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Smart materials in endodontics

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Abstract
Change is unavoidable, but advancement is a choice; because to breakthrough new technology, modern dentistry today has access to a wide range of excellent restorative materials. Biomimetic materials are frequently employed nowadays due to their biocompatibility and good physio-chemical characteristics. They can be used as long-lasting aesthetic and restorative materials, as well as cement, root repair materials, root canal sealers, and filling materials, thanks to their improved biocompatibility, high stress resistance, sealing ability, and antibacterial qualities. Since their qualities mimic natural tooth substance such as enamel or dentine, the concept of producing smart materials in dentistry has gained attention. These materials have the potential to provide novel and ground-breaking dental procedures with dramatically improved clinical outcomes. To eliminate the canal microbials, a variety of medicaments and irrigants are used. Many pathogens have developed resistance to the medications and irrigants that have been employed. Antibacterial nanoparticles have thus been developed to address this issue. Nano dentistry refers to the use of nanomaterials and dental nanorobots in diagnostic and therapy with the goal of improving overall oral health. We can have a better knowledge of these materials with the help of this review.

Keywords: Smart materials, biomimetic, endodontics, nanoparticles

Introduction
Smart materials have been used for a large number of applications. The terms 'smart' and 'intelligent' were first used in the 1980s in the United States to describe materials and systems. These smart materials were developed by the government agencies working on military and aerospace projects but recently their use has been transferred into the civil sector for applications in various areas. The first smart material use began with magnetostrictive technology, which featured the use of nickel as a sonar source to locate German U-boats by Allied forces during World War I [1].

Definitions
McCabe Zrinyi defined smart materials as "Materials that are able to be altered by stimuli and transform back into the original state after removing the stimuli" [3].

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." 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".[1]

The property that can be changed is colour, refractive index, distribution of stresses and strains or a volume change [2].

Routinely used materials in dentistry were designed to be passive and inert, that is, they exhibit little or no interaction with body tissues and fluids [1].

Based on their interaction with the environment the materials can be classified as bioinert, bioactive and bio-responsive/smart materials [4].

Materials designed for long term use in body or oral cavity are considered to be "passive" in nature and are designed so that there is no interaction with the internal environment [5].

These are called "biomimetic" because their qualities are similar to natural tooth structures like enamel and dentin [1].

It was coined by Otto Schmitt in 1950. Biomimetic is basically defined as the study of structure & function of biological systems as models for design and engineering of materials & machines [4].
Takagi (1990) described them as intelligent materials as they respond to environmental changes at the most favourable conditions and reveal their own functions according to the environment. These materials have special characteristics like they can sense stimuli from surrounding environment and react to it in useful, reproducible, beneficial and reliable manner.
The use of smart materials in dentistry makes work easier and more reliable.
There is a list of smart materials introduced in dentistry such as restorative materials like composites, smart ceramics, amorphous calcium phosphate releasing pit and fissure sealants, smart sutures and smart burs, orthodontic shape memory alloys wire, Material intelligence can be classified in three functions: sensed information is processed, sensing change in environmental conditions is sensed and finally decisions are made by moving to the stimulus [6].
Some researchers insist that no material by itself is truly smart, by being simply responsive. They insist that materials cannot be considered smart by just producing a response in proportion to a stimulus, but should include principles, such as adaptation and feedback and the most important property of any biomaterial is biocompatibility [7].

Biomimetic paradigms

1. Maximum bond strength – Reduction in polymerization stress to the developing hybrid layer results in increase in bond strength. This strong bond allows the biomimetically restored tooth to function & handle functional stresses like an intact natural tooth.
2. Long term marginal seal: a strong & secure bond allows for long term marginal seal to be established & maintained during functional stresses.
3. Increase Pulp Vitality
4. Reduced Residual stress – Reduced residual stress while maintaining the maximum possible bond strength is the ultimate goal of any biomimetic restorative technique. [4]

Mechanism of smart materials

Bio-smart materials works by two mechanisms:

- To promote tissue repair and regeneration, it has inductive and instructional effects on cells and tissues by responding to external and internal stimuli such as pH, temperature, magnetic and ionic strength.
- It has intelligently altered individuals' properties and controlled functions to actively engage in tissue regeneration [8].

Criteria for a smart material

- Asymmetrical nature
- Receiving and responding to stimuli
- Include at least one material with a smart structure [8]

Nature of smart materials

Smart materials, by definition and general agreement, are materials with properties that can be controlled by stimuli such as stress, temperature, moisture, pH, electric or magnetic fields [9].

1. **Piezoelectric material:** These are materials which produce a voltage when stress is applied or vice versa. Likewise, a change in shape can be used to generate a voltage which can be used for the purpose of monitoring [9].

2. **Electro strictive materials:** Properties as piezoelectric material, but the mechanical change is proportional to the square of the electric field. This property always results in displacements in the same direction.

3. **Magneto strictive materials:** Similar to piezoelectric, respond to only magnetic fields rather than electric. One example used in dentistry is magnetostrictive ultrasonic scaler. For example, Dentsply Cavitron™.

4. **Elastostrictive materials:** These smart materials exhibit high hysteresis between stress and strain. The atoms in a part of an elastostrictive material do not restore to their original configuration when stress or strain is removed.

5. **Electrorheological materials:** By applying an electric or magnetic field to these materials, they can rapidly modify their rheological properties.

6. **Magnetorheological materials:** These fluids contain either ferromagnetic or ferromagnetic particles that are dispersed or suspended, and a magnetic field is used as a stimulus.

7. **Thermoresponsive material:** The presence of a glass transition temperature distinguishes amorphous and semi-crystalline thermoplastic polymers.

8. **pH sensitive materials:** Materials that change colour due to changes in acidity are known as pH-sensitive materials. The term "photochromic" refers to materials that change colour in reaction to light.

9. **Light sensitive materials:** There are several material families that exhibit different types of behaviour to light stimulus. Electro-chromism is a change in colour as a function of an electric field.

10. **Smart polymer:** Smart polymers or stimuli-responsive polymers are high-performance polymers that change according to the environment they are in. [2]

11. **Smart gels:** The concept of smart gels combines the basic concept of solvent-swollen polymer networks with the ability of the materials to respond to a variety of stimuli. Some gels can expand to hundreds of times their original volume or could collapse to expel upto 90% of their fluid content with a stimulus of temperature [9].

12. **Unusual behaviour of materials:** As one researches in the field of smart materials and structures, one realizes that there are many smart materials or that there are many material behaviours that are reversible within their lifetime. It is up to one's imagination to create useful goods out of smart materials, example water, it is a very unique material

Classification of smart materials [1, 10]

Passive smart materials: The materials that release ions in the oral cavity continuously with or without the necessity to prevent caries. These materials respond to external changes without any external stimuli.

1. Glass ionomer cement,
2. Compomers
3. Dental composites
4. resin-modified glass ionomer cement

Active smart materials: The materials that can react favourably when there is a hazardous variation in the environment surrounding the restoration or when there is a need for materials.

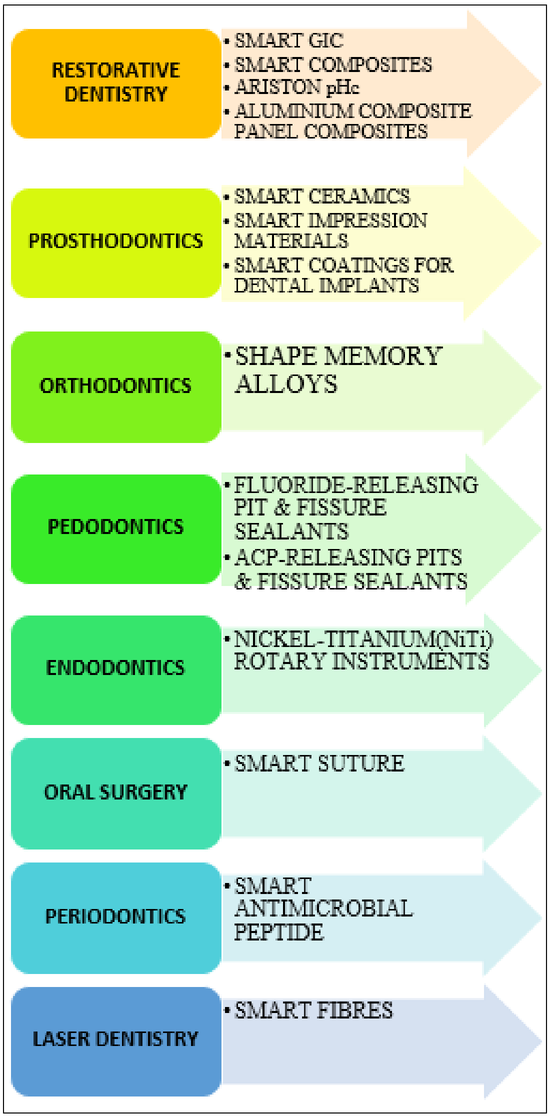

Fig 1: Smart materials in dentistry

In Endodontics

NiTi rotary instruments

Walia *et al*. introduced NiTi to endodontics in 1988. The super elasticity of NiTi rotary instruments provides improved access to curved root canals during the thermomechanical preparation, with less lateral force exerted. It allows for more centered canal preparations, less canal transportation, and fewer canal aberrations [11].

When stressed at a constant temperature, nitinol transitions from an austenitic (strong and hard) crystalline phase to a martensitic (very elastic) structure. Bending requires only a light force in this martensitic phase. When the stress is released, the structure returns to its original austenitic phase and shape. This phenomenon is called stress-induced thermo elastic transformation [1].

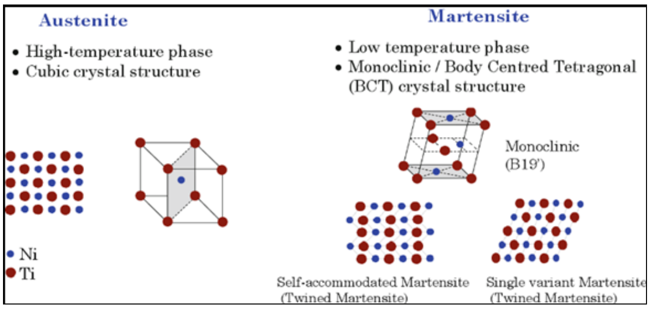

Fig 2: Phases of NiTi alloy

Restorative dentistry

Smart composites

SKRTIC created novel biologically active restorative materials with an aluminium composite panel (ACP) filler enclosed in a polymer binder, which may encourage tooth structure regeneration by releasing considerable amounts of calcium and phosphate ions over time [1].

Self-healing composites

One of the first self-repairing or self-healing synthetic materials reported interestingly shows some similarities to resin-based dental materials, since it is resin-based [11]. Because this is an epoxy system with resin-filled microcapsules, if the epoxy composite material cracks, some of the microcapsules disintegrate near the crack, releasing the resin. The resin then fills the crack and reacts with a Grubbs catalyst placed in the epoxy composite, causing the resin to polymerize and the crack is repaired [1].

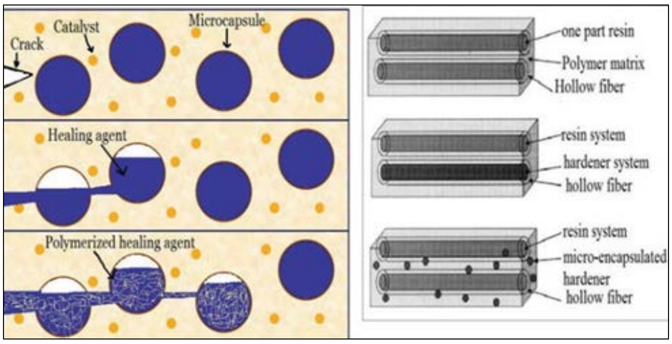

Fig 3: Mechanism of the microcapsule approach in Self-healing composite

Smart glass ionomer cement (RMGIs)

After many studies on coefficient of thermal expansion it was seen that Glass Ionomer Cement (GIC) has potential thermo responsive smart behaviour. Davidson first suggested the smart behaviour of GIC. It is related to gel structure's capacity to absorb or release solvent quickly in response to a stimulus such as temperature or pH change. As a result, the glass-ionomer materials can be said to be smart enough to simulate the behaviour of human dentine [1].

The other aspect of the smart behaviour of these materials is the fluoride release and recharge capacity [11].

Resin-modified glass ionomer cement, compomer or giomer are also seen to exhibit these smart characteristics.

E.g. GC Fuji IX EXTRA

Smart prep burs

Smart prep burs are polymer burs are used to 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 selectively remove carious dentin while keeping healthy dentin intact. The polymer cutting edges wear down on coming into contact with harder materials, such as healthy dentin and becomes blunt [1].

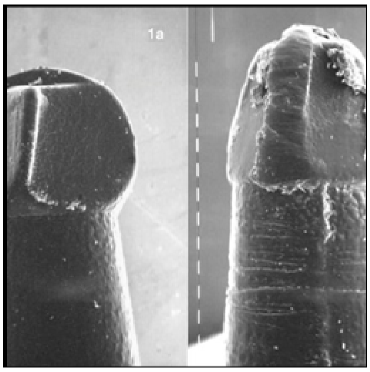

Fig 4: Smart prep burs intact before the cavity preparation and disintegrate after removing carious dentin

As gutta-percha is an impermeable material, leakage between the sealer and the dentin, and between the gutta-percha and the sealer, as well as the presence of voids, leads to treatment failure. A root canal obturating technology called Smartseal TM was designed to overcome these issues and improve treatment outcomes.

- It's a hydrophilic endodontic point with a sealer attached.
- Pro-point and smart paste/smart paste bio are included. It is available in different tip sizes and tapers. One pro-point covers all tip sizes [13]

The C Point system, also known as the smart seal obturation system, is a point-and-paste root canal filling procedure that uses prefabricated hydrophilic endodontic points and a sealer. The deformable endodontic point (C Point) is designed to grow laterally without expanding axially by absorbing leftover water from the instrumented canal space [11].

To avoid microbial reinvasion, the obturating material should lock the constructed canal space in three dimensions decreased microbial invasion, improved bactericidal action, increased sealer substantivity, and improved antimicrobial activity dispersion are all benefits of using nanoparticles in sealers and restorative materials.

Incorporation of nanoparticles in composites led to the invention of nanocomposites. These features improved mechanical qualities and handling characteristics, as well as a high initial polish and polish retention.

In a zinc oxide–based root canal sealer and a resin–based root canal sealer, the inclusion of chitosan nanoparticle and zinc oxide nanoparticles improved the bactericidal action. Bioactive glass nanoparticle has showed to encourage termination of the intermediate gap between canal enclosure and obturating substance. Incorporating bioactive glass particles into the polymers, rendered composite bioactive, increased its initial locking ability in one rooted canal, polyisoprene and polycaprolactone composites with bioactive glass responded well.

Most NPs showed contact-mediated and time-dependent antibacterial activity. As a result, their integration into materials increased the bactericidal effect by preventing the formation of microbial biofilms on the resin-dentin interface [12].

Nanoparticles in dental application

Since their introduction, the use of nanoparticles in numerous sectors of dentistry has increased significantly. To achieve the desired results, these nanoparticles can be added into a sealer, obturating substance, intracanal medicament, and irrigating solutions. Nanotechnology is a branch of science concerned with the creation of new materials with novel properties and functionalities by manipulating and restructuring materials on a nanometer scale of less than 100 nanometers [12].

History

Richard P. Feynman first mentioned Nanotechnology in the year 1960. 'Nano' is a Greek term that means "dwarf." James Clerk Maxwell developed the concept of nanorobots in 1867. Nanomaterials are unbound natural or manmade materials or aggregate materials with particle sizes ranging from 1 to 100 nanometers. Nanomaterials have a variety of characteristics, including extremely small diameters, a high surface area to mass ratio, and enhanced chemical reactivity. Nanoparticles have advantage of interacting with human body at subcellular and molecular level. In endodontics it was introduced to improve antimicrobial efficacy, tissue regeneration and mechanical integrity of already affected dentin [13].

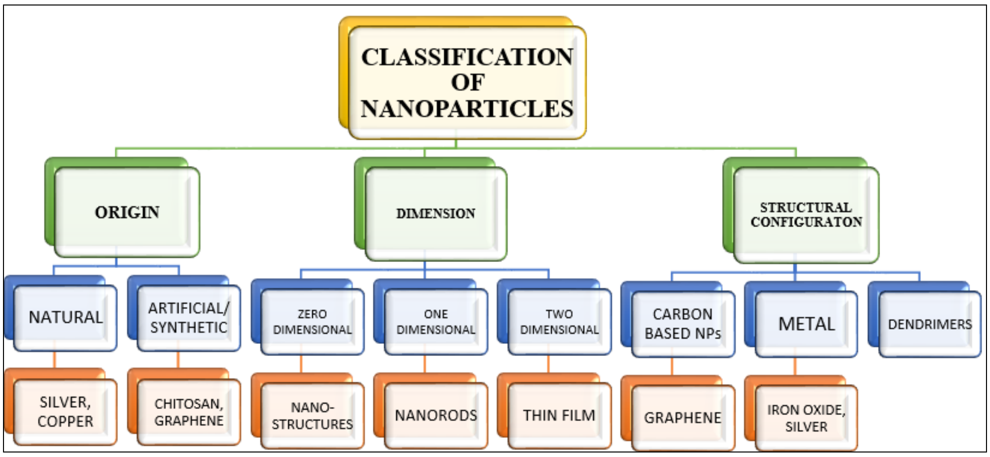

Fig 5: Classification of nanoparticles

Irrigation

"Washing by a stream of fluid" is how root canal irrigation is defined, and "intracanal irrigation promotes physical removal of debris from the canal and introduction of chemicals for antibacterial action, demineralization, tissue dissolution, bleaching, and deodorizing and haemorrhage control".

The most routinely used irrigants are

- chlorhexidine (CHX),
- ethylenediaminetetraacetic acid (EDTA) and
- sodium hypochlorite (NaOCl).

Although Chlorhexidine is safer than sodium hypochlorite, but it does not remove biofilm or smear layers from root canal dentine. Because of the limits of traditional irrigants, nanoparticles have been used to create new irrigation materials. Chitosan nanoparticles have been shown to have improved antibiofilm efficacy and the ability to deactivate bacterial endotoxins. The accelerated bacterial breakdown caused by these nanoparticles can be seen in the organised release of singlet oxygen species. Because they are non-toxic to eukaryotic cells, they are recommended for use as a finishing rinse in root canal irrigation.

Inter appointment Intracanal medicaments

Intracanal medications are anti-inflammatory and antibacterial medications that can be used between appointments. They are available in the form of pastes, gels, and points that are inserted into the canal.

The most widely used material is calcium hydroxide paste. It causes the production of hydroxyl ions, which raises the pH within the root canal, causing damage to microorganism DNA, cytoplasmic membranes, and enzymes.

When calcium hydroxide was used alone or in combination with chlorhexidine, silver nanoparticles (size 20 nm) mixed with them demonstrated improved antibacterial effect. A commercially available product Nanocare Plus Silver and Gold has shown promising antimicrobial properties as an intracanal medicament [14].

Obturation

Obturation is the process of three-dimensionally filling a canal after it has been chemically and mechanically treated and disinfected. In order to do this, a bulk filler (solid or semisolid) is used in conjunction with a sealer [14].

Bulk filler

The following bulk fillers are widely used in the obturation process:

- Gutta percha (GP),
- silver points, and
- Resilon.

GP is a biocompatible, inert, and structurally stable obturating material. Nanoparticles and bioglass have been included into recent formulations to obtain oroactive characteristics from GP. The nano-diamond GP (NDGP) composite embedded with amoxicillin was found to have greater mechanical qualities (such as strength and elastic modulus) than the commonly used Gutta percha [14].

Sealers

To produce a good three-dimensional seal in the root canal system, a mix of endodontic sealers and obturating materials is required. GP cannot be retained to the root dentin despite being heated in the root canal to increase its flowability.

As a result of this flaw in GP obturating material, a sealer is needed to fill the gaps between the obturating material and root dentine and produce a fluid-tight closure. In obturating sealers, chitosan and zinc oxide nanoparticles were used

The findings revealed that these NPs reduced bacterial penetration in the canal, leading to the conclusion that using them in sealers resulted in a beneficial outcome. A nanoparticle of zinc oxide has been produced for use as a sealant and is commercially available as Nano Seal-S (Prevest DenPro) [14].

Conclusion

The development of these newer and better smart materials will completely revolutionize various treatment modalities in the fields of dentistry, making them more comfortable for the patient and convenient for the operator. The level of intelligence of smart materials is always increasing, and dentists investing in these materials will undoubtedly be a wise move. Based on their ability to recognise, evaluate, and discriminate, these bio responsive materials can anticipate difficulties

There is always room for improvement and advancement, which will eventually lead to an improvement in the quality of dental treatment procedures.

In endodontics, nanoparticle-based treatments can improve the bactericidal effect. Functionalised nanoparticles via surface modifications would provide a chance to administer drug to infection area to specifically interconnect with cell layer and microbes. On the basis of clinical needs, new nanoparticle compositions are being introduced. Nanoparticles should be prioritised in medical research and dentistry for future progress.

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