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Review Article

SMART MATERIALS: REVIEW ARTICLE

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Abstract

With time new advancements occur in every field. Presently in dentistry revolution of smart materials is on peak, these are called smart materials as they can be altered in a controlled fashion by stimulus such as stress, temperature, moisture, pH, electric or magnetic field. Some of them are biomimetics and can mimic the natural tooth structures such as enamel and dentin. These materials hold a promising future in terms of improved efficiency and reliability and mark the beginning of a new era that is smart dentistry.

Keywords: Behavior, Composite, NiTinol, Restoration, Stress

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INTRODUCTION

Smart materials are defined as those materials whose properties can be changed or altered significantly when some external stimuli like stress, temperature, moisture, magnetic and electric field is applied in a controlled fashion[1] but these materials return to their original form when that stimulus has been removed.[2]

Smart materials are also called responsive materials as these are highly responsive and have a great capacity to sense and respond to any environmental change.[3] The materials have created many advances which are helpful for their applications in bio-medical fields.[4] Earlier, smart material applications started with magnetostrictive technologies which involves the use of nickel as a sonar source during World War I to find the German U-boats by allied forces.[5] Depending on changes in some external conditions, smart materials change their properties (mechanical, electrical appearance), their structure or composition or their functions.[6]

Types of smart material

Piezoelectrics, shape memory alloys, electrostrictive materials, magnetostrictive materials, electrorheological fluids, magnetorheological fluids, polyelectrolyte gels, pyroelectrics, photostrictive materials, photoferroelectric materials, magneto optical materials, and superconducting materials.[7]

Today, one of the challenging tasks is to manufacture new multifunctional materials which possess intelligence at the material level which is classified in to three functions:

1.Environmental conditions are sensed
2.Then this information is sensed
3. Making judgment (actuating) by moving away from or to the stimulus.[8]

DISCUSSION

Programming of smart materials are generally done by material composition, special processing, introduction of defects, or by microstructure modification and there "IQ" is measured in terms of their "responsiveness" to environmental stimuli and their "agility".[4]

Criteria for Smart Materials[9]

- Action should be reversible of receiving and responding to stimuli.
- Asymmetrical nature (primarily critical for piezoelectric materials).
- Inclusion in smart structures i.e. structures with at least one smart material incorporated within its structure and from the effect of the smart material causes an action.

Component of smart structure are sensors (nerves), actuators (muscles) and a control (brain). Thus, the term biomimetic is associated with smart structures.

Their degree of smartness is measured in terms of their *responsiveness* (a large amplitude change) to environmental stimuli and their agility (fast response). Relationship between the stimulus and response is the basis of classification[5,7]

What is biosmart dentistry?

"Biosmart Dentistry" is the use of smart materials in the field of dentistry. This is the new upcoming material in field of orthodontics and cosmetic dentistry.[10]

Smart materials possess many important properties like biocompatibility, exceptional super elasticity, good shape memory and resistance to wear which are very important property that a biomaterial should possess.[5,11]

Requirements of Smart Materials

Smart materials can respond to eternal 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.[12]

Smart materials respond by[13] preventing secondary caries, preventing fracture of restoration, preventing fracture of tooth, providing a good marginal integrity, reducing wear, preventing marginal discrepancies and preventing wear.

On the basis of interactions with the environment, dental materials are currently broadly categorized as bioinert (passive), bioactive and bioresponsive smart materials.[14] Nickel titanium alloys, or SMAs (used as orthodontic wires) were the first smart materials to be used in dentistry.[6] Davidson was the first to suggest the potential thermo responsive smart behavior of some glass ionomer cements and was then demonstrated as a result of attempting to measure the coefficient of thermal expansion.[15]

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 cemnt, compomers, resin-modified glass ionomer cement etc.[14]

Active smart materials: The materials that can react favourably when there is a hazardous variation in the environment surrounding the restoration or when there is a need for materials.[4]

Active Smart Materials in Dentistry According to their Use[5,10,13]

1. Restorative dentistry

   Smart glass ionomer cement (GIC)

   Smart composites

   Smart seal obturation system

   Self‐healing composites

2. Prosthetic dentistry

   Smart ceramics

   Smart impression materials

3. Orthodontics

   Shape MemoryAlloys

4. Preventive dentistry

   Fluoride and Amorphous calcium phosphate (ACP) releasing pit and fissure sealants

5. Periodontics

   Smart antimicrobial peptide.

6. Endodontics

   NiTi rotary instruments

7. Oral and maxillofacial surgery

   Smart sutures

8. Smart fibers for laser dentistry

   Hollow core photonic fibers

Smart behavior of Glass Ionomer Cement

Davidson was the first to suggest smart behavior of GIC.[15] Smart behaviour was seen for the 1st time in GICs.[13] When samples of glass ionomers were heated to determine their values of coefficient of thermal expansion in wet conditions. When heating and cooling between 20°C and 50°C , there are little or no dimensional changes, but when heated above 50°C in dry conditions, it showed a marked contraction.[5] which can be explained by the expected expansion on heating is compensated by fluid flow to the surface of the material to cause a balancing of the dimensional changes.[6]

Water content and the way in which this react to changes in the environment is the basis of smart behaviour of GIC or any related materials. Contraction occur due to increased fluid flow to the surface and rapid loss of water on heating.[15,16] , as this behavior is akin to that of human dentin where similar changes are seen as a result of flow of fluids in the dentinal tubules.[6] Hence, the glass ionomer materials can be said to be mimicking the behavior of human dentin through a type of smart behavior. and it provides good marginal adaptation to the restorations.[17]

Fluoride release and recharge capacity are the other aspect of the smart behavior of GIC Initial high fluoride release in products is followed by gradual decrease over a period. The smart behavior of materials containing GIC salt phases is attributed to their property of getting “recharged” when the material is bathed in a high concentration of or mouthrinse fluoride as may occur in toothpaste or mouthrinse.[5] Commercially available as GC Fuji IX GP EXTRA (incorporates a “SmartGlass” filler).[10]

Smart behaviour of Composites

It is a light activated alkaline, nanofilled glass restorative material.[2] Smart composites contain Amorphous Calcium Phosphate (ACP), one of the most soluble of the biologically important calcium phosphates.[18] ACP is used as a filler phase in bioactive polymeric composites. When intraoral pH values drop below the critical pH of 5.5, there is release of calcium, fluoride and hydroxyl ions, counteracting the demineralization process of the tooth surface and making conditions favorable for remineralization.[19,20] These ions are then deposited into tooth structures as apatitic mineral, which is similar to the hydroxyapatite (HAP) found naturally in teeth and bone.[21] These materials can be cured in bulk thicknesses of up to 4 mm as these relies on mechanical retention, requiring no etching and bonding agent.[5] The application is quick and easy. It finds its use in restoration of class I and class II lesions in both primary and permanent teeth.[10] Commercially available as Ariston pH control introduced by Ivoclar -Vivadent (Liechtenstein) Company. It is available only in a single universal white shade, and is not tooth colored; therefore, it is suitable only for posterior restorations.[2,5]

Smartseal Obturation System

Guttapercha is an impermeable material, failure of treatment occur due to leakage between sealer and dentin and gutta-percha and sealer and presence of voids. To overcome these problems and improve the treatment outcome, a root canal obturating system called Smartseal TM (known as Prosmart TM outside UK) was developed.[2] which is hydrophilic endodontic point and an accompanying sealer. It consists of propoint and smart paste/smart paste bio.[1]

Smartpaste bio is a resin based sealant designed to swell through the addition of ground polymer.[22] The manufacturer claims that the addition of bioceramics, gives the sealer exceptional dimensional stability and makes it non-resorbable inside the root canal.[13] Smartpaste bio produces calcium hydroxide and hydroxyapatite as byproducts of the setting reaction, which make material both anti-bacterial while setting and very biocompatible once set. Also, it has a delayed setting time (4-10 hr), and is hydrophilic in nature, allowing the propoint to hydrate and swell to fill any voids.[23]

Minute amount of water present in the root canal can be absorbed by the points because of hydrophilic nature of propoints . The rate and extent of this expansion which occurs due to 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 is controlled as part of the manufacturing process.[13]

Self healing Composites

After a period of use, materials degrade due to different physical, chemical, and/or biological stimuli. These may include creep or dynamic (fatigue) forces, internal stress states, corrosion, dissolution, erosion or biodegradation which finally leads to its failure.[24] Self healing has become one of the most desired properties in material development.[5] Self-healing composite are inspired by biological system such as bone. Continuous efforts are being made to replicate this biological model in material science.[25] The first self healing resin based synthetic material has been developed by White *et al*. Structure of the material was an epoxy system which contained resin filled microcapsule dicyclopentadiene, a highly stable monomer with excellent shelf life, encapsulated in thin shell made of urea formaldehyde.[18]

Environmental stimuli occurring on the material rupture the microcapsule from which resin is released which polymerizes in the presence of Grubb's catalyst and hence repairs the crack.[26]

It can be expected that dental composites using this technology would have a significantly longer duty cycle and enhanced clinical performance.[1] The main problems may occur from the toxicity of the resins in the microcapsules and from the catalyst. However, seem to be rather small and may well be below the toxicity threshold.[24]

Smart behaviour of Ceramics

This invention was introduced in the market as CERCON®‑Smart Ceramics System by the dental supplier Degudent,which has opened up a new era of ceramics in dentistry.[27] Various improved properties are with respect to esthetics demands, excellent biocompatibility and absence of hypersensitivity reactions.[28] They find use in making porcelain veneer restoration and full cast or porcelain fused to metal crown restoration in pediatric dentistry.[29] In orthodontics, they also find use as smart bracket braces containing microchip capable of measuring the forces applied to the bracket/tooth line.[5]

Smart Impression Material[10,18,30]

These materials exhibit following characteristics

- Void-free impression due to hydrophilic nature.

- Shape memory so during elastic recovery it resists distortion for more accurate impression and toughness resists tearing.
- Precise fitting restorations without distortion due to a snap - set behavior.
- They cut off working and setting times by at least 33%.
- They have low viscosity and hence high flow.

Eg: Imprint TM 3 VPS, ImpregimTM, Aquasil ultra (Dentsply)

Smart behaviour of NiTi

The term "smart material" or "smart behaviour" in the field of dentistry was probably first used in connection with Nickel-Titanium (NiTi) alloys or shape memory alloys (SMAs) which are used as orthodontic wires.[1]Reversible changes occur in the crystal structure at the yield stress point.[18] In 1962, Buehler and co-workers, of the U.S. Naval Ordnance Laboratory, discovered the shape memory effect which began to be known as Nitinol.[31] The smart behaviors of NITI alloy because of their exceptional superelasticity, shape memory, good resistance to fatigue and wear and relatively good biocompatibility.[32] The ability of the NiTi file to come back to its original straight form without showing any sign of lasting deformation called shape memory.[33] Nitinol basically exist in two phases. The low temperature phase is called the martensitic or daughter phase and the high temperature phase is called the austenitic or parent phase.[13] 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.[1,13,34] The lattice organization can also be altered by stress and on the removal of the stress, the structure returns to an austenitic phase and its original shape; a phenomenon called as stress-induced thermoelastic transformation.[35]

NiTi alloys are used for fabrication of brackets and orthodontic wires. Due to flexibility and resistance, super elastic wires are preferred. SMA applies gentle, continuous forces, which are in physiological ranges, over a longer period.[36], thus producing greater ease of use and increased patient comfort both during installation and treatment[5]. Also in long run during whole period of treatment ,consumption of very hot or very cold food does not lead to complications in these braces if the austenite and martensite phases are well chosen.[5,37]

NiTi alloys have also found a place in rotary endodontics.[10] Due to improved access to curved root canals during cleaning and shaping, instrumentation become easier and faster than conventional hand instrumentation , which reduces operator fatigue and gives a more centered canal preparation with less canal transportation, a decreased incidence of canal aberration and minimal postoperative pain to the patient.[13,38]

Casein phosphopeptide ‑amorphous calcium phosphate (CPP-ACP)

Casein for caries prevention was addressed in the 1980s followed by introduction of ACP technology in the early 1990s and concept of using CPP-ACP as a remineralizing agent was introduced in 1998[5].A high concentration of ACP in close proximity to the tooth surface is possible as CPP‑ACP has been shown to bind readily to the surface of the tooth, as well as to the bacteria in the plaque surrounding the tooth. Reinforcement to the tooth's natural defense system is possible because of ACP only when its needed. ACP at neutral or high pH remains ACP but in response to an acidic challenge (at or below 5.8 occurs during a carious attack), there is an increase in plaque calcium and phosphate ions which maintain the supersaturation state inhibiting demineralization and enhancing remineralization.[39,40] Unstabilized ACP, CPP stabilized ACP, and bioactive glass containing calcium sodium phosphosilicate are some of the systems available.[16,39] Their use in dental cements and adhesives, pit and fissure sealants and composites are possible because of preventive and restorative properties.[14] Also available in dentifrice formulation, as a mouth rinse and as a nonsugar containing chewing gum.[5] It is commercially available as GC Tooth Mousse Plus.[10]

Amorphous calcium phosphate releasing pit and fissure sealants

Aegis is a light‑cured sealant that contains the "smart material" ACP, which has controlled flowability along with being resilient and flexible, creating a stronger and longer lasting sealant. Studies have demonstrated the remineralization potential of Aegis.[40,41,42]

Smart Prep burs

These are polymer burs with shovel like straight cutting edges which are available in three ISO sizes 010, 014, and 018 and are meant for single use only (self‑limiting action). These burs follow minimal invasive excavation i.e remove carious dentin selectively whereas, healthy dentin is not affected , as the cutting edges wear down in contact with harder materials.[5,43] Also these should be used with light pressure and direction of excavation should be from the center to the periphery to avoid contact with the harder dentin.[44]

Pheromone Guided Smart Antimicrobial Peptide

Based on the fusion of a species-specific targeting peptide domain with a wide spectrum antimicrobial peptide domain , a new class of pathogen selective molecule called specifically (or selectively) Targeted Antimicrobial Peptides (STAMP) have been developed.[45] This pheromone-guided "smart" material peptide is targeted against the killing of Streptococcus mutans, the principal microorganism responsible for dental caries.[10] Utilizing Competence Stimulating Peptide (CSP), a pheromone produced by S.mutans, the Streptococcus mutans can be eliminated from multi-species biofilm without affecting the nation-cariogenic microorganisms.[18] Their molecules have the potential to be developed into "probiotic" antibiotics that have advantage of selectively eliminating pathogens while preserving the protective benefits of a healthy oral flora. Ex: Pheromone guided "smart" antimicrobial peptide.[46]

Smart Sutures

These sutures are made up of thermoplastic polymers that have both shape memory and biodegradable properties.[47] 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 shrinks and tightens the knot, applying the optimum force.[48] The thermal transition temperature is close to human body temperature and this is of clinical significance in tying a knot with proper stress in surgery. Due to presence of temperature sensors and microheaters, these sutures can detect infections Eg: Novel MIT Polymer (Aachen, Germany).[10,18]

Smart Coatings for Dental Implants

"Smart coating" that helps surgical implants bond more closely with bone and ward off infection has been developed by North Carolina State University researchers. This has resulted in a pathway for safer hip, knee, and dental implants as they run the risk of having a rejection of the implant.[1] Crystalline layer next to the implant and an amorphous outer layer surrounding bone is created by this coating but amorphous layer dissolves over time and releases calcium and phosphate, which encourages bone growth and due to this bone growth improved bonding osseointegration occur due to which implant become more functional as load is shared by bone and implant.[18]

Silver nanoparticles had been introduced throughout the coating to reduce infections. As the amorphous layer dissolves, silver incorporated into the coating is released which acts as an antimicrobial agent.[1] and will provide protection from infection at the implant site for the life of the implant and also there is reduction in antibiotics post surgery.[18] As patient come under healing phase release of silver become less in contrast to maximum release just after surgery therefore it is called as smart coating.[49]

Smart Fibres for Laser Dentistry

Hollow core photonic crystal fibers (PCFs) for the delivery of high-fluence laser radiation capable of ablating tooth enamel have been developed.[17] Sequences of picosecond pulses of Nd: YAG laser radiation is transmitted through a hollow-core photonic crystal fiber with a core diameter of approximately 14 micrometers and is focused on a tooth surface to ablate dental tissue.[50] The hollow core PCF supports the single fundamental mode regime for 1.06-micrometer laser radiation.[17] For detection and optical diagnostics the same fiber is also used to transmit emission from plasmas, which is produced by laser pulses on the tooth surface in the backward direction.[18]

CONCLUSION

In recent years due to significant enhancement and development of materials in dentistry, smart materials have been introduced to overcome the disadvantages of previous materials. Various smart materials used are smart composites, GIC, ceramics, obturating materials, fibre, sealer etc. The use of smart materials promises improved reliability and long-term efficiency because of their potential to select and execute specific functions intelligently in response to various local changes in the environment, thereby significantly improving the quality of dental treatment.

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