

REVIEW ARTICLE

Dental Smart Materials

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ABSTRACT

Dental materials are stable and have greater durability if they do not react with the environment and remain passive. At the same time, it is hoped that the materials will be well accepted and will cause neither harm nor injury. This is an entirely negative approach to material tolerance and biocompatibility. This outlook hides the possibility through which positive gains can be achieved by using materials that behave in a more dynamic fashion in the environment in which they are placed. The current dental materials are improvised. The use of smart materials has made a great revolution in 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 and other materials, such as orthodontic shape memory alloys, smart burs, etc.

Keywords: Biosmart dentistry, Fluoride release, Smart materials.

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INTRODUCTION

New, safer materials are used for restoration of teeth. Strong, durable, and esthetically pleasing materials have replaced the old unesthetic conventional dental materials. Smart materials are those materials that respond to a stimulus from their environment in a useful way.¹ These materials have properties that may be altered in stress, temperature, moisture, pH, and electric or magnetic fields. The key feature of smart behavior includes the ability to return to the original state after the stimulus has been removed. Smart materials are also called

responsive materials, as they are highly responsive and have capabilities to sense and react according to changes in the environment.^{1,2} Some researchers insist that no material by itself is truly smart, as opposed to being simply responsive. They insist that being smart is not just a matter of producing a response in proportion to a stimulus, but includes principles, such as adaptation and feedback. Smart materials are biocompatible, which is the most important property of any biomaterial.⁴ The use of smart materials in the field of dentistry is referred to as "Biosmart dentistry."^{1,3,5}

Smart materials have various advantages in dentistry especially in restorative dentistry.

REQUIREMENTS OF SMART MATERIALS

According to Williams,⁶ "smart" materials can respond to an external stimulus in a specific, controlled way. Conventional filling materials fail because of the formation of secondary caries, fracture of restoration, fracture of tooth, marginal discrepancies, or wear. Materials developed are smart to reduce failures by adding additives to the materials.

Smart materials respond by:

- Preventing secondary caries
- Preventing fracture of restoration
- Preventing fracture of tooth
- Providing a good marginal integrity
- Reducing wear
- Preventing marginal discrepancies
- Preventing wear.

CLASSIFICATION⁵

Smart materials can be classified into

- Passive smart materials
- Active smart materials

Passive smart materials: The materials that release ions in the oral cavity continuously with or without the necessity to prevent caries. These materials respond to external changes without external control. For example, glass ionomer cement, compomers, resin-modified glass ionomer cement, etc.

Active smart materials: The materials that can react favorably when there is a hazardous variation in the environment surrounding the restoration or when there is a need for materials.

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- Restorative dentistry
Smart GIC, smart composites, smart ceramics, smart compomers
- Endodontics
Nickel-titanium (NiTi) rotary instruments, smartseal
- Prosthetic dentistry
Smart ceramics, smart impression materials
- Orthodontics
Shape memory alloys
- Pediatric and preventive dentistry
Fluoride-releasing pit and fissure sealants, amorphous calcium phosphate (ACP)-releasing pits and fissure sealants.

Smart Behavior of Glass Ionomer Cement

Smart behavior was seen for the 1st time in GICs. On intake of hot or cold food and fluids, the restorative materials may show thermal expansion or contraction in response to thermal stimuli.⁷ The mismatch of thermal expansion and contraction between a restoration and the tooth structure may result in stresses at the interface, and this may lead to microleakage.⁸ In dry conditions, the materials showed a marked contraction when heated above 50°C. The explanation for this behavior is that the expected expansion on heating is compensated by fluid flow to the surface of the material to cause a balancing of the dimensional changes. On cooling, the process was reversed. In dry conditions, the rapid loss of water on heating results in the observed contraction. This behavior is akin to that of human dentin where very little dimensional change is observed on heating in wet conditions and a marked contraction is noted in dry conditions. Both results can be explained by flow of fluids in the dentinal tubules. Hence, the glass ionomer materials can be said to be mimicking the behavior of human dentin through a type of smart behavior.⁹ Hence, GICs are described as “smart materials” with respect to their thermal behavior.

Smart Behavior of Composites

These are light-activated, nano-filled restorative materials. Amorphous calcium phosphate is used as a filler phase in bioactive polymeric composites. Such composites release calcium, fluoride, and hydroxyl ions when intra-oral pH values drop below the critical pH of 5.5 and prevents the demineralization of the tooth surface and also aids in remineralization.¹⁰ These ions are then deposited into tooth structures as apatitic mineral, which is similar to the hydroxyapatite (HAP) found naturally in teeth and bone.¹¹

Smart Behavior of Compomers

Compomers are designed to release fluoride in beneficial amounts. Fluoride is present in the reactive glass filler and becomes available for release, which results in the reaction of this glass with the acid functional groups, started by moisture uptake. In addition, commercial compomers contain fluoride compounds, such as strontium fluoride or ytterbium fluoride, which are capable of releasing free fluoride ions under clinical conditions and augment the relatively low level of release that occurs from the polysalt species that develops. Fluoride release is enhanced in acidic conditions.¹² Few authors have also demonstrated that the fluoride-releasing ability of compomers can be regenerated by using a topical fluoride agent. High-release compomers appear to have greater recharge capacity than low-release ones.^{12,13}

Smart Behavior of Smart Ceramics

Ceramics are available since a long time and were used to fabricate crowns. Their increasing esthetic demand in dentistry has revolutionized the use of ceramics for their esthetic capability, biocompatibility, color stability, wear resistance, and low thermal conductivity.¹⁴ The most recent advancement to the dental ceramics family is zirconia, which in its pure form is a polymorphic material that occurs in three temperature-dependant forms: Monoclinic crystal structure between room temperature and about 950°C. Above 950°C, zirconia converts to the tetragonal crystal structure. This transformation accompanies a greater than 1% shrinkage during heating and an almost equivalent expansion during cooling. At higher temperatures, the zirconia changes from tetragonal to a cubic structure. With properly controlled chemical additions and heat treatments, a microstructure can be achieved during cooling that consists of lens-shaped “precipitates” of tetragonal zirconia in cubic grains of zirconia. Normally, during cooling, the tetragonal material would transform to the monoclinic form, but expansion is must. The high strength of the surrounding cubic zirconia prevents this expansion, so the zirconia retains its tetragonal form down to room temperature. As a result, each tetragonal zirconia precipitate is under stress and full of energy that wants to be released. Each tetragonal precipitate will expand if a crack tries to form, for breaking the ceramic. Tetragonal precipitates next to the crack are now able to expand and transform back to their stable monoclinic form (Fig. 1). This expansion adjacent to the crack presses against the crack and stops it. This is the mechanism of transformation toughening.¹⁵ This makes it a smart material.

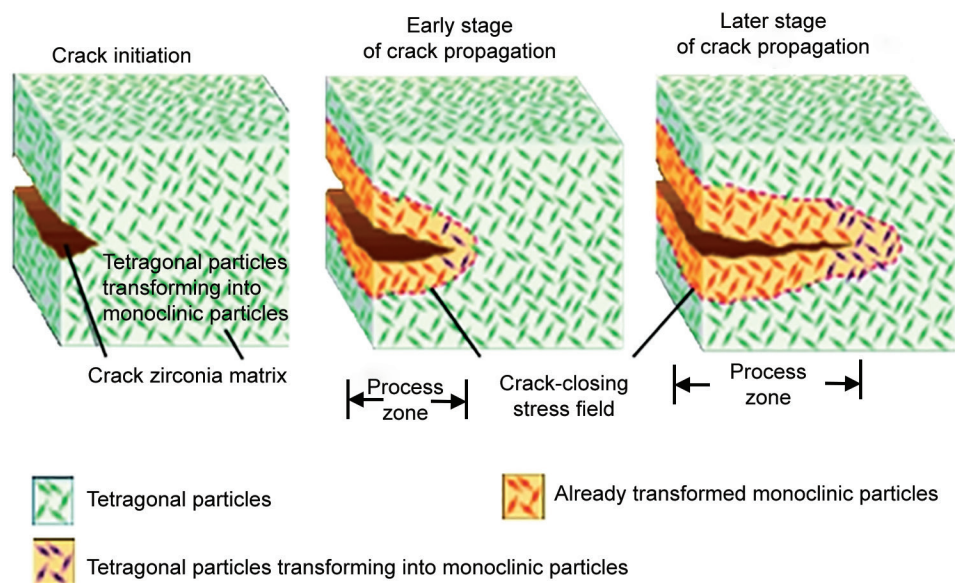


Fig. 1: Phase transformation in zirconia

Smart Behavior of NiTi

The term “smart material” or “smart behavior” in the field of dentistry was used firstly in connection with NiTi alloys, or shape memory alloys (SMAs), which are used as orthodontic wires. Nickel–titanium was developed 50 years ago by Buehler et al in the Naval Ordnance Laboratory (NOL) in Silver Springs, Maryland.¹⁶ These alloys are considered a smart material because of two salient features, “superelasticity” and “shape memory.” This “smart” property is the result of the substance’s ability to undergo a phase change. Nitinol basically exists in two phases. The low-temperature phase is called the martensitic or daughter phase (a body-centered cubic lattice), and the high-temperature phase is called the austenitic or parent phase (hexagonal lattice). This lattice organization can be altered either by stress or by temperature. In endodontics, root canal treatment causes stress to NiTi files, and a stress-induced martensitic transformation occurs from the austenitic to the martensitic phase within the speed of the sound. A shape change occurs, together with volume and density changes. This ability of resisting stress without permanent deformation, going back to the initial lattice form, is called superelasticity. Shape memory effect is the ability of the NiTi file to come back to its original straight form without showing any sign of lasting deformation.¹⁷ When an SMA is cold, or below its transformation temperature, it has a very low yield strength and can be deformed quite easily into any new shape, which it will retain. However, when the material is heated above its transformation temperature, it undergoes a change in crystal structure, which causes it to return to its original shape (Fig. 2).

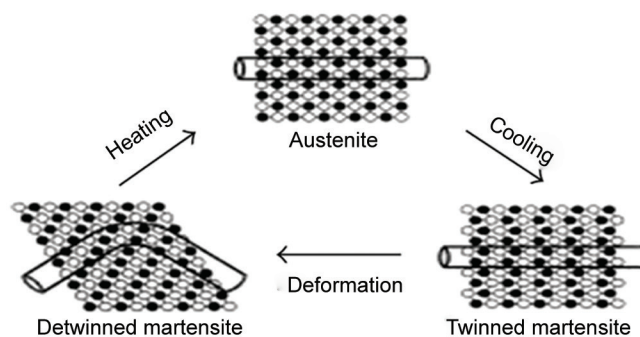


Fig. 2: Shape memory effect of NiTi alloy

The superelasticity of NiTi rotary instruments provides improved access to curved root canals during the chemomechanical preparation, with less lateral force exerted. It allows more centered preparations with less canal transportation. Nitinol normally exists in an austenitic crystalline phase that transforms to a martensitic structure on stressing at a constant temperature (Fig. 3). 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 thermoelastic transformation.¹⁸ The superelasticity of NiTi allows deformations of as much as 8% strain to be recoverable in comparison with a maximum of less than 1% with stainless steel. This is critical for rotary endodontic instruments for curved canal preparation.¹⁹ External stresses transform the austenitic crystalline form of NiTi into a martensitic crystalline structure that can accommodate greater stress without increasing the strain. When the material is in its martensite form, it is soft and ductile and can easily be deformed. Superelasticity NiTi is highly elastic, whereas

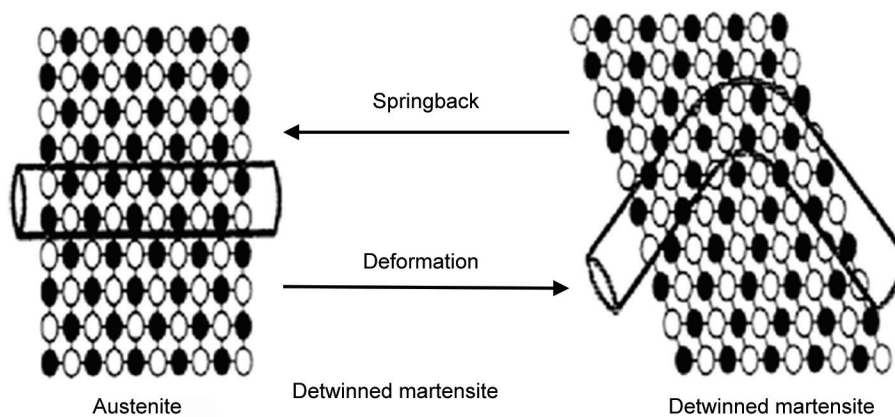


Fig. 3: Superelasticity effect of NiTi alloy

austenitic NiTi is quite strong and hard.²⁰ Nickel-titanium wires apply continuous gentle forces on the teeth because of their superelasticity and shape memory.²¹

Smart Behavior of Smartseal Obturation System

Smartpaste bio is a resin-based sealant designed to swell through the addition of ground polymer.²² The addition of bioceramics gives the sealer dimensional stability and makes it nonresorbable inside the root canal. Smartpaste bio produces calcium hydroxide and hydroxyapatite as byproducts during setting, making the material both antibacterial while setting and very biocompatible once set. Also, it has a delayed setting time (4–10 hours) and is hydrophilic in nature, allowing the propoints to hydrate and swell to fill any voids. The hydrophilic nature of propoints allows the minute amount of water present in the root canal to be absorbed by the points. The rate and extent of this expansion is controlled as part of the manufacturing process. The expansion occurs with a miniscule force that is claimed to be well below the reported tensile stress of dentin and a fraction of the force generated when using traditional techniques, such as warm vertical compaction.²³

Smart Behavior of Smartprep Burs

The Smartprep instrument is a polymer that removes decayed dentin, leaving healthy dentin intact. The hardness of the instrument is less than that of healthy dentin and enamel but harder than carious dentin. The polymer instrument is self-limiting and will not cut sound dentin unless applied with great force, and then it will only wear away, rather than cut, the healthy dentin.

The hardness of sound dentin ranges from 54 to 65 KHN and of carious dentin 20 KHN or less. The hardness of Smartprep bur is 50 KHN; thus, it remove only the carious part of the dentin and is worn off when it comes

in contact with healthy dentin. Smart bur has the capability to self-limit (selectively) what it cuts, which means it will cut only what is carious, and when in contact with healthy dentin, the bur will only wear away. It has been shown that the use of a polymer bur for caries removal provides a safety net to not overprepare the dentin when removing caries.²⁴

This unique property of the bur allows to selectively remove a carious tooth structure without unnecessarily removing or damaging a healthy tooth structure. In some cases, caries can be removed without the need for local anesthesia.²⁴ During cavity preparation, a polymer bur can be used to safely and effectively remove carious dentin without removing sound, healthy dentin.

CONCLUSION

Smart materials have properties that may be altered according to the environment, such as stress, temperature, moisture and pH, and electric or magnetic field. A key feature of smart behavior includes the ability to return to the original state even after the stimulus has been removed. 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. These innovations in the material science have marked the beginning of an era of biosmart dentistry, a step into the future.

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