doi:10.5368/aedj.2013.5.4.4.2

BIOSMART DENTISTRY

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ABSTRACT:. A good aesthetic appeal occupies a top priority in all fields of dentistry, which leads to an increased quest and concern towards better and more efficient technological perspectives. It poses a great challenge that has always been soaring high eventually from time immemorial. Today the most promising technologies for life time efficiency and improved reliability include the use of smart materials and structures. Smart materials are being used, and are continually being developed, for medical, defensive and industrial purposes. The recent advances in the design of smart materials have created novel opportunities for their applications in bio-medical fields. One of the important application is dental restoratives.

KEYWORDS: Dentistry, Smart, Restoratives, Materials

INTRODUCTION

Mostly all the materials were designed to act in a passive way with no interactions with the oral environment. This was to ensure the materials could survive longer and to allow them to be used for long periods. Then, it was realised that some materials were able to act in an 'active' way. For example, the ability to release and absorb fluoride, which can positively react in an oral environment. Materials showing this type of behavior are considered as “Smart materials”[1, 2]. McCabe Zrinyi[2] defined smart materials as "Materials that are able to be altered by stimuli and transform back into the original state after removing the stimuli". The stimuli can be derived from temperature, pH, moisture, stress, electricity, chemical or biomedical agents and magnetic fields. Due to the interesting behavior of smart materials, scientists have been encouraged to apply them in various fields, mostly in biomedical science and dentistry. There are various different types of smart materials currently available such as piezoelectric materials, shape memory alloys or shape memory polymers, pH sensitive polymers, polymer gels and others that have shown their own smart behavior.

Today it is one of the challenging tasks to manufacture new multifunctional materials which possess intelligence at the material level. Material intelligence is classified in to three functions: sensing changes in environmental conditions, processing the sensed information and finally making judgment (actuating) by moving away from or to the stimulus.[1]

By definition, 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 behavior includes an ability to return to the original state after the stimulus has been removed.[2] Smart materials are highly responsive and have a great capacity to sense and respond to any environmental change. Hence these materials are also known as “Responsive Materials”.

Classification

The classification of the smart materials used in dentistry is shown in table -1.

Applications of smart materials in Dentistry

SMART GIC

In developing new materials, proper investigation and design should be carried out; particularly in developing smart materials to ensure the outcome, the beneficial properties and the biocompatibility of the materials to be used with patients. However, the smart behavior of some materials was first noted by chance and the significance of special characteristics may not be identified in the practical use until sometime later. For example, it is vital to measure the coefficient of thermal expansion for dental filling materials because one of the major problems with

Table-I. classification of Smart materials

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

2. **PROSTHETIC DENTISTRY**
- Smart ceramics
- Smart impression materials

3. **ORTHODONTICS**
- Shape memory alloys.

4. PEDIATRIC AND PREVENTIVE DENTISTRY
- Fluoride releasing pit and fissure sealants
- ACP releasing pits and fissure sealants.

5. ENDODONTICS
- NiTi rotary instruments.

6. **SMART FIBERS FOR LASER DENTISTRY**

dental restorations is that they may contract and expand more than the tooth tissues when exposed to cold or hot stimuli which can leads to improper marginal seal. An interesting observation was made in a few studies as a result of attempting to measure the coefficient of thermal expansion of dental filling materials and Glass Ionomer Cements (GIC) have shown a potential thermo-responsive smart behavior . GICs have a coefficient of thermal expansion close to that of dental hard tissues. Through observation, there were minimal or no dimensional changes in GICs in terms of heating (expansions) and cooling (contractions) in wet conditions but the materials demonstrated a marked contraction when heated at 50° C in dry conditions. This action was due to the movement of water in or out of the structures which mimic the behavior of human dentin and indirectly shows the behavior of smart features. Due to this behavior , GICs can provide a good marginal adaptation to the restorations.

The potential beneficial effects of fluoride release of materials has been the subject of a lot of research over many years. There is some doubt about the efficacy of fluoride release in caries prevention since even products with high initial fluoride release tend to rapidly lose the ability to release fluoride in significant amounts. Even in the case of GICs the fluoride release rate can become negligible within a week.[3,4,5,6] However, the smart behavior of materials containing GIC salt phases offers some long term solutions to this problem. There is evidence that the fluoride released from salt phases can be replaced when the material is bathed in a high concentration of fluoride as may occur in a toothpaste or mouthrinse.[3,7,8.] In the long term, the fluoride re-released after recharging may be much more important than the initial 'burst' which is sustained only for a short time.

As the material becomes depleted of its inherent fluoride it is interesting that the 'spikes' of fluoride in the 24h period after recharging appear to increase slightly with age. This implies that the more inherent fluoride lost the greater capacity for uptake through re-charging. The levels of fluoride release maintained can be increased by beginning the recharging process as soon as possible after setting. Other work has shown that the rates of fluoride release and recharging are temperature sensitive.[7] Hence, a more rapid recharging could be accomplished by using warm fluoride containing solutions and this can generate a more sustained release at mouth temperature.

Mahmoud GA et al 2007 concluded that the use of fluoride releasing cements can minimise the demineralisation around orthodontic brackets and that this effect is not simply dependent upon the extent of the initial fluoride release. This has been studied using Quantitative Light-induced Fluorescence (QLF). [9]

Larmour CJ et al 2000 concluded that smart material involves the development of materials having mechanical properties adequate for the retention of brackets but which enable easy debonding of brackets at the end of treatment.[10]

SMART COMPOSITES

Smart composites contain Amorphous Calcium Phosphate (ACP), one of the most soluble of the biologically important calcium phosphates. The basic building blocks of tooth enamel is hydroxyapatite; it is also an inorganic component of dentin. In the case of carious attack hydroxyapatite is removed from the tooth resulting in cavities or white spots. The carious attack is usually the result of exposure to low pH conditions (acid attack) either from bacteria, other biological organisms releasing acid, food (carbohydrate decomposition products) or acidic beverages. ACP at neutral or high pH remains ACP. When low pH values ie., at or below 5.8 occurs during a carious attack, ACP converts in to 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 calcium and phosphate ions.[11]

ARISTON PHc

Ivoclar Vivadent (Liechenstein) introduced Ariston pHc (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.

PROSTHETIC DENTISTRY

SMART CERAMICS

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.[12]

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 strength and technology of Cercon allows bridges 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 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 (ZrO_2) 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.[12]

ORTHODONTICS

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. In 1975, Andreasen, of Iowa University, made the first implant of a superelastic orthodontic device. SMAs have come into wide use because of their exceptional superelasticity, shape memory, good resistance to fatigue and wear, and relatively good biocompatibility.[13]

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. Visits may be needed to the orthodontist for re-tensioning every three to four weeks in the initial stages of treatment. Superelastic wires are now used for these corrective measures. Owing to their elastic properties and extendibility, the level of discomfort can be reduced significantly as the SMA applies continuous, gentle forces which are in physiological range, over a longer period. Visits to the orthodontist are reduced significantly. Movements of 6mm in 6 months are possible with minimum discomfort. Devices also exist that can apply torsional forces in the case of a “twisted” tooth. Other wireforms can then be fitted to the brackets to push, pull, twist or force other movements that facilitate corrective measures for cosmetic or clinical reasons.[14]

PEDODONTICS

FLUORIDE RELEASING PIT AND FISSURE SEALANTS

Considering the fact that occlusal surfaces constitute only 12% of the tooth surface, they are eight times as vulnerable as smooth surfaces to caries.[15] So, prevention of occlusal caries assumes paramount importance in the preservation of tooth structure. The most appropriate period for the placement of occlusal sealants is soon after eruption of the permanent molars, because recently erupted teeth are less mineralized and teeth have also not undergone the benefits of post eruptive maturation of the enamel and may be thus more prone to acid attack. [16]

Two common methods of fluoride incorporation in to fissure sealant materials: a.) the anion exchange system(organic fluoride compound chemically bound to the resin), b) addition of fluoride salt to the unpolymerised resin. Examples are Fluoroshield and Deltonplus, contains sodium fluoride and release fluoride ions as the salt dissolves.[17]

Lygidakis NA, Oulis KI 1999 compared retention rates and caries increments between a fluoride-containing filled sealant (FluoroShield) and a conventional (not containing fluoride or filler) sealant (Delton) over 4 years in a regular biannual preventive program including topical gel application. They concluded that the fluoride-containing filled sealant (FluoroShield) appeared to have a lower complete retention rate when compared with (Delton). However, total sealant loss and caries increment was similar in both groups.[18]

The mechanism of fluoride release from the fluoride fissure sealant remains speculative. Fluoride release might occur from the insoluble sealant material as a result of porosity. It might also occur because the fluoride ion or the fluoride glass is not tightly bound to the polymerized resin molecules. Release in fluoride glass containing sealants may also be due to fluoride glass grains depositing on the surface of the resin.[19]

ACP RELEASING PIT AND FISSURE SEALANTS

ACP was first described by Aaron S. Posner in 1963 and today they are used as components of calcium phosphate coated implants, dental ceramics, chewing gums, toothpastes, mouthwashes and sealants.[14] Amorphous calcium phosphate is referred to as a "smart material" because it only releases calcium and phosphate ions when the surrounding pH drops (5.9) to a level where it could start to dissolve the tooth. Once the calcium phosphate is released, it will act to neutralize the acid and buffer the pH. ACP acts as a reinforcement to the tooth’s natural defense system only when it’s needed. A simple swish of water will bring the pH back to a neutral pH 7.4. Recent decade has introduced sealants that contain fluoride and ACP.[20]

ENDODONTICS

Nitinol endodontic files for root canal procedures offer superior flexibility, durability, and torqueability as compared to stainless steel files. This shape memory effect and super elasticity are useful in endodontics, which helps the superelastic files to benefit by maintaining close contour to the canal shape without concern of file breakage.[21]

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 FIBRES.[14]** 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.[22]

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!

References

1. Gandhi MV, Thompson BS. Smart materials and structures. 1992;Chapman and Hall, London, Glassgo, Newyork, Tokyo, Melbourne, Madras.
2. 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.
3. Al-Naimi OT, Itota T, Hobson RS, McCabe JF. Fluoride release for restorative materials and its effect on biofilm formation in natural saliva. Journal of materials science 2008; 19: 1243-1248.
4. McCabe JF, Carrick TE, Sidhu SK. Determining low levels of fluoride released from resin based dental materials. European journal of oral sciences 2002; 110: 380-384.
5. Momoi Y, McCabe JF. Fluoride release from light activated Glass Ionomer restorative cements. Dent Mater 1993; 9: 151-154.
6. Shaw AJ, Carrick T, McCabe JF. Fluoride release from Glass-Ionomer and Compomer restorative materials: 6-month data. Journal of dentistry 1998; 26: 355-359.
7. Yan Z, Sidhu SK, Mahmoud GA, Carrick TE, McCabe JF. Effects of temperature on the fluoride release and recharging ability of Glass Ionomers. Journal of Operative Dentistry. 2007 Mar-Apr; 32(2):138-43.
8. Itota T, Carrick TE, Yoshiyama M, McCabe JF. Fluoride release and recharge in giomer, compomer and resin composite. Dent Mater 2004; 20: 789-795.
9. Mahmoud GA, Pretty IA, Gordon PH, McCabe JF. Effect of fluoride-release on Enamel de-mineralisation adjacent to orthodontic brackets. BSDR. Durham, UK, 2007.
10. Larmour CJ, McCabe JF, Gordon PH. An ex vivo assessment of resin-modified Glass Ionomer bonding systems in relation to ceramic bracket debond. Journal of orthodontics 2000; 27: 329-332.
11. D.Skrtic J.M. Antonucci, E.D.Eanes Amorphous calcium phosphate- Based Bioactive Polymeric Composies for Mineralized Tissue Regeneration. J.Res.Natl.Inst.Stand.Technol 2003; 108:167-182. www.cercon-smart-ceramics.com
12. Maho Fukuizumi, Hiroshi Kakigawa and Yoshio Kozono. Utility of Ni-Ti Shape Memory Orthodontic Wire. Dental Materials Journal 18 (4): 413-424, 1999.
13. Pawan Gautam and Ashima Valliathan. Bio-smartdentistry. Stepping in to future. Trends Biomater. Artif. Organs 2008; 21(2): 94-97.
14. Parvathy Kumaran. Clinical Evaluation of the Retention of Different Pit and Fissure Sealants: A 1-Year Study. International Journal of Clinical Pediatric Dentistry, September-December 2013;6(3):183-187.
15. Charbeneau GT, Dennison J. Clinical success and potential failure after single application of a pit and fissure sealant: Four-year report. J Am Dent Assoc 1979;98: 559-564.
16. Tonia L. Morphis, Jack Toumba. K and Nick A. Lygidakis. Fluoride pit and fissure sealants: A review. International Journal of Paediatric Dentistry 2000; 10: 90-98.
17. Lygidakis NA, Oulis KI. A comparison of Fluroshield with Delton fissure sealant: Four year results. Pediatr Dent. 1999; 21:429-431.
18. Richard J. Simonsen. Pit and fissure sealant: Review of the literature. Pediatr Dent. 2002;24: 393-414.
19. Pit and fissure sealant with ACP products restorative aegis® pit & fissure sealant with ACP. Harry J. Bosworth Company, 2002-2013.
20. Revathi M Rao CVN and Lakshminarayanan L. Revolutions in Endodontic instruments- A review. Journal of Endodontology 2001; 13.
21. Stanislav O Konorov. Hollow-core photonic-crystal fibres for laser dentistry Phys. Med. Biol 2004; 49: 1359- 1368 .

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