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Intelligent Materials: Breaking New Grounds in Dentistry

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ABSTRACT

Intelligent materials are the smart materials, whose properties can be altered in a controlled manner by stimuli like stress, temperature, pH, moisture, magnetic or electric fields, for e.g.- pit and fissure sealant, smart antimicrobial peptides, smart impression materials, smart cement, smart sutures etc. Shape memory polymers are thermo responsive and sensitive to pH, which swell or shrink in response to change in pH. Bio smart materials can sense these one or more properties by environmental stimulus (pH, temperature). This type of change in properties is useful and beneficial for various purposes in the world of dentistry. Cement based piezoelectric functional composite are also introduced. Some of them are biomimetic and can mimic the natural tooth appearance and structures such as enamel and dentine. These materials hold future in term of improved efficiency and mark the beginning of a new era or generation in Smart dentistry.

Key Words: intelligent materials, smart materials, shape memory alloy, smart cement

INTRODUCTION

Intelligent materials can be defined as the materials that have properties which may be changed in controlled manner by stimuli such as stress, temperature, pH, moisture, electric and magnetic fields.[1] Takagi (1990) explained them as intelligent materials that respond to environmental changes at the most optimum conditions and reveal their own functions according to the environment.[2, 3,4,5]

These materials also have very important and special characteristics, that materials can sense stimuli from surrounding environment and react to it in useful, reproducible, beneficial and reliable manner. Therefore, they are called "Intelligent Materials".

By introducing smart materials in dentistry world, work becomes very easy and reliable. There is a list of smart materials introduced in dentistry such as restorative materials like composites, smart ceramics, amorphous calcium phosphate releasing pit and fissure sealants and orthodontic shape memory alloys wire, smart sutures and smart burs.

Today this is one of the challenging tasks to manufacture multifunctional materials, which have all intelligent material level.

Material intelligence can be classified in three functions: processing sensed information, sensing change in environmental conditions and finally making decisions by moving to the stimulus.[2,3]

CLASSIFICATION OF INTELLIGENT MATERIALS

Intelligent materials are of two types namely passive and active materials.[4,5]

A. Passive Smart Materials: They are materials that sense the external change and react to it without external control.

1. GIC.

2. Resin Modified GIC.
3. Compomer.
4. Dental Composites.

B. Active Smart Materials: They are materials that sense change in the environment and respond to them.

1. Restorative Dentistry:
   - Smart GIC.
   - Smart composites.
   - Smart Prep Burs.
2. Prosthodontic materials:
   - Smart ceramics
   - Smart impression materials
3. Orthodontics:
   - Shape memory alloys.
4. Pediatric and Preventive Dentistry:
   - ACP releasing pit and fissure sealants
   - Fluorides releasing pit and fissure sealants
5. Endodontics :
   - Niti Rotary Instruments.
6. Smart Fibers in Laser Dentistry:
   - Hollow-core Photonic- Fibers.

PROPERTIES OF INTELLIGENT MATERIALS [6, 7, 8,9,10]

Smart materials sense change in the environment around and responds in an intelligent manner.

1. Piezoelectric
An electric current is generated when a mechanical stress is applied.

2. Thermo chromic
Color change by changing in temperature.

3. Shape Memory
Can change the shape whenever required and can return to original shape once force/ pressure is applied is removed.

4. Photochromic
Materials change color in response to change in light conditions.

5. pH sensitive
When surrounding pH is changes, they change their shape.

6. Magneto rheological
They become solid from liquid when placed in a magnetic field.

7. Biofilm formation
If a biofilm is present on the surface of material, it affects the interaction of the surface with the environment.

BENEFITS OF INTELLIGENT MATERIALS IN WORLD OF DENTISTRY

1. Smart composites

Aaron S. Posner first described amorphous calcium phosphate (ACP).[11] in mid-1960s. Amorphous calcium phosphate type composites are developed for various uses like base/liners, endodontic sealers, orthodontic adhesive, pit and fissure sealants.[12] Smart composites contain amorphous calcium phosphate (ACP), which is a highly soluble and biologically important calcium phosphates. Hydroxyapatite crystals are elementary unit of enamel and inorganic components of dentin. In case of carious attack, hydroxyapatite is dislodged from the tooth that leads to cavities or white spots. The carious attack is usually the result of exposure to low pH conditions (acid attack) in the form of bacteria releasing acid, food (carbohydrate decomposition products) or acidic beverages. Amorphous calcium phosphate (ACP) at neutral or alkaline pH remains ACP. When the pH is acidic i.e. below 5.8, there is a carious attack; ACP converts into hydroxyapatite (HAP) and precipitates. Hence the hydroxyapatite is lost to the acid attack. So, when pH in the mouth falls below 5.8, these ions emerge within seconds to form a gel. In not more than 2 minutes, the gel becomes amorphous crystals, resulting in calcium and phosphate ions.[13]

2. Self-Healing Composites

Dental materials generally have a limited shelf life and they expire due to different physical, chemical and biological factors. These factors are creep or dynamic forces, internal stress states, corrosion, dissolution, erosion, or biodegradation. This leads to the degradation of the structure of the materials over a period of time, and finally failure of the material occurs.[14]

These materials are influenced by healing property of fractured bone. The healing process of bone consists of multiple stages of deposition and assembly of materials.

Recently, White et al. developed a self- healing polymer. This is first self-healing synthetic materials. It is resin based material. Materials contain epoxy system which contain resin filled microcapsule Dicyclopentadiene (DCPD), a highly stable monomer with excellent shelf life, was encapsulated in thin shell made of urea formaldehyde. By any reason crack occurs in epoxy composite materials, the resin is released from some of the microcapsules that rupture near the crack. This resin reacts with the Grubbs catalyst in epoxy composite and fills up the crack, resulting in polymerization and thus sealing the crack. This results in repair of the crack.[15]

3. Smart Ceramics

Aesthetics is important aspect in modern era and ceramic play important role since long time. Fabricated crowns with metal substructure as porcelain fused metal crowns are used. This metal reduces the aesthetic quality of the restoration. Today we have high tech ceramic zirconia.

The first all-ceramic Teeth Bridge was invented at ETH Zurich in 1995, which is based on a process enabled the direct machining of ceramic teeth and bridges. The process technique and materials were tested and then introduced in the market as CERCON. The strength of CERCON is unique; the bridge that was produced was without stainless steel or metal. The Zirconia-based all ceramic materials are created from one unit without the use of the metal unlike baking it in layers. The overall product is metal-free, which is biocompatible restoration with strength that helps resist cracks formation. Now dark margins and artificial grey shadows from the underlying metal is no longer a problem with CERCON. It is used in implant and other non-metal applications extensively as they are bio-responsive and more aesthetic.[16]

4. Nickel-Titanium Alloy

In 1975, Andreasen, of Lowa University, made the first implant of a super elastic orthodontic device. In endodontic, 55 wt. % Ni and 45 weight % Ti are commonly used, referred to as "55NiTiNOL." introduced by Walia et al. in 1988.[1] The smart behaviors of NITI alloy is because of their shape memory, super elasticity, fatigue resistance, wear resistance, and relatively good biocompatibility.[17] Super elasticity is defined as the ability of resisting stress without permanent deformation and going back to initial lattice form. Shape memory is defined as the ability of the NITI file to come back to its original straight form without showing any sign of lasting deformation.[18]Such alloys that show shape memory are called as Shape Memory Alloy.

Shape Memory Alloy (SMA) remembers its shape at a particular temperature. They are of two types, one way shape memory alloys and two ways shape memory alloys. One way SMA changes its shape or has a memory affect just once. Two way SMA remembers two shapes one below the memory temperature and one above the memory temperature.[19] Due to the super elasticity of NITI rotary instruments access to curved root canal during cleaning and shaping is improved and there is less exertion of lateral forces. It also finds its use in the field of orthodontics because of its Super elasticity and Shape memory. Such materials give more accurate canal preparations with less canal transformation and a decreased incidence of canal eccentricity. Nitinol exists in two phases, martensitic or low temperature phase and austenitic or and high temperature phase or parent phase (hexagonal phase). The lattice form of the material can be changed either by stress or temperature. Materials that are in its martensitic form are soft and ductile and hence can be deformed easily. Martensitic NITI is highly elastic and opposite to austenitic. NITI is quite strong and hard. Only a light force is required for bending in martensitic phase. It exhibits stress- induced thermo elastic transformation. It means that when the stress is released, the structure goes back to an austenitic phase and its original shape.

5. Smart Impression Materials

These impression materials demonstrate characteristic like, they are water loving or hydrophilic to obtain a void-free impression. They have snap set behavior and this result in precise fitting restoration without distortion. They have low viscosity and highflow.[20]They have shape memory so it resists distortion and gives more accurate impressions.

6. Smart preparation burs

They are made up of polymer and used in removing only infected dentin. The affected dentin has ability to remineralize and remain intact to tooth. Use of smart cutting bur is to avoid the overcutting of tooth structure. Smart burs are used for removing carious dentin. It leaves the healthy dentin intact. The bur is made up of a polymer material that wears down on coming into contact with harder materials. Thus healthy dentin is conserved and only the infected dentin is removed.[21]

7. Smart sutures

These are made of thermoplastic polymer having both properties which is shape memory and biodegradability. They are loosely applied in its temporary shape and the ends of the sutures are fixed. When temperature is raised above the thermal transition temperature, the sutures shrink and get tightened forming a knot, applying the optimum force. The thermal transition temperature is close to body temperature and this is clinically significant. This type of suture made up of plastic or silk. The flexibility of smart sutures allows them to be sewn in three dimensions, rather than the traditional two dimensional diagnostic devices. They are covered with temperature sensors and micro heaters that are used in detecting infections.[20]

8. Smart seal Obturation System

It consists of a point and smart paste bio sealer. It is available in different tip size and taper. Hydrophilic property helps the point to swell and adapt the canal wall and expand laterally. It is claimed that the lateral expansion of C point (EndoTechnologies, LLC, Shrewsbury, MA, USA) is because of a hydrophilic endodontic point and an accompanying sealer.[22] The lateral expansion of C Point occurs non-uniformly. It absorbs residual water from instrumented canal space and from naturally occurring intra-radicular moisture. It does not expand apically but it expands laterally, thus sealing the canal and preventing further infections.

9. Smart glass ionomer cement

Davidson was the first person to suggest the smart behavior of GIC. [23.24] The intelligent behavior of the GIC is found to be related to the moisture content and the way it reacts with the changes in the environment. It mimics the human dentine. Its gel structure rapidly absorb or release solvent in response to stimuli like change in pH, temperature etc.

10. Smart Fibers for Laser Dentistry:-

Photonic fibers are known as smart fibers. 40 ps of laser pulses with a total energy up to 2mJ coupled into a hollow core of a Photonic Crystal Fiber with a core diameter of approximately 14 μm are focused on a tooth surface to induce an optical breakdown, resulting in plasma formation and dental tissue ablation.[25]

Photonic Crystal Fiber is not only to transport the high power laser pulse to a tooth surface, but also to transmit plasma emission to the system for detection and optical diagnosis. Care should be taken while working with these fibers because they may spurt off laserlight, this causing injury to the tissue.[26, 27]

CONCLUSION

Intelligent materials have created a new era in the dental world. These materials are very useful and time saving. These can be used in a very easy manner and handling properties are very good. They have ability to sense the environment stimulus. They provide benefit to patients by reducing their time. With the passing time more and more researches are being done in this field.

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