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Nanotechnology (Nanohydroxyapatite Crystals): Recent Advancement in Treatment of Dentinal Hypersensitivity

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Abstract

Dentinal hypersensitivity is often a chief concern among patients. A wide range of commercially available products for the treatment of dentinal hypersensitivity contain potassium, strontium, oxalates, fluoride salts and recently calcium sodium phosphosilicate and proarginine. More recently, the toothpastes containing carbonated hydroxyapatite nanocrystals are being studied. These have high reactivity by which they bind to enamel and dentine apatite producing a biomimetic coating on enamel, contrasting plaque formation. They also prevent tooth from decay, rebuild and revitalize the teeth and seal dentinal tubules, annulling hypersensitivity. In near future new products of this kind will be a breakthrough in the treatment of dentinal hypersensitivity.

Keywords: Dentine hypersensitivity; Nanotechnology; Nanoparticles; Nanohydroxyapatite crystals

Introduction

Dentine hypersensitivity is characterized by short sharp pain arising from exposed dentine in response to stimuli typically thermal, evaporative, tactile, osmotic or chemical and which cannot be ascribed to any other form of dental defect or pathology [1]. Tooth hypersensitivity differs from dentinal and pulpal pain in that the patient's ability to locate the source of pain is good. Dentinal hypersensitivity is a response from a non-noxious stimulus, is a chronic condition with acute episodes, whereas dentinal pain is a response from a noxious stimulus, and is usually an acute condition [2].

Varieties of treatment modalities are available for its treatment. Desensitizing agents tried clinically are summarized in Table 1 [3].

Chemical agents incorporated into dentifrices accepted by the American Dental Association are strontium chloride and potassium nitrate. In office treatment options include noninvasive (oxalates, cavity varnishes, strontium chloride, composite resins, GLUMA, calcium hydroxide, lasers, iontophoresis) and invasive (pulpectomy, class V restorations, gingival graft surgery) methods. The availability of a wide variety of treatments certainly indicate that there is still no ideal desensitizing agent which can provide sustained or prolonged action for the treatment of dentine hypersensitivity. Most of the composite resins have limitation of handling and flow and microleakage due to shrinkage after polymerization. More recently, toothpastes containing carbonated hydroxyapatite nanocrystals are used to resolve this long-standing problem [4].

The term "nano" is derived from the Greek word "dwarf". Nanotechnology is the science of manipulating matter measured in the billionths of meter or nanometer, roughly the size of 2 or 3 atoms [5]. Richard Feynman, a physicist, gave first idea of nanotechnology in 1959 in a lecture called "Plenty of Room at the Bottom" for which he won Noble Prize. Feynman's idea remained largely undiscussed until the mid-1980s, when the MIT educated engineer K Eric Drexler published "Engines of Creation", a book to popularize the potential of molecular nanotechnology [6]. Prof. Kerie E. Drexler, a researcher and writer of nanotechnology [7], coined the term nanotechnology. First defined by Norio Taniguchi in 1974, "Nanotechnology mainly consists of the processing of separation, consolidation, and deformation of material by one atom or one molecule" [8].

Mode of Administration	
At home desensitizing agents	In office treatment
On the basis of mechanism of action	
Nerve desensitization	Potassium nitrate
Protein precipitation	Gluteraldehyde
	Silver nitrate
	Zinc chloride
	Strontium chloride hexahydrate
Plugging dentinal tubules	Sodium fluoride
	Stannous fluoride
	Strontium chloride
	Potassium oxalate
	Calcium phosphate
	Calcium carbonate
	Bio active glasses (SiO2-P2O5-CaO-Na2O)
Dentine Adhesive Sealers	Fluoride varnishes
	Oxalic acid and resin
	Glass ionomer cements
	Composites
	Dentin bonding agents
Lasers	Neodymium: yttrium aluminum garnet (Nd-YAG) laser
	GaAlAs (galium-aluminium-arsenide laser
	Erbium-YAG laser
	Homeopathic medication
	Propolis

Table 1: Classification of desensitizing agents [3].

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Nanotechnology has achieved a tremendous progress in the past several decades. Nanomaterials are those materials with component less than 100 nm in at least one dimension, including clusters of atoms, grains less than 100 nm in size, fibers those are less than 100 nm diameter, films less than 100 nm in thickness, nanoholes, and composites. They have evoked a great amount of attention for improving disease prevention, diagnosis and treatment. From the definition provided by the National Nanotechnology Initiative, nanotechnology exploits specific phenomena and direct manipulation of materials on the nanoscale [9]. However, nanotechnology is much more than the study of small things; it is the research and development of materials, devices, and systems exhibiting physical, chemical, and biological properties that are different from those found on a larger scale [10].

In nanoland, tiny differences in size can add up to huge differences in function. Ted Sargent, author of the dance of Molecules, says matter is tunable at nanoscale. For example, quantum dot is a nanocrystal made of semiconductor materials that is small enough to exhibit quantum mechanical properties, changing the size of semiconductors, changes the spectrum of color light due to quantum confinement. Sergent made a three-nanometric dot that 'glows' blue, and four nanometer dot that glows red and a five nanometer dot that emits infrared rays or heat [11].

Nanotechnology will affect everything, as advocated by William Atkinson, author of Nanoscom. The unique quantum phenomena that happens at the nanoscale, draws researchers from many different disciplines including medicine, chemistry, physics, engineering, and dentistry [6].

In 2000, Freitas introduced the term nanodentistry and stated that "new treatment opportunities, permanent hypersensitivity cure, complete orthodontic realignments during a single office visit, covalently bonded diamondized enamel and continuous oral health maintenance through the use of mechanical dentifrobots [12]."

Properties of Nanoparticles [13]

1. Nanoparticles have significant surface effects, size effects, and quantum effects.

2. Nanoparticles have special properties, including chemical, optical, magnetic, and electro-optical properties, which differ from those of either individual molecules or bulk species.

3. Nanostructured materials are the development of self-assembly, an autonomous organization of components into patterns or structures without human intervention occurs.

Fabrication Techniques

In 'top - down' techniques, the micro-nano dimensions of the hydroxyapatite are obtained by milling larger particles of commercial synthetic hydroxyapatite. Only recently, the development of nanotechnologies has opened new opportunities in obtaining cheap HA micro-nanoparticles using the "bottom up" methods, in order to improve the biological responses of natural HA.The bottom-up fabrication technique has been summerized in Figure 1.

Various Nanostructures [10]

1. Nanopores
2. Nanotubes
3. Quantum dots
4. Nanoshells

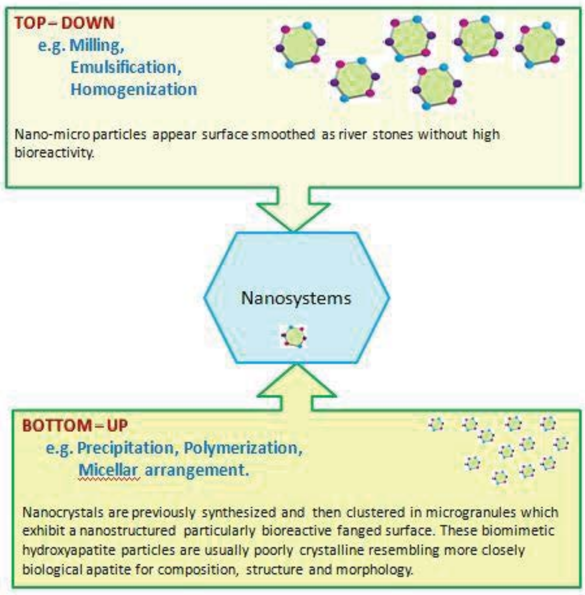

Figure 1: Fabrication techniques.

Dendrimers

A nanopores is a small hole with an internal diameter of the order of 1 nanometer. A nanotube is a nanometer scale tube like structure. Quantum dots also known as nanocrystals, are nanosized semiconductors, depending upon their size, they can emit light of all colours of the rainbow. Nanoshells also referred to as core-shells, and are spherical cores of a particular compound surrounded by a shell or outer coating, which is few nanometers thick. Dendrimers are highly branched structures gaining wide use in nanomedicine because of the multiple molecular "hooks" on their surfaces that can be used to attach cell-identification tags, fluorescent dyes, enzymes and other molecules. The first dendritic molecules were produced around 1980, but interest, knowledge and advancement in nanotechnology has blossomed more recently with the discovery of their biotechnological uses.

Nanoparticles

Composite resins are also used for curing dentinal hypersenitivity by sealing dentinal tubules. Nanocomposites have shown better results in comparision to the hybrid or last generation of the resins. Nonagglomerated discrete nanoparticles are homogenously manufactured in resin or coating to produce nanocomposite. The nanofiller used included an aluminosilicate powder having a mean particle size of about 80nm and 1: 4 M ratio of alumina to silica. The deliberate placement, manipulation and higher level of control on the sub 100nm scale particles in the resin matrix that display the polish of a microfill but the strength and wear resistance of hybrid composite [14].

Gary and Leinfelde (2009) have summerized the types of nanoparticles in composite resins as below [15]

Type I: Subtype A: Nanomeric particles dispersed as a single unit within the resin matrix.

Type I: Subtype B: Consists of agglomerated cluster of nanoparticles.

Type II: Consists of cage like structure that is composed of eight silicon atoms and twelve oxygen atoms.

Characteristics of nanofillers in dental composites make the nanocomposites superior to the conventional composites and blend with natural tooth structure much better.

- Superior hardness
- Superior flexural stength
- Superior modulus of elasticity
- Superior translucency, esthetic appeal, excellent color density, high polish and polish retention
- About 50% reduction in filling shrinkage
- Excellent handling properties

Nano-resins are "utility in fielder" with ability to flow over the walls of the cavity preparation, wetting the surface of dentine to ensure better adaptation. These materials can be used as sealants and as cement for thin staked porcelain veneers. Septodont's N'Durance- Dimer flow, is a new flowable composite, which features unique chemistry and nanotechnology formulation. Nanocomposite have minimum shrinkage, has ease of handling, and is highly esthetic material. Nanotechnology in dentistry is giving significant occupany in different forms as stated in Table 2.

Teeth Remineralization by Nanotechnology

Hydroxyapatite $Ca_{10}(PO_4)_6(OH)_6$ building block of enamel, are the main constituent of dental tissues representing in enamel and dentin 95% - 97% wt and 75 % respectivily and responsible for mechanical behaviour of dental tissues. Hydroxyapatite (HA) is the most stable form of calcium phosphate. Enamel prismatic HA crystals consist of a weaving of prisms ranging from 3 to 5 µm in diameter. A single prism reveals a highly organized array of fastened needle like HA crystallites (approximately 30 nm thick, 60 nm wide, and several millimetres long). Unlike bone, in enamel and dentine when HA is dissolved or abraded, it cannot spontaneously remineralize because enamel is deprived of regenerative cells and contrarily dentine apposition occurs only towards the pulp tissues [16].

Biogenic Hydroxyapatite V/S Biomimetic Synthetic Hydroxyapatite (Nanohydroxyapatite)

Biogenic carbonate hydroxyapatite (CHA) nanocrystals, constituents mineral phase of calcified tissues such as bone, dentin and enamel. They contain 4-8 wt % of carbonate anions, approximately 25 nm wide, 2-5 nm thick and 60 nm in length. They exhibit a non-stoichiometric composition and have low degree of crystallinity.

Synthetic biomimetic CHA nanocrystals are very similar to biogenic CHA nanocrystals. Biomimetic CHA nanocrystals have been synthesized, containing 4 ± 1 wt% of carbonate ions, about 20 and 100 nm in size with an acicular and plate morphology respectively. They are nearly stoichiometric in bulk Ca/P molar ratio of about 1.6-1.7 [17]. Synthetic bioresorbable biomimetic hydroxyapatite nano and micro crystals exhibit excellent properties like bone filler biomaterial, such as biocompatibility, bioactivity, osteoconductivity, direct bonding to bone, etc., exciting new applications of HA in the fields of bone tissue engineering and orthopaedic therapies.

Bottom up approach	Top down approach
Local anesthesia	**Nano composites**
Hypersensitivity cure Nanorobotic dentifrice Dental durability & cosmetics Orthodontic treatment Photosensitizers & carriers Diagnosis & treatment of oral cancer	Nano solutions Impression materials Nanoencapsulation Nanoneedles Bone replacement materials

Table 2: Application of nanotechnology in dentistry.

Recently, synthetic CHA biomimetic nanocrystals have been shown to produce, *In Vitro*, re-mineralization of the altered enamel surfaces and closing of dentinal tubules, thus showing a potential use in desensitizing dentifrices. Hefferren et al. have suggested that, increased re-mineralization occurs more with apatite particles sizes <4 µm [18]. The potential desensitizing effect of biomimetic CHA nanocrystals, is due to the progressive closure of the tubular openings of the dentine with plugs within a few minutes until the regeneration of a mineralized layer has occurred within a few hours.

Natural hypersensitive teeth have eight times higher surface density of dentinal tubules and diameter with twice as large than nonsensitive teeth [19]. Reconstructive dental nanorobots, using native biological materials, could selectively and precisely occlude specific tubules within minutes, offering patients a quick and permanent cure [20]. Field Emission Scanning Electron Microscope (FE-SEM) observation of the nano-HAP-treated dentine surface showed that nano-HAP uniformly occluded the dentinal tubules with a dentinal plug and a protective layer on the surface of the dentine was also formed [21].

Nanotechnology Offers a Unique Approach to Overcome the Shortcomings of Many Conventional Materials

- Fluoride remineralisation, is based mainly on surface enamel apatite modification, whereas biomimetic hydroxyapatite forms a new coating.
- Potassium reduces nerve excitability whereas biomimetic hydroxyapatite acts as alternate substance, not only alleviate pain but also cures sensitivity.
- Conventional hydroxyapatite has poor affinity and is randomly oriented resulting in easy loss of crystals, whereas biomemmitic hydroxyapatite has high affinity and self-assembly property (Figure 2).

Challenges Faced by Nanodentistry [21]

- Precise positioning and assembly of molecular scale part
- Economical nanorobot mass production technique
- Biocompatibility
- Simultaneous coordination of activities of large numbers of independent micron-scale robots
- Social issues of public acceptance, ethics, regulation and human safety

Problems for Research in Nanotechnology in India [21]

- Painfully slow strategic decisions
- Sub-optimal funding
- Lack of engagement of private enterprises
- Problem of retention of trained manpower

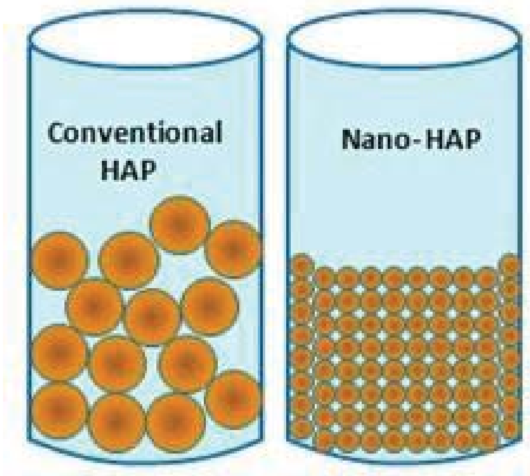

Figure 2: Conventional HAP and Nano HAP.

Conclusion

Carbonated hydroxyapatite nanocrystals synthesized with tailored biomimetic characteristics for composition, structure, size and morphology can chemically bind themselves on the surfaces of teeth tissues, filling the scratches, producing a bound biomimetic apatitic coating and protecting the enamel surface structure. Only recently, the development of nanotechnologies has opened new opportunities in obtaining cheap hydroxyapatite micro-nano particles by the "bottom up" methods. These hydroxyapatites are surface nanostructured and have higher surface area and consequently higher reactivity, allowing them to bind to enamel and dentine apatite producing a biomimetic coating on enamel, contrasting plaque formation and sealing dentine tubules and annulling hypersensitivity.

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