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Review Article

Nanotechnology in orthodontics: A detailed review

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ABSTRACT

Nanotechnology is a technological revolution that has caught the scientific world's attention in recent decades. This is perhaps one of the most quickly moving fronts in recent times, with widespread applicability in a variety of fields, including health care. This article aims to summarize and describe the most recent and well-known nanotechnology innovations in dentistry, with a particular emphasis on orthodontics and the use of new nanomaterials in the fabrication of orthodontic elastomeric ligatures, orthodontic power chains, and orthodontic Mini screws.

1. Introduction

The study of manipulating matter at the molecular and atomic levels is known as nanotechnology. Greek for "dwarf" is where the word "Nano" comes from. The American physicist and Nobel Laureate Richard Feynman is credited with developing the idea and beginning nanotechnology in 1959. On December 29, 1959, he delivered a paper titled "There is Plenty of Room at the Bottom" at the American Physical Society's annual meeting at California Institute of Technology.[1] This was made possible by Eric Drexler's emphasis on the promise of molecular nanotechnology in the middle of the 1980s. Nanomaterials are substances with at least one dimension smaller than 100 nm, according to N. Taniguchi, who invented the term.[2]

It is characterized as an interdisciplinary discipline that focuses on developing new materials, gadgets, and systems at the nanoscale. They don't go beyond 100 nm because they get a superior surface to mass ratio. These elements might take the shape of grains, clusters, nanoholes, or a mix of these. They are referred to as sheets in one dimension, nanowires and nanotubes in two dimensions, and quantum dots in three dimensions Figure 1. The fact that these new particles have a higher surface area per unit mass than larger particles considerably affect the material's physical and chemical properties. This article seeks to summarize and detail the most current advancements in orthodontic nanotechnology.[3,4]

2. Nanodentistry

It is the science and technology of maintaining near perfect oral health through use of nano materials including tissue engineering and nanorobots.

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As dentistry on whole comprises of many interdisciplinary branches, and all of which nanotechnology in use comprising of nanorobotics, nano electronics and nano biotechnology. Each of these has different application in different areas of dentistry like advanced diagnosis in oral medicine and diagnosis, local drug delivery and anesthesia in oral surgery and periodontal drug delivery, biomechanics in orthodontics.[5]

3. Various Approaches for Synthesis of Nanoparticles[6]

Table 1:

Method	Process involved	
	Ball milling	Top-Down Approach
Physical	Mechanochemical synthesis	
	Plasma vapor deposition	
	Laser pyrolyis	
	Inert gas condensation	
	Flame hydrolysis	
Chemical	Sol-gel or gel-sol conversions	Bottom-Up Approach
	Plasma/laser/flame enhanced chemical vapor deposition	
	Sol thermal synthesis	
	Fungi	Intracellular
	Bacteria	Fig:.2 And
Biological	Yeast	Extracellular
	Plant extracts	Synthesis

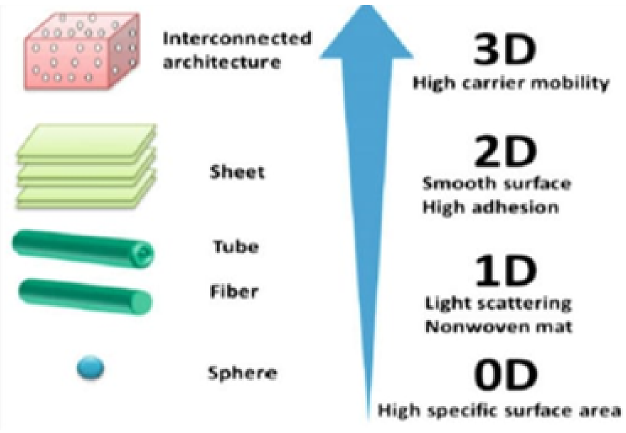

Figure 1: Various kind of nanomaterials and specific properties[6]

4. Nanotechnology in Orthodontics

According to nano indentation and atomic force microscopy investigations on orthodontic brackets and arch wires, the surface properties of the brackets, such as roughness and surface free energy (SFE), have an important role in minimizing friction and plaque formation. To analyze

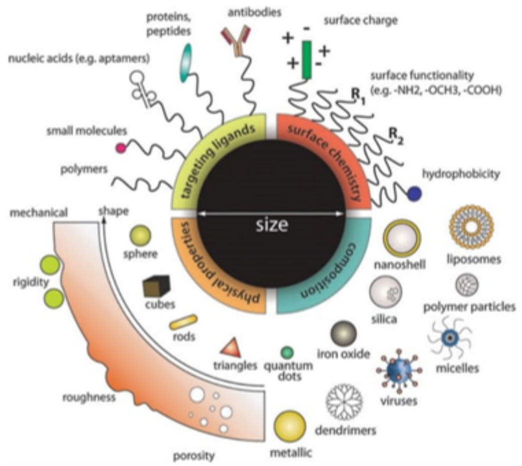

Figure 2: Designing nanoparticles for intracellular applications[6]

nanoscale surface properties of bio-materials, a nano indenter paired with an atomic force microscope (AFM) is utilized. Nano indentation studies have also been utilized to analyze mechanical parameters like as hardness, elastic modulus, yield strength, fracture toughness, scratch hardness, and wear qualities.

Atomic force microscopy (AFM) or scanning force microscopy (SFM), which was developed after the invention of the scanning tunneling microscope (STM), is a very high-resolution type of scanning probe microscopy, with demonstrated resolution on the order of fractions of a nanometer, more than 1000 times better than the optical diffraction limit. The AFM is made up of a cantilever with a tip made of silicon or silicon nitride and with a radius of curvature on the order of nanometers. The attraction and repulsion forces between the tip and the sample are determined by Van der Waals forces, which create a deflection of the cantilever in accordance with Hooke's Law.[7]

A laser light reflected from the top of the micro-lever is used to quantify deflection, which is detected by a four-quadrant photodiode. A feedback loop regulates the distance between the tip and the sample to maintain a constant force between them for perfect scanning of all surface asperities. To examine the surface, the sample is put on a piezo-electric tube that can move perpendicularly (z direction) while maintaining a constant force in the plane (x and y directions). The generated map (x, y) represents the surface sample's topography.

A typical AFM has lateral resolutions of 1 nm and vertical resolutions of 0.07 nm (sub-angstrom). In numerous investigations, AFM has been used to examine the nanoscale dimensions of the orthodontic armamentarium and the alterations that occur throughout treatment. D'Ante et al. used AFM to examine the surface roughness of stainless-steel (SS), -titanium (-Ti), and nickel-titanium

(Niti) wires. The analysis revealed that AFM has numerous advantages, including the ability to generate topographical three-dimensional images in real space with extremely high resolution (10 A). The most significant disadvantage of AFM is the tiny scan size, which, when combined with the sluggish scanning velocity, frequently prevents a comprehensive study of the sample.[8]

5. Applications of Nanotechnology in Orthodontics Nanoparticles in Elastomeric Ligatures

Orthodontic elastomeric ligatures (OEM) are synthetic elastic polyurethane modules with features such as ease of application and patient comfort; they are frequently a cost-effective solution in clinical practice.

During orthodontic therapy, there is an unavoidable microbiological colonization of the material, first and foremost due to the obvious increase in the retention surface: there is an increase in the accumulation of bacterial plaque, bacterial colonization, and enamel decalcification, as well as a worsening of bleeding rates. The uneven surfaces of the orthodontic auxiliary are also contributing to the growth in bacterial plaque. Maintaining proper oral hygiene and self-cleansing are therefore more difficult. Bacterial counts nearly triple after six weeks due to an increase in Streptococcus mutans, Lactobacilli and Staphylococcus aureus.

Several studies have attempted to emphasize the correlations based on the chemical properties of different elastic ligatures and the necessity for adjustments to mitigate the impact of microbiological biofilms on oral health. Some studies have evaluated fluoride-releasing ligatures, but the results have been mixed and controversial: some emphasize how, in particular, there is long-term ineffectiveness linked to the ligatures' inability to guarantee a prolonged release over time; they also appear to be ineffective even against decalcification.[9,10]

Elastomeric ligatures, it has been proposed, can operate as a support for the transport of nanoparticles, which can be molecules with anticariogenic or anti-inflammatory properties and/or antibacterial medicines (such as benzocaine) embedded into the elastomeric matrix. In addition, medicinal wax was used. Orthodontic brackets that minimize discomfort produced by mucosal irritation induced by the brackets by slowly and continuously delivering benzocaine have been demonstrated to be much more effective. The most recent research appears to assess the possibility of ligature connection with silver nanoparticles, a substance that looks to be capable of combating dental biofilm and decreasing plaque the enamel demineralization induced by bacterial plaque formation, without damaging the mechanical features of the material itself and hence the efficiency of orthodontic therapy.

Nanotechnology used to materials in dentistry is novel in terms of the concept of leading to better outcomes. Silver particles have anticariogenic properties; they have been added into many products and can be achieved by minimally invasive procedures. It is well known that silver has more antibacterial properties than other metals, and it also possesses an impact of cytotoxicity on a variety of microorganisms: The exact process is unclear, although it probably acts by causing the respiratory cycle and DNA synthesis enzymes to become denaturated. Additionally, silver is not extremely harmful and compatible with human cells. But now, additional research is required to find out if they are actually biocompatible.[11,12]

6. Application of Nanoparticles for Controlling Oral Biofilm in Orthodontics

By offering retentive regions, brackets and fixed orthodontic appliances increase bacterial accumulation. According to reports, 50–70% of patients receiving fixed orthodontic appliance therapy experienced enamel demineralization (white spot lesions or cavities) around the brackets. Several methods—many of which depend heavily on patient compliance—have been proposed to lessen demineralization and the development of white spots during treatment. The removal of mechanical plaque biofilm and the administration of fluoride and/or antimicrobial treatments are the mainstays. Fluoride is used in toothpaste, mouthwash, professional applications, and adhesives to strengthen the resistance of enamel and dentine and to prevent the metabolism of the bacteria that cause caries. Due to the biocidal or adhesion-resisting properties to manage the oral biofilm, certain NPs have been added to orthodontic adhesives. When NPs are added to traditional orthodontic adhesives, the crucial issue with adhesives and appliances is that the not combining physical and chemical qualities negatively impacted, resulting in less than optimum clinical outcomes performance. In addition, the antibacterial and adhesive qualities and the new product's security ensured nano-adhesives over a physiologically relevant surface pertinent time period.

NPs-containing compounds or covering the bracket surfaces NPs have been utilized to gain from distinctive features of certain NPs.[13] Furthermore, nano-sized gold particles can be utilized on orthodontic machines e.g., aligners, to expand its antibacterial action, by forestalling biofilm development as should be visible in fig:4. Both the gingiva and teeth are covered by aligners for practically the whole day, which is a gamble factor for plaque gathering. Gold particles likewise show positive biocompatibility both in vitro and in vivo.[14]

6.1. Nanoparticles

1. Titania (Ti02)
2. Silver (Ag)
3. Gold (Au)

4. Silica (Si02)
5. Copper (Cu/Cu0)

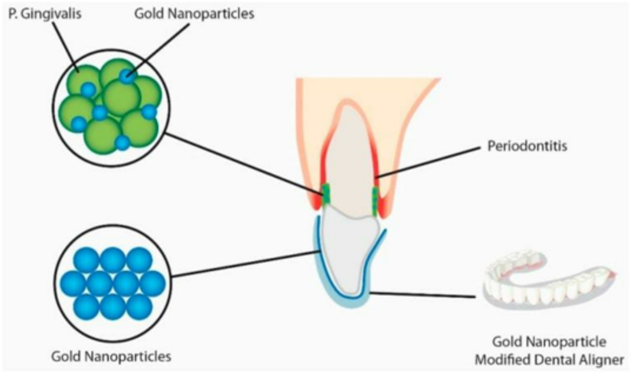

Figure 3: Aligners coated with modified gold nanoparticles causing enhanced antibacterial activity against porphyromonas gingivalis. Due to presence of coated aligner, the number of bacterial cells was decreased, causing increased biofilm formation prevention.[14]

7. Nanotechnology in Adhesives

In orthodontics, nanomaterials can be utilized as adhesives to increase mechanical strength or lower the risk of enamel damage. Glass ionomer cements (GICs) and composites are the two adhesives that are most frequently used to attach bands and brackets to the surfaces of teeth. Nanoparticles can be utilized as orthodontic adhesives because they have better mechanical qualities and a lower chance of damaging the enamel. Nanoclusters (composites) and nanomers (glass ionomers) are two categories of materials. Additionally, there are two categories of nanocomposites: Nanohybrids, which are made up of bigger particles (400–500 nm) with additional nanometer-sized particles, are nanofills with nanometer-sized particles (1–100 nm) dispersed throughout the resin matrix.[15,16] Due to the filler particles' smaller size and ability to penetrate the resin tags, it is possible to achieve an enlarged filler load, which results in less polymerization shrinkage and improved mechanical characteristics. A great peripheral seal to dentin and polish can be achieved similarly. Excellent optical qualities, convenient handling characteristics, and polishability round out the list of benefits. Additionally, the inclusion of nanofillers reduces surface roughness, which lowers the likelihood of bacterial attachment.

Because of its tendency to release fluoride, GIC is frequently used in orthodontics for band cementation. The addition of N-vinyl pyrrolidone, nano hydroxy, and fluorapatite polyacids improved the mechanical performance of conventional GIC. Additionally, it was discovered that the compressive strength, diametral tensile strength, and biaxial flexural strength were higher than those of traditional GIC. Recently, a resin-modified GIC with good mechanical qualities and high fluoride release was introduced. It is made of nanofillers flouroaluminislicate glass and other nanofillers clusters.[17,18]

8. Orthodontic Power Chains

Since their invention in the late 1960s, power chains are regularly employed in all orthodontic offices. They typically consist of polymeric substances (polyesters or polyethers) created by the polymerization process. They offer various clinical benefits, including affordability, user-friendliness, ease of patient adjustment, and the provision of light, continuous pressures. They are distinguished by great flexibility and improve extraction situations' space closure.

On the other side, power chains also have disadvantages. It has been clearly shown that their mechanical performance is time-limited, necessitating frequent replacement. Orthodontic power chains' strength is influenced by both internal and external elements, which also determine whether permanent deformation occurs. The outward morphology, production processes, and material composition are the intrinsic factors. The temperature, pH, and moisture absorption of the mouth cavity are external influences. They are less suitable for preserving oral health since they absorb fluids from the oral cavity and exhibit hydrophilic traits that cause them to discolor with time.[12]

In a work carried out in Taiwan, Cheng et al. attempted to enhance the physical characteristics of power cables through the application of a surface treatment known as nanoimprinting. The process of treatment entails creating nanopillars, which are nanostructures, on the chains' surface. The process of turning the material from hydrophilic to hydrophobic and addressing the drawbacks of these orthodontic aids appears to have produced good outcomes.[12]

9. In Orthodontic Archwires

Some challenges arise from the frictional force that opposes the movement of the arch wires. Additionally, it may result in dental problems. It is feasible to solve these issues by using the proper lubricants. To enhance the qualities of lubricants, nanotechnology has been used. Arch wires can be lubricated with nano-based substances to make them move more easily. Katz et al. used a self-lubricating covering that contained nanoparticles that resembled fullerene. According to the results, using this lubricant reduced friction, which led to the arch wires moving more favorably. In addition to employing lubricants, the right coating can result in less resistance to the movement of arch wires. In a study, smooth and uniform nanoparticle layer (nanoceramics) was applied on three wires made of stainless steel, nickel-titanium, and titanium molybdenum alloy. It was noticed that applying the coating can improve the surface topology, which reduces friction-related issues. To lessen friction force, several kinds of nanoparticles can be put on orthodontic wires. Orthodontic wires composed of stainless steel were coated with ZnO nano particles in the size range of 40–45 nm by Kachoei et al. When compared to reference wires, it was found that the presence of nanoparticles reduced friction between the wires and brackets by 51%. The nanoparticles' role as lubricants was thought to be the cause of the reduced friction.[19,20]

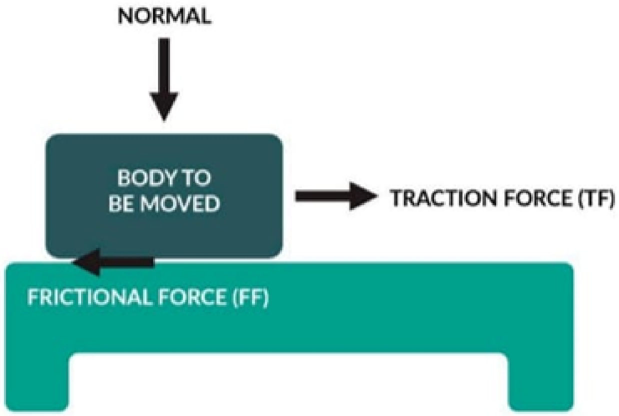

Figure 4: Different forces acting over a body under traction on top of a surface. Body to be moved, traction force, friction force, contact surface[14]

10. Shape Memory Polymers i n Orthodontics

In the last ten years, there has been a surge in demand for the production of aesthetic orthodontic wires to go with tooth-colored brackets. Research on shape-memory aesthetic polymers is conceivable. Shape memory polymers (SMPs) are substances that, given particular temperature and stress circumstances, can be altered and set to a temporary or dormant shape after memorizing a macroscopic or equilibrium shape. Under thermal, electrical, or environmental conditions, they can later relax to the original, stress-free condition. The elastic deformation that was stored during earlier manipulation is connected to this relaxation. A sufficient and specified force, beneficial for orthodontic tooth movement, or a macroscopic shape change, useful for ligation processes, can accompany the SMP's return to its equilibrium shape. Once in the mouth, these polymers may be triggered by body heat or by light-induced photoactive nanoparticles, which will cause tooth movement.[21,22]

The SMP orthodontic wires can offer advantages over conventional orthodontic materials since they will apply lighter, more consistent forces, which may result in reduced discomfort for the patients. The SMP materials also offer the patient a more aesthetically pleasing appliance throughout treatment because they are clear, colorable, and stain resistant. Fewer visits for the patient are necessary as a result of the SMP appliance's high percent elongation (up to roughly 300%), which enables the administration of continuous forces over a wide range of tooth movement.[23,24]

11. Nano Lipus Devices

LIPUS nanodevices - low intensity pulse ultrasound, a type of mechanical energy that is conveyed as an acoustic pressure wave through and into biological tissues, is widely employed in medicine as a therapeutic, surgical, and diagnostic tool. Low-intensity pulsed ultrasound (LIPUS) has been demonstrated to be successful in freeing preformed fibroblast growth factors from a macrophage-like cell line (U937), as well as improving angiogenesis during wound healing.

LIPUS has also been shown to improve bone growth into titanium porous-coated implants, as well as bone repair following fracture and mandibular distraction osteogenesis. The precise processes by which US stimulation affects bone cell activity remain unknown.[25] El-Bialy et al. used LIPUS for a few minutes each day on the temporomandibular joint (TMJ) region of growing rabbits and baboon monkeys.[26,27] Their findings demonstrated a considerable increase in mandibular cartilaginous development. In another investigation, Oyonartea et al. stimulated experimental rats with LIPUS in the TMJ region unilaterally for 10 or 20 minutes for 20 days. The findings revealed that LIPUS treatment can influence mandibular growth pattern in rats by acting at the cartilage and bone levels. This approach can also be used to minimize root resorption during orthodontic therapy. El-Bialy et al. found that LIPUS can enhance dental tissue formation in rabbits and that it could be utilized to treat root resorption.[28]

12. Biomems/Sems f or Orthodontic Teeth Movement

They are composed of micromachined components, typically made of silicon, such as linear and rotary motors, gears, and motors for use in biological systems. Nanoscale devices that integrate mechanical and electrical functionality are known as nanoelectromechanical systems (NEMS). The evidence indicates that orthodontic tooth movement can be improved by adding electrical forces in addition to mechanical ones. Electric stimulation, which increases cellular enzymatic phosphorylation activities and speeds up tooth movement in animal experiments, has been proven to promote tooth movement. The science and technology of operating at the microscale for biological and biomedical purposes, which may or may not incorporate any electrical or mechanical functionalities, is known as biomedical microelectromechanical systems (Bio MEMS).[29,30]

In animal tests, it was found that osteoblasts and periodontal ligament cells had higher concentrations of the second messengers cAMP and cGMP when 15–20 microamperes of low direct current (dc) were delivered to the alveolar bone by changing the bioelectric potential. These results imply that electrical stimulation increased cellular enzymatic phosphorylation activities, resulting in secretory and synthetic processes linked to faster bone remodeling. However, a significant issue that needs to be resolved is the intraoral source of energy.

It has been suggested that orthodontic tooth movement could be aided by the use of microfabricated biocatalytic fuel cells (also known as enzyme batteries). When positioned on the gingiva close to the alveolar bone, an enzymatic micro battery may serve as a potential electrical power source to quicken orthodontic tooth movement. It is suggested that this non-invasive, non-Osseo integrated device employs organic compound (glucose) as its fuel and is non-invasive. Two enzyme electrodes can be combined with biocatalysts like glucose oxidase or formate dehydrogenase to create the enzyme battery, which can produce power. However, there are a number of concerns that need to be addressed, including soft tissue biocompatibility and the impact of food with varying temperatures and pH levels on the output of such a microfabricated enzyme battery. Due to problems with enzyme stability, electron transfer rate, and enzyme loading, micro enzyme batteries have a poor power density and a shorter lifespan. It has been shown that a variety of nanostructured materials, including mesoporous media, nanoparticles, nanofibers, and nanotubes, are effective hosts for enzyme immobilization. The enormous surface area of these nanomaterials, when utilized in nanostructures of conductive materials, can boost enzyme loading and facilitate reaction kinetics, improving the power density of the biofuel cells. In the coming years, it is anticipated that the MEMS/NEMs-based system will be used to create biocompatible, potent biofuel cells that may be safely implanted in the mandibular or maxillary alveolus to facilitate tooth movement during orthodontic treatment.[31,32]

13. Nano Remineralizing Agents

Problems with demineralization and white spot lesions are frequent during and after orthodontic treatment. Enamel that has lost its calcium is being remineralized using nanoparticles.

A paste form of nanohydroxyapatite has been created. Because of the increase in surface area and wettability of HA (hydroxyapatite) nanoparticles caused by the use of calcium nano phosphate crystals smaller than 100 nm, the product has better bioactivity and forms a protective layer on the enamel surface that prevents erosion.[33]

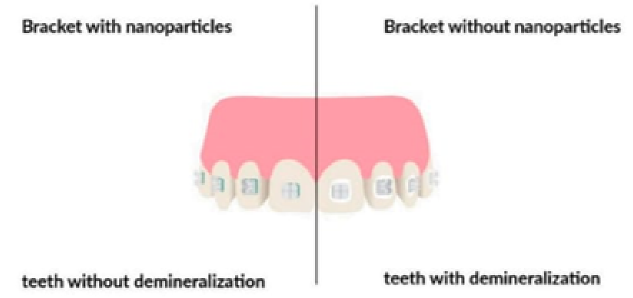

Figure 5: Comparison of teeth demineralization development with and without nanoparticles covered brackets

14. Nanorobots

Orthodontic nanorobots would directly modify periodontal tissues, allowing for fast tooth alignment. In the far future, the notion of use of such nanorobots could be extended to dentistry and orthodontics, where nanorobots with particular motility mechanisms would navigate through periodontium to directly modify it, allowing quicker orthodontic tooth movement. This approach can also be used to minimize root resorption during orthodontic therapy. Nanotechnology has taken a huge step forward in overcoming problems such as friction, which interferes with the alignment or retraction of teeth during the treatment or retraction of teeth.[34,35]

Painless tooth up righting, rotating, and vertical repositioning, as well as rapid tissue repair, are all made possible by orthodontic nano robots. A new stainless-steel wire with nanotechnology combines ultra-high strength with good deformability, corrosion resistance, and surface finish is studied.

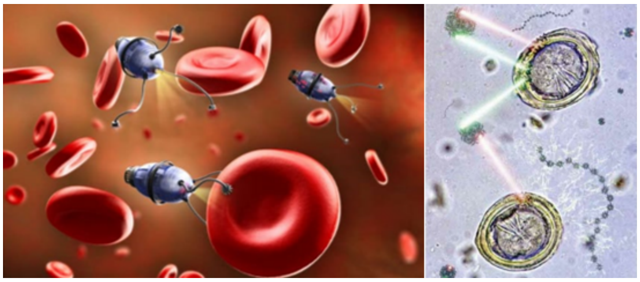

Figure 6:

In the future, orthodontic nanorobots may be able to directly control periodontal tissues such as gingivae, periodontal ligament, cementum, alveolar bone, allowing for quick and painless tooth alignment, rotating and vertical repositioning within minutes to hours. In comparison, molar uprighting procedures take weeks or months to accomplish.[35]

15. Smart Brackets with Nanomechanical Sensors

Recently, a concept for intelligent brackets with an integrated sensor system for 3D force and moment measurement was published. In order to give the orthodontist instantaneous feedback about the applied orthodontic forces, nanomechanical sensors can be made to be incorporated into the base of orthodontic brackets. This will enable the orthodontist to adjust the applied force to be within a biological range to effectively move teeth with a minimum of side effects

The ability to manage teeth precisely in all directions, more effectively move teeth, spend less time at the chairside, and receive treatment more quickly are the main benefits of smart brackets.[36,37]

16. Orthodontic Miniscrews

Due to increased stability and stronger resistance to orthodontic stresses, it is crucial to have a close closeness between the bone and the Mini screw's surface. Inflammatory processes can also damage the screw's primary stability and cause it to lose its strength too soon.

The stability and osseointegration of Mini screw surfaces modified by nanotechnology have been assessed in two investigations; the surface under study was distinguished by arrays of TiO_2 (titanium dioxide) nanotubes.[38,39]

RhBMP-2 (recombinant human bone morphogenetic protein-2) and ibuprofen were added to the TiO_2 nanotube arrays before they were compared to a control set of regular Mini screws. The study examined how drug-modified Mini screws improved tissue health in order to assess the medications' effects in vivo. In order to lessen swelling at the insertion site and patient discomfort, these modified Mini screws can also deliver other medications, such as antibiotics, aspirin, and vitamin C. When compared to typical products, this alteration to the materials has also proven crucial in ensuring increased surface roughness of the aids and improved wettability.[39]

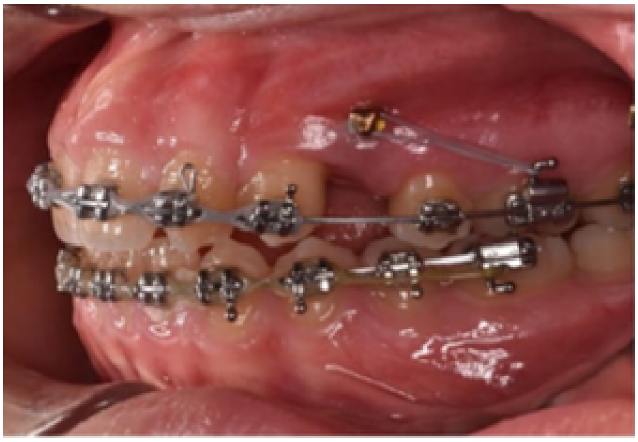

Figure 7:

17. Nanosilver Mouth Rinse

Most of the mouth washes normally contain ethanol to reduce bacterial development which is viewed as irritating for some patients with periodontal infection. Silver nano particles were integrated into an ethanol free mouth wash at exceptionally low concentrations and compared with economically accessible mouth rinses. They observed that there was no distinction between the Silver nano built up mouth rinses and other commercially available mouth rinses.[40]

18. Conclusion

Since nanotechnology has the potential to bring about substantial improvements and benefits, it now plays a bigger and more consistent role in the dentistry industry. The current encouraging findings must serve as a catalyst for additional study, particularly in the area of orthodontics. We have discussed the several benefits that nanoparticles have brought to this industry, particularly with regard to their mechanical and antibacterial capabilities. The essential goal of orthodontic treatment coordination and safety management is frequently referred to by the restrictions of dental materials and technical methods; nevertheless, science and nanotechnology have helped to partially resolve some of these limitations, enhancing patient management in the clinical pathway. However, due to ongoing production technological challenges and engineering issues, nanotechnology must develop in order to realize its full potential.

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None.

20. Source of Funding

None.

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