INTERNATIONAL JOURNAL OF ADVANCE RESEARCH AND DEVELOPMENT
IJARnD

(Volume3, Issue6)
Available online at: www.ijarnd.com

Smart materials in dentistry: A review

Dr. Vertika Gupta
Assistant Professor, Hind Institute of Medical Sciences, Lucknow, Uttar Pradesh

ABSTRACT

Smart materials have revolutionized many areas of dentistry. The quest for an ideal restorative material leads to the discovery of a newer generation of materials in dentistry called the smart materials. These materials are called smart 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: *Smart materials, Biomimetics*

1. INTRODUCTION

Smart materials have been around for many years and they have found a large number of applications [1]. The use of the terms 'smart' and 'intelligent' to describe materials and systems came from the United States and started in the 1980's. Many of these smart materials were developed by the government agencies working on military and aerospace projects but in recent years their use has been transferred into the civil sector for applications in various areas. The first smart material application started with magnetostrictive technologies that involved the use of nickel as a sonar source during World War I to find German U-boats by Allied forces.

By definition, smart materials are materials that have properties that may be altered in a controlled fashion by stimuli, such as stress, temperature, moisture, pH, and electric or magnetic fields [2]. They are highly responsive and have the inherent capability to sense and react according to changes in the environment, hence they are called "responsive materials" [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 most important key feature of smart behavior includes its ability to return to original state even after the stimulus has been removed [4]. These properties have a beneficial application in various fields including dentistry.

Traditionally materials used in dentistry were designed to be passive and inert, that is, to exhibit little or no interaction with body tissues and fluids. Materials used in the oral cavity were often judged on their ability to survive without interacting with the oral environment.

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. Some of these are also "biomimetic" in nature as their properties can mimic natural tooth structures such as enamel or dentin.

The current dental materials were improvised make them smarter. The use of these smart materials has revolutionized 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, etc. and other materials such as orthodontic shape memory alloys, smart impression material, smart suture, smart burs, etc.

2. Classification of smart materials

Smart materials can be mainly classified into:

- Passive materials-E.g. Resin-modified glass ionomer, Compomer, Dental composites,
- Active materials-E.g. Smart composites, Smart ceramics

Passive materials respond to external change without external control. They also possess a self- repairing characteristics [5-6].

Active materials sense a change in the environment and respond to them [6].

Table 1: Smart materials used in dentistry

Restorative materials	Types
Prosthodontics	✓ Smart impression material
Orthodontics	✓ Shape memory alloys
Pediatric and Preventive Dentistry	✓ Fluoride-releasing pit and fissure sealants, ACP releasing pit, and fissure sealants
Dental materials	✓ Smart composites ✓ Smart ceramics
Conservative Dentistry and Endodontics	✓ Ni-Ti rotary instruments ✓ Smart prep burs
Oral surgery	✓ Smart suture
Periodontics	✓ Smart antimicrobial peptide
Laser Dentistry [7]	✓ Smart fibers

3. PROPERTIES

Smart materials sense changes in the environment around them and respond in a predictable manner [8]. In general, these properties are:

- Piezoelectric — when a mechanical stress is applied, an electric current is generated [9].
- Shape memory— after deformation, these materials can remember their original shape and return to it when heated. eg:- NiTi alloys [10,11]
- Thermochromic — these materials change color in response to changes in temperature. Eg. Thermochromic brushes (Fig 1)

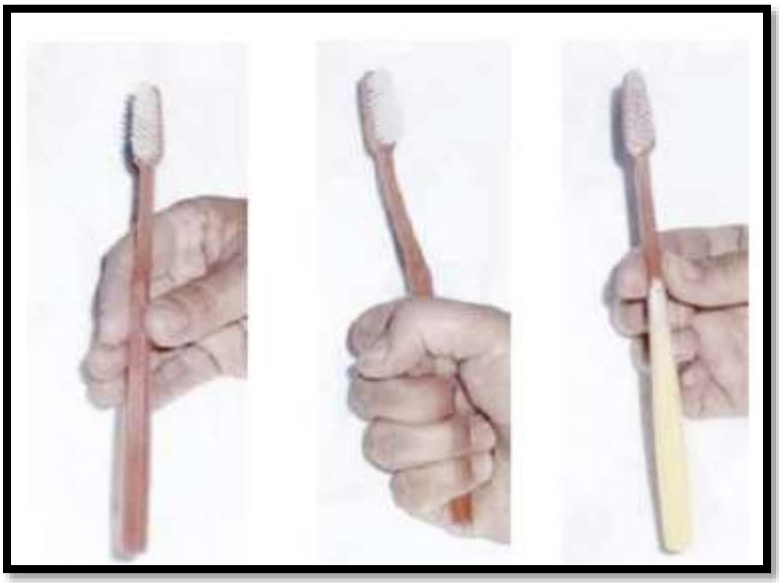

Fig. 1: Thermo chromic brushes

- Photochromic — these materials change color in response to changes in light conditions. eg: -Clinpro™ Sealant(3M)
- Magnetorheological — these are fluid materials that become solid when placed in a magnetic field.
- pH-sensitive — Materials which swell/collapse when the pH of the surrounding media changes.eg: - Smart composites containing ACP (amorphous calcium phosphate) [12].
- Biofilm formation — Presence of biofilm on the surface of material alters the interaction of the surface with the environment [13].
- 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 tend to rapidly lose their ability to release fluoride in significant amounts [14-16]. However, the smart behavior of materials containing GIC salt phases offers some long-term solutions by the sustained re-release of fluoride after initial recharging which may be much more important than the initial burst.

4. BIOMEDICAL APPLICATION

Recent advances in the design of stimuli-responsive polymers have created opportunities for novel biomedical applications. Stimuli-responsive changes in shape, surface, solubility, the formation of an intricate molecular self-assembly and a sol-gel transition enabled several novel applications in the delivery of therapeutics, tissue engineering, cell culture, bioseparations, biomimetics actuators, immobilized biocatalyst, drug delivery and thermoresponsive surfaces.[17-18]

4.1 SMART PRESSURE BANDAGES

Polyethylene glycols bonded to various fibrous materials such as cotton and polyester possesses the intelligent properties of thermal adaptability and reversible shrinkage. Reversible shrinkage involves imparting a dimensional memory to the material such that when the material is exposed to a liquid it shrinks in the area. Such materials could be used for pressure bandages that contract when exposed to blood [17-18].

4.2 Hydrogel

Hydrogels exhibit plastic contraction with changes in temperature, pH, magnetic or electrical field. It has a vast number of applications. For example soft actuators in the biomedical field or for controlled drug release.

4.3 Smart shirt

Georgia Tech along with Sensa Tex. Inc.developed a t-shirt that functions like a computer with optical and conductive fibers integrated into the garment. The shirt monitors the wearer's heart rate, respiration, temperature, vital functions alerting the wearer if there is a problem [17-18].

4.4 Countering radioactive rays

Composite containment structures can be used to counter radioactive or chemical waste materials. Fibers with chemically sensitive coating or radiation sensitive coating may be provided which are adapted to release scavenger compounds when radiation or chemical waste is detected [17-18].

5. SMART MATERIALS IN DENTISTRY

5.1 Smart Memory Alloy (SMA)

The term "smart material" or "smart behavior" in the field of dentistry was probably first used in connection with Nickel-Titanium (NiTi) alloys, or shape memory alloys (SMAs).SMAs are one of the most well-acknowledged types of smart material and they have found widespread use in the 70 years since their discovery. The shape memory effect was first discovered in copper-zinc and copper-tin alloys by Greniger and Mooradian in 1938. The shape memory effect (SME) was observed in the gold-cadmium alloy in 1951, but this was of insignificant use [19]. Ten years later in 1962, an equiatomic alloy of titanium and nickel was found to exhibit shape memory effect [19] (Fig 2).

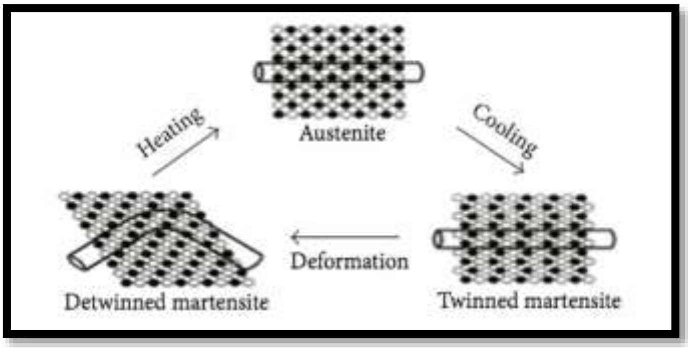

Fig. 2: Change in structure associated with shape memory effect of NiTi alloy

The SME describes the manner of a material changing shape or remembering a particular shape at a particular temperature (i.e. its transformation or memory temperature). Materials that can only demonstrate the shape change or memory effect once are known as one-waySMAs. However, some alloys can be skilled to show a two-way effect in which they remember two shapes, one below and one above the memory temperature. At the memory temperature, the alloy undergoes a solid-state phase transformation i.e. the crystal structure of the material changes resulting in a volume or shape change and this change in structure is called a thermoelastic martensitic transformation. This occurs as the material has a martensitic microstructure below transformation temperature, which is characterized by a zig-zag arrangement of the atoms, known as twins. The martensitic structure is soft and is easily deformed by removing the twinned structure. The material has an austenitic structure above the memory temperature, which is stronger. To change from the martensitic to the austenitic shape the material is heated through the memory temperature. Cooling down reverts the alloy to the martensitic state. (Fig 3)

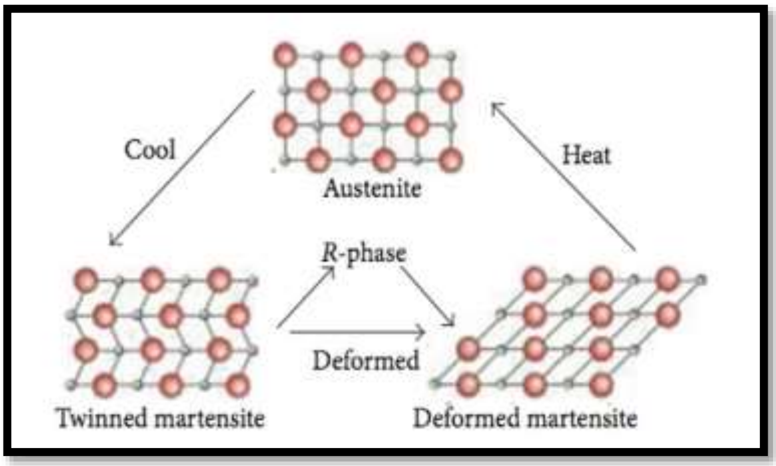

Fig. 3: Force and temperature dependent transition from austenite to martensite

In endodontics, NiTi endodontic files offer super flexibility, durability, and torqueability as compared to the stainless steel files used [20]. Another important application of NiTi is in the field of orthodontics. Superelasticity of these wires along with shape memory applies continuous, gentle forces that are within physiological range over a longer period with less discomfort. (Fig 4)

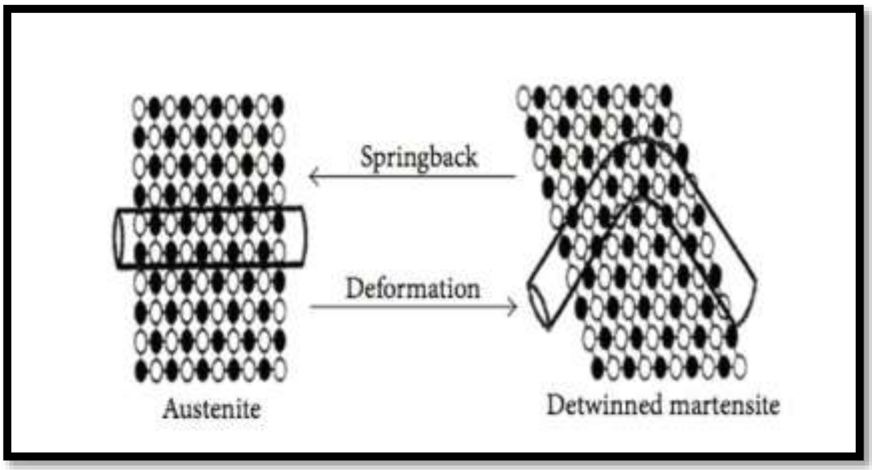

Fig. 4: Change in structure associated with superelasticity effect of NiTi alloy

Wires that exhibit shape memory behavior at mouth temperature contain copper and or chromium in addition to nickel.

Other SMA devices are also being used for healing fractured bone, staples of the shape memory materials are attached to each part of the bone and these staples then apply a constant force to pull the two pieces together, as the SMA is warmed by the body temperature it tries to return to its original configuration. (Fig 5)

Fig. 5: NiTi Bone plates for approximating fractured bones

6. SMART COMPOSITES

It is a light activated alkaline, nano-filled glass restorative material, which releases calcium, fluoride and hydroxyl ions when intraoral pH values drop below the critical pH of 5.5 and counteract the demineralization of the tooth surface and help in remineralization [21]. The material can be adequately cured in bulk thickness up to 4mm. It is recommended for the restoration of class I and class II lesions in both primary and permanent teeth.

Ex: Ariston pH control-introduced by Ivoclar- VivadentCompany

Smart composites containing ACP (amorphous calcium phosphate) is one of the most soluble of the biologically important calcium phosphates, exhibiting the most rapid conversion to crystalline hydroxyapatite (HAP). ACP when integrated into specially designed and formulated resins to make a composite material, will have an extended time release nature to act as a source for calcium and phosphate which will be useful for preventing caries.ACP has been evaluated as a filler phase in bioactive polymeric composites. Active restorative materials that contain ACP as filler encapsulated in a polymer binder, may stimulate the repair of tooth structure because of releasing significant amounts of calcium and phosphate ions in a sustained manner. In addition to excellent biocompatibility, the ACP containing composites release calcium and phosphate ions into saliva milieus, especially in the oral environment caused by bacterial plaque or acidic foods. Then these ions can be deposited into tooth structures as apatitic mineral, which is similar to the hydroxyapatite (HAP) found naturally in teeth and bone. ACP at neutral or high pH remains as ACP. When low pH values (at or below 5.8) occur during a carious attack, ACP converts into HAP and precipitates, thus replacing the HAP lost to the acid. So, when the pH level in the mouth drops below 5.8, these ions merge within seconds to form a gel. In less than 2 minutes, the gel becomes amorphous crystals, resulting in the release of calcium and phosphate ions [22]. This response of ACP containing composites to pH can be described as smart.

7. 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.

A key focus of current scientific research is the development of newerbioinspired material systems. One of the first self-repairing or self-healing synthetic materials reported interestingly shows some similarities to resin-based dental materials. As this is an epoxy system that contains resin filled microcapsules, if a crack occurs in the epoxy composite material, some of the microcapsules disintegrate near the crack and they release the resin. The resin subsequently fills the crack and reacts with a Grubbs catalyst that is dispersed in the epoxy composite, resulting in a polymerization of the resin and a repair of the crack (Figure 6). The self-repairing mechanism based on microcapsules disintegration may have a promising future and composites repaired in that way may perform better than those repaired with macroscopic repair approaches [23].

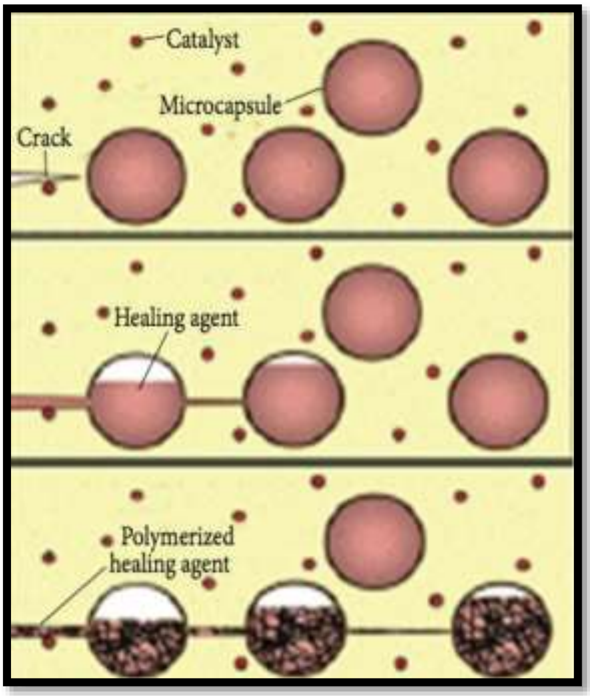

Fig. 6: Mechanism of the microcapsule approach in Self-healing composite

8. 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. The strength and technology of CERCON allow the bridge to be produced without stainless steel or metal. The zirconia-based all ceramic material is not baked in layers on the metal but is created from one unit with no metal. The overall product is metal-free, biocompatible lifelike restoration with a strength that helps resist crack formation. With CERCON unsightly dark margins and artificial grey shadows from the underlying metal are no longer a problem. It is used in implants and other non-metal applications extensively as they are bioresponsive [24].

9. SMART IMPRESSION MATERIAL

These materials exhibit following characteristics:

- They are hydrophilic to get a void-free impression.
- They possess Shape memory so during elastic recovery it resists distortion for more accurate impression and toughness resists tearing.
- They have a snap - set behavior those results in precise fitting restorations without distortion.
- They cut off working and setting times by at least 33%.
- They have low viscosity and hence high flow [25].
  Eg: Imprint ^{TM} 3 VPS, Impregim^{TM}, Aquasil ultra (Dentsply)

10. SMART GLASS IONOMER CEMENT (RMGIs)

Davidson first suggested the smart behavior of GIC [26]. It is related to the ability of a gel structure to absorb or release solvent rapidly in response to a stimulus that can be temperature, change in pH etc. The smart ionomer mimics the behavior of human dentin. Resin-modified glass ionomer cement, compomer or giomerare also seen to exhibit these smart characteristics.
Ex. GC Fuji IX EXTRA

11. SMART PREP BURS

These are polymer burs that remove only infected dentin. The affected dentin, which has the ability to remineralize, remains intact. Overcutting of tooth structure, which is usually seen with conventional burs, can be avoided by the use of these smart preparation burs. Smart Burs remove carious dentin selectively leaving the healthy dentin intact. The polymer cutting edges wear down on coming into contact with harder materials, such as healthy dentin and becomes blunt [27]. (Fig 7).
Eg: SS White diamond and carbide preparation kit. (Fig 8)

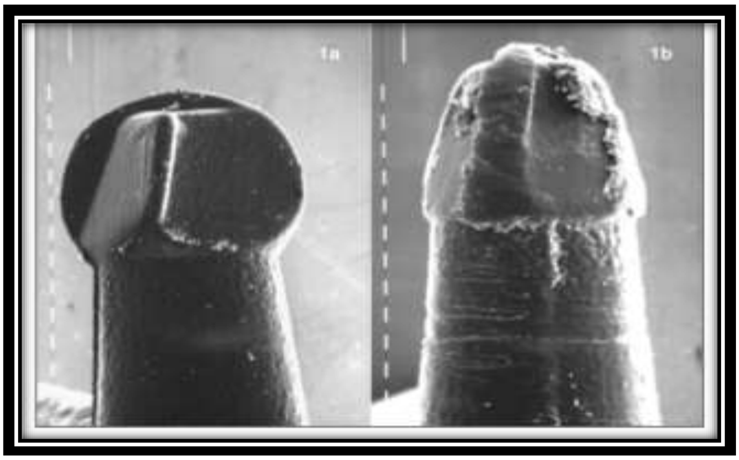

Fig. 7: Smart prep burs before and after the cavity preparation

Fig. 8: Smart prep bur kit

12. SMART SUTURES

These sutures are made up of thermoplastic polymers that have both shape memory and biodegradable properties. They are applied loosely in its temporary shape and the ends of the suture are fixed. When the temperature is raised above the thermal transition temperature, the suture shrinks and tightens the knot, applying the optimum force. 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 (Fig 9). Smart sutures are made of plastic or silk threads covered with temperature sensors and microheaters, which can detect infections. (Fig 10). Eg: Novel MIT Polymer (Aachen, Germany) [28].

Fig. 9: A smart suture shrinks and tightens the knot when the temperature is raised above the thermal transition temperature

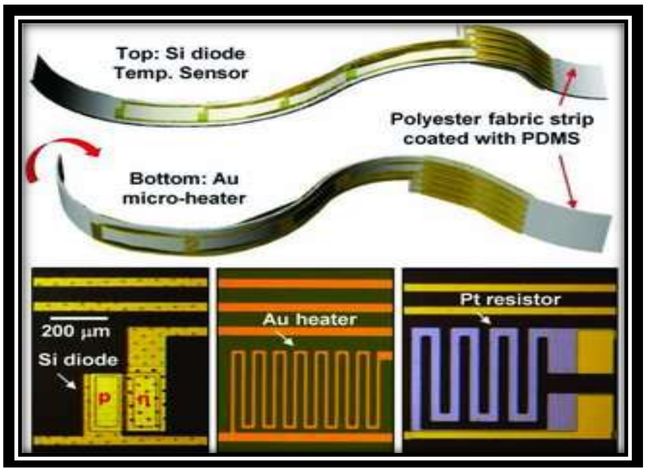

Fig. 10: Sutures integrated with silicon diode (Si) temperature sensor and Gold (Au) microheater

13. PHEROMONE GUIDED SMART ANTIMICROBIAL PEPTIDE

A new class of pathogen selective molecule called specifically (or selectively) Targeted Antimicrobial Peptides (STAMP) have been developed based on the fusion of a species-specific targeting peptide domain with a wide spectrum antimicrobial peptide domain. This pheromone-guided "smart" material peptide is targeted against the killing of Streptococcus mutans, the principal microorganism responsible for dental caries. 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-cariogenicmicro-organisms. Their molecules have the potential to be developed into "probiotic" antibiotics that will selectively eliminate pathogens while preserving the protective benefits of a healthy oral flora [29].
Ex: Pheromone guided "smart" antimicrobial peptide.

14. SMARTSEAL OBTURATION SYSTEM

Obturation of the root canals should prevent reinfection of the root canal space and ultimately prevent periapical disease. This may be achieved by the three-dimensional filling of the instrumented canal and accessory canals. While different canal filling techniques are currently available to achieve this goal, there is ongoing interest in developing simplified obturating materials/techniques for filling irregularly shaped canals and to minimize voids created during obturation procedures, which may act as nidi for the growth of residual biofilms [30].

The C Point system (EndoTechnologies, LLC, Shrewsbury, MA, USA), a smart seal obturation system is a point-and-paste root canal filling technique that consists of premade, hydrophilic endodontic points and an accompanying sealer. The deformable endodontic point (C Point) is available in different tip sizes and tapers and is designed to expand laterally without expanding axially, by absorbing residual water from the instrumented canal space. The inner core of C Point consists of a mix of two proprietary nylon polymers: Trogamid T and Trogamid CX. The polymer coating is a cross-linked copolymer of acrylonitrile and vinyl pyrrole, which are polymerized and cross-linked using allyl methacrylate and a thermal initiator. The lateral expansion of C Point occurs non-uniformly, with the expandability depending on the extent to which the hydrophilic polymer is prestressed (i.e., contact with a canal wall will reduce the rate or extent of polymer expansion). This nonisotropic lateral expansion enhances the sealing ability of the root canal filling, thereby reducing the possibility of reinfection.

15. SMART COATINGS FOR DENTAL IMPLANTS

North Carolina State University researchers have developed a "smart coating" that helps surgical implants bond more closely with bone and ward off infection. 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. The coating creates a crystalline layer next to the implant and an amorphous outer layer surrounding bone. The amorphous layer dissolves over time and releases calcium and phosphate, which encourages bone growth. The bone grows into the coating resulting in improved bonding osseointegration. This bonding also makes the implant more functional, because the bonding helps the bone and the implant to share the load.

The researchers have also incorporated silver nanoparticles throughout the coating to reduce infections. As the amorphous layer dissolves, silver incorporated into the coating is released which acts as an antimicrobial agent. This will limit the amount of antibiotics patients will need the following surgery, and will provide protection from infection at the implant site for the life of the implant. Moreover, the silver is released more quickly after surgery, when there is more risk of infection, due to the faster dissolution of the amorphous layer of the coating. The silver release will slow down while the patient is healing, therefore, it is called as smart coating [31].

16. 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. 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 [32].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.

17. CONCLUSION

In recent years there has been a significant enhancement and development of materials in dentistry. As the field of dentistry is dependent on the use of different materials, 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.

18. REFERENCES

[1] Badami V, Ahuja B.Biosmart materials: breaking new ground in dentistry.The Scientific World Journal. 2014; 14:1-7.
[2] McCabe JF, Yan Z, Al Naimi OT, Mahmoud Get al.Smart materials in dentistry. Aust Dent J. 2011; 56(1): 3–10.
[3] Gautam P, Valiathan A.Bio-Smart Dentistry: stepping into the future.Trends Biomater Artif Organs. 2008; 21(2): 94-7.
[4] Zrinyi M, Szilagyi A, Filipcsei G, Feher J, Szalma J, Moczar G. Smart gel-glass based on the responsive properties of polymer gels. Polymers for Advanced Technologies. 2001; 12: 501-505.
[5] Dube M, Ponnappa KC. Smart ART. J Int Oral Health. 2009; 1:52-7.
[6] Shanthi M, Sekhar EVS, Ankireddy S.Smart materials in dentistry: think smart. J Pediatr Dent. 2014; 2:1-4.
[7] Mangaiyarkarasi SP. Manigandan T, Sivagami S, Rajendran V et al. Biosmartdentistry. Annals and Essences of Dentistry. 2013; 5(4): 34-38.
[8] Available from:http://www.parliament.uk/parliamentary_offices/post/pubs2008.cfm
[9] Allameh SM, Akogwu O, Collinson M, Thomas J, Soboyejo WO. Piezoelectric generators for biomedical and dental applications: Effects of cyclic loading. J Mater Sci Mater Med. 2007; 18:39-45.
[10] Gil FJ, Planell JA. Shape memory alloys for medical applications. Proc Inst Mech Eng H. 1998; 212:473-88.
[11] Lendlein A, Langer R. Biodegradable, elastic shape-memory polymers for potential biomedical applications. Science. 2002; 296:1673-6.
[12] Stayton PS, El-Sayed ME, Murthy N, Bulmus V, Lackey C, Cheung et al. 'Smart'delivery systems for biomolecular therapeutics. OrthodCraniofa Res.2005; 8:219- -25.
[13] Rolland SL, McCabe JF, Robinson C, Walls AW. In vitro biofilm formation on the surface of resin-based dentine adhesives. Eur J Oral Sci.2006; 114:243-49.
[14] Shaw A, McCabe JF, Carrick TE. Fluoride release from glass ionomers and compomers. J Dent. 1998; 26:355–360.
[15] Momoi Y, McCabe JF. Fluoride release from light-activated glass ionomer restoration cement. Dent Mater. 1993; 9:151–154.
[16] McCabe JF, Carrick TE, Sidhu SK. Determining low levels of fluoride released from resin-based dental materials. Eur J Oral Sci. 2002; 110:380–384.
[17] Anson T. Shape memory alloys:Medical applications.Materials world.1999;7(12) :745-47.
[18] El Feninat, Laroche G, Fiset M, Mantovani D. Shape memory materials for biomedical applications. Adv Eng Mater. 2002; 4:91-104.
[19] Gautam, Valiathan A. Bio-smart Dentistry: stepping into the future. Trends Biomater. Artif.Organs.2008; 21(2):9-97.
[20] Revathi M, Rao CVN, Lakshmi Narayanan.Revolutions in endodontic instruments- a review. Endodontology. 2001; 13:43-47.
[21] Xu HH, Weir MD, Sun L, Takagi S, Chow LC. Effects of calcium phosphate nanoparticles on calcium phosphate composite. J Dent Res. 2007; 86:378-83.
[22] Skrtic D, Antonucci JM, Eanes, ED. "Amorphous calcium phosphate-based bioactive polymeric composites for mineralized tissue regeneration,"Journal of Research of the National Institute of Standards and Technology.2003;108 (3):167–182.
[23] Jandt KD, SiguschBW.Future perspectives of resin-based dental materials. Dental Materials.2009; 25(8): 1001–1006.
[24] Available from: http://www.cercon-smart-ceramics.com.
[25] Terry DA, Leinfelder KF, Lee EA, James A. The impression: A blueprint for restorative success. Int Dent SA.2006; 8:12-21.
[26] Davidson CL. Glass ionomer cement, an intelligent material. Bull Group IntRech SciStomatolOdontol.1998; 40:38-42.
[27] Dammaschke T, Schafer E. Efficiency of the polymer bur smart prep compared with conventional carbide bud bur in dentin caries excavation. Operative Dentistry.2006; 31(2): 256-60.
[28] Available from:http://www.technologyreview.com/news/428969/smart-sutures-that-detect-infections/.
[29] Eckert R, He J, Yarbrough DK, Qi F, Anderson MH, Shi W. Targeted killing of Streptococcus mutans by a pheromone-guided "smart" antimicrobial peptide. Trends Antimicrob Agents Chemother 2006; 50:3651-7.
[30] Economides N, Gogos C, Kodonas K, Belts C, Kolokouris I. An ex vivo comparison of the push-out bond strength of a new endodontic filling system (Smartseal) and various guttapercha filling techniques. Odontology.2012; 100(2):187–191.
[31] Bai X, More K, Rouleau CM, Rabiei A. Functionally graded hydroxyapatite coatings doped with antibacterial components.ActaBiomaterialia. 2010;6(6): 2264–2273.
[32] Konorov SO, Mitrokhin VP, Fedotov AB, BiryukovDAS et al. Hollow-core photonic-crystal fibers for laser dentistry. Phys Med. Biol. 2004; 49(7): 1359-1368.

