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Smart Materials in Dentistry

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ABSTRACT *Most dental materials are designed to have a relatively 'neutral' existence in the mouth. It is considered that if they are 'passive' and do not react with the oral environment they will be more stable and have a greater durability. At the same time, it is hoped that our materials will be well accepted and will cause neither harm nor injury. This is an entirely negative approach to material tolerance and biocompatibility and hides the possibility that some positive gains can be achieved by using materials which behave in a more dynamic fashion in the environment in which they are placed. Some materials which are normally resistant to the healthy oral environment can undergo controlled degradation at low pH in order to release ions which may prove beneficial or protective. So Smartness is a relative term.*

INTRODUCTION

Conventionally, materials designed for long-term use 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 realization of the benefit of fluoride release from materials.

The nature of smart materials

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.[1]

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[2]. 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 alloys[3] or shape memory polymers[4] adopt 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.[5] Other materials change colour in response to changes in pH, light or applied voltage. One common example of this sort of technology is the light-sensitive sunglasses which darken when exposed to bright sunlight. Polymer gels offer a potential for smart behaviour.[1,6] 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 polyvinyl alcohol (PVA), polyacrylic acid (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.

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.[6,7] Recent work with saliva, using live⁄dead staining techniques[23] has shown that fluoride release from materials does not prevent biofilm formation or growth. More interesting are the results which show that when the specimens are cycled through both acidic and neutral conditions, an increase in fluoride release is seen at day 1 and then also at day 2 after placing into acidic conditions. This offers some proof that fluoride becomes concentrated within the biofilm and is made available when the film is disturbed. 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. 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.[16] 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.

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 glass-ionomer cements. However, these products are known to have limited durability and longevity due to their brittleness and solubility.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[12]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

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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,[17] 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.

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