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College of Dentistry

Nanotechnology in Dentistry

A Project Submitted to The College of Dentistry, University of Mosul, Department of Oral surgery in Partial Fulfillment for the Bachelor of Dental Surgery

By

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Certification of the Supervisor

I certify that this project entitled " Nanotechnology in Dentistry " was prepared by the fifth-year student Mohammed Falah under my supervision at the College of Dentistry/University of Mosul in partial fulfilment of the graduation requirements for the Bachelor Degree in Dentistry.

Supervisor's name:

Assist.Prof.Dr. Alyaa Ismael Naser

Date: / / 2025

Dedication

“To my Mother and Father, who never stopped believing in me.

To my lovely sisters and brothers.

To my supervisor Assist. Prof. Dr. Alyaa Ismael Naser, who taught me the value of critical thinking and the power of the pen.

To my friends, and all those who stood by me and helped me with everything they had, and in many areas."

Acknowledgements

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Introduction

Healthcare biotechnology is a field that is always exploring more technological interventions for better healthcare management worldwide. Nanotechnology is one such essential part of healthcare that, along with other updated technologies, maintains an advanced outlook with practical implications in the field of medicine (Jandt, K.D. *et al.,* 2020).Nanodentistry is an emerging field in dentistry that involves the use of nanomaterials, nanorobots, and nanotechnology to diagnose, treat, and prevent dental diseases (Malik, S. *et al* 2023).The focus of nanodentistry is to achieve precise and targeted delivery of therapeutic and diagnostic agents. Nanotechnology is a field of molecular manufacturing or engineering that involves structural adjustment of characteristics of materials, owing to the small size of nanomaterials within dimensions of 0.1–100 nm (Barot, T. *et al* 2021). Dental health science offers opportunities to enhance patient satisfaction by improving the efficiency of dental tools, medications, and treatments. It also focuses on optimizing the kinetics reactions and mechanical strength of dental materials, resulting in stronger, more effective, and aesthetically pleasing products with better biocompatibility. Ultimately, this leads to easier and more efficient handling of dental products for the benefit of both practitioners and patients (Barot, T. *et al* 2021;Subramani, K. *et al* 2019). The vast scale applications of nanodentistry can be used in several dental procedures, such as cavity repair, teeth whitening, and orthodontic treatment (Kennedy, S. *et al* 2019);(Contera, S. *et al* 2020). It can also be used to improve the durability of dental restorations and to develop new materials that are stronger, more durable, and more biocompatible (Deepali, S. *et al* 2021; Patel, R.M. *et al* 2020). One of the most promising areas of nanodentistry is the development of nanorobots that can be programmed to perform certain dental procedures, such as cleaning and repairing teeth. These nanorobots can work at the molecular level and can even be controlled remotely using magnetic fields (Soto, F. *et al* 2020;Amissah, F. *et al* 2021). Overall, the focus of the present study is to explore how nanodentistry has revolutionized the field of dentistry, providing more precise and effective treatment options that are less invasive and more comfortable for patients. Additionally, the target of this study is to explore the implications of nanotechnology in dentistry within the aspects of diagnostics, preventive medicine, treatment options, restorative, and personalized medicines alongside cosmetics, industrial, and aesthetics applications (Amissah, F. *et al* 2021; Mirsasaani, S.S. *et al* 2019). This study will also highlight the improvement of dental materials with the passage of time that impart them with better mechanical properties, durability, antimicrobial activities, strengthening characteristics, pain-preventing techniques, and prompt recovery tactics (Joseph, B 2023; Haleem, A. *et al* 2023). We will also discuss some major implications of nano-dental materials, including nanocomposites, ceramics, glass ionomers, ceramics, metal needles, anesthetic components, and nanorobots, among others. In summary, a brief descriptive analysis will be presented to cover the tremendous applications of nanodentistry with the aspects of redefining and refreshing positive oral healthcare management. Overall, nanotechnology is a tool in the hands of researchers to explore awide spectrum of continuous state-of-the-art nano-dental technology development with the hindsight aspects of better healthcare management.

Aims of the study

This review aims to explore the advancements and applications of nanotechnology in dentistry, focusing on its role in enhancing dental materials, treatment techniques, and drug delivery systems. It highlights innovations such as nanomaterials, nanorobots, and nano-coatings, along with their benefits like improved durability, antibacterial properties, and biocompatibility. Additionally, the review examines challenges and potential risks while discussing its applications in restorative dentistry, endodontics, periodontics, and implantology. Ultimately, it provides insights into the prospects of nanotechnology in improving dental care and clinical outcomes.

Chapter one:

Review of literature

1.1. The definition of nanotechnology

The word nano comes from Greek, meaning "dwarf". The idea of nanotechnology was first elaborated in 1959 by Richard Feynman, a nobel prize-winning physicist, in a lecture titled "There's plenty of room at the bottom". He ended the lecture by concluding that this science "is a development which I think cannot be avoided" (Freitas, 2000).

1.2. The many fields of use of nanotechnology

Nanotechnology finds applications in many fields. Such applications include the following: medicine: diagnostics, drug delivery, tissue engineering; chemistry and environment, catalysis, filtration; energy, reducing energy consumption, and increasing the efficiency of energy production; information and communication, novel semiconductor devices, novel optoelectronic devices, displays, and quantum computers; heavy industry, aerospace, refineries, and vehicle manufacturers; and consumer goods and foods.

1.2.1 Nanodiagnostics

Nanodiagnostic devices can be used for early disease identification at the cellular and molecular levels. Nanomedicine could increase the efficiency and reliability of in vitro diagnostics, through the use of selective nanodevices to collect human fluids or tissue samples and to make multiple analyses at the subcellular level. Nanodevices can be inserted into the body to identify the early presence of a disease or to identify and quantify toxic molecules and tumor cells. (Haleem, A. *et al* 2023;Tetè S. *et al* 2008)

1.2.2 Diagnosis and treatment of oral cancer

Exosome is a membrane bound secretory vesicle containing a proteomic and genomic marker whose level is elevated in malignancy. This marker has been studied by using atomic force microscopy which employs nanoparticles. The nanoelectromechanical system, oral fluid nanosensor test, and optical nanobiosensor can also be used for diagnosing oral cancer. Nanoshells which are miniscale beads are specific tools in cancer therapeutics. Nanoshells have outer metallic layers that selectively destroy cancer cells while leaving normal cells intact. Undergoing trial are nanoparticle-coated, radioactive sources placed close to or within the tumor to destroy it.(Braceras I. *et al* 2009)

1.2.3 Tissue engineering and dentistry

Potential applications of tissue engineering and stem cell research in dentistry include the treatment of orofacial fractures, bone augmentation, cartilage regeneration of the temporomandibular joint, pulp repair, periodontal ligament regeneration and implant osseointegration. Tissue engineering enables the placement of implants that eliminate a prolonged recovery period, that are biologically and physiologically more stable than previously used implants, and that can safely support early loading.(Ellingsen JE. *et al* 2000),(Meirelles L. *et al* 2008). Bone grafts with better characteristics can be developed with the use of nanocrystalline hydroxyapatite. It was shown that nanocrystalline hydroxyapatite stimulated the cell proliferation required for periodontal tissue regeneration. (Park JW. *et al* 2009)

1.2.4 Bio-nano surface technology and dental implants

Osteoblast proliferation has been induced through the creation of nano-size particles on the implant surface.(Meirelles L. *et al* 2008);(Saravana KR. *et al*. 2006) Roughening the implant surface at the nanoscale level is important for the cellular response that occur in the tissue.(Deyhle, H. *et al* 2011; Chung, C.-J. *et al*

2011) Many studies have shown that nanotopography of the implant surface considerably affects osteogenic cells and that the nanoscale surface morphology enhances osteoblast adhesion. The nanoscale surface morphology augments area and thus provides an increased implant surface area that can react with the biologic environment.(Beniash, E. *et al* 2019; Cheong, Y. *et al* 2012)

1.2.5 Bone replacement materials

Nanotechnology aims to emulate the natural structure present on bone, which is composed of organic compounds (mainly collagen) and reinforced with inorganic ones. Nanocrystals show a loose microstructure, with nanopores situated between the crystals. The surfaces of the pores are modified such that they adsorbed protein, due to the addition of silica molecules. Bone defects can be treated using hydroxyapatite nanoparticles. (Lacruz, R.S. *et al* 2017)

1.3 Bio-nanointerfaces of clinical significance

To restore partial (enamel and dentin) or complete tooth loss, dental composite or implants are normally used. The retention of resin composite or dental implants is obtained mainly through micromechanical retention. The interface between resin composites and dental tissues or between dental implants and bone is therefore important for the success of these restorations. Looking at the structure of enamel, dentin, and bone, they are composed of organic matrix, mainly collagen and no collagenous proteins and hydroxy- apatite (HA). The ratio of the organic to mineral phase varies according to the tissue. This section reviews the importance of resin composite–tooth as well as implant–bone interface and how nanotechnology has been employed to modify these interfaces to increase the longevity of resin composites and dental implants, respectively.

1.4 Preventive Nanodentistry

Modern dentistry’s goal is to prevent rather than treat biofilm-dependent oral diseases, e.g., dental caries and endodontic and periodontal diseases.

Nanotechnology offers new approaches for preventive therapies in oral diseases, particularly dental caries and periodontal diseases.

1.5 Nanostructure of Tooth

Human teeth are built of tissues that constitute a hierarchical structure. The outer Tissue of a tooth, the enamel, is a biocomposite that consists mainly of hydroxyapatite. High mineralization and its specific structure make enamel the hardest tissue of the human body as shown in Figure(1) (Meirelles L. *et al* 2008)-(Saravana KR,*et al*. 2006). In enamel, hydroxyapatite forms crystallites with nano-rod-like shape, having a vertical array. Such an alignment also results in anisotropic properties (Meirelles L. *et al* 2008; Saravana KR, *et al*. 2006; Deyhle, H. *et al* 2011). The enamel acts as an insulating barrier and protects the rest of the tooth from injuries due to physical, chemical or thermal forces (Chung, C.-J. *et al* 2011). The boundary between the enamel and dentine is called a dentin–enamel junction (DEJ). It is a place in which the orientations of the enamel and dentin nanostructures change (Meirelles L. *et al* 2008). The DEJ is formed in ridges, which probably increase the adhesion of enamel and dentine, and therefore, reduce shearing of the enamel while the tooth works (Beniash, E. *et al* 2019). Due to its unique mechanical properties, the junction can prevent traversing of cracks from enamel into dentin (Chung, C.-J. *et al* 2011).

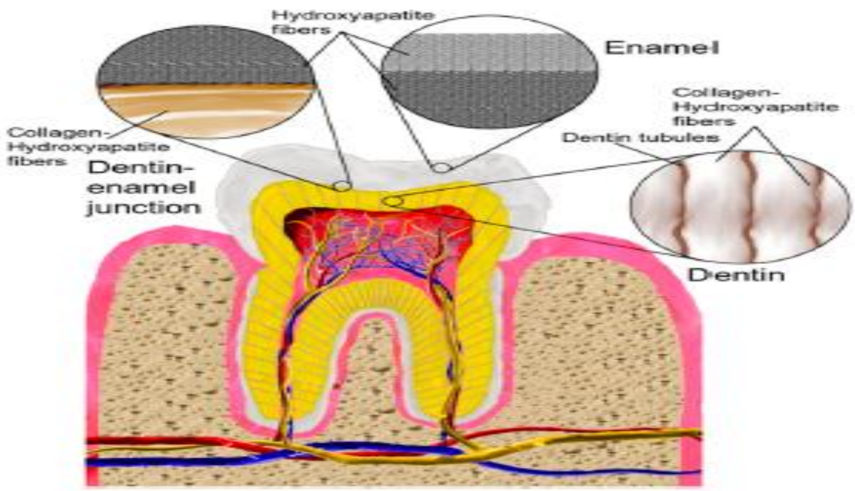

Figure 1. Nanostructure of a tooth.

1.6 Approaches in Nanodentistry

A number of nanotechnology approaches as shown in figure(2) are being used for a range of practical applications in dentistry (Saravana KR*, et al* 2006);(Deyhle, H. *et al* 2011). There are two key approaches (top down and bottom up) in nanotechnology for creating smaller or better materials and use of smaller constituent into more complex assembling. Top-down approach is based on solid-state processing of materials. Typical examples of top down processes are milling, machining and lithography. The "top-down" approaches such as chemical vapor deposition (CVD), monolithic processing, wet and plasma etching are used to fabricate functional structures at micro and nanoscales (Chung, C.-J. *et al* 2011). These approaches are successfully used in electronics industry and for coatings of medical implants and stent using CVD technology to enhanced blood flow and biocompatibility (Beniash, E. *et al* 2019). The "bottom-up" approach entangles the fabrication of materials via edifice up particles by harvesting atomic elements (Subramani, K. *et al* 2019). Bottom-up processing is based on extremely organized chemical synthesis and growth of materials. The best example of this approach is present in nature. e.g., repairing of cells, tissues or organ systems and protein synthesis as well (Cheong, Y. *et al* 2012).

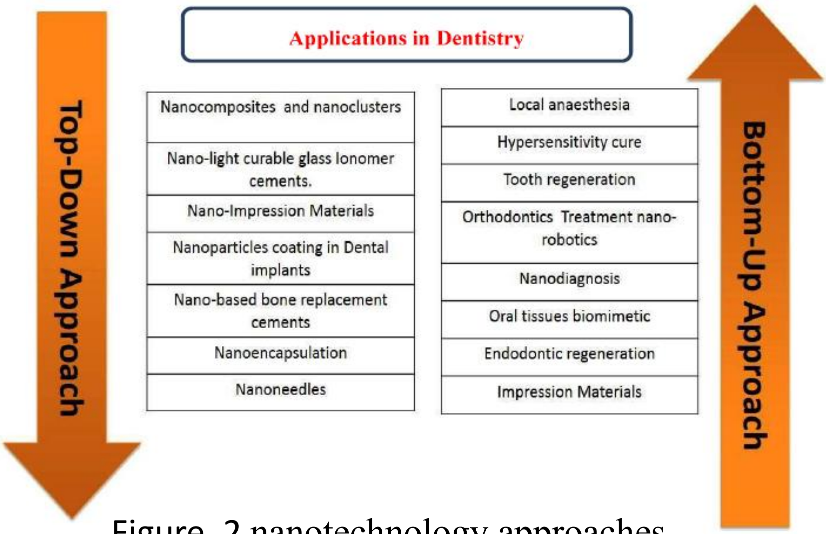

Figure. 2 nanotechnology approaches

Chapter Two

Discussion

2.1. Future of Nanodentisty

Undoubtedly nanodentistry confers numerous advantages over conventional systems, such as higher bio-regeneration, a notable antimicrobial effect due to anti-biofilm properties, increased hardness of composites, and better sealing of fillers, but at the same time, its overpricing, precise placement, associated toxicity, costly development, and international regulations limit the clinical exploration. Though despite all the stated hurdles, scientists are now working hard to find the least expensive methods to synthesize NP scaffolds that fits in the regulatory framework as well as assist in placing the NPs into the right place. There are multiple unconventional NPs, including nanodiamonds, quantum dots, nanoshells, and carbon nanotubes, which have been explored widely in research and have better outcomes to be used in future commercial markets. Its superior surface and chemical nature make it a very suitable candidate for use as a filler in dental nanocomposite fabrication.

2.1.1. 3D Printing

3D printing is one technique that is being employed for the synthesis of the most

complex gematrical scaffold that might be difficult to make when using different processes. Chau et al. fabricated vancomycin releasing polycaprolactone/nHA nanocomposite using 3D modeling. The scaffolds showed higher strength and sustained drug release for up to 14 days which may assist tissue regeneration with antimicrobial activity (Lacruz, R.S. *et al* 2017). However, despite the success in bone regeneration scaffold synthesis, little research has been done in the nanodentistry domain, making it a potential area for future research.

2.2. Maxillofacial Surgery

Nanotechnology in maxillofacial surgery, despite intensive development in recent decades, has been still a relatively new branch of dentistry. Since the science of design, synthesis, characterization and application of materials and extremely small devices can be part of nanotechnology, its use in surgical practice can be very diversified. According to Nandagopal et al., three basic approaches of dental nanotechnology can be distinguished:-(1) bottom-up approach—building particles by combining atomic elements; (2) top-down approach—using equipment to create mechanical nanoscale objects; and (3) regenerative nanotechnology—bio-mimicry (Subramani, K. *et al* 2011). Taking into account the benefits of using nanomedicine (such as advancement in the fields of drug delivery systems, gene therapies, body and organ imaging, surgical tools, and diagnostic procedures), it is obvious that it has found its use in dental surgery (Mikkilineni, M. *et al* 2013).

One of the areas of nanotechnology application in dental surgery is pain management, especially orofacial pain. Orofacial pain (OFP) can result from various physiological disorders and has very different etiology. Most common causes are related to temporomandibular disorders (TMDs), which include a number of clinical problems that involve the masticatory musculature, the temporomandibular joint (TMJ) or both. Trigeminal neuritis may also be an important factor triggering OFP. Its most important causes include injury secondary to dental procedures, dysfunction of the nervous system, neoplasias and/or infections. Neurovascular disorders can also cause chronic orofacial pain. Currently, the treatment of OFP consists of mono- or polytherapy containing non-pharmacological and pharmacological modalities. A multidisciplinary and multi-pronged approach seems to be crucial and beneficial for optimizing therapy (Zhang, L.; *et al* 2009). A novel approach is the use of nanotechnology to eliminate or mitigate OFP, including OFP resulting from surgical procedures. For instance, vibrotactile devices (battery operated vibrators VibraJact, DentalVibe, Accupal) are operated on the principle of gate control theory through the simultaneous activation of nerve fibers via vibrations. Another pain control method used is the computer controlled local anesthesia system (CCLAD) (WandTM/CompuDentTM system) (Roszek, B. *et al* 2005). This technology allows for a modifiable and controlled method of administering the anesthetic preparation through light-weight hand-piece and foot control. An interesting topic, although still in the conceptual sphere, is the potential of anesthetic microrobots. The idea involves the use of a suspension containing nanobots that can reach the dentin and move in a specific direction to the dental pulp. The navigation factor could be, for example, a temperature gradient, chemical agents and/or a computer used externally by the dentist. After reaching the site of action, the nanobots would modify neurotransmission until the end of the medical procedure. Despite the increased opportunity for the development of such technological constructs since the discovery of the scanning tunneling microscope and the atomic force microscope, they have not been developed further (Wickson, F. 2008). One of the most interesting compounds from the point of view of nanotechnology in dental surgery is poly(L-lactic acid) (PLLA). PLLA is a safe and biodegradable material used for various applications, such as reversing signs of aging, treating facial fat loss, and serving as a scaffold in tissue engineering and drug delivery. Moreover, PLLA has been approved by the FDA for use in the reconstructive surgery of bone. It occurs in various numerous combinations, including hydroxyapatite and morphogenic protein 2 (BMP-2). A product based on magnesium–hydroxyapatite (HA) and human demineralized bone matrix under the trade name DB Sint has been already approved for clinical use (Nandagopal, N. *et al* 2021). An interesting material with potential application in dentistry was obtained by Wang et al. It was based on nano-TiO_2 combined with medical silicone elastomer in various proportions. Silicone elastomer filled with 2% TiO_2 nanoparticles results in a material with improved physical properties for the maxillofacial prostheses. At the same time, it is very important to note that in clinical practice, the addition of the nanomaterial significantly counteracted thermal aging of the material. It should be emphasized that currently the use of TiO_2 in medicine is widely discussed in the world of science and there are no unambiguous opinions about its safety. Cytotoxicity tests were performed in the experiment, revealing that silicone elastomer filled with nano-TiO_2 particles had short-term biocompatibility (Ver Halen, J. *et al* 2014). Nanosilver has emerged as a valuable material in maxillofacial surgery due to its potent antimicrobial properties, biocompatibility, and ability to enhance bone regeneration. The incorporation of nanosilver into β-tricalcium phosphate (β-TCP) provides adjuvant antimicrobial characteristics, reducing the risk of infections in bone grafting and implant procedures. Studies have shown that silver/β-TCP nanocomposites significantly improve bone mineral density, as observed through CBCT imaging after two months, making them beneficial in maxillofacial reconstructive procedures. Additionally, histological analysis has demonstrated increased bone formation when nanosilver-enhanced β-TCP is combined with injectable platelet-rich fibrin (i-PRF), supporting its role in accelerating bone healing. Immunohistochemical findings further confirm that nanosilver-containing materials promote faster and more effective osseointegration, whether used alone or in combination with biological growth factors. These properties make nanosilver a promising material in maxillofacial surgery, particularly in bone grafting, implantology, and the management of post-surgical infections.(Naser AI., *et al* 2024)

2.3. Orthodontics

Orthodontics is a branch of dentistry concerning the treatment of malocclusions. Correct bite is not only an esthetic issue but more importantly, it enables proper food grinding. What is interesting is that malocclusions can be a primary cause of gastrointestinal problems. In orthodontic treatment, arch wires, power chains, elastomeric ligatures and many others are commonly used to move teeth (Romero-Reyes, M. *et al* 2014; Verma, H.;*et al* 2020). Nanotechnology is garnering more attention to form new-shape memory materials (i.e., providing lower ion leaking), brackets (i.e., preventing caries formation) and ligatures (i.e., wearing resistance) with better properties.

It is well known that some metal ions could be toxic for humans and cause severe complications. Following long lasting orthodontic treatment, the oral cavity is exposed to different metals (arch wires, brackets, etc.). Therefore, Kumarasinghe et al. applied plasma-induced polymerization to coat orthodontic brackets to lower metal ion leak into the oral environment. Firstly, polyoxazoline was deposited on the brackets. Next, the functionalization with tryptophan of the obtained surface coat was performed as shown in (Figure 3). These coated brackets showed only minimal metal ion leak in comparison to the untreated ones. Moreover, in the cytotoxicity assessment, decrease in viability of the fibroblast was not observed (Verma, S.K.;*et* al 2014).The key issue in orthodontic treatment is maintaining the achieved occlusion. For this purpose, stainless steel retainers are commonly used. This causes long lasting metal ion leak.

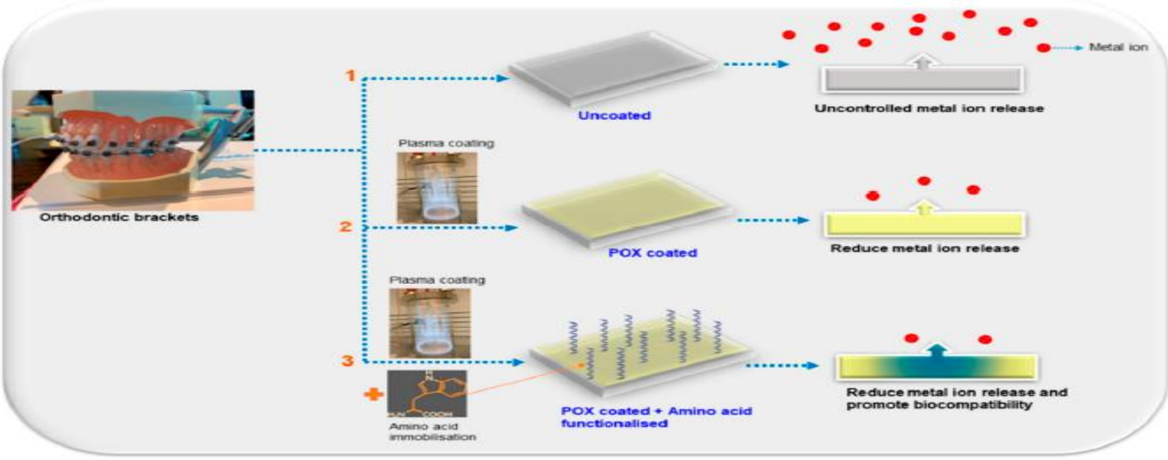

Figure 3. Schematic illustration of the design of surface-functionalized orthodontic brackets

2.4. Nanomaterials for Restorative Dentistry

There has been a drastic evolution in recent years for restorative materials, particularly in tooth color materials. Nanotechnologies have been applied for the manufacturing of dental composites (nanocomposites) (Zhang, L.; *et al* 2009), glass-ionomers cements (nano-ionomers), endodontic sealers and tooth regeneration.

2.4.1. Nanocomposites

The development in the use of nanocomposites patented in response to the persistent and discouraging issues of polymerization shrinkage, strength, microhardness, and wears resistance essential in posterior occlusal applications (Roszek, B. *et al* 2005). Bowen developed the resins [Bisphenol A-Glycidyl Dimethacrylate (Bis-GMA)] and used silane couplers. Around the same era, words like "nano" were coined by the noble laureate Sir Richard Feynman in 1959 (Roszek, B. *et al* 2005). This discovery was a landmark for advances in dental composites. Since then, composite fillings have become an essential component of the restorative armamentarium. The last decade has witnessed rapid advances in dental restorative materials including the resin-based composites. The introduction of nanotechnology led to the discovery of nano-filler particles. All efforts were and are being made to achieve considerable advances in physical properties and tackle issues like polymerization shrinkage, wear resistance, micro hardness and achieve patient satisfaction in terms of the aesthetic appearance (Freitas RA Jr. 2000; Wickson, F. 2008).

2.4.2. Composition

Nanocomposites are composed of two or more materials that include matrix material and nanoscale particles. The matrix should be a biocompatible polymeric, metallic, or ceramic material. In nanocomposites, it is possible to operate the mechanical properties by incorporating secondary nanoparticles to obtain the same characteristic features of natural bone (Nandagopal, N. *et al* 2021). The properties of nanostructured materials are completely controlled by their synthesis method, processing means and their chemistry (Ver Halen, J. *et al* 2014). It has been acknowledged that the intrinsic molecular identification of the molecules is governing the formation, morphological development and crystallography of the nanocomposites (Romero-Reyes, M. *et al* 2014).

2.4.3. Evolution of Organic Resin Matrix

Conventional Resin Based Composites (RBC) were based on organic polymer matrix mainly Bis-GMA and triethylene glycol di-methacrylate (TEGDMA). Due to the hydrogen bonding interactions that are present in between hydroxyl groups and monomer molecules, Bis-GMA becomes very viscous. To obtain working viscosity, they are mixed with more fluid monomers. In some instances, Bis-GMA is combined with tri-ethylene glycol di-methacrylate (TEGDMA) or urethane di-methacrylate (UDMA) or even in some cases by ethoxylatedBisphenol-A-dimethacrylate (Bis-EMA). To tackle issues of shrinkage, aging and other environmental factors such as temperature changes and moisture, Bis-GMA is replaced with UDMA or other dimethacrylates (Wickson, F. 2008); (Verma, H.; *et al* 2020). Most of the existing methacrylate resin shrinks depending on the number of polymerizable units. This shrinkage is related to the monomer percentage. Two methodologies have been used to reduce polymerization shrinkage; either by reducing the reactive sites or using different types of resins. By increasing the filler loading or increasing the molecular weight per reactive group will reduce the density of reactive sites per volume (Freitas RA Jr. 2000). The properties of nanocomposites (good translucency, contouring and surface finish) are excellent and can restore lost or damaged dental tissues as shown in (Figure 4). Current research is now focussed on reducing the polymerization shrinking. The addition of using monovinyl methacrylate monomers into dental resin was introduced by Decker, and reported enhanced polymerization kinetics and improved mechanical properties. They were made up of secondary and tertiary functionalities including urethanes, carbonates or cyclic carbonates. They were also referred to as ultra-rapid monomethacrylates. Recently researchers are investigating options of adding acidic functional groups in monomers (Verma, S.K.; *et al*. 2014).

Figure 4. Clinical applications of tooth colored nanocomposite restorative materials (a) Root treated and unrestored premolar tooth; (b) Crown build up with a post and core using a modern nanocomposite restorative material

2.4.4. A Paradigm Shift of Nano Fillers to Clusters to Hybrids

Carbon nanotubes have superior and exceptional mechanical properties as well as unique bioactivity (Shakib, K. *et al* 2014; Wang, L. *et al* 2014). On the other hand carbon nanotubes lack some essential properties such as hydrophobicity and chemical inertness, which in turn limit their applications (Shakib, K. *et al* 2014]. Reinforcing dental composite with carbon nanotubes could help reduce such defects and provoke the advantages gained by excellent mechanical and biological characteristics (Pinheiro, S.L. *et al* 2014). Inorganic component of dental composites is made up of filler particles and comprised of quartz or engineered glass particles. Their purposes are to increase strength, modulus of elasticity, reduce polymerization shrinkage and have positive effects on coefficient of thermal expansion and water absorption. Nanohybrid or nanofilled composites are two types of materials referred to the terminology of nanocomposites (Kardach,

H. *et al* 2019). In the process of evolution of dental composites, the alteration of filler size, shape, morphology and loading efficiency still remains a landmark. Various methods adapted to synthesize nanofillers are flame pyrolysis, flame spray pyrolysis or sol-gel processes. Since the dimensions of these filler particles are below that of visible light, it is impossible for them to either scatter or absorb visible light. This phenomenon plays a key role in getting excellent aesthetic properties and can be used for anterior teeth restorations as shown in (Figure 5). Filler loading efficiency can be greater as the size is very small. A direct relationship exists between the filler loading and surface area of filler particles, this has an effect on the wettability of fillers. What nano-based filler particles are doing is they help to improve the continuity in between the macroscopic (40 nm to 0.7 nm) natural tooth structure and nano-sized filler particle. This eventually results in a more natural and advanced interface. As shown in Figure 6 depicts the variations in distribution of these nano-filler particles. A homogenous and non-homogenous distribution of nano sized fillers and presence of nanoclusters results in composites with different bulk and surface properties that can be tailor made according to the site of application (Roszek, B. *et al* 2005).

Figure 5. Aesthetic applications of resin nanocomposite restorative materials (a) Preoperative labial aspect of defective maxillary anterior segment with recurrent decay and discoloration; (b) Composite layering technique adapted to restore decayed tooth structure and midline; (c) Postoperative appearance of midline correction using a nanocomposite dental restorative material.

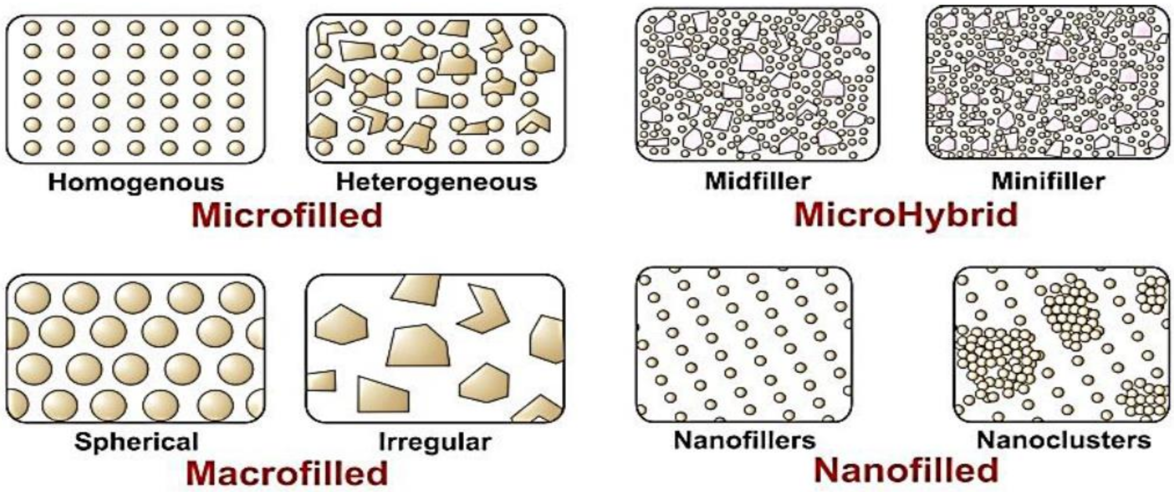

Figure 6. Classification of dental composites on the basis of particle size and structure.

Nanofills and nanohybrids are the two different types of more commonly available nanocomposites. Nanofills are dominated by the presence of 1 to 100 nm size particles mainly and nanohybrids are comprised of larger particles ranging from 0.4 to 5 µm, hence they are not truly nanofilled and are called hybrids. For example, NANOSIT™ (Nordiska Dental, Angelholm, Sweden) is a nanohybrid composite comprised of inorganic particles ranging from 7 nm to ≤2000 nm. The uniformity of particle distribution in nanofillers ranges from 5 to 20 nm in a commercially available product 3M ESPE (Filtek™ Supreme Plus, 3M ESPE, St. Paul, MN, USA). Similarly, such interface (hybrid materials) enables increased filler loading and improved adaptability of dental composites. In case of nano-filled composites, it is extremely difficult to control the particle size precisely hence particle size range is used. Various sized nanoparticles facilitate better interface and loading. Comparable results are obtained using nanohybrid and cluster materials.

One of the key purposes of using nanomeric particles is to reduce the particle size to the wavelength of visible light (400 nm to 800 nm). This helps in obtaining highly translucent materials, high surface area to volume ratio and molecular interactions as the polymer size range is usually in the same dimensions. One of the two types of nanomeric particles are nano-agglomerated particles made up of silica or zirconia, surface coated with coupling agent to enhance bonding. Highly filled composites if made using nanomers of the same size have a poor effect on rheological properties (Freitas RA Jr. 2000); (Wickson, F. 2008).In order to overcome this drawback nanoclusters were synthesized by lightly sintering nanomeric oxides resulting in controlled particle size distribution. Nanoclusters act as a bunch of grapes with an average size range of 0.6 µm. These nanoclusters are also surface treated with silane to improve chemical bonding and adhesion with the organic resin matrix. Filtek™ Supreme Plus (3M ESPE) has pioneered the combination of nanoclusters and nanoparticles to obtain better wear resistance. A considerable improvement in the wear properties was observed using the three-body wear test performed on an oral wear simulator (Freitas RA Jr. 2000); (Wickson, F. 2008).

2.5. Prosthodontic

With the advent of technology, living standards have drastically improved attitudes towards oral health. Therefore, interest in prosthodontics for advancing research on artificial restorative materials has been shifted to the upside (Kumarasinghe, L.S. *et al* 2021). Classically, these materials are broadly categorized into ceramics, resins, polymers, and metals (Mitra, S.B. *et al* 2011). However, a few issues are still unsolved to cater to the need for prosthodontics. Here, nanotechnology played a vital role, and different nanomaterials have been synthesized/utilized to cover the untapped areas of prosthodontics. Nanotechnology has also significantly improved the properties of existing materials, such as ceramics, impression materials, denture bases, and types of cement used in prosthodontics. Prosthodontics are mainly classified into removal or fixed type (tooth-supported or implant-supported) .

2.5.1. Removable Type

In this category, Polymethylmethacrylate (PMMA) polymers and silicone elastomers are mainly used for denture and maxillofacial prostheses, respectively. However, dimensional changes with PMMA polymers and poor tensile and tearing strength of silicone elastomers pave the way for using nanotechnology in these types of restorative materials(Ozak, S.T.; *et al* 2013). Firstly, carbon nanotubes lead to a bond formation with PMMA resins/polymers by weak van der Waal force to improve its dimensional stability for better fit and tensile strength (Chen, M. 2010). Secondly, metal-based NPs (Ag, TiO2, etc.) reinforce PMMA polymers to improve their tensile strength and antimicrobial activity (Ben-Nissan, B. *et al* 2006). Moreover, polyhedral oligomeric silsesquioxanes (POS), a nano (1.5 nm) silica cage, and metal NPs support silicone elastomers to improve their tensile strength and physical properties (Choi, A.H. *et al* 2013),(Choi, C. *et al* 2000). Moreover, nanotechnology improved the pathological states like denture stomatitis induced by adherence of biofilm of Candida albicans over the denture base materials (Kaur, P. 2011). Moreover, Alumina NPs were synthesized and evaluated for improving osseointegrity and curative process when the dental implant was installed (Cramer, N.B. *et al* 2011).

2.5.2. Fixed Type

In this category, tooth and implant-supported nanomaterials, nanocomposites, and nanocoatings are primarily used as fixed prostheses. The issue of dimensional unfolding persisted in the conventional fixed types of restorative materials. Conventional materials also showed cytotoxic effects by leaching organic monomers into surrounding gum tissues (Hahn, B. *et al* 2009). Nanocomposites based on nanofiller technology solve these issues (Kealley, C. *et al* 2006). Silica or Zirconia-silica NPs were synthesized by treating silica particles with 3-methacryloxypropyltrimethoxysilane to improve flexural strength and hardness. Nanotechnology also brings hope and new vistas in improving the adhesion and durability of implants. Carbon nanotubes, polyvinyl alcohol, and silica-based NPs were used in addition to calcium phosphate to synthesize nanocomposites and sometimes scaffolds for improving mechanical strength and tissue regeneration (Wepasnick, K.A. *et al* 2010). In addition, the improvement of calcium carbonate-silicone dioxide NPs improves tear strength and hardness of maxillofacial silicone elastomers (Terry, D.A. 2004). In another study, Persson et al. synthesized glass-ceramic in Zirconia-silica NPs using the sol-gel method to improve the corrosion resistance and hardness. Few commercial products are also available in the market to understand the potential of nanotechnology in prosthodontics. Clearfil Majesty Posterior is a product (a superfilled nanohybrid composite) of Kuraray America and is an ideal amalgam alternative (92% filled with nano-sized alumina and glass materials) and shows high physical properties with superior surface wear resistance. PremiseTM, a product of Kerr corporation (84% filled), a nanocomposite that shows significant improvement in durability, wettability, and sculptability .

Chapter Three

Conclusion

Nanotechnology is set to revolutionize clinical dental practice. In no distant future, oral health care services will become less stressful for the dental surgeons, more acceptable to patients and the outcome will significantly become more favorable. Rapidly progressing investigations will ensure that developments that seem unbelievable today are possible in the future. Optimal utilization of the advantages and opportunities offered by nanotechnology in clinical dental practice will facilitate improvements in oral health. However, as with all technologies, nanotechnology carries significant potential for misuse and abuse on a scale and scope never seen before if not properly controlled and directed.

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