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Smart Materials in Prosthodontics

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Abstract

Last few decades have seen emergence of newer dental materials with enhanced biological properties. Search for an ideal restorative material leads to the discovery of entirely newer generation of materials called the "smart materials". These materials are said to be smart as they can be altered by different types of stimulus such as temperature, moisture, ph, stress, electric and magnetic field, etc. These materials have the inherent quality to sense any change in the environment and react according to such changes. Thus, they are called "responsive materials". Usage of these smart materials has revolutionized dentistry. There are various smart materials available such as smart composites, composers, smart ceramics, smart impression materials , etc.

Keywords: Smart Materials; Prosthodontics; Impression Materials; Ceramics; Implants

Introduction

Currently, the criterion of judging any material has changed. Now days, materials has to be functional. "Bioactive materials" are one of the most reliable and long-time effective materials. Smart materials are the materials that can sense stimulus received from the environment and reacts in a way to make it useful, reliable, reproducible and usually reversible manner. Stimulus can be in the form of temperature, pH, stress, moisture, electric and magnetic field which can lead to alteration of properties like change in colour, refractive index, change in volume and distribution of stresses and strains. One of the key features of smart material is its inclusion in the structure of material making it smart structure. Smart structures are the structures having atleast one smart material included in its structure and that causes an action from the effect of smart material. These structures tend to make our life more easy and productive [1].

Due to the smart behaviour of these materials, scientist are now trying to utilize smart behaviour of these materials in various fields, most commonly in dentistry and biomedical sciences [2]. In dentistry different types of smart materials are used like shape memory alloys, smart ceramics, etc. Smart behaviour of some materials can happen by chance or they can be designed like that to incorporate smartness in them [2].

Definitions

- **Smart materials:** materials that have properties which can be altered in a controlled manner when exposed to different stimuli like stress, moisture, temperature, Ph, magnetic and electric field.
- **McCabe Zrinyi** defined **smart materials** as "materials that are able to be altered bu different stimuli and can transform back into its original state after removal of stimulus" [3].
- **Responsive Materials:** They are also called by this name as they are highly responsive and have the ability to sense changes in their environment and react accordingly [4].
- **Bio-mimmetic Materials :** Smart materials are also

known as bio-mimmetic materials because their qualities are very much similar to enamel and dentin [3].

Requirements

According to Williams "smart" materials can respond to an external stimulus in a specific, controlled way. Conventional restorative materials fail because of many reasons which include secondary caries, fracture of restoration, and fracture of tooth, marginal discrepancies, or wear. Smart materials tends to reduce these failures by adding certain additives to them [4].

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

Classification

In the modern world, the concept of smart materials has changed from a standard elastic system "passive" to an adaptive or "active" (lifelike) multifunctional structural and electronic system with inherent capabilities for self-sensing, diagnosis, and control capabilities [4-6].

Passive Smart Materials can act as sensors, but not as transducers or actuators. For example, fiber optic material is used. React to external change without external control. They have self- repairing ability as well.

- GIC
- Resin Modified GIC.
- Compomer.
- Dental composites

Active Smart Materials: They sense even minute change in the environment and adapt accordingly. According to Fairweather active smart materials are those materials which, under the influence of thermal, electric or magnetic fields, can change their geometry or material based properties, thus developing an internal ability to transduce energy.

Followings is the list various types of smart materials used in the different dental specialities:

Restorative Dentistry: Smart GIC

- Smart composites
- Smart Prep Burs
- Smart bonding system

Prosthetic Dentistry:

- Smart ceramics
- Smart impression materials
- Smart implant coating

Orthodontics:

- Shape memory alloys.
- Smart orthodontic adhesive

Pediatric and Preventive Dentistry:

- Fluoride releasing pit and fissure sealants
- ACP releasing pits and fissure sealants.

Endodontics: Niti Rotary InstrumentsSmartseal obturation system

Laser Dentistry:

- Smart Fibers.

Periodontics:

- Smart antimicrobial peptide

Implant Dentistry:

- Smart coatings on implant

Oral surgery: S

- mart sutures

Mechanism of Smart Materials

Bio-smart materials works by two mechanisms:

- promoting tissue repair and regeneration. They have inductive and instructional effects on body cells and tissues in prescence of external and internal stimuli such as temperature, pH, magnetic and ionic strength [3].
- they can smartly and intelligently alter individuals' properties and controlled functions to engage actively in tissue regeneration.

Criteria for a Smart Material

Criteria for a smart material

- Asymmetrical nature
- Receiving and responding to stimuli
- Include at least one material with a smart structure [3]

Nature/Properties of Smart Materials

- **Piezoelectric Material**: These are the materials which produce voltage when stress is applied and vice versa. Structures made using this property of materials can therefore change their shape (bend, expand or contract) when voltage is applied. In dentistry, this property is seen in piezo scalers, (PIEZO soft), smart ceramics and smart burs. Other than dentistry they can also be used in computer keyboards, optical-tracking devices, magnetic heads, micro-phones, pressure sensors, transducers and igniters for gas grills [3,5,7-9].
- **Electrostrictive Materials:** These materials have similar properties as piezoelectric material, but the mechanical change shown by the material is proportional to the square of the electric field. This change will always produce displacements in the same direction. (Susmita Kamila, 2013

- **Magnetostrictive Materials:** They have similarity to piezoelectric materials but response is shown only to the magnetic fields. Magnetostrictive materials consists of ferromagnets. They are typically used in low-frequency, highpower sonar transducers,etc. One such example used in dentistry is ultrasonic scaler. For example, Dentsply Cavitron™
- **Elastosrtictive Materials:** These type of materials show high hysteresis. (James A Harvey, 2009) On removal of stress or strain from these materials, the configuration of atoms in a part of material does nocome back to its original form.
- **Electrorheological Materials:** The rheological properties of these materials, although usually uniform, instantly change on the application of an electric field.
- **Magnetorheological Materials:** These fluids consist of ferromagnetic particles and magnetic field is the stimulus. These materials, when kept in magnetic field, change their state from fluid to solid.
- **Thermoresponsive Material:** These are Amorphous and semi crystalline thermoplastic materials. These polymer change their specific volume polymer and rate of change when heated upto their glass transition temperature which affects multitude of physical properties. One example is smart pressure bandages which are made up of fabric based on polyethylene glycol modified cotton which on application of temperature and moisture act as one.
- **pH Sensitive Materials:** these materials show colur change their colour with change in pH. For eg.Smart composites and ACP releasing pit and fissure sealants. photochromic materials awhich change their colour in response to light are photochromic materials as seen in light sensitive spectacles. Certain paints are also available which change colour on heating and on exposure to light. These and other such similar materials are known as thermochromic (smart impression materials) and photochromic respectively.
- **Light Sensitive Materials**: These materials show different behavior to change in light stimulus like thermochromism, electrochromism, photostrictism, colour changes, shape changes.
- **Smart Polymer:** These are high-performance polymers. They are used to produce biodegradable packaging, hydrogels and extensively in biomedical engineering. In the field of biotechnology and medicine, they are usually referred as aqueous polymer solutions, interfaces and hydrogels. These polymers can respond strongly to even slight changes in the external conditions (change in its volume).
- **Smart Gels:** functioning of these materials are based on the concept of polymer networks being swollen in presence of solvent and being responsive to other types of stimuli. Some of them can either expand to almost hundreds times their original volume or vice versa. This property is used in artificial muscles for robotic devices, gel based actuators, controlled release drug system, etc.
- **Smart Catalysts:** Unlike traditional one, these catalyst functions in an opposite way. With rise in temperature, they becomes less soluble, thus precipitates out of solution and becomes inactive. In the similar way, with decrease in temperature of the solution, this catalyst re-dissolves itself and becomes active again.
- **Shape Memory:** Some materials have the potential of changing their shape under pressure and once it is released they regain their original shape for e.g. NiTi. Rotary instruments. They are unique in a way that they can recover permanent strains when heated above a certain degree of temperature.
- **Unusual Behavior of Some Materials:** Researches now know that there are many available smart materials which can reverse their behaviour within their lifetime. Using one's imagination useful products can be developed from smart materials.

Smart Behavior by Chance or Design

In the upcoming years many smart materials are going to develop which will incorporate degree of 'smart behavior' in their designing. Initially smart behavior was discovered by chance but its significance was not considered useful at that time. For e.g thermo-responsive materials, either shape memory alloys or polymers. Smart alloys are considered to be first smart dental materials because of their remarkable characteristics that they can change in their properties/ structure with changes in strain and temperature [10,11].

Design of Smart Materials

Scientist and researchers are searching answers to few questions like

- Whether "smartness can be designed into future materials?
- Can this behaviour be incorporated into these materials without any effect on other requirements such as longevity and clinical function?

Amongst currently available materials, Glass Ionomer Cement is the one which most positively reacts with its environment and can be interpretated as smart. However, it has limited longevity and durability because of its brittleness and solubility in the oral environment [3].

For a material to behave smart and to have better longevity, it should have a stable resin matrix and co-existenting salt matrix or discrete gel phase. Such features can be incorporated into compounds by use of nano-technology. But according to Friend technology to develop such materials at the atomic scale is still developing. However, development of smart materials interacting actively with their environment is now seems to be possible outside the scope of nanotechnology. Next stage of development is to use present day technology into designing of smart materials taking care of the requirements of longevity and durability.

Smart Ceramics

There was a time when if somebody wanted to have aesthetically pleasing, long lasting and strong restoration, porcelain fused to metal was the only option available. But the presence of metal substructure could make esthetic unpredictable. The invention of all-ceramic technology has made this process easy and predictable.[1]These are metal free restorations which shows excellent biocompatibility. In 1995, first “all ceramic teeth bridge” was delievered at ETH, Zurich using technology that allows direct machining of ceramic teeth and fixed partial dentures [4,12,13].

The range of indications and uses of all ceramic technology is continuously increasing since 1980. CAD-CAM technology in particular has opened up new avenues for all ceramic restorations and brought zirconia into limelight [4].

Zirconia when pure, is a polymorphic material which occurs in three state depending on temperature.

- Monoclinic crystal phase- between room temperature and about 950˚c
- Tetragonal crystal phase- above 950˚c
- Cubic structure- present at higher temperatures

This change in phase from monoclinic to tetragonal leads to greater than 1% shrinkage during heating and opposite behavior during cooling. When zirconia is cooled from firing temperature to room temperature there is 4.4% volume expansion. If this expansion remains unchecked, crumbling of material occurs on cooling. With latest advancements in technology, researchers learn to make tetragonal phase stable at room temperature with controlled additions of chemicals (calcium followed yttrium or cerium) and heat treatment. By this method a microstructure is formed on cooling which consists of lens shaped tetragonal zirconia precipitates which are lens shaped surrounded by cubic grains of zirconia. Cubic zirconia has high strength which does not allow for expansion of material so it remains in its tetragonal form at room temperature [4]. Because of this, each tetragonal zirconia precipitate is only “metastable”, which means that material each precipitate is under stress and has some trapped energy within itself which tends to change it back to monolithic state. If a crack tries to form, each tetragonal zirconia precipitate which is present next to the crack will now be able to expand thus transform back to the monolithic phase (Figure 1). This will stop further propagation of the crack by pressing against it. This mechanism is known as transformation toughening of ceramic and is responsible for its smart behavior [13].

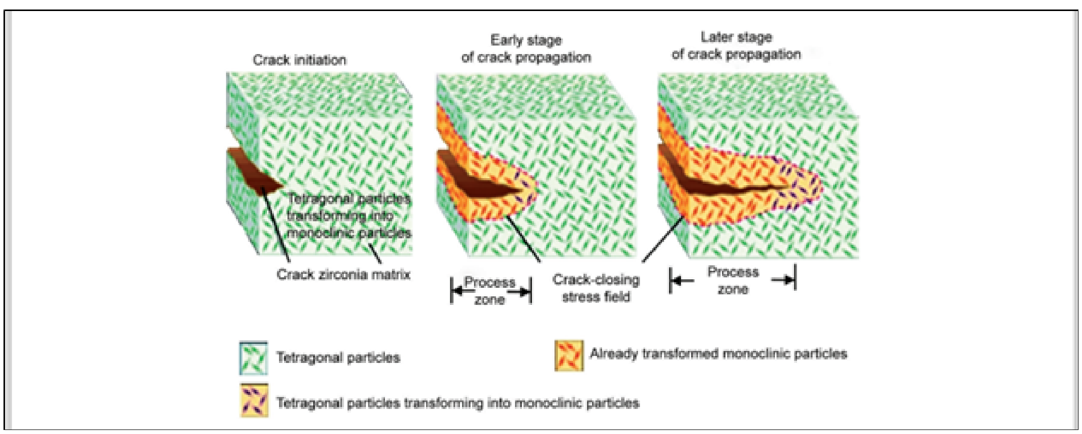

Figure 1: Phase transformation in Zirconia.

CERCON system (smart ceramic system) was first introduced as computer aided manufacturing (CAM) system for fabricating crown and bridges in the dental laboratories. Now they are used for many other applications like implant supported frameworks, customised all ceramic implant abutments. Other systems are also available like mica based glass ceramics. Excellent machinability and minimal abrasiveness are major advantages of this system. The interface of glass and mica matrix is followed by crack propagation which is difficult because of its irregular surface. Therefore numerous branches are formed followed by crack propagation can happen, thus machinability and prevention of crack propagation is guaranteed.

Smart Impression Materials

Accurate impression is a foremost step for any kind of successful restoration. Elastomeric impression mater9

smart wettingials such as polyether and polyvinyl siloxane are commonly used impression materials now a days. Every material has its own shortcomings and quest for an ideal impression making material is still going on. Few desirable characteristics of an ideal material are hydrophilic properties, shape memory, thixotrophic property [2,4-6,8,14,15].
Newly developed smart impression material

- is designed to make small contact angle(smart wetting) to make it hydrophilic and free of voids
- maintains low viscosity at the time of setting hence high flow
- shape memory during elastic recovery to resist its distortion
- toughness which is important to resist tearing of impression
- have snap set behaviour which results in precise fitting of restoration
- less working and setting time by atlest 33%
- Recently developed impression materials include Vinylsiloxane Ether in which hydrophilicity of polyether is amalgamated with advantages of vinylsiloxane to be used in challenging situation excessive salivation and narrow gingival sulcus. Fast seting elastomers are of great use to reduce chair side time and impression making in a gag reflex patient. Some examples are Imprint™ 3VPS, Impregim™, Aquasil Ultra (Dentsply)

Smart Implant Coating

Researchers at state University of North Carolina have developed a coating for surgical (hip, knee or dental) implants that behaves smartly and help them to bond more efficiently with bone thus prevent infection. The smart coating creates amorphous layer next to the bone and crystalline layer next to the implant. Over a period of time, dissolution of this amorphous layer takes place which liberates calcium and phosphate, thus encouraging bone growth. Bone growth takes place within this coating which results in improved osseointegration, thus makes the implant functional.

Further development in his field includes incorporation of silver nanoparticles throughout the coating which act as antimicrobial agent and provide protection at the implant site from any kind of infection. There is another reason for calling it smart coating as this silver release also vary. It is more rapid immediately after surgery when there is increased risk of infection and gradually slows down during healing period. This occurs because of faster dissolution of amorphous layer. This behaviour of smart coating will reduce antibiotics usage following surgery.

Future and Scope of Smart Materials

Smart material are the futuristic materials which have covered all areas of science and technology. Their usage as a material or structure that one can design depends on capabilities and talent of an individual. In dentistry also widespread research is going on for inventing/developing materials having smart properties unique to that material. That day is not far off when dentistry and smart materials would be considered synonymous to each other.

Conclusion

Researches in the field of smart materials have created new opportunities for application in dentistry which will make dental treatment much more comfortable for the patient and convenient for the operator. In the near future there is a possibility that more sophisticated types of smart materials which will emulates biological system will be developed and will mark the beginning of a new era in dentistry, biosmart dentistry.

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