these properties are:

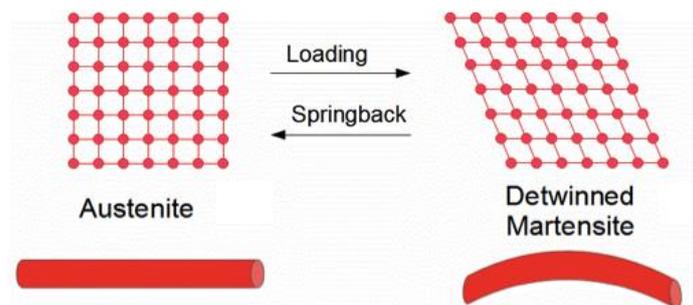
- Piezoelectric - An electrical field is generated if a mechanical force is applied to the material to change its shape which is known as the piezoelectric effect. Piezoelectric materials are the oldest type of smart material. These materials, which are mainly ceramics, have since found a number of uses.
- Shape memory— after deformation these materials can remember their original shape and return to it when heated.
- Thermo chromic — these materials change color in response to changes in temperature.
- Photo chromic — these materials change color in response to changes in light conditions.
- Magneto rheological — these are fluid materials become solid when placed in a magnetic field.
- PH sensitive — materials which swell/collapse when the pH of the surrounding media changes.
- Bio film formation — presence of bio film on the surface of material alters the interaction of the surface with the environment.

**SMART MATERIALS IN DENTISTRY**

**Shape Memory Alloys**

They have come into wide use in dentistry because of their exceptional advantageous properties like super elasticity, shape memory, resistance to fatigue and wear, and biocompatibility. Nitinol, an almost equiatomic nickel titanium alloy is of particular interest and was discovered in 1959 by William J.

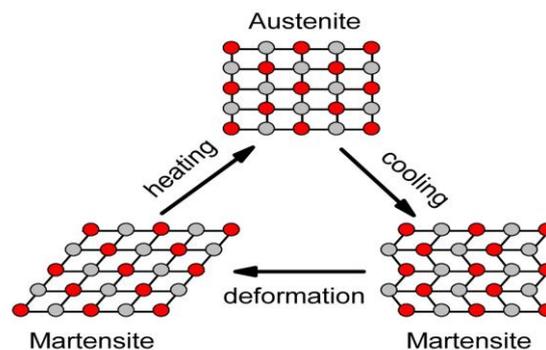
Buehler of the U.S. Naval Ordnance Laboratory, and its subsequent development was done by Buehler and Frederick E. Wang[7]. In dentistry it is having applications mainly in the field of orthodontics and endodontics. The smart behavior of nickel-titanium (NiTi) alloys is because of two unique features termed “superelasticity” and “shape memory.”



**Diagrammatic representation of the superelasticity effect of NiTi alloy**

The lattice organization can be altered either by stress or temperature during which the alloy exhibit dramatic changes in its physical properties like modulus of elasticity (stiffness), yield strength, and elastic

resistivity and give rise to the shape memory and super elastic characteristics. Shape memory effect is the ability of the NiTi alloy to come back to its original form without showing any permanent deformation.



**Diagrammatic representation of the shape memory effect of NiTi alloy Source:**

In orthodontics, these materials are used in arch wires for the alignment of teeth, during the initial stages of treatment. They can be drawn into a resilient, rectangular wire that allows accomplishing simultaneous rotation, levelling, tipping and torqueing movements early in the treatment. They also offer the advantage of reduced treatment time and cost [8].

Nitinol endodontic files for root canal procedures offer superior flexibility, durability, and torque as compared to stainless steel files. Nitinol normally exists in an austenitic crystalline phase that transforms to a martensitic structure on stressing at a constant temperature. In this martensitic phase, only a light force is required for bending. If the stress is released, the structure recovers to an austenitic phase and its original shape. This phenomenon is called stress-induced thermoplastic transformation.

**Smart Composites**

Stimuli responsive-smart dental composites may be quite useful with various applications including the “release-on-command” of antimicrobial compounds or demineralizing elements and fluoride to fight microbes or secondary caries respectively[9], Composites containing Amorphous calcium phosphate (ACP) are generally considered as smart composites. Due to their bioactive nature and extended time release of calcium and phosphate, they possess high prophylactic value in preventing caries by highly reducing the demineralization, promoting the remineralization of tooth and reducing the cariogenic microflora

**Self-Healing Composites**

A key focus of current scientific research is the development of bioinspired materials systems. One of the first self-repairing synthetic materials reported interestingly shows some similarities to resin-based

dental materials, this was an epoxy system which contained resin filled microcapsules. If a crack occurs in the epoxy composite material, some of the microcapsules are destroyed near the crack and release the resin which subsequently fills the crack and reacts with a Grubbs catalyst dispersed in the epoxy composite, resulting in a polymerization of the resin and a repair of the crack. The self-healing system consists of an encapsulated dicyclopentadiene and Grubbs catalyst.

### Smart Ceramics

With the introduction of smart ceramics by CERCON in 1995, the concept of “all ceramic teeth bridge” was materialized. Ceramics, though available since a long time to fabricate crowns and bridges, have been used with a metal substructure as porcelain fused metal (PFM) crowns. This metal substructure reduces the aesthetic quality of the restoration. The introduction of high tech ceramic, zirconia has allowed the fabrication of crowns and bridges without the metal substructure. Zirconia is a polycrystalline ceramic in which all of the atoms are regularly arranged in crystalline arrays. This arrangement poses greater resistance to the development and Propagation of crack through it compared to other forms of ceramics and hence zirconia is tougher and stronger than alumina or other ceramics’

The mechanism termed as transformation toughening results in the smart behavior of the material. Zirconia is stabilized in tetragonal phase at room temperature by the addition of yttrium or cerium. But the mineral is only metastable processing the trapped energy within it. At the time of crack propagation this trapped energy is released whereby causing the phase transition of zirconia from tetragonal to monoclinic phase. The volume change associated with this phase transition reduces the local stress around the crack tip ultimately preventing the crack propagation [10],

### Smart Glass Ionomer

The aluminum-to-silica ratio in the powder of this cement has increased compared to silicate cement powder, which gives rise to an increase in the reactivity of glass hence that it reacts faster with polyacrylic acid because this acid is weaker than the phosphoric acid used in the silicate cement. The liquid contains an aqueous acrylic acid or a copolymer of maleic acid/acrylic acid [11].

Smart behavior was reported for the 1<sup>st</sup> time in GICs; these materials do not undergo great dimensional changes in a moist environment in response to heat or cold and it appears heating results only in water movement within the structure of the material. These materials exhibit noticeable shrinkage in a dry environment at temperatures higher than 50°C, which is similar to the behavior of dentin. The other aspect of the

smart behavior of these materials is the fluoride release and recharge capacity [11].

### Amorphous calcium phosphate (ACP)

ACP is an antecedent in the biological formation of hydroxyapatite (HAP). It has both preventive and restorative properties, which justify its use in dental cements and adhesives, pit and fissure sealants and composites [12].

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. 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 buffer the pH.

Casein phosphopeptide (CPP), a milk derivative is complexes with ACP and this CPP — ACP complex is used in dentifrices as a remineralizing agent in the reversal of incipient white spot lesions under the name ReCaldent. It is commercially available as GC tooth mousse plus®

### Smart Impression Materials

The impression is considered as the foundation and blueprint for the success of a restoration. Smart impression materials include a group of newly introduced materials that are exhibiting various advantageous properties over the conventional ones like increased hydrophilicity to get void free impressions, shape memory during elastic recovery and snapset behavior to resist distortion, and low viscosity ensuring better flow of the material. These materials exhibit more hydrophilicity, shape memory, precise fit without distortion, and reduced setting and working times. Ex: Imprint™ 3 VPS,

### Smart Fibres for Laser Dentistry

Hollow-core photonic-crystal fibres (PCFs) for the delivery of high-fluence laser radiation capable of ablating tooth enamel have been developed. Sequences of pico second pulses of Nd:YAG-laser radiation are transmitted through a hollow-core photonic-crystal fibre with a core diameter of approximately 14µm and are focused on a tooth surface to ablate dental tissue. The hollow-core PCF is shown to support the single fundamental- mode regime for 1.06µm laser radiation, serving as a spatial filter and allowing the laser beam quality to be substantially improved. The same fiber is used to transmit emission from plasmas produced by laser pulses on the tooth surface in the backward direction for detection and optical diagnostic’

### Smart seal Obturation System

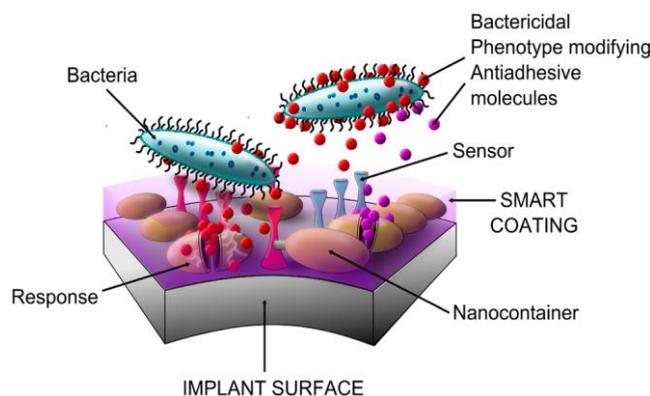
Attempts made to modify the usage of gutta percha have largely failed due to expensive equipment,

technique sensitivity or material not compatible for human use. To overcome these problems and improve the treatment outcome, a root canal obturating system called Smartseal™ was developed. This product is considered to exhibit smart behavior and incorporates developments in hydrophilic polymer plastics. Smartseal is a two-part system consisting of 1) Propoint 2) Smartpaste/Smartpaste Bio.

### Smart Coatings for Dental Implants

Researchers at North Carolina State University have developed a “smart coating” that helps surgical implants bond more closely with bone and ward off

infection. When patients have hip, knee, or dental replacement surgery, they run the risk of having their bodies reject the implant. The coating creates a crystalline layer next to the implant and a mostly amorphous outer layer that touches the surrounding bone. The amorphous layer dissolves over time, releasing calcium and phosphate, which encourages bone growth. “The bone grows into the coating as the amorphous layer dissolves, resulting in improved bonding, or osseointegration.” This bonding also makes the implant more functional, because the bonding helps ensure that the bone and the implant do a better job of sharing the load.



### Smart antimicrobial peptide

A pheromone-guided “smart” antimicrobial peptide is targeted against killing of *Streptococcus mutans* which is the principal microorganism responsible for the cause of dental caries. The BRAX-I gene [13] has been isolated along these lines that is thought to be responsible for control on enamel growth,

### Smart sutures

These sutures are made up of thermoplastic polymers that have both shape memory and biodegradable properties. They are applied loosely in its temporary shape and the ends of the suture were fixed. When the temperature is raised above the thermal transition temperature, the suture would shrink and tighten the knot, applying the optimum force. This thermal transition temperature is close to human body temperature and this is of clinical significance in tying a knot with proper stress in surgery. Smart sutures made of plastic or silk threads covered with temperature sensors and micro-heaters can detect infections.

### CONCLUSION

Smart materials are a new generation of materials which hold a good promise for the future in the field of “bio-smart dentistry.” They are in their initial stages of development, and considerable research is required in this field of material science. Pediatric dentists 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 holistic treatment. The numerous applications of smart

materials have revolutionized many areas of dentistry and there is no doubt that “smart materials” hold a real good promise for the future.

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