ISSN- O: 2458 - 868X, ISSN–P: 2458 – 8687
National Library of Medicine - ID: 101731606

International Journal of Medical Science and Innovative Research (IJMSIR)
IJMSIR : A Medical Publication Hub
Available Online at: www.ijmsir.com
Volume – 7, Issue – 2, March – 2022 , Page No. : 165 - 175

The future trends in nanotechnology and its uses in orthodontic treatment – A review

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Citation this Article: Dr. I Girish Kumar, Dr. Raghunath N, Dr. Pradeep S, Dr. Jyothikiran H, "The future trends in nanotechnology and its uses in orthodontic treatment – A review", IJMSIR- March - 2022, Vol – 7, Issue - 2, P. No. 165 – 175.

Type of Publication: Review Article

Conflicts of Interest: Nil

Abstract

Nanotechnology is emerging interdisciplinary field of rapid development and has brought extensive changes in medicine and dentistry. Nanomaterials based on a design that can impersonate tissue's structural and mechanical properties and aid bio-integration.

Nanotechnology has countless dentistry applications, including renaturalization therapy for dentin hypersensitivity.

It enhances properties of root canal sealers and Oral health maintenance by using mechanical dentifrobots and accomplishes orthodontic teeth alignment treatment in single visit. There is wide range of synthetic nanoparticles like hydroxyapatite, titanium, zirconia, bio glass, and silver nanoparticles for dental restoration materials, metal brackets, orthodontic archwires, elastomeric ligature, power chains, and orthodontic mini-implants. This review article focuses the future trends and developments in nanomaterials and their application in Nano dentistry and orthodontic materials and treatment.

Keywords: Nano Dentistry, Nanoparticles, Nanomaterials, Orthodontics.

Introduction

Nanotechnology is the word known to those areas of science and technologies that rates at magnitudes in the nanometre scale developed in the design, categorization, manufacture, and tender of materials, structures, devices, and structures. In the natural world, there are many instances of structures take place with nanometre dimensions. Necessary molecules inside the human body and mechanisms of foods, many technologies have involved nanoscale structures for many years. Only in the last quarter of century can actively and intentionally modify the molecules and structures within size range. This control at the nanometre scale distinguishes nanotechnology from other areas of technology[1.]

It described as the study and use of structures between 1 nanometer and 100 nanometers in size. It will take eight hundred nanometer particles to match the size of a human hair**.** Nanotechnology encloses the manufacturing and application of the chemical, physical, and biological

systems at the scale of which ranges from individual molecules into submicron dimensions and the integration of the nanomaterials into larger systems. It can change the point of view and allow us define global concerns. The discovery and use of carbon nanomaterials presented new technology areas in nanomedicine, biosensors, and bioelectronics[2]. currently years, nanotechnologies has developed apparent in field of multidisciplinary. It has obtained and become an integral part of medical, pharmacy, and dentistry and delivers next generation functional materials like comprehensive uses. Exploring new materials and operation at the nanoscale and advancing novel theoretical and unique experimental techniques for research purposes provides a possibility for improving innovation nano structural materials and nanosystems[3]. There are various current and expected advancements in nanoscale science and nanotechnology in applications in medicine, pharma drug delivery, and Dentistry, especially in Orthodontics. The growth of nanotechnology made at a brisk increasing rate. The present review designates the science and technologies, effects, and modern nanotechnology presentations in dentistry and orthodontic appliances and commercially accessible anew advanced materials and supportive literature that benefit dentists in empathetic the clinical importance and efficiency of such materials equated to the ones presently used in general dental practice.

Methods and Materials

To recognize publications, An electronic database search we piloted. The search including was PubMed, Medline, and Scopus. The keywords used to search for nanotechnology, Nanomaterials used in dentistry, orthodontics, and applications. Language limitations set, the articles were reviewed, written, and published in English. Initially, 64 articles rectified from the databank, and reports were reflected and published from 2010 to 2021. The articles included were mainly about literature reviews that evaluated the broad application of nanoparticles in all different aspects of dentistry and orthodontics.

Nano-medicine

Nanomedicine is a division of medicine, which relates to the acceptance which aids in nanotechnology for the prevention and treatment in dentistry. It implies using nanoscale materials, like biocompatible nanoparticles and nanorobots, for the diagnosis, delivery, and identifying tenacities. Advancement in biotechnology have resulted in the formation a new arena termed nanomedicine[4]. Nanomedicine is the science of diagnosing, preventing and treating disease utilizing nano size molecules. Nanotechnology experts deliver drugs to specific cells in the shape of nanoparticles. The drug use and its after-effects will be reduced remarkably by depositing the active agent in the target zone area. Target drug delivery reflected to decrease drug complicacy and decrease use and high treatment charges. It also focuses on escalating the bioavailability at precise places of the human body and above a period. It can be attained by the molecules targeted by the nano-engineering device. Nano-medicine has scope for improvements in various available techniques for fully developing new strategies in nanomedicine[5]

Nano dentistry

The improved attention in nanotechnology future in the dental application has been trending a new to dentistry. The evolution of nano dentistry will deliver a high standard of oral health using nanomaterials and biotechnology, including tissue engineering and nanorobots like new treatment in dentistry, delivery of local anaesthesia to simplify the dentition re-

naturalization, permanent solution for the cure of hypersensitivity, complete treatment of teeth alignment in the shorter duration time of the treatment, and progressive oral health maintenance in dentistry[6].

Approaches in Nanotechnology

The Bottom-up approaches: The bottom-up approach is also called a self-build method used in chemical and physical forces, employing nanoscale produces the basic units into large structures by the nanofabrication process. The actual size will decreased in nano-manufacturing. The bottom-up approach gives progressive addition to top-down techniques. The Bottom-up approaches come from biological systems, wherever nature has to use chemical forces to create essential structures required by life. Researchers and Scientists have aspired to reproduce nature's capability to yield small clusters of molecules, which will later self-assemble into more positive detailed structures[7].

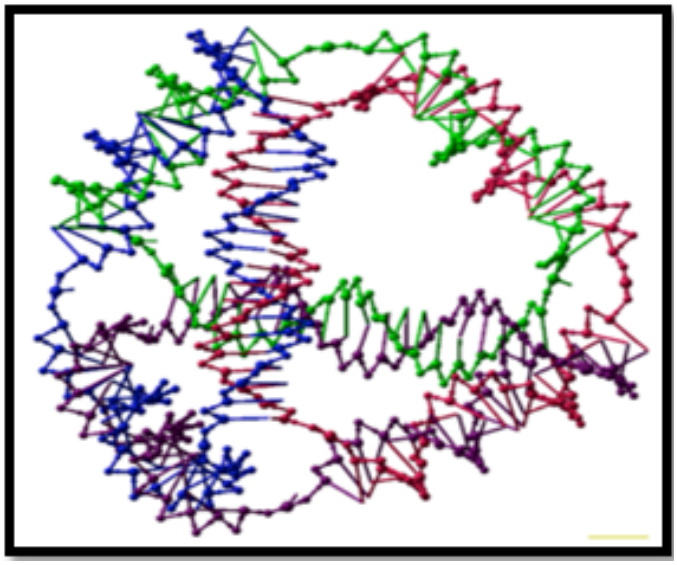

Fig. 1: DNA - Deoxyribonucleic acid tetrahedron is an artificial prearranged nanostructure made to produce DNA - nanotechnology. The edge of tetrahedron has a base pair of 20 DNA Double helix, and each tip has a three-arm junction[8].

The bottom-up approaches have developed nanoparticles production;

The self-assembly accomplishes restricted control over both development and arrangement in the extension quantum dots. A Liquid phase technique established on globules of the lipid molecules floats in a non-aqueous solution has developed, and it produces the selected size of nanoparticles such as magnetic, semiconductors, and other resources.

The DNA-assisted clusters deliver method that combines the heterogeneous hybrid section into a precise sole device which combines self-assembly and self-organization in a wet environment. The weekend electrochemical forces play a substantial role (Fig.1). In the bottom-up approach. The polymers finished with corresponding DNA strands can be used as an intelligent adhesive tape solution that attributes in the middle of the polymers when the exact pair is available. This kind of assembly can be united with electrical fields to guide and locate the attachment site and which results in new permanent attachment approaches, like electro-depositions and metallization

DNA nanostructures

DNA Nanotechnology, joined with the native biocompatibility of DNA, contributes to an unparalleled opportunity to develop DNA nanostructures that are altered for biomedical applications and exhibit finely tender the modified cell and distribution of profiles (Fig .2). For example, they have examined as directed therapies for enlightening the efficiency and decreasing the side effects of current treatment approaches[9]

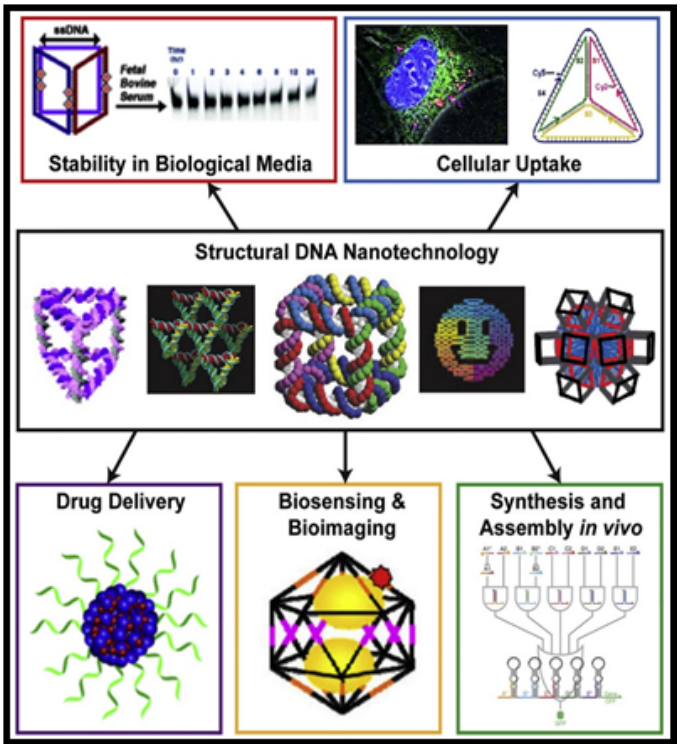

Fig. 2: Biological interface with DNA Nanostructures**.**

Top-down approaches

- Top-down approaches progressed to build assemblies at the micrometre scale (μm). The bottom-up technique accumulates into a small group of molecules at nanometres (nm) scale. And it combines the approaches to produce extended structures at the nanoscale in Top-down approaches.
- Several technologies have reduced from solid-state silicon conventional approaches to producing microprocessors, which effectively create structures minor than 100 nm. The Giant magnetoresistance-built hard drives are, at present on the market, suitable for this depiction[10].

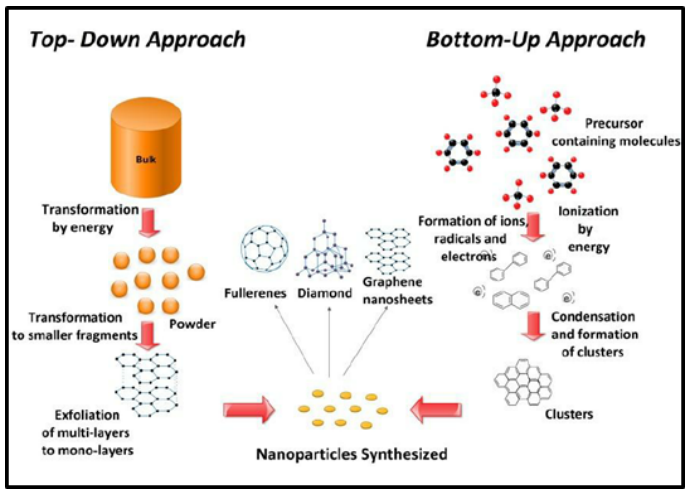

Fig. 3: Top-down and Bottom-up approaches for building structures at the micrometre scale.

- A solid-state technique used to generate Nano-electromechanical systems, which linked to micro-electromechanical systems.
- The absorbed ion beams can straight remove or bond the acceptable precursor gasses that are relevant. This system used to create sub100 nm sections of materials used to break down electrons microscopy.
- The atomic energy microscopic tips can be used as a nanoscale compose head to bond to resist, monitored by an impression development to confiscate material in a top-down method.

The Functional Approaches

- The Functional approaches progress the mechanism of functions without esteem that they might accumulated. Molecular-scale electronics try to build molecules with electronic properties. These properties can used as single-molecule components in a nano-electronic device.
- The amalgamation of anisotropic super-paramagnetic materials such as magnetic nano-chains developed by Magnetic Assembly[11]. Molecular-scale electronics seek to advance the functional molecules with beneficial electronic properties. It can used as a single-molecule mechanism in a nano-electronic device. Synthetic

chemical methods can generate molecular motors, such as Nano ca.

The Biomimetic approaches

- The biomimetic approach is interconnected to biomineralization, leading to remarkable biomedical innovation. The biomimetically engineered products could be higher to any of its other alternatives. The evolution of biomimetic approaches has provided relevant understanding of the current tissue engineering challenges. Structuring the polymorphs of calcium carbonate in calcite and aragonite in a shell helps the organism achieve mechanical properties for its protective envelope.
- Bio-nanotechnology is the adoption of biomolecules used for nanotechnology, In conjunction with the assembly of virus and lipid[12]. Nanocellulose is conceivable large-scale application in biotechnology.

Health implications in Nanotechnology

- According to the US, federal-state agencies estimated and evaluated the extent of health concern, Beginning with the identification problem.

a. Risk assessment of dose-response
b. Risk assessment of exposure and
c. Risk characterization[13]

- The cosmetics have no clinical trials but have many products with nanoparticles. Nanoparticles in all these products have stated will cause erythema, cobalt, and chromium nanoparticles, which penetrates the skin barrier and damage the fibroblasts.
- The Nanoparticles toxicity be contingent on their surface properties, coating, structure, size, and accumulation capacity. Nanoparticles have poor solubility, and they might cause cancer as nanoparticles have a significant surface area to volume ratio, which may increase biological and chemical reactivity.
- Several studies suggested that nanoparticles can be breathed in and infiltrate cell membranes, reaching the human body's bone marrow, liver, spleen, and lymph nodes.

Nanoparticles in orthodontics

According to British Standards Institution (BSI 2005), resoluted nanoparticles are the constituent part in which all the proportions are the nanoscale range at the atomic level of 100nm. Nanomaterials are materials with peripheral dimensions or internal structures, showing new characteristics associated with the same material without features nanoscale. Scientific Committee Emerging and Newly Identified Health Risks (SCENIHR) [14].

Nanocoatings in Orthodontic Metal and Molar bands with tubes

- Patients have difficulty cleaning and maintaining oral hygiene, which surges the caries incidence in wearing orthodontic brackets and molar bands with tubes.
- The most common bacteria, Streptococcus mutans and Lactobacilli, can generate high lactic acid levels, which affects the demineralization of teeth. Enamel demineralization involves an infuriated appearance, which termed as white spot lesions.
- It can be in the brackets within one month of bonding, and the incidence of white spot lesion has stated to be 48% in 4 to 6 months, 65% in 6 to 12 months after the progression of the orthodontic treatment, and 50% at the final phase of the fixed orthodontic treatment.
- Fluoride is the utmost pertinent agent that inhibits White spot lesions' development throughout the treatment.
- Orthodontic patients can apply Fluoride regularly with different forms like topical fluoride preparations,

application of varnish in the form of gel, and solvent all round.

- White spot lesions shown that it will reduce in and around fixed braces and molar tubes and bands when a patient uses mouthwashes and brushing with fluoride toothpaste, only 20% of orthodontic patients follow the advice.
- A study conducted about the antibacterial properties and which releases ions of nano silver electroplated orthodontic brackets and bands—comparing the properties of silver on the quantity of adhesion of cariogenic streptococcus, which provides trial for the hindrance of white spot lesions in conventional orthodontic brackets[15]. The test result of the silver nanoparticles coated on metal brackets and molar bands will decline the attachments of Streptococcus mutants and caries during fixed orthodontic treatment.

Nanocoatings in orthodontic archwires

- Frictional forces among the orthodontic wire and brackets slot application of nano-coatings have the latent to proliferation the tooth movement and effect less duration in orthodontic treatment.
- Nanoparticles can utilized in the procedure of dry lubricants. They are dense form materials capable of decreasing the resistance amid two surfaces that slide alongside each other without liquid media.
- A study by Shaza et al. examined the effect of Zinc oxide nano-coating. NiTi orthodontic wires and antibacterial activity, which modifies its mechanical properties, Adhered Zinc oxide nano-coating on NiTi wires procured. The coated wires had remarkable antibacterial activity against staphylococcus aureus, Group A streptococcus pyrogens, and Escherichia. Coli had a decrease in frictional forces by 35%. Zinc oxide nano-coating will improve NiTi wires' antibacterial effects and reduce frictional resistance. The nano-coatings may introduced in orthodontic treatment for safer and faster treatment[16].
- A study conducted by Keerthi et al. estimated the result of titanium dioxide coating on the surface roughness of NiTi archwires and its impact on Streptococcus mutans adhesion or attachment and enamel mineralization at the end of 30 days and to assess the veracity of the titanium dioxide coatings. Un-coated NiTi archwires and titanium dioxide nanoparticle-coated NiTi archwires and after 1 month of intraoral use were imperilled to the analysis of surface roughness using surface topography using electron scanning-microscopy. Streptococcus mutans bond was assessed on the recovered archwires using polymerase chain reaction (PCR). The enamel mineral content in the arches interrelated to the uncoated and coated archwires assessed using a Diagnodent (LASER Fluorescence technology) pen and an instrument used to detect the development of lesions and caries. Titanium dioxide nanoparticle coating on NiTi archwires causes an initial decrease in surface roughness, but surface roughness will completely mislaid at the end of 30 days. Streptococcus mutans attachment is significant on the coated wires, which could imputed to reduced preliminary surface roughness and antibacterial property of titanium oxide. Orthodontic archwire seems to have a restricted role in the demineralization of enamel [17].

Nanoparticle Adhesives in Orthodontics

- A innovative class of material called Polymer nanocomposites packed through nanofillers with 0.004 - 0.02um size. The filler particles yield strong composites such as macro, hybrid, and micro-hybrid composites. Like mined quartz, melted glasses, and ceramics, the hefty particles produce the particles into tiny small sizes.

The filler load reduces the element of the filler particles and an extensive range of delivery it increases and lowers shrinkage of the polymers and improves the mechanical properties like tensile strength, compressive strength, and intransigence to rupture [18].

- According to Sug-Joon et al., Trial composite adhesives comprising silica nanofillers and silver nanoparticles associated with two conventional Composite bonds and a Resin-modified glass ionomer bond. The evaluate the surface physical characteristics, properties, and antibacterial properties against cariogenic streptococci. The surface roughness and surface free energy physical characteristics were determined using the sessile drop method and measured using laser scanning microscopy; the metal brackets interface's shear bond strength and bond failure examined to compare the physical properties. Antimicrobial activities evaluated by a disk diffusion test, a bacterial adhesion assay, and an optical density amount of bacterial suspension, which contains individual adhesives. The study suggested Experimental composite bonds can help avoid enamel demineralization from one place to another the surfaces deprived of arbitration to the characteristic physical properties[19].

Nanoparticles in orthodontic elastomeric ligature

- Conventional elastomeric ligatures ties have used to clasp the orthodontic wires firmly in the bracket slot during the orthodontic treatment. It can provide a carter for the distribution of nanoparticles and act as anti-inflammatory, anti-cariogenic, and antibiotic drug molecules entrenched in the elastomeric matrix. The study determined that fluoride release described by an initial release of Fluoride throughout the first and second day, and logarithmic scale decreases seen after placement of elastomeric ligature. The elastomeric fluoride ties should be changed monthly once as scheduled for maximum clinical advantage. These ties increased weight intraorally with residual fluoride present in fluoride-infused and non-fluoride elastomeric ligature ties after 30 days of intraoral use due to saturation.
- In another study, The silver ions from silver-zeolite that integrated into an elastomer. An ortho-shield safe-T-tie, a nano elastomeric ligature, has been presented to reduce bacterial development in and around the orthodontic metal brackets and wires. The study concluded that no substantial difference between the antimicrobial effect on the silver ions contained elastomeric ties and the conventional elastomeric ties. The elastic modulus integrated through silver nanoparticles can impede the development of Gram-positive microorganisms like Streptococcus mutans, Lactobacillus, Staphylococcus. Aureus and Gram-negative bacteria like Escherichia. Coli shown that the composite acquires broad-spectrum antibacterial activity. The elastic modules coated with silver nanoparticles with advanced physical properties with determined strength, strain, and displacement than conservative elastomeric ligature ties. The effects indicate the probability of the composite to vacillate against the dental plaque, and it will drop the frequency demineralization of dental enamel, securing its protection and presentation in treating orthodontic patients. [20] **A shape-memory polymer materials in orthodontics**
- Shape memory polymers are materials can commit to memory or retain the macroscopic or equilibrium shape and then can be employed and fixed to a reshaping form under definite conditions of stress and temperature.
- They can recline to their unique shape, stress-free underneath thermal, electrical, or environmental environments. Dimplex is a commercially existing shape

memory polymer. It has a high-performance waterproof, moisture permeable membrane on urethane, and has superior biocompatibility. Biocompatible SMPU can applied in some biomedical applications.

- SMPU offers a substitute to custom materials used for the management of malocclusions. Furthermore, an SMP archwire in brackets for teeth alignment is more pleasing than a conventional archwire. A conducted by Jung and Cho [21]. They used a saturated Shape memory polymer wire attached to stainless steel brackets bonded to teeth with a ligature tie in a study model. When heated, the teeth slowly moved into position.

BioMEMS/NEMS devices in the orthodontic movement of the tooth

- Bio-MEMS are the science and technology that functions microscale for biological and biomedical uses, incorporating any electronic and mechanical functions.
- NEMS is the device that combines the processes electrical and mechanical levels of nanoscale. It suggested that micro-fabricated biocatalytic fuel cells, which are enzymatic batteries, can produce electricity to assist the orthodontic tooth movement. An enzymatic micro-battery on the gingiva near the alveolar bone will achieve an electrical power source to accelerate the orthodontic tooth movement. Nevertheless, specific concerns like soft tissue biocompatibility, with altered pH ranges and temperatures on the yield of micro-fabricated enzyme batteries. BioMEMS/NEMS based on a system will be significant and useful. The growth of biocompatible powerful biofuel cells will be the future over the coming years, which can be securely embedded in the alveolus of the maxilla or mandible to increase accelerated movement tooth [22].

Nano LIPUS devices in Orthodontics

- Ultrasound is an energy generated by sound waves, sound energy, or acoustical energy with frequencies above human hearing. It is a system of mechanical energy transferred into body tissues as high-frequency acoustic wave. Ultrasound has dissimilar intensification in distinct effects on body tissues (table.1)

Different types of ultra sounds	Rate of Intensity
Therapeutic Ultrasound	30-70 W/cm2
Operative Ultra sound (shock waves)	0.05-27,000 W/cm2
Diagnostic Ultrasound	5-18 50 mW/cm2

Table 1: Ultrasounds used for different purposes and intensity range

It has achieved popularity over last few years due to exceptional stimulation effects on tissues of body. The most widely used parameters of LIPUS are: Pulsed frequency 1.5 MHz, when signal breaks out in width of 200 µs, a effort with recapitulation frequency of 1 kHz, and rate of intensity with 30 mW/cm2[23]

- A study conducted by Tarek El-Bialy et al. evaluated the potential effect of (LIPUS) on orthodontic tooth movement and resorption of roots in patients. In this study, 21 patients comprised in a split-mouth study. The GROUP-1 and 10 additional patients comprised the LIPUS device used as the negative control group GROUP-2. GROUP-1 patients were designated with LIPUS devices aimlessly to the upper or lower arches. LIPUS was randomly placed to the selected side using transducers that yield the ultrasound with a pulse frequency of 1.6 MHz, a pulse replication rate of 1 kHz, and regular output intensity, 30 mW/cm2. LIPUS increases the rate of orthodontic tooth movement, and it falls the induced root resorption when applied for 25 min per day for up to 6 to 8 months. On the study results,

LIPUS treated side has improved accelerated orthodontic tooth movement and reduced resorption of root than that of the control side in the upper and lower arches [24]

Temporary anchorage devices (TAD's)

- TADs have developed innovative dimension extensively used in orthodontic practice all over world as an absolute Anchorage for orthodontic tooth movement.
- It is commercially available by different manufacturers of TADs, and it exhibits a success rate of 70 to 80%.
- TADs are a device that temporarily fixed to the bone (Transosteally and subperiosteally) are factory-made with even titanium surfaces since it has absolute osseointegration and thus makes complex during removal TADs. The drawback was insufficiency of osseointegration that might lead to fracture and lead to failure of TADs.
- A study conducted, Wen You et al. Magnesium-Beta-Tricalcium Phosphate Nanocoating was applied on Titanium-Minis crews. Nano clay has exceptional mucoadhesive adaptability and has excellent high mechanical properties, which enhances the immovability of minis crews. The nano-coating enhances the grade of osseointegration by conveying nanofeatures to TADs. Magnesium substituted Beta -TCP, a decomposable calcium phosphate, will dilute in biological media and be substituted by bone during implantation, which increases the degree of fractional osseointegration.
- Nanocoating prolonges the minis crews retention time by adding nano porosity and nano surface roughness of the TADs. Nano porosity and Surface roughness have presented to improve osseointegration by strengthening the functions of osteoclasts and osteoblasts [25].

Control of Oral Biofilms during orthodontic treatment

- The biofilms are a thin, healthy layer of mucilage stuck to a solid surface and encompassing a community of bacteria and other microorganisms. The controlled bacteria, fungi, or yeasts form heterogeneous organizations on biotic and abiotic surfaces. It discharges extracellular polymeric substances and protects specific cells from incongruous aspects, such as immunological defence mechanism and restriction of nutrients antibacterial agents.
- The characteristics features like genotype and phenotype of cells in biofilms varies from other free-floating bacteria, and differentiation makes them firmly resistant to antibiotics.
- The mechanism, which forms biofilms within the oral cavity, the function of their anti-adhesive, biocidal activity, and distribution are now coming under close investigation. The likely use of prosthetic device coatings, as an application of topical agents, and in dental materials investigated, and more studies are have been taking place. The latest perception about the presentation of nanoparticles in the control of oral infections and application in photodynamic therapy.s
- Copper, gold, silver, titanium, and zinc has antibacterial and antibiofilm properties, which deal with antibiotic substitutes without any risk of resistance growth.
- The surface roughness of metal-coated biomaterials relies on coating techniques, like drenching, sintering, plasma, sandblasting, anodization, and electron beam vaporization. Additionally, devices formed using these procedures exhibit altered bacterial adhesions, protein absorption, and tissue assimilation[26].
- The conventional metal-based nanoparticles have much enhanced antimicrobial effects than the micro-sized equivalent.

Nanomechanical sensors with Smart brackets

An innovative bracket integrated with CMOS (complementary metal-oxide semiconductors) and the base of the bracket base. A micro-electro-mechanical system with stress-related sensors spread over designed chip space. The sensors are engaged at bottommost of the brackets which evaluates the amount of force. The epoxy resin coating smeared beyond and lower the sensors to shield them from peripheral aspects. The previously developed innovative bracket model had an 8 x 8 mm base and was about 2.5 times greater than a standard orthodontic bracket. The cutting-edge intelligent bracket designs have the same size as a conventional bracket. A study as conducted by Bernd G Lapatki[27], The three-dimensional (3D) force-moment systems functional for beneficial tooth movement are of significance, about the probability of the sequence of tooth movement and the decreases traumatic complication. The concept of the study was about an innovative bracket with an incorporated sensor system for 3D force and measurement of the moment. This method's viability established using finite-element simulation and 2.5 times distended accurate, innovative bracket system.

Conclusions

Much attention has concentrated on nanotechnology in orthodontics. The main concern is the biosafety of nanoparticles and their materials. Further studies should focus on the toxicity of nanoparticles sheltered uses in vivo-study. In the future orthodontic treatment will level of standards in treatment exceptionally through nanotechnology. Further research in a wide range of fabrication areas of orthodontic accessories combined with available and new technologies will boost the future of orthodontic treatment.

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