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Biosmart Materials: Pioneering Innovation in Dental field

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Abstract: The majority of dental materials are made to live rather "neutrally" in the mouth. They'll be more stable and durable if they're 'passive' and don't react to the oral environment. It is also anticipated that our materials would be favorably received and not be harmful or injurious. This is a wholly unfavorable approach to material tolerance and biocompatibility, and it obscures the prospect that employing materials that respond more dynamically to their surroundings may yield some benefits.

Keywords: smart material; passive; active; shape memory; dentistry.

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Introduction

The needs for materials have increased during the last few decades. The ongoing human drive to improve the efficiency of all kinds of structures is the cause of this. An extensive range of high-performance materials have been employed to satisfy these growing needs. It has long been believed that materials intended for prolonged usage in the body—more especially, the mouth—survive longer when they are "passive," meaning they don't interact with their surroundings. The understanding of the advantages of fluoride release from materials may have been the initial inkling that a "active" as opposed to a "passive" material could be appealing (1). A class of materials known as "smart materials" is highly responsive and possesses the innate ability to sense and respond to changes in their surroundings. They are frequently referred to as "responsive materials" as a result. The stimulation may come from the outside or the inside. From the use of passive materials to active materials and ultimately to intelligent materials with more sophisticated identification, discrimination, and reaction capabilities, materials science has clearly evolved since its inception (2).

Definition:

The term "smart materials" refers to materials whose characteristics can be modified by external factors such pH, temperature, moisture, stress, and electric or magnetic fields (1). Not only can "smart" materials sense changes in their surroundings, but they can also respond appropriately. Consequently, it may be claimed that they have actuator and sensor properties (3).

Nature of Smart Materials:

Piezoelectric materials, which generate a voltage in response to applied stress or vice versa, are examples of existing smart materials. When a voltage is applied, structures constructed with these items can be made to vary in size or shape. Similarly, a voltage that can be used for monitoring can be produced by a change in form. Because of their extraordinary and regulated structural changes, thermo-responsive materials, including shape memory alloys or shape memory polymers, adopt distinct shapes at different temperatures. pH-sensitive polymers are materials that expand or contract in reaction to changes in the media's pH, while magnetic shape memory alloys are materials that can change their shape in response to a change in magnetic field (1).

Smart Materials in Dentistry:

Tissue engineering and thermoresponsive polymers for the administration of therapeutic molecules are two examples of the biomedical uses of smart materials in the dental profession (4). Shape memory alloys for orthodontic wires, coils, and springs, as well as cercon smart ceramics, which provide a dental repair with remarkably natural looks, are a few examples of smart materials used in dentistry. Furthermore, amorphous calcium phosphate-containing smart composites promote the restoration of damaged teeth and smart glass ionomer. High-fluence laser radiation is delivered via smart fibers to remove dental enamel. With these advancements in material science, a new era of Bio-Smart Dentistry has begun—a stride into the future!

An ***example*** here is titanium, which is used for dental implants and in orthopedic devices. When fresh titanium is exposed to air it reacts rapidly with atmospheric oxygen to form a surface oxide which is typically a few nanometers thick. The oxide stoichiometry is approximately TiO_2. The surface is never perfectly clean TiO_2, for the TiO_2 terminated surface tends to bind molecules or atoms from the surroundings as a mono-molecular layer (1).

Thermoresponsive Polymers

Since polymers can be more easily customized and are less expensive than metals or ceramics, they form the basis of one of the main categories of "smart" materials. These "smart" polymeric materials react to a variety of stimuli, including temperature, pH, and chemical and biological stimuli. Temperature-responsive polymers find use in tissue engineering, medication delivery, and gene delivery, among other biological applications. Based on their three-dimensional structure, thermoresponsive polymers can be classified as hydrogels, films, micelles, crosslinked micelles, and interpenetrating networks (4).

Drug Delivery

As the name implies, drug delivery is the process or method of giving a pharmaceutical molecule (drug) to an animal or human in order to generate a therapeutic effect. Getting the medication to the correct place at the right time in the right concentration are crucial. Nevertheless, there are numerous barriers in the way of effective medication administration. These challenges include, but are not limited to, the medicines' low solubility, rapid body clearance rates, enzymatic or environmental degradation, non-specific toxicity, and failure to pass biological barriers (5,6). Drug delivery vehicles, the majority of which are based on polymers, are being used to get around these problems (5-7).

However, it is challenging to achieve the desired regulated release rate even when employing a carrier to administer the medication. In particular, drug delivery is frequently troublesome because the released drug's concentration in the target area is either too high or too low, and it is not supplied for the desired duration of time. Therefore, it is difficult to achieve the desired, regulated medication release that is frequently associated with a zero-order kinetic rate. Consequently, medication delivery uses "smart" polymeric carriers. Because these carriers release the drug only in reaction to an external stimulation, medication can be delivered at the appropriate timing and concentration. For instance, when the temperature rises, a carrier's polymer chains may expand, allowing the medication to diffuse out and be freed from the carrier (8).

Gene Delivery

As a method of fixing faulty genes that cause various genetic diseases, gene therapy attempts to treat a wide range of hereditary illnesses. of particular, a crucial stage of gene therapy is introducing the right therapeutic gene (DNA) into the cells to replace, repair, or regulate the damaged gene responsible for the illness. However, because DNA is a negatively charged, hydrophilic molecule, it is not possible to carry it into the cell's nucleus through the similarly negatively charged, hydrophobic cell membrane.(4)

As a result, carriers for gene delivery—also referred to as vectors or vehicles—have been created (9, 10). Since polymers are less expensive, safer, and easier to work with than alternative gene delivery vehicles like liposomes, a large number of these are based on polymers (8–12). Utilizing a polymeric carrier, also known as transfection, entails the following steps: (1) complexation of DNA and polymer; (2) addition of DNA/polymer complex (also known as polyplex) onto cells for a duration of time commonly referred to as the transfection time; (3) complex removal from the cells; and (4) incubation time, during which the cells are left to incubate until outcomes are observed. While the incubation and transfection phases are held at 37 °C (the body temperature that the cells require to live), complexation is often carried out at room temperature (4).

Tissue Engineering

The multidisciplinary discipline of tissue engineering uses concepts from biology and engineering to create biological replacements that enhance or restore tissue function (13). In tissue engineering, a scaffold or other substance is used to seed cells, which cause the tissue to mature as a result. This necessitates the employment of a biocompatible scaffold or substance, typically made of synthetic polymers or natural materials like proteins, with the right 3D shape to give encapsulated cells enough mechanical support and the ability to transfer growth hormones and nutrients (14). In tissue engineering, thermoresponsive polymers are frequently utilized in two ways: as injectable gels for in situ scaffolding and as substrates that support cell growth and proliferation. In the first application, the polymers' capacity to respond to heat is employed to control how tightly or loosely cells adhere to a surface. In the second use, cells are enclosed within a three-dimensional bodily structure. By adopting minimally invasive approaches, defects of any shape can be treated with encapsulated cells, nutrients, and growth factors thanks to the in situ construction of the scaffold, which differs from the construct's in vitro formation. In particular, the cells and thermoresponsive polymer are combined at room temperature before being injected into the body. The temperature rises to 37 °C during injection, causing the polymer to physically gel. The gel's three-dimensional structure contains the cells (4).

Shape Memory Alloys

In the 1930s, the form memory effect in materials was first noticed. Working with an alloy of gold (Au) and cadmium (Cd), Swedish physicist Arne Olander (1932) discovered an intriguing occurrence. The Au-Cd alloy underwent plastic deformation when cooled, and it reverted to its initial or "memorized" dimensional shape when heated. The alloys that displayed this behavior were referred to as Shape Memory Alloys (SMA), and the phenomenon was named the Shape Memory Effect (SME). Greninger and Mooradian (1938) used temperature c hangs to examine the emergence and disappearance of a martensitic phase in a Cu-Zn alloy. Additional investigation turned up more materials that proved this phenomenon as well. At the US Naval Ordnance Laboratories, the shape memory capabilities of nickel titanium alloys were unintentionally found in 1962. Nitinol (Nickel Titanium Naval Ordnance Laboratory) was patented (15).

The ability of shape memory alloys (SMAs) to go through a solid-to-solid phase transition distinguishes them from other metals. Because of this property, they can adopt two distinct crystalline lattice structures (austenite and martensite), which vary according to temperature and applied stress (15).

The crystallographic term for a SMA's low temperature phase, which begins to develop during cooling, is martensite. This is because, below a specific transition temperature, the martensitic crystalline structure is more thermodynamically stable. Depending on the local stress field, martensite can have a wide variety of lattice patterns when it emerges from austenite crystals in different directions. The structure may also seem de-twinned or twinned. Because the molecular arrangement can readily shift to a lattice layout that is more favorably aligned with the local stress field, this phase is when a SMA is most easily deformed. The twinned borders' movement is mostly to blame for this (15). A phase transition is usually brought about by a temperature shift. The martensite-start temperature (Ms) is the temperature at which the SMA begins to transition into the martensite phase. When the temperature drops below the martensite-finish temperature (Mf), this transition is finished (15).

A shape memory alloy's strong, high-temperature austenite phase makes up the second crystalline lattice structure. The alloy exhibits a high modulus of elasticity due to the symmetrical structure of its cubic molecular arrangement in the austenite structure. Compared to the martensitic structure, this austenitic structure is far stronger.

Once more, temperature changes cause the phase transition to occur. At the austenite-start-temperature (As), the austenite phase begins to develop from the martensite phase. When the temperature rises above the austenite-finish-temperature (Af), this process is finished. Nonetheless, an applied stress has the ability to cause the change of austenite to martensite above the Af temperature. We refer to this as SIM, or strain-induced martensite. This SIM is the superelastic Effect's operating theory. The precise chemical makeup of the SMA can cause a large range in the transition temperatures (15).

In summary, temperature and stress can both cause transformation between the martensite and austenite forms. The low-temperature, high-stress form is called martensite, whereas the high-temperature, low-stress form is called austenite (16). Three unique qualities are displayed by SMAs as a result of this solid-to-solid phase transition: the Shape Memory Effect, Martensitic Deformability, and Superelastic Effect (15).

Shape Memory Effect

The ability of SMA, which has been "plastically" distorted, to restore a "memorized" shape by heating it sufficiently to finish the solid-to-solid phase transition is known as the Shape Memory Effect (SME). An SMA element can provide a significant amount of effort during this form recovery (15, 17).Thus, by heating the element over a specific temperature, SMA elements are able to regain a "memorized" or preset shape. The element is given the predefined shape during high-temperature manufacturing, which results in the SMA being in its austenitic state. This effect is based on the SMAs' solid-to-solid phase transition, which occurs within a particular temperature range. (15, 17). A SMA element will be fully in the martensite phase, where it is easily deformable, if its temperature is lowered below the Mf temperature. The element will stay distorted following a clear "plastic" deformation as long as the temperature remains below the transition point, which keeps the SMA in the martensitic phase.

The structure of the SMA will, however, revert to its austenite state, which is set up in the wire's initial shape, if the element is heated over the Af-temperature. The element will so revert to its initial "memorized" shape (15, 17). Furthermore, a SMA element might produce a lot of work and very high forces during the phase transformation if an external mechanical component prevents this shape recovery. For this reason, SMA components have a range of applications where they can be effectively used as actuators (15, 17). The one-way and two-way effects can now be separated into two groups inside the SME:

One-Way Effect

The differently aligned martensite structure will de-twine if a SMA member is deformed while it is in the martensitic state. When the load is released, the SMA element will maintain its distorted shape, much like regular plastic deformation. Nevertheless, the material will change from its martensite to its austenite condition and revert to its initial, "memorized" shape when heated. The SMA element can produce a substantial amount of work during this form change. As long as there is no external stress during this transition from austenite to martensite, the element usually does not undergo a reverse shape change if it is subsequently cooled to its martensitic phase (15, 17).

Two-Way Effect

The term "two-way effect" refers to a unique type of SME in which a shape change is caused by both the heating and cooling of a SMA element. This two-way phenomenon allows SMA components to "remember" both a low-temperature, martensitic structure and a high-temperature, austenitic shape. A SMA element can alternate between these two shapes based on temperature because to its property. Such an impact might be caused by a certain thermomechanical treatment (15, 17).

Martensite Deformability

In the martensitic phase, a SMA member is extremely malleable. This implies that it has a far lower risk of fracture than traditional materials since it may be bent repeatedly without strain hardening. The martensite structure's twinned structure is the cause of this. The twin borders are freely movable and do not create dislocations, which are thought to be the first signs of fracture. Martensite Deformability is the term for this characteristic. Moreover, following deformation, the element can regain its original shape when heated. The Shape Memory Effect helps achieve this (15, 17).

Superelastic Effect

When a load is applied to typical materials that exhibit elastic deformation, the deformation will eventually dissipate when the force is removed. This normal elastic deformation differs from the superelastic deformation that takes place in SMAs in that the former can be elastically stretched or compressed five to ten times more than that of conventional materials. This phenomenon is known as the superelastic effect (in engineering material science, pseudoelasticity). At temperatures higher than those required to convert the SMA from martensite to austenite (Af), this effect can be seen. The alloy's chemical composition should be changed to match the transformation temperature to the outside temperature where the SMA is meant to be used in order to exhibit the PE (15, 17).

The superelastic Effect happens without a temperature shift, in contrast to the Shape Memory Effect. This is due to the fact that the application of a load has the ability to produce the solid-to-solid phase change that gives rise to the unique features of SMAs. An SMA element exhibits elastic initial behavior when it is loaded during the austenitic phase. Simply because of the loading, the austenite structure changes into martensite when the load is increased to a particular point. The term "stress induced martensite (SIM) transformation" refers to this procedure. Since the martensite phase is far less stiff than the austenite phase, if this transformation is complete, the material will begin to deform elastically once more (15, 17).

The material will unload elastically until the stress is low enough to initiate the transition back into the parent austenite phase if the loading is removed before the material plastically yields. This is made possible by the element's constant temperature above the transition temperature Af. The material will finish transforming back into its austenite phase and will unload elastically until the zero stress point is reached if the stress is decreased even further. The SMA element can regain all of its generated strain and its original, undeformed shape at zero stress during this unloading process (15). The phase transitions from austenite to martensite and vice versa include energy loss (hysteresis). For both full and partial transformations, the amount of energy wasted is proportionate to the degree of transformation finished during the loading cycle. Minor loop hysteresis cycles are another name for these partial transformations, which cause the SMA to simultaneously consist of the austenite and martensite phases (15, 17).

References

1- **McCabe JF, Yan Z, Al Naimi OT, Mahmoud G, Rolland SL**. Smart materials in dentistry – future prospects, Dent Materials J 2009; 28(1): 37-43.
2- **Akhras G.** Smart Materials and Smart systems for the future, Canadian Military Journal 2000; 25-32.
3- **Wijst MW** . Shape Control of Structures and Materials with Shape Memory Alloys. Ph.D. Thesis, Eindhoven University of Technology, Netherlands, 1999.
4- **Ward MA, GeorgiouTK.** Thermoresponsive Polymers for Biomedical ApplicationsPolymers 2011, 3, 1215-1242; doi:10.3390/polym3031215.
5- **Juillerat-Jeanneret L.** The targeted delivery of cancer drugs across the blood-brain barrier Chemical modifications of drugs or drug-nanoparticles? Drug Discov. Today 2008, 13, 1099-1106.
6- **GoodmanTT, Pun SH.** 3-D tissue culture systems for the evaluation and optimization of nanoparticle-based drug carriers. Bioconjugate Chem. 2008, 19, 1951-1959.
7- **Ganta S, Devalapally H, Shahiwala A, Amiji M.** A review of stimuli-responsive nanocarriers for drug and gene delivery. J. Control. Release 2008, 126, 187-204.
8- **Hatefi A, Amsden B**. Biodegradable injectable in situ forming drug delivery systems. J. Control. Release 2002, 80, 9-28.
9- **Merdan T, Kopecek J, Kissel T**. Prospects for cationic polymers in gene and oligonucleotide therapy against cancer. Adv. Drug Deliv. Rev. 2002, 54, 715-758.
10- **Felgner PL**. Nonviral strategies for gene therapy. Sci. Am. 1997, 276, 102-106.
11- **Han S, Mahato RI, Sung YK, Kim SW.** Development of biomaterials for gene therapy. Mol. Ther. 2000, 2, 302-317.
12- **Kabanov AV.** Taking polycation gene delivery systems from in vitro to in vivo. Pharm. Sci. Technol. Today 1999, 2, 365-372.
13- **Langer R, Vacanti JP.** Tissue engineering. Science 1993, 260, 920-926.
14- **Place ES, George JH, Williams CK, Stevens MM.** Synthetic polymer scaffolds for tissue engineering. Chem. Soc. Rev. 2009, 38, 1139-1151.

15- **Rutten S.H.** 'Smart' Materials in Automotive Applications, Mechanical Engineering/ Computational and Experimental Mechanics/ Mechanics of Materials. Technishe Universiteit Eindhoven. MT03.19, 2003: 1-12.
16- **Anusavice KJ.** Phillips' Science of Dental Materials, Eleventh Edition, Saunders, 2003; 646-649.
17- **Janocha H.** Adaptronics and Smart Structures, Basics, Materials, Design and Applications. Springer-Verlag, Berlin, 1999.