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Bio-Smart Materials in Dentistry -A Modern Approach to Materials and Review

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ABSTRACT:

Material in dentistry is not ideal in nature. As the hunt for an “ideal restorative material” continues, a newer materials was introduced. These are termed as “smart’’ as these materials support the remaining tooth structure. These materials may be altered in a controlled fashion by stimulus such as stress, temperature, moisture, pH, electric or magnetic field. These are “Biomimetic” in nature as their properties mimic natural tooth. The use of smart materials has revolutionized dentistry which includes the use of restorative materials such as smart composites, smart ceramics, compomers, resin modifed 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. This article attempts to highlights the use of “smart materials” in conventional restorative techniques in dentistry.

Introduction:

Traditionally, materials designed for long term use in the body or more specifically in the mouth are thought to survive longer if they are ‘*passive* ‘and have no interaction with their environment. Materials such as amalgams, composites and cements are often judged on their ability to survive without interacting with the oral environment. Perhaps the first inclination that an ‘*active*’ rather than *passive*’ material could be attractive was the realisation of the benefit of fluoride release from materials.[1]

Dental materials, processes and techniques are the subject of much applied research and development work, and the translation of this technology into new products is a part of future development. Smart or intelligent materials are materials that have the intrinsic and extrinsic capabilities, first, to respond to stimuli and environmental changes and, second, to activate their functions according to these changes. Smart materials may thus be defined as a class of materials that are highly responsive and have the inherent capability to sense and react according to changes in the environment. For that reason they are often also called responsive materials. The stimuli could originate internally or externally. Since its beginning, materials science has undergone a distinct evolution: from the use of inert structural materials to materials built for a particular function, to active or adaptive materials, and finally to smart materials with more acute recognition, discrimination and reaction capabilities.[1]

By definition and general agreement, smart materials are materials that have properties which may be altered in a controlled fashion by stimuli, such as stress, temperature, moisture, pH, electric or magnetic fields. Earlier smart material applications started with magnetostrictive technologies. This involved the use of nickel as a sonar source during World War I to find German U-boats by Allied forces. Depending on changes in some external conditions, "smart" materials change their properties (mechanical, electrical, appearance), their structure or composition, or their functions.[2]

Classification of Smart Materials:

1. ***Passive smart materials*** that respond to external change without external control. Passively smart materials possess self- repairing or stand-by characteristics.[1]

2. ***Active smart materials*** that utilize a feedback loop to enable them to function like a cognitive response through an actuator circuit;[1]

3. ***Very smart materials*** that sense a change in the environment and respond (e.g., by altering one or more of their property coefficients, tuning their sensing, or actuation capabilities); and[1]

4. ***Intelligent materials*** that integrate the sensing and actuation functions with the control system.[1]

Classification of Smart Materials used in Dentistry[3]

I. Passive Smart Restorative Materials: Respond to external change without external control.

- GIC
- Resin Modified GIC
- Compomer
- Dental Composites

Ii. Active Smart Restorative Materials:
Utilize a feedback loop to enable them to function like a cognitive response through an actuator circuit.

1. Restorative Dentistry

- Smart GIC
- Smart composites
- Ariston pHC

Prosthetic Dentistry

- Smart ceramics
- Smart impression materials

3. **ORTHODONTICS**

- Shape memory alloys

4.**ENDODONTICS**

- Niti rotary instruments

5.Smart Fibers For Laser Dentistry

Properties of SMART Materials

1. Nature of Smart Material

By definition and general agreement, smart materials are materials that have properties which may be altered in a controlled fashion by stimuli, such as stress, temperature, moisture, pH, electric or magnetic fields. A key feature of smart behaviour includes an ability to return to the original state after the stimulus has been removed.

Existing smart materials include piezoelectric materials which produce a voltage when stress is applied or vice versa. Structures made from these products can be made to change shape or dimensions when a voltage is applied. Likewise, a change in shape can be used to generate a voltage which can be used for the purpose of monitoring. Thermo-responsive materials, such as shape memory alloy or shape memory polymers adapt different shapes at different temperatures due to remarkable and controlled changes in structure. Magnetic shape memory alloys can change their shape in response to a change in magnetic field. PH-sensitive polymers are materials which swell ⁄collapse when the pH of the surrounding media changes.

Other materials change colour in response to changes in pH, light or applied voltage. Polymer gels offer a potential for smart behaviour. They consist of cross-linked polymer networks which may be inflated with a solvent such as water. The labile nature of the solvent enables a rapid and reversible swelling or shrinkage in response to a small change in their environment (e.g. temperature). The most common gel forming polymers are polyvinylalcohol (PVA), polyacrylicacid (PAA) and polyacrylonitrile (PAN). Microsized gel fibres may contract in milliseconds, while thick polymer layers may require much longer to react. It has been suggested that these gels can potentially deliver a stress equivalent to that of a human muscle of about equivalent size.[4]

2. Smart materials by chance or design

The future use of smart materials will involve a degree of ‘smart behaviour’ by design. However, smart behaviour was first noted in some materials by chance and the significance of the special nature may not be recognized as being of any practical use until sometime later. This was certainly the case for thermo-responsive materials, either shape memory alloys or shape memory polymers.

Shape memory alloys based upon NiTi alloys have been used in orthodontics for many years and their remarkable properties have been commented upon without any

insight into how the properties could be harnessed for a practical purpose. Likewise the potential thermo-responsive smart behaviour of some glass-ionomer cements was first suggested by Davidson and was then demonstrated as a result of attempting to measure the coefficient of thermal expansion. Heating or cooling of these materials may result in minimal dimensional change as the expected expansions (heating) or contractions (cooling) appear to be offset by a compensating reaction related to the movement of water in or out of the structure.[4]

3. Smart alloys – the first smart dental materials

The term ‘smart material’ or ‘smart behaviour’ in the discipline which is now loosely defined as ‘dental materials science’, was probably first used in connection with nickel-titanium alloys, or shape memory alloys (SMAs), which are used as orthodontic wires. Frustratingly, although these materials were found to have fascinating characteristics in relation to the way their structure ⁄ properties changed in response to strain and temperature, it has never been clearly explained how their characteristics could be used beneficially during patient treatment. The smart behaviour is essentially related to the ability of the alloy to initially undergo strain in response to stress in the normal way, but at the point identified as the yield stress there is a further increase in strain which in ‘normal’ alloys would be identified as irreversible yielding.[4]

In the SMA alloys, however, this ‘yielding’ is related to a reversible change in the crystal structure. The reverse process is temperature dependent, and this leads to difficulty in harnessing the characteristic for clinical benefit as the temperatures required can be very high. The phase changes involved in the crystal transitions involve a small exothermic ⁄endothermic response which can be used to monitor or measure the extent of the change. In order to fully utilize the super-elastic or shape memory characteristics, it would be essential to enable the phase transitions to occur in a controlled fashion. Wires exhibiting shape-memory behaviour at controlled temperature normally contain copper and ⁄ or chromium in addition to nickel and titanium.[4]

4. The bit part of water

Many types of smart behaviour are related to the ability of a gel structure to absorb or release solvent rapidly in response to a stimulus such as temperature. In the oral environment, the key solvent is water and the structures may be gels or salts which contain water which may be bound either strongly or loosely and therefore may be absorbed or released at different rates. Some types of smart behaviour may also be defined by any species, such as fluoride ions dissolved in the water and which are capable of undergoing reversible interactions with the gel, salt or oral structures. Depending upon the nature of the water and how strongly it is bound, the observed changes may be dependent upon the dimensions of the structures.[4]

5. Smart thermal behaviour

The vast majority of materials responds to a temperature change in a predictable manner. This involves a dimensional change characterized by the coefficient of thermal expansion or expansivity. One problem with dental filling materials is their tendency to expand and contract to an extent than the natural tooth tissue when subjected to hot or cold stimuli. When samples of restorative materials were heated to determine their values of coefficient of thermal expansion, an interesting observation was made. For composite materials, expansion and contraction occurred in the expected way and a coefficient could readily be determined, and whether testing was done dry or wet made little or no difference. For glass -ionomers, little or no change in dimension was observed when heating and cooling between 20 ºC and 50 ºC in wet conditions (Fig 1). In dry conditions, the materials showed a marked contraction when heated above 50 ºC. The explanation for this behaviour is that the expected expansion on heating is compensated by fluid flow to the surface of the material to cause a balancing of the dimensional changes. On cooling, the process was reversed. In dry conditions, the rapid loss of water on heating results in the observed contraction. This behaviour is akin to that of human dentine (Fig 2) where very little dimensional change is observed on heating in wet conditions and a marked contraction is noted in dry conditions. Both results can be explained by flow of fluids in the dentinal tubules. Hence, the glass-ionomer materials can be said to be mimicking the behaviour of human dentine through a type of smart behaviour. [4]

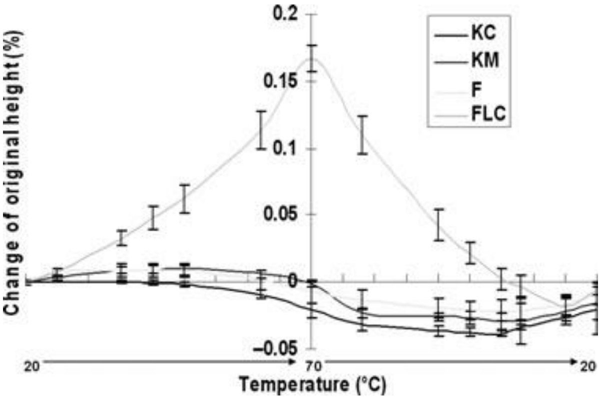

Fig 1. Dimensional change plotted against temperature for three glass-ionomers (KC, KM, F) and one resin modified glass-ionomer (FLC).[4]

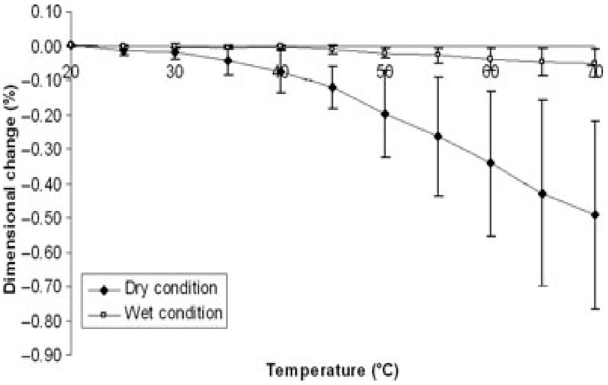

Fig 2. Dimensional change of human dentine when heated under wet or dry conditions.[4]

6. The role of porosity

The smart behaviour of glass-ionomers and related materials is closely linked to their water content and the way in which this can react to changes in the environment. One important feature which helps formation of reservoirs within the material is porosity. The number and size of pores within a cement can be controlled by the method of mixing and is conveniently measured using micro-CT scanning. (Figure 3) shows typical scans of glass-ionomer cement mixed mechanically in capsules or hand mixed. In the low viscosity material, hand-mixing reduces the porosity significantly compared to mechanical mixing, either by shaking or rotation. For the viscous material the levels of porosity are low and not significantly affected by mixing. Hence, this aspect of the smart behaviour of dental cements can be controlled by the operator.[4]

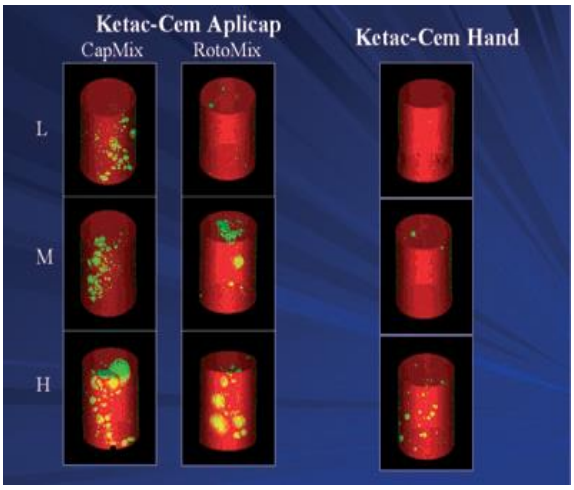

Fig 3. Micro-CT scans of a glass-ionomer cement (Ketac-Cem) mixed mechanically by shaking (CapMix) or rotating (RotoMix). L, M and H refer to low, medium and high examples of porosity within each group.[4]

7. Expansion and radial pressure

Smart materials which combine a special interactive characteristic with an acceptable durability or longevity are likely to combine some salt or gel characteristic with a resin component imparting some stability. The manufacturing of such materials presents a problem of compatibility. Traditionally, such problems are solved by also incorporating species with both hydrophilic and hydrophobic groups which have the function of bridging or coupling the two distinctly different ingredients. The most used of these compounds is hydroxyethylmethacrylate (HEMA). However, the large and rapid water absorption of polymers containing HEMA can cause problems; not only does the absorption result in swelling but a considerable radial pressure can also be linked to the process. Profiles of cavities containing a blend of GIC and resin phases with HEMA constrained within a cavity show the ‘growth’ of the material out of the cavity and this is combined with a considerable radial pressure measured as around 26 MPa compared with <3 MPa caused by the water absorption of a typical resin matrix composite.[4]

8. Biofilms and smart behaviour

Biofilms formed on the surface of materials in the mouth may enhance the smart behaviour of materials containing fluoride releasing salt phases. Recent work with saliva,

using live ⁄ dead staining techniques, has shown that fluoride release from materials does not prevent biofilm formation or growth. Figure 8 shows that the daily fluoride release in natural saliva is significantly lower than the release into distilled water or artificial saliva. However, when samples are stored in acidified (pH 4) saliva the rate of fluoride release is markedly increased (Fig 9).[4]

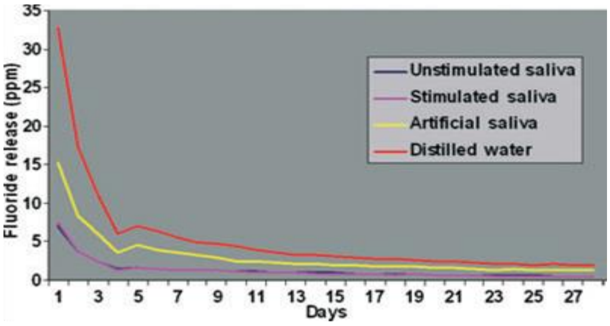

Fig 8. Fluoride release (24-hour values) from a GIC into different storage media. Release into natural saliva is slower than into water or artificial saliva.[4]

The presence of a biofilm on the surface of a material alters the interaction of the surface with the environment and in the case of a restorative material, the biofilm may act as a lubricant which prevents abrasive wear (Fig 10). The formation of biofilms and the way in which this changes the interaction of the materials with the environment represents a clear example of smart behaviour for these materials. It seems that biofilms can protect surfaces from abrasive forces and at the same time concentrate fluoride which is liberated through a change in pH or mechanical debridment.[4]

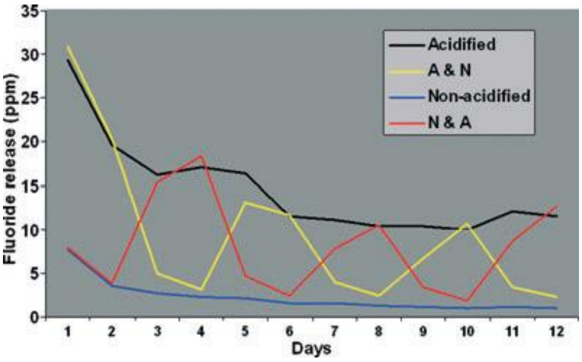

Fig 9. Fluoride release into natural saliva in acidified, neutral or cycled (A&N or N&A) conditioned. Note the marked increase in fluoride release over both the first and second day of placement into acidic conditions.[4]

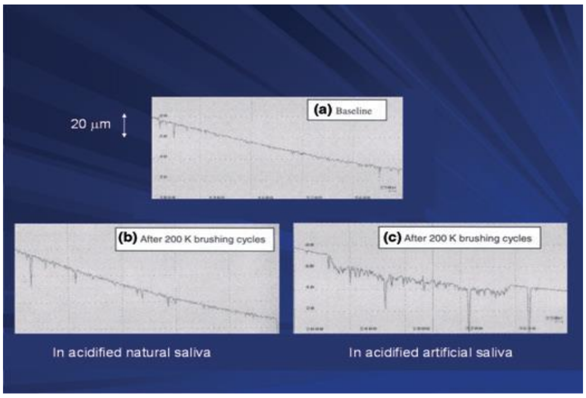

Fig 10. Surface profiles of a GIC at baseline and after brushing in acidified saliva (natural or artificial). This illustrates the protective effect of the biofilm formed in natural saliva.[4]

9. Design of smart materials

Now that the ways in which materials containing a polysalt matrix can exhibit smart behaviour have been demonstrated, it is appropriate to consider whether future materials can have 'smartness' designed into them. If so, can the smart behaviour be accommodated without compromising the other key requirements, such as clinical function and longevity. Of the currently available dental materials, the products which most positively react with their environment in a manner which could be interpreted as smart are the glassionomer cements. However, these products are known to have limited durability and longevity due to their brittleness and solubility.

Materials demonstrating an optimum combination of smart interactions and longevity are likely to have some combination of stable resin matrix combined with a coexistent salt matrix or discrete gel phase. The rapid developments in nanotechnology suggest that such features can be manufactured into compounds by using building blocks at a molecular or even atomic level.

However, in 1996 Friend stated, 'The development of true smart materials at the atomic scale is still some way off, although the enabling technologies are under development. These require novel aspects of nanotechnology (technologies associated with materials and processes at the nanometre scale, (10)9 m) and the newly developing science of shape chemistry'. This statement still holds true to an extent today. However, our understanding of the potential benefits of smart behaviour have enabled scientists to appreciate the

potential benefits of ‘active’ as opposed to ‘passive’ materials and the development of materials exhibiting smart behaviour is now recognized to be possible outside the realms of nanotechnology with its rather artificial and restricting boundaries and definitions.

Hence, even with existing technologies we are able to consider building materials with controlled structure and properties. Within the spectrum of materials which lie in the continuous scale between resin matrix composites and salt matrix glass-ionomers, we are already able to identify various materials described as resin modified GICs (RMGICs), polyacid-modified resin composites (compomers) or glass-ionomer composites (giomers).

These have been shown to exhibit some smart characteristics, albeit more through chance than design. The next stage is to harvest the current knowledge into the design of materials with controlled and designed structure in which the requirements of longevity and smart interaction are balanced. For example, when resin matrix and salt matrix setting reactions are competing during the setting of an RMGIC material, it is possible to conceive of means of controlling the extent to which one or other of the processes dominates and hence to influence the structure and properties of the set material.[4]

GIC- SMART GIC

The smart behavior of glass-ionomer (GI) cements was noted for the 1st time by Davidson. Glass-ionomer cements (GICs) are widely used in various branches of dentistry. One of the advantages of GI, compared to other restorative materials, is that they can be placed in cavities without any need for bonding agents; they also have good biocompatibility. Although GI are usually used as cements in dentistry, they have disadvantages, too. The most important disadvantage of conventional GI is lack of sufficient strength and toughness. In order to improve the mechanical properties of conventional GI, resin-modified glass-ionomers (RMGIs) have been introduced, which contain hydrophilic monomers and polymers like HEMA.

In some recent studies, bioactive glass (BAG) has been added to GI structure to improve its bioactivity and tooth regeneration capacity. There is increasing attention to and interest in the use of bioactive materials in dentistry, particularly in an attempt to remineralize dentin. BAG contains silicon, sodium, calcium and phosphorus oxides with specific weight percentages, which was introduced by Larry Hench in 1969 as 45S5 Bioglass with the following chemical composition and weight percentages: Na2O, 24.5%; SiO2, 45%; P2O5, 6%; and CaO, 24.5%.

Clinically, this material was initially used as a biomaterial to replace the lost osseous tissues in the human body. It produces a strong bond with bone through production of hydroxyapatite and formation of a strong bond between the collagen and the hydroxyapatite and is not rejected by the body.

Recent studies evaluated the effect of adding BAG on the setting and mechanical properties of RMGI. They reported that the compressive strength of the composition decrease a little, but it is much higher when it is compared with the conventional GIC containing BAG. They reported compressive strength values of 203.1 and 148.7 MPa for RMGIs (Fuji II LC) and its combination with 33 wt% of BAG, respectively. In a study carried out by Yli-Urpo *et al.*, too, BAG was added to (GIC). Then, the compressive strength, Young’s modulus and Vicker’s hardness of the composition were evaluated; it was reported that the experimental composition is biologically active under physiologic conditions and can mineralize human dentin *in vitro*. The material had also some antimicrobial activity. Xie used the polyacid he had invented to improve the mechanical properties of GI and BAG. He measured the compressive strength, diametral tensile strength, and hardness of the material and reported that its strength is comparable to that of commercially available Fuji II LC cement. However, only a limited number of studies have evaluated the effect of this material on the mechanical properties of tooth structures. Given the remineralization capacity of these materials in several studies, it is highly probable that these BAG-ionomers materials might be more effective in tooth restorations in open/close sandwich techniques or root surface restorations compared to RMGI or conventional GI, particularly in patients at a high-risk for caries. In addition, their use as a liner is highly contemplative[5].

SMART Composites

Composites containing Amorphous Calcium Phosphate (ACP). Amorphous Calcium Phosphate is one of the most soluble of the biologically important calcium phosphates, exhibiting the rapid conversion to crystalline hydroxyapatite.

Amorphous Calcium Phosphate is stable at neutral and at a high pH, but at a low pH (5.8 or less), Amorphous Calcium Phosphate converts into crystalline hydroxyapatite and precipitates thus replacing the hydroxyapatite lost. In the presence of a low pH these ions merge within seconds and form a gel. In less than 2 minutes this gel becomes amorphous crystals, resulting in calcium and phosphate ions. Crystalline hydroxyapatite is the final, stable product in the precipitation of calcium and phosphate ions from neutral or basic.[1]

ARISTON PH

Ivoclar Vivadent (Liechenstein) introduced Ariston pH (pH control) in 1998, which is claimed to release fluoride, hydroxide and calcium ions, when the pH in restorations of this material falls to the critical pH. This is said to neutralize acid and counteract the decalcification of enamel and dentin.[1]

SMART CERAMIC

Alumina, bioglass, hydroxyapatite, and tricalcium phosphate do not have high fracture toughness and flexural strength as in the case of zirconia. But all these materials work well within the human body for several reasons. They are inert, and because they are resorbable and active, the materials can remain in the body unchanged. They can also dissolve and actively take part in physiological processes. 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 – Smart Ceramics. 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 life like restoration with strength that helps resist crack formation. With Cercon unsightly dark margins and artificial grey shadows from the underlying metal are no longer a problem. Whether for "front" or "back" teeth, single unit or multi-unit bridges, Cercon Smart Ceramics deliver outstanding aesthetics without reservations or compromise. Zirconium oxide (ZrO2) is a highly stable ceramic oxide, typically used in industrial applications requiring high strength and stability and has a history as a biomaterial dating back to the1970s. It is used in implants and other non-dental applications extensively and is currently the material of choice for use in total hip replacements. The fracture toughness and flexural strength of zirconia are significantly higher than that of alumina or any other currently available All ceramic. The Cercon system offers a comprehensive solution to these needs by taking advantage of the strength, toughness, reliability, and biocompatibility of zirconium oxide. So the Cercon ceramics are said to be smart material as they are bioresponsive.[3]

SMART Impression Materials

These materials exhibit more:

- Hydrophilic to get void free impression.
- Shape memory during elastic recovery resists distortion for more accurate impression, toughness resists tearing.
- Snap — set behavior results in precise fitting restorations without distortion.
- Cut of working and setting times by at least 33%.
- Viscosity — materials with low viscosity have high flow.

Ex: Imprint™ 3 VPS, Impregim™, Aquasil ultra (3M ESPE Dental Products, USA).[11]

Shape Memory Alloys (SMA)

Shape memory alloys (SMA) constitute a group of metallic materials with the ability to recover a previously defined length or a shape when subjected to an appropriate thermo mechanical load. The remarkable properties of SMA have been known since 1930's. In 1932, Chang and Read noted the reversibility of the Au-Cd alloy not only by metallographic observations, but also by the observation of changes in resistivity. In 1938, Greninger and Mooradian observed the shape memory effect in Cu-Zn and Cu-Sn alloys. Nevertheless, it was only in the 1960's that SMA attracted some technological interest. In 1962, Buehler and co-workers, of the U.S. Naval Ordnance Laboratory, discovered the shape memory effect in an equiatomic Ni-Ti alloy which began to be known as Nitinol, as a reference to the initials of the laboratory. Raychem developed the first industrial application of SMA for the Aeronautic industry during 1960's. SMAs have come into wide use because of their exceptional superelasticity, shape memory, good resistance to fatigue and wear, and relatively good biocompatibility. Another commercially important application is the use of superelastic and thermal shape recovery alloys for orthodontic applications.

Archwires made of stainless steel have been employed as a corrective measure for malaligned teeth for many years. Owing to the limited flexibility and tensile properties of these wires, considerable forces are applied to teeth, which can cause a great deal of discomfort.[3]

Nickel Titanium Alloy:

Greniger and Mooradian in 1938, first noticed shape memory property of copper- zinc and copper tin alloys.Nickel-Titanium was developed 50 years ago by Buehler et al. in the Naval Ordinance Laboratory (NOL) in Silver Springs, Maryland. Nitinol basically exists in two phases. The low -temperature phase is called the martensitic or daughter phase (a body - centered cubic lattice) , and the high -temperature phase is called the austenitic or parent phase (hexagonal lattice).This lattice organisation can be altered either by stress or temperature.

In endodontics, 55wt% Ni and 45 wt% Ti are commonly used, referred to as 55NiTiNOL. Walia et al. in 1988 introduced Ni- Ti to Endodontics. The super-elasticity of NiTi rotary endodontic instruments provide improved access to curved root canals during the chemomechanical preparation with a less lateral force exerted. It allows more centered canal preparations with less canal transportation and a decreased incidence of canal aberrations. Nitinol shows stress-induced thermoelastic transformation. It is in an austenitic crystalline phase that gets converted to a martensitic structure on stressing at a constant temperature. In this martensitic phase, only a light force is sufficient for bending. If the stress is released, the structure recovers to an austenitic phase and its original shape.

In orthodontics, NiTi arch wires are used instead of stainless-steel owing to their limited flexibility and tensile properties. NiTi wires, because of their superelasticity and shape memory, apply continuous gentle forces on the teeth, which are in physiologic range over a longer period.[7]

Ni-Ti Rotary Protaper Files

SMARTSEAL OBTURATION SYSTEM

Obturation of the root canals should prevent reinfection of the root canal space and 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 need 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.

SMART FIBRES FOR LASER DENTISTRY

Transmission of high- energy laser pulses capable of ablating dental tissues is a crucial issue in laser dentistry (wigdor at al 1995, Fried1999, Strassl et al 2002). Flexible and convenient circuits for the delivery of laser radiation are needed to make the solution technologically attractive, which leaves no alternative to fibre-optic delivery. Laser radiation of high- fluency can be easily delivered by Hollow-core Photonic-Fibers (PCFs) i.e., the laser radiations can easily be snaked through the body using this Hollow-core Photonic-Fibers which are capable of ablating tooth enamel been developed. These 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 Fibre with a core diameter of approximately 14 µm are focused on a tooth surface to ablate dental tissue. Laser radiation transmitted through the Hollow- core PCF and focused upon the surface of a dry carious human tooth (in-vitro) induces an optical breakdown, resulting in plasma formation and dental tissue ablation. The laser breakdown was visulaized as optical characterization of the ablated enamel surface. Emission from laser produced plasmas transmitted through the Hollow core PCF in the backward direction and analysed with a Monochromator and a CCD camera. Thus, Photonic Crystal Fibre are 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. While using these fibers we ought to be very careful because there is a risk factor that in some cases the fiber walls fail and the laser light may escape and harm the healthy tissue.[3,20]

Smart Prep Burs:

Techniques used in caries removal include the mechanical rotary or non-rotary instruments, chemo-mechanical techniques and lasers. The non-invasive techniques include air abrasion, air polishing, ultrasonic and sonic abrasion. Smart Prep Burs are polymer burs which have ability cuts only infected dentin. The affected dentin which has the ability to remineralize is left intact. The cutting blades will deflect and deform upon encountering normal or partially decalcified dentin, thereby enabling the reduction of cutting efficiency. The time required for caries removal may be slightly longer, but when considered against the benefits they are awesome.[7,13]

Smart Sutures:

They are made up of thermoplastic polymers that have both shape memory and biodegradable properties. Smart sutures made of plastic or silk threads covered with temperature sensors and micro-heaters can detect infections. Sutures are loosely tied, once the temperature is increased above the thermal transition temperature; sutures gets shrinked and tightened. Ex: *Novel MIT Polymer* (Aachen, Germany).[7]

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.[19]

Conclusion:

The recent advances in the design of smart materials have created novel opportunities for their applications in bio-medical fields. These numerous applications of "Stimuli-Responsive or Smart Materials", no wonder tells us that these materials hold a real good promise for the future. The most sophisticated class of smart materials in the foreseeable future will be that which emulates biological systems. This class of multifunctional materials will possess the capability to select and execute specific functions intelligently in order to respond to changes in the local environment. Furthermore, these materials could have the ability to anticipate challenges based on the ability to recognize, analyze, and discriminate. These capabilities should include self-diagnosis, self-repair, self-multiplication, self-degradation, self-learning, and homeostasis. Furthermore, a material that has been damaged and is undergoing a process of self-repair would reduce its level of performance in order to survive. This intelligence should be inherent in future generations of smart materials. So, we're looking forward to the future, waiting impatiently to see what wonderful discoveries will appear in the materials domain. Investing in smart materials maybe a **SMART** decision for ensuring that future products will be competitive.[3,16]

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