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Nano Science and Root Canal Therapy: A Literature Review

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Abstract

Nano science and nanotechnology have revolutionized all aspects in the endodontic field. The aim of the present study was to describe the application of nanotechnology in endodontics by reviewing the literature. Application of nanomaterials, with a smaller size, for surface modification has reduced the incidence of failure in the rotary nickel-titanium files. Nanoparticles with the ability of rapid dispersion into the hard-to-reach spaces in the complex root canal system have a better antimicrobial effect. The incorporation of nanoparticles in the obturating materials promotes the sealing properties and antimicrobial efficacy. Nanoscaffolds in the pulp regeneration approaches, bioceramics as retrofilling, and repair materials, and Nanorobots and nanoterminators as new technologies for local anesthesia with fewer side effects are some examples in this regard.

Keywords: Endodontics; Nanomaterials; Nanostructures; Nanotechnology

Introduction

Richard P Feynman (a Nobel physicist), in 1959, introduced his famous idea of nanotechnology (1). In the mid- 1980s, K Eric Dexler propounded this idea in his book “Engines of Creation” about the potential of molecular nanotechnology (2).

Nanotechnology is a combination of a prefix “Nano” (a Greek word for dwarf) and technology. This prefix is applied for objects that exhibit billionth (10 -9) meter dimensions. Nanotechnology is defined as the development and use of materials, devices, and techniques with physical, chemical and biological properties that are different from those found on a large scale (3).

Along with the evolution of human societies, the critical length in the functional devices has shifted from millimeter to micrometer to nanometer scale (4). Nanoscience is not a new technology and for centuries, size dependent properties have been applied (5). But nowadays, advanced imaging techniques make the understanding of these nanoparticles possible (6). Nanotechnology has initiated extraordinary advances in many different disciplines such as medicine, chemistry, physics, engineering, dentistry and etc.

Nanodentistry have promoted the quality of treatment and maintenance of comprehensive oral health through applying nanomaterials, biotechnology (i.e. tissue engineering) and dental nanorobotics.

Nanomaterials, due to their nanoscale features, have novel properties including better compatibility with biological systems and being more permissive for cell growth and differentiation(7). Nevertheless, some biological consequences such as inflammation and oxidative stress may be expected (7).

Tissue engineering is a new therapeutic application of nanobiotechnology. Nanobiomaterials, in this era, act as a microenvironment-like substance with three elements: a various resident cell types including stem cells b. rich extracellular matrices and c. instructive signals positioned in a direct physical contact with cell surface receptors (8).This nanoscale mechanical interactions with cell surface receptors lead to various cellular responses (i.e. adhesion, migration, DNA and protein synthesis) and serve intended diagnostic and therapeutic purposes (9).

Nanorobots are microscopic elements that should work together in a very large numbers to affect in the microscopic and macroscopic dimension (3, 7). Dental nanorobots, under the control of an onboard nanocomputer, crawl through human tissue with specific motility mechanisms and could affect the monitoring, interrupting or altering nerve impulse traffic in an individual nerve cell in real time (10).

Local anesthesia, permanent hypersensitivity cure, tooth renaturalization, nanorobotics dentifrices (dentifirobots) and endodontic regeneration are some examples for application of nanotechnology in dentistry (11, 12).

Nanostructured biomaterials and nanotechnology have revolutionized the all aspects of science and endodontic is no exception. Although research into the applications of nanotechnology in the root canal treatment has been initiated in several treatment areas, but further studies and improvements are essential in this regard.

Nanotechnology in endodontics

The microbial infection of the pulp via their toxins and noxious metabolic byproducts, in addition to the presence of disintegrated pulpal tissue are the primary causes of apical periodontitis and clinical endodontics is mainly directed towards curing or preventing apical periodontitis (13).

Endodontic treatment is consisted of the main two integrated phases: cleansing and shaping (14).

Nano science and nanotechnology have revolutionized all aspects in the endodontic field. Application of nanomaterials, with a smaller size, for surface modification have reduced the incidence of failure in the rotary nickel-titanium files (15). Nanoparticles with the ability of rapid dispersion into the hard-to-reach spaces in the complex root canal system have a better antimicrobial effect (16).The incorporation of nanoparticles in the obturating materials promotes the sealing properties and antimicrobial efficacy (17). Nanoscaffolds in the pulp regeneration approaches, bioceramics as retrofilling, and repair materials ,and Nanorobots and nanoterminators as new technologies for local anesthesia with fewer side effects and are some examples in this regard (18).

Materials and Methods

Instruments modifications

Rotary nickel-titanium files have become widely used instruments in endodontic treatment. Andreasen and Morrow, in a classic article, described the mechanic properties of this alloy including: very low elastic modulus and very wide elastic working range in comparison to stainless steel (19).

The potential application of NiTi for endodontic files was first introduced by Harmeet Walia in 1987 (20). NiTi files possess many desirable characteristics such as very low elastic modulus, super elasticity, excellent shape memory and resistance to cyclic fatigue and corrosion (20).

Super elasticity facilitates the negotiation of curved root canals and promotes the quality cleansing and shaping in the complex root canal system (21). The resistance to cyclic fatigue permits the application of these instruments in a rotary hand piece with superiority in comparison to stainless steel files (20).

Despite these favorable features, NiTi files have some limitations including significant ductility in bending and torsion, cyclic fatigue and fracture (22).

Surface quality plays an important role in the instrument fracture; therefore several strategies have been employed to improve the clinical performance of NiTi instruments. Electropolishing the machined surfaces, ion implantation to create harder surfaces, heat treatment and coating the surface with special materials are some examples in this regard (23, 24).

More recently, the smaller sized nanomaterials have been proposed as surface coating material to overcome NiTi instruments characteristic short comings and promote the wear and fatigue resistance (15). According to Adini et al (25), surface modification of NiTi files using cobalt coatings with impregnated fullerene-like WS2 nanoparticles, significantly improved the fatigue resistance and time to breakage of the coated files. Thus, nanoparticles, as surface coating materials, play an important role in the clinical performance of NiTi instruments.

Materials modifications

Following mechanical instrumentation, organic pulpal materials and inorganic dentinal debris accumulate within the root canal spaces and into the accessory canals, fins and isthmuses (26, 27). In cases of pulpal necrosis, dentinal debris may be contaminated and microbiota present in these untouched area could survive and reactivate in a proper condition (26).

Irrigation solution and intracanal medicaments have been introduced to eradicate microbiota and disinfect the root canal system. Therefore, mechanical shaping should be accompanied with the chemical disinfection to maximize the antimicrobial efficacy of endodontic procedures (28, 29).

Three-dimensional obturation of the radicular space has been considered a critical step for long-term success in the endodontic treatment. The objective of obturation is to create a watertight seal along the whole length of the root canal spaces from the coronal part to the apical terminus, maintain a clean and disinfected environment within the root canal system and finally create an optimum condition for the health of the periapical tissues (30).

Various experimental techniques and materials have been advocated for obturating purposes, promoting the quality of seal and increasing the clinical success rate after root canal therapy (31, 32).

Unfortunately, all materials and techniques have some limitations that result in some degree of leakage (33). More research and improvements should be conducted to promote the quality of seal after root canal obturation.

a. Root canal disinfection

A major biologic aim of cleansing and shaping is to eliminate the apical periodontitis by disinfection of the root canal system. Mechanical enlargement of the canal space cannot sufficiently disinfect root canals and therefore the use of antimicrobial irrigants and medicaments has been recommended along with the mechanical preparation (34).

i.Irrigants

Irrigation solutions are applied to eradicate microbiota in the root canal system, dissolve necrotic tissue, lubricate the canal and remove the smear layer without irritating healthy tissues (28). Up to the present, different irrigants (i.e. sodium hypochlorite, chlorhexidine, EDTA and etc. (and techniques (both manually and machine assisted) have been introduced, but none of them meet all the requirements outlined (29).

Over the last decades, some types of nanoparticles and nanoparticle based strategies have been evaluated in regard to the quality of root canal disinfection as well as the tissue reaction to these materials (35).

Gomes- Filho et al. (16) evaluated the tissue response of 47 and 23 ppm silver nanoparticles dispersion material and sodium hydrochloride over a 90- day period. Based on the results of this study, silver nanoparticles dispersion material at 23ppm concentration has promising biocompatibility in comparison to the other materials. Nanoparticle-based antimicrobial photodynamic therapy has also provided a new alternative for conventional endodontic irrigation (36). Since the application of these kinds of material have some limitations such as inflammatory response, genotoxicity and cytotoxicity, further studies are needed for safety use of these nanoparticles (37).

ii. Medicaments

After chemo mechanical preparation, many of root canals contain viable microorganism, therefore a variety of intracanal medicaments have been used for complete disinfection of canal between appointments. Intra canal medicaments have been used to decrease the bacterial count, prevent bacterial regrowth and also to reduce inter appointment pain (38). Ca (OH) 2 is an intracanal agent with alkaline PH that could kill bacteria, neutralize biologic activity of bacterial lipopolysaccharide and also makes necrotic tissue more susceptible to the solubilizing action of NaOCl at the next appointment (39).

E.faecalis is a facultative gram-positive bacteria that has been commonly recovered from multiple visit treated cases and is extremely resistant to most of the intracanal medicaments particularly calcium hydroxide-containing dressings (13, 40).

Chitosan (CS-np) and zinc oxide (ZnO-np) nano particulates have been shown to possess significant antibacterial properties against E.faecalis (41). These materials could eliminate the planktonic E.faecalis totally and reduce the biofilm thickness significantly, but this character is time and concentration dependent and further studies are needed in this regard (41).

b. Obturating materials

According to Schilder(42), total obturation of the root canal space is the final objective of endodontic procedure and three-dimensional (apically, coronally and laterally) sealing of the radicular space is crucial for long-term success.

Although, various materials and methods have been advocated in this regard, but all materials and techniques have some degree of leakage (33). Most techniques employ a semi-solid or solid core material in conjunction with a sealer. Whether the obturation material is core or sealer, both are irritants especially sealers before setting (43).

Gutta-percha is the only one universally accepted and commonly used material that has many properties of an ideal root canal filling material highlighted by Grossman (44).However, it possesses some limitations such as ease of displacement under pressure, lack of rigidity and adhesiveness, minimal antimicrobial property and shrinkage if thermo-plasticized (45).

Nanoparticles have enhanced the adaptation of obturating material to the dentinal walls with increasing the surface area (15). Bioactive glass 45S5 is a new application of nanoparticles in endodontics with increased contact surface area and higher antimicrobial effect especially against E.faecalis (46). Mohn et al (47), in a survey, concluded that nanosized bioactive glass modified with bismuth oxide, as on opacifying agent, could perform as a radiopaque bioactive root canal filling material.

Root canal sealers must be used in conjunction with the primary obturating material to seal the space between the dentinal wall and obturating core. Based on the Grossman criteria for an ideal sealer including: tissue tolerance, no shrinkage with setting, slow setting time, adhesiveness, radiopacity, absence of staining, solubility in solvent, insolubility to oral and tissue fluids, bacteriostatic properties and ability to create a seal, none of the currently available sealers has all these ideal properties (44). Nanopraticle-based sealers have better antimicrobial activity and because of thin size, they could penetrate the dentinal tubules deeply and enhance the sealing ability (48).

Another concern in the application of sealers is their long-term potent antimicrobial properties. Incorporation of insoluble quaternary ammonium polyethylenimine nanoparticles into the endodontic sealers, may lead to a long lasting antibacterial effect on the E.faecalis along with non-cytotoxicity (17).

Nanocrystalline bioceramic sealers have a high pH during the initial setting process (strongly antimicrobial), are hydrophilic, biocompatible, do not shrink or resorb, have strong sealing ability, set quickly and are easy to use (49).

Further investigations are necessary to establish clinical relevance of the aforementioned properties in the nanoparticles obturating materials.

c. Retro filling and root-repair materials

An ideal root-end filling material should have the following properties: providing hermetic seal, adherence to walls of cavity, biocompatible, nonresorbable, dimensionally stable over time, induce regeneration of the PDL complex, easy to use and proper working time (50).

Today, Mineral Trioxide Aggregate (MTA), Super-EBA and Geristore are the most widely used materials as root-end filling but none of them have all the requirements of an ideal root end filling material (51).

Difficult handling and prolonged setting time of MTA, solubility and short setting time of super EBA and setting shrinkage and bacterial leakage of Geristore compomer are some drawbacks of these materials for the clinical application (52).

Nanotechnology could promote the characteristic of these root-end filling materials to some extent. Nanomodified MTA is a new introduced material with enhanced physicochemical properties such as decreased setting time and increased micro hardness (53).

Nano composites are polymeric materials including minimal amounts of nanoparticles such as clays, carbons nanotubes and etc (54).Although polymeric nano composites (PNCs) have a very low filler content, but they have shown an improved mechanical and thermal properties such as heat resistance, stiffness, dimensional stability, reduced electrical conductivity and more important inherent antimicrobial properties after setting and drug elusion capabilities (15, 55).

Root-end filling materials placed in a close approximation into the periradicular tissues and antimicrobial properties of these materials could improve the outcome of periradicular surgery.

In comparison to Geristore, PNCs have more less leakage and revealed a tight interface with the dentinal tubules (15). PNCs have also shown no statistically significant difference in cytotoxicity in comparison to Pro Root MTA and Geristore (56). Further investigations should be accomplished for better understanding of the effect of nanotechnology in developing superior root-end filling materials.

Treatment strategies

Local anesthesia

Effective pain control through local anesthesia is an important and prerequisite stage for delivery of a qualified root canal therapy. Inflammation of pulpal and periodontal tissues along with the emotional disturbance in the endodontic patient could impair the effectiveness of local anesthesia (57).

A large number of high-quality, randomized, controlled experiments have been done to promote the quality of anesthesia in a painful patient. However, new methods and formulations should be evaluated to aid clinicians for obtaining a successful anesthesia.

a. Nano robots

Effective local anesthesia is an important step in the root canal treatment. Research continues in the development of new or improved anesthetic materials and strategies for better treatment of patient in pain.

Nanorobots are active analgesic micron-sized particles in a colloidal suspension that instill at the surface of the crown or gingival mucosa (3). These particles migrate into the gingival sulcus, pass painlessly through the lamina propria and reach the dentin (3). Afterwards, these particles based on the chemical gradient, temperature differentials, positional navigation and under the control of an onboard nanocomputer directed by a dentist, proceed toward the pulp (58).

Nanorobotics analgesia is a new technique with more patient comfort, reduced anxiety, no needles, greater selectivity and controllability of the analgesic effect, fast and completely reversible switchable action and avoidance of most side effects and complications (3).

b. Nanoterminators

Application of nanorobots may be uncontrollable to some extent and if these particles pass through the blood stream and arrive at one of the vital centers, they may confound these systems and a catastrophic happen. Nanoterminators (killers of nanorobots) and also self-destruction of nanorobots are new proposed mechanisms have been developed to destroy these nanorobots and overcome this problem (7).

Pulpal repair and regeneration

Maintenance of pulpal health in the cases of pulpal inflammation or regeneration of healthy pulpal tissue in cases of pulpal necrosis with systems and mechanisms are the main concerns in the endodontic science.

Concept of regeneration was first introduced by Dr.B.W.Herman with the application of calcium hydroxide for vital pulp therapy (59)and Professor Nygaard-Qstby(60) with the evaluation of revascularization for reestablishing a pulp-dentin complex in permanent teeth with pulpal necrosis.

Guided tissue or bone regeneration (GTR, GBR), distraction osteogenesis, bone augmentation with platelet rich plasma, regeneration of periodontal tissues with Emdogain, augmentation of bone with recombinant human bone morphogenic protein and periodontal tissue regeneration with fibroblast growth factor 2 are some examples in this regard(61).

Dental pulp is a unique low-compliance connective tissue that is completely sensory and has infinite capacity to repair itself. The aforementioned characters have both protective and disturbance effects on the pulpal immunity.

Microleakage of microorganisms and other toxic materials may lead to pulpal tissue damage and interfere with the tooth protective mechanisms. Thus, a hermetic seal is an important factor for success of pulpal repair and regeneration.

Incorporation of nanoparticles in the bonding and restoration materials, and application nanostructured assemblies for pulpal repair has demonstrated promising characters such as lower micro leakage and toxicity (62, 63). Nanotechnology is also applied for evaluation of nano-and micromechanical properties of a biologic and mechanical tissue like dentin(64).

Nanorobots are also speculated to use as nanosensors for the delivery of precise amounts of a therapeutic agent such as pulp capping material and drugs (i.e. antibiotics) (15).

Nanostructured polymer scaffolds could also serve as a synthetic replica of the naturally occurring extra cellular matrix in order to promote the new tissue formation and enhance the biological regulation of cell behavior for tissue regeneration and repair (65). There is still very much to understand that how we could technically integrate the structural and biologic mechanisms to return the pulp-dentin complex to normal form and function.

Conclusion

Nanotechnology has revolutionized all aspects of science and endodontic is no exception. Nanosized particles with significantly superior properties compared to the similar materials at larges scales of measurement have improved the quality of treatment. Understanding of dental tissue at the nanoscale, enabling the precise design of materials and instruments with ultrafine architecture and improving the present techniques in clinical dentistry have significantly promoted the quality of treatment.

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Declarations

Conflict of interest

None

Authors' contributions

All authors contributed equally to this work

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