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IP Indian Journal of Conservative and Endodontics

Journal homepage: https://www.ijce.in/

Review Article

Smart materials in dentistry

Ruchi Srivastava[1]*, Pushpendra Kumar Verma[2]

[1]*Dept. of Periodontology, Saraswati Dental College & Hospital, Lucknow, Uttar Pradesh, India*
[2]*UP Govt Medical Services, Lakhimpur Kheri, Uttar Pradesh, India*

ARTICLE INFO

Article history:
Received 22-10-2023
Accepted 27-11-2023
Available online 16-12-2023

Keywords:
Bioactive material
Responsive materials
Smart ceramics
Resinmodified glass ionomer

ABSTRACT

Smart materials are the result of recent developments in dental materials. One of the most enduringly useful and dependable materials is bioactive material. Since there has never been a material in dentistry that is perfect in every way and satisfies all standards for a superlative material, smart materials have been developed in an attempt to find the perfect material, which could eventually lead to smart dentistry. Materials classified as "smart" have the ability to modify their properties under regulated conditions in response to various stimuli, including pH, temperature, moisture, stress, and electric or magnetic fields. When a substance detects a signal from its surroundings and responds to it in a practical, dependable, repeatable, and typically reversible way, that material is said to exhibit smart behavior. The ability of intelligent behavior to revert to its initial condition even in the absence of a stimulus is one of its most crucial characteristics. These qualities are useful in a number of industries, including dentistry.

1. Introduction

Since its introduction many years ago, smart materials have been used in a wide range of contexts. The terms "intelligent" and "smart" were first used to characterize materials and systems in the United States in the 1980s.[1] Although many of these smart materials were created by government organizations working on aerospace and military programs, in recent years their use has expanded into the civil sector for a variety of purposes. Using nickel as a sonar source, Allied forces employed magnetostrictive technologies to find German U-boats during World War I. This was the initial use of intelligent materials.[2]

By definition, smart materials are those whose characteristics are susceptible to external stimuli such as pH, temperature, moisture, stress, and magnetic or electric fields. They are also referred to as "responsive materials" because to their remarkable reactivity and natural ability to sense and react to changes in their environment.[3] Smart behavior generally occurs when a material senses some stimulus from the environment and reacts to it in a useful, reliable, reproducible, and usually reversible manner. The ability of intelligent behavior to revert to its initial condition even in the absence of a stimulus is one of its most crucial characteristics. These qualities are useful in a number of industries, including dentistry. Historically, dental materials have been designed to be either passive or inert, which means they should interact with body fluids and tissues as little as possible or not at all. It was common practice to assess the longevity of materials used in the oral cavity separately from the oral environment.[4]

In order to increase the effectiveness of dental practice, the current review article compares the biological and functional characteristics of the various smart materials that are now on the market and provides clinical information

* *Corresponding author*.
E-mail address: drruchi117@gmail.com (R. Srivastava).

https://doi.org/10.18231/j.ijce.2023.037

about them. As there was no single material in dentistry that is ideal in nature and fulfills all the requirements of an ideal material, the quest for an "ideal restorative material" continued and 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. By comparing the biological and functional characteristics of the many smart materials now on the market, the current review paper seeks to increase dental practice efficacy by offering clinical information on each one.

Since their characteristics might resemble those of actual tooth structures like dentin or enamel, some of these are also "biomimetic" in nature.[5] The dental materials used today were modified to make them more intelligent. The use of these smart materials has revolutionized dentistry. These materials include orthodontic shape memory alloys, smart impression material, smart suture, smart burs, and other materials. Restorative materials include smart composites, smart ceramics, compomers, resin-modified glass ionomer, amorphous calcium phosphate releasing pit and fissure sealants, etc.[6]

1.1. Smart materials can be mainly classified into

1. Passive material - E.g. Resin-modified Glass ionomer, Compomer, Dental Composites,
2. Active Materials – E.g. Smart Composites, Smart ceramics.

Passive materials respond to external change without external control.

Active materials sense a change in the environment and respond to them.

2. Properties

Smart materials sense changes in the environment around them and respond in a predictable manner. In general, these properties are:[7]

1. Piezoelectric- when a mechanical stress is applied, an electric current is generated.
2. Shape memory- after deformation, these materials can remember their original shape and return to it when heated. E.g. NiTi alloys.
3. Thermochromic- these materials change colour in response to changes in temperature. E.g. Thermochromic brushes.
4. Photochromic- these materials change colour in response to changes in light conditions.[8] E.g. clinpro sealant.
5. Magnetorheological- these are fluid materials that becomes solid when placed in magnetic field.[9]
6. pH sensitive- materials which swells/collapse when the pH of the surrounding media changes. E.g. Smart composites.
7. Biofilm formation- presence of the biofilm on the surface of the material alters the interaction of the surface with the environment.[10]
8. Ion release and recharging- The beneficial effect of fluoride release of dental materials has been the subject of much research over many years as the products even with high initial fluoride release tends to rapidly lose their ability to release fluoride in significant amount. However, the smart behavior of materials containing GIC salt phases offers some long-term solution by sustained re-release of fluoride after initial recharging which may be much more important than the initial burst.[11]

   (a) Piezoelectric — when a mechanical stress is applied, an electric current is generated.
   (b) Shape memory— after deformation, these materials can remember their original shape and return to it when heated.

2.1. Smart memory alloy (SMA)

Dentists most likely first encountered the term "smart material" or "smart behavior" in relation to shape memory alloys (SMAs), also known as nickel-titanium (NiTi) alloys.[12] In the seventy years following its discovery, SMAs have become one of the most widely recognized classes of smart materials. Greniger and Mooradian found the shape memory phenomenon in copper-zinc and copper-tin alloys for the first time in 1938. Although the shape memory effect (SME) was discovered in 1951 in the gold-cadmium alloy, it was not very useful. A titanium and nickel equiatomic alloy was discovered to have shape memory effect in 1962, ten years later. The SME explains how a material transforms or remembers its shape at a specific temperature (also known as its transformation or memory temperature). One-way SMAs are materials that can only exhibit the memory effect or shape change once. However, some alloys can be educated to show a two-way effect, which allows them to remember two different shapes: one above and one below the memory temperature. At the memory temperature, the alloy undergoes a thermoelastic martensitic transition, also known as a solid-state phase transformation. The material's volume or form changes as a result of this structural change. This occurs because the material has an atom-by-atom arrangement below the transformation temperature known as a martensitic microstructure, or twins, which are an atom-by-atom arrangement, below the transformation temperature. The soft martensitic structure is easily pliable upon removal of the twinned structure. The material has a stronger austenitic structure above memory temperature. To change from a martensitic to an austenitic shape, the material is heated to the memory temperature. After cooling, the alloy reverts to its martensitic state. Compared to stainless steel files, NiTi endodontic files provide superior flexibility, durability, and torque ability in endodontics. In the field of orthodontics, NiTi finds significant application. These wires' superelasticity and shape memory work together to apply constant, mild forces that are comfortable over an extended period of time and fall within the physiological range.

3. Smart Composites

It is an alkaline, light-activated glass restorative material that contains nanoparticles. When intraoral pH values fall below the critical pH of 5.5, the material releases calcium, fluoride, and hydroxyl ions to counteract demineralization of the tooth surface and aid in remineralization. The bulk thickness of the material can be adequately cured up to 4mm. It is advised for the repair of primary and permanent teeth with class I and class II lesions.[13]

Eg: Ariston pH control-introduced by Ivoclar- Vivadent Company

Among the physiologically significant calcium phosphates, amorphous calcium phosphate (ACP) is one of the most soluble and converts to crystalline hydroxyapatite (HAP) at the fastest rate in smart composites. ACP will act as a source of calcium and phosphate that will be helpful in avoiding caries when combined with specifically made and engineered resins to create a composite material. ACP has been considered for use in bioactive polymeric composites as a filler phase. Active restorative materials contain ACP filler, which is encased in a polymer binder and may facilitate tooth structural repair by gradually releasing significant amounts of calcium and phosphate ions. Apart from their exceptional biocompatibility, composites containing ACP also release calcium and phosphate ions into saliva milieus, particularly in the oral environment where acidic foods or bacterial plaque are present. The apatitic mineral that these ions form, which is comparable to the hydroxyapatite (HAP) that occurs naturally in teeth and bone, can then be deposited into tooth structures. ACP remains ACP at high or neutral pH values. Low pH levels (at or below 5.8) during a carious assault cause ACP to convert into HAP and precipitate, restoring the HAP that was lost to the acid. Thus, these ions combine in a matter of seconds to generate a gel when the mouth's pH falls below 5.8. The gel transforms into amorphous crystals in less than two minutes, releasing phosphate and calcium ions in the process. One could characterize the reaction of composites incorporating ACP to pH as intelligent.

4. Self Healing Composites

Materials usually have a limited lifespan and degrade due to different physical, chemical, and/or biological stimuli. These may include external static or dynamic forces, internal stress states, corrosion, dissolution, erosion or biodegradation. This progressively leads to a deterioration of the materials structure and failure of the material.[14]

The primary goal of current scientific research is developing novel bioinspired material systems. Remarkably, dental materials based on resin have some similarities with one of the first synthetic materials to be claimed to be self-repairing or self-healing. Since the epoxy system contains resin-filled microcapsules, in the event that the epoxy composite material cracks, some of the microcapsules will degrade near the fracture and release the resin. Once the crack has been filled, the resin reacts with a Grubbs catalyst that has been mixed into the epoxy composite, causing the crack to heal and the resin to polymerize. Composites restored by the self-repairing technique, which relies on the dissolution of microcapsules, may fare better in the future than those restored by macroscopic repair.

5. Smart Ceramics

In 1995 the first all-ceramic teeth bridge was invented at ETH Zurich based on a process that enabled the direct machining of ceramic teeth and bridges. Since then the process and the materials were tested and introduced in the market as CERCON.[15]

The bridge can be made without stainless steel or other metal thanks to CERCON's strength and technological capabilities. The zirconia-based all-ceramic material is made from a single, metal-free unit rather than being baked in layers on top of the metal. The end result is a biocompatible, metal-free repair that looks realistic and has a strength that prevents cracks from forming. Unwanted dark edges and fake gray shadows from the underlying metal are eliminated using CERCON. Due to their bioresponsiveness, implants and other non-metal applications make substantial use of them.

6. Smart Impression Materials[16]

These materials exhibit following characteristics:

1. They are hydrophilic to get a void-free impression.
2. They possess shape memory so during elastic recovery it resists distortion for more accurate impression and toughness resists tearing.
3. They have a snap –set behavior those results in precise fitting restorations without destortions.
4. They cutoff working and setting times by atleast 33%.
5. They have low viscosity hence high flow.
   E.g. Imprint 3 VPS, Impregim, Aquasil Ultra (Dentsply
   (a) They are hydrophilic to get a void-free impression.
   (b) They possess Shape memory so during elastic recovery it resists distortion for more accurate impression and toughness resists

7. Smart Glass Ionomer Cement (RMGIs)

It was Davidson who first suggested GIC's astute actions. It has to do with the ability of a gel structure to swiftly absorb or release solvent in response to a range of stimuli, including temperature or pH changes. The intelligent ionomer mimics the way human dentin behaves. These ingenious characteristics are also seen in resin-treated glass ionomer cement, compomer, and giomer.[17] E.g. GC Fuji IX EXTRA

8. Smart Prep Burs

These burs are polymer-based and only remove dentin that is infected. Dentin that has been damaged does not remineralize; it remains intact. Overcutting of the tooth structure, which is usually seen with traditional burs, can be avoided by using these ingenious preparation burs. Smart Bursts maintain healthy dentin while removing diseased dentin.[18] The polymer cutting edges dull when they come into contact with other more durable materials or well-maintained dentin. SS, for example, and carbide package for preparing white diamonds.

9. Smart Sutures

These sutures are made of thermoplastic polymers, which naturally break down and regain their shape.[19] The sutures are applied loosely in their temporary shape and their ends are secured. At a temperature higher than the thermal transition point, the suture contracts and tightens the knot, applying the maximum force. Practical considerations for appropriately stressing a surgical knot result from the fact that the thermal transition temperature is nearly identical to body temperature. Smart sutures with integrated temperature sensors and microheaters can identify infections in plastic or silk threads. Eg: Novel MIT Polymer (Aachen, Germany).

10. Pheromone Guided Smart Antimicrobial Peptide

Targeted Antimicrobial Peptides (STAMPs) are a novel class of pathogen-specific molecules that are specifically (or selectively) produced by combining a species-specific targeting peptide domain with a wide spectrum antimicrobial peptide domain.[20] This peptide-based pheromone-guided "smart" material targets Streptococcus mutans, the main microbe responsible for dental caries. Competence Stimulating Peptide (CSP), a pheromone produced by Streptococcus mutans, can be used to remove the bacteria from multi-species biofilm without damaging the nation-cariogenic microorganisms. These substances could be utilized to make "probiotic" antibiotics, which would both eliminate pathogens and preserve the advantageous effects of a healthy oral flora balance. Example: "Smart" antibacterial peptide guided by a pheromone.

11. 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.[21] 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. The hollow core PCF supports the single fundamental mode regime for 1.06-micrometer laser radiation. 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 for detection and optical diagnostics.

12. Conclusion

Dental materials have been developed and improved in recent years. Utilizing materials that respond more dynamically to their surroundings in order to achieve favorable results might be feasible in the future thanks to scientific advancements in the study of novel materials. Because smart materials can choose and perform specific tasks intelligently in response to different local changes in the environment, they promise increased reliability and long-term efficiency while also greatly enhancing the quality of dental care. The use of diverse materials is essential to the field of dentistry.

13. Source of Funding

None.

14. Conflict of Interest

None.

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Author biography

Ruchi Srivastava, Associate Professor

Pushpendra Kumar Verma, Dental Officer

Cite this article: Srivastava R, Verma PK. Smart materials in dentistry. *IP Indian J Conserv Endod* 2023;8(4):193-197.