Effect of Nanotechnology in Orthodontic Materials : An Overview

Dr. Kajal[1]; Dr. Divya Lohia[2]; Dr. Varun Goyal[3]; Dr. Rajkumar Singh[4]
Dr. Gurkeerat Singh[5]; Dr. Sushma Chaurasia[6]; Dr Triparna Kapoor[7]; Dr. Anushree Bansal[8]
Sudha Rustagi College of Dental Sciences and Research, Faridabad

Abstract:- Nanotechnology is defined as the multidisciplinary approach in materials and devices at the nanoscale level to detect and exploit the useful properties that derive from these dimensions; materials with components less than 100 nm in at least one dimension are called nanomaterials. Enhancing human life and health is the aim of various advancements in this field. The most recent advancements in nanotechnology in dentistry, particularly in orthodontics, are to be summed up and described in this article. Additionally, we discuss the potential use of nanotechnology in orthodontics.

Keywords:- *Nanodentistry; Nanoparticles; Smart Brackets; Micro Implants; Nano Composite; Nanoimprinting; Nanoelectromechanical System.*

I. INTRODUCTION

The term "Nano" was derived from a Greek word that means "dwarf." One billionth of a meter, or 10-9, is a nanometer. Atom by atom, matter is being manipulated by nanotechnology. [1–3] The American scientist and Nobel Laureate Richard Feynman is credited with coining the term "nanotechnology" in 1959.4. Eric Drexler highlighted the potential of molecular nanotechnology in the mid-1980s, which pioneered the way for application of nanotechnology. [5-6]

The multidisciplinary approach to materials and devices at the nanoscale level is known as nanotechnology. Their size is smaller than the critical lengths defining many physical occurrences, which is what makes the idea of nanotechnology unique and fascinating. Three methods are used in the production of nanoparticles: functional, top-down, and bottom-up approaches. 7. The objective of the functional approach is to create a nanoparticle with a certain function. Numerous nanoparticles that we use on a daily basis have been created due to science and technology. Nanopores, nanotubes, quantum dots, nanoshells, dendrimers, liposomes, nanorods, fullerenes, nanospheres, nanowires, nanobelts, nanorings, nanocapsules, and more are some of the different kinds of these nanoparticles.

Over the past few decades, the scientific community has been fascinated by the technological revolution known as nanotechnology. With broad applications in many fields, including healthcare, this is arguably one of the fronts that has advanced the fastest in recent years. With several nanoparticles added to various dental materials to improve their qualities, nano dentistry is a new discipline that has undergone exponential research. It has been proposed that fluoride-containing products can regulate the demineralization of enamel surrounding orthodontic brackets while fixed appliance treatment is underway. Through advances like the use of nanotechnology through the insertion of nanofillers, their characteristics have improved. While certain dental nanotechnology uses have already undergone testing and are currently in use across multiple industries, others require more investigation and scientific study.[8]

The purpose of this article is to provide an overview and description of the latest advancements in nanotechnology in dentistry, particularly in the field of orthodontics. In order to assess and document the most important advancements in the field of orthodontics, the authors carefully examined the most recent literature. They paid particular attention to the use of novel nanomaterials in the creation of orthodontic elastomeric ligatures, orthodontic power chains, orthodontic miniscrews, and composites.

II. NANOTECHNOLOGY APPLIED IN ORTHODONTIC MATERIALS

Through the integration of nanomaterials and biotechnologies, such as tissue engineering and dentistry, nanodentistry will provide almost perfect dental health. Dental implants and bio-nano surface technology, dental nanorobots, dental nanocomposites, artificial teeth composed of nanocomposite, dental tissues and nanostructures, and dental caries prevention via nanotechnology. There are various future prespectives and current implications of nanotechnology in orthodontics (Figure1).

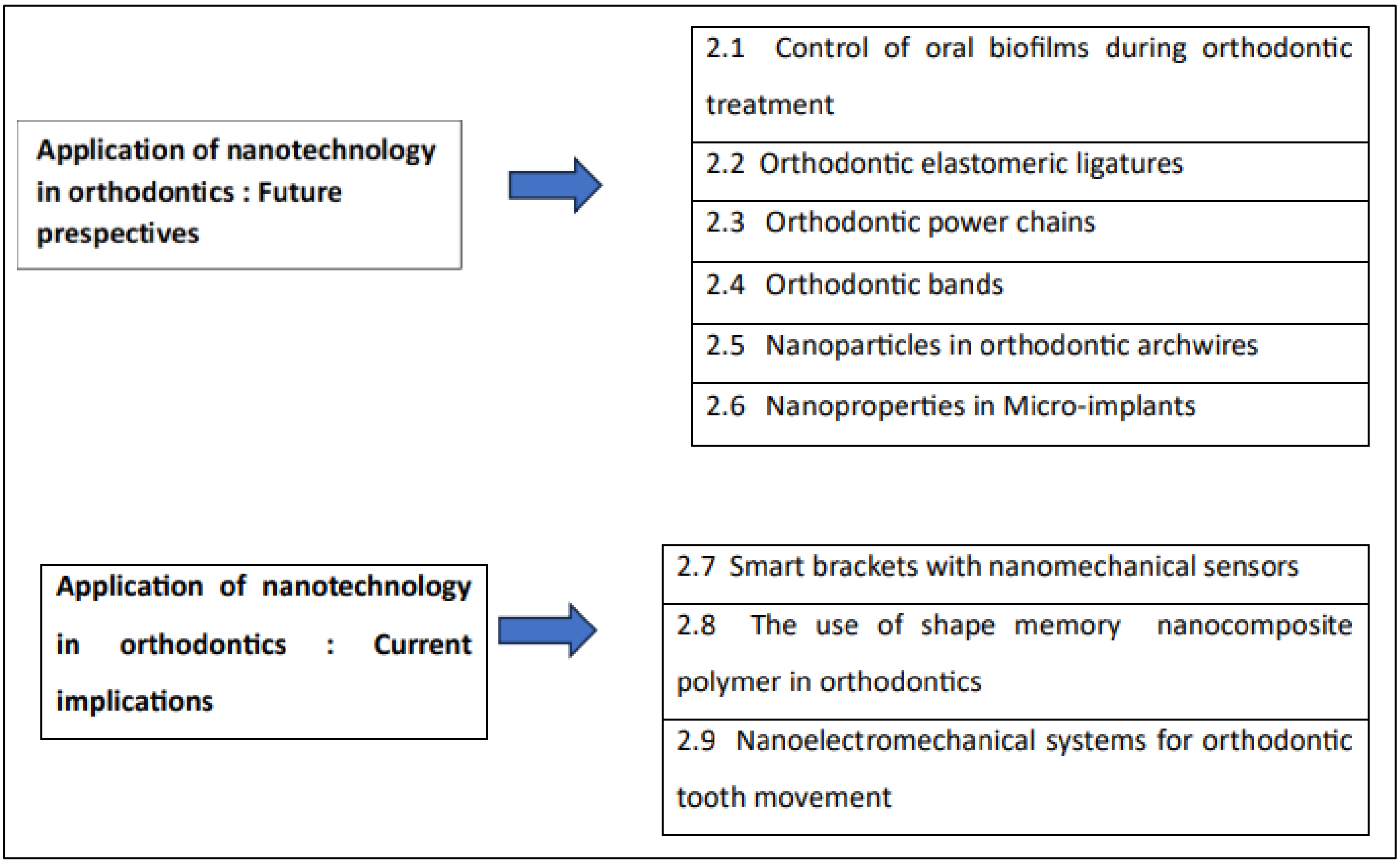

Fig 1 Future Prespectives and Current Implications of Nanotechnology in Orthodontics

➢ *Control of Oral Biofilms during Orthodontic Treatment*

- *Mechanism*

Biofilm inhibition: Bacterial biofilms are colonies of bacteria embedded in a matrix that they have formed themselves, and they are affixed to a surface and/or to one another. One efficient method of preventing oral infections is to decrease the adherence of biofilms. According to certain data, NPs may have an impact on the development of biofilms and bacterial adherence. 9.

Extracellular antibacterial actions: By rupturing the bacterial cell membrane, NPs demonstrate antibacterial effects prior to entering bacterial cells. The following are the primary disruption techniques:

- ✓ Interaction with the elements of the cell membrane and surface deposition.
- ✓ Oxidative stress brought on by reactive oxygen species (ROS).
- ✓ Dissolved metal ion effects.

Effects of intracellular antibacterials: NPs enter bacterial cells and interact with key functional molecules to suppress bacterial cell growth in the following ways:

- ✓ ROS-induced oxidative stress: ROS can damage proteins and stop some periplasmic enzymes from working, which is necessary to keep bacterial cells' normal shape and physiological functions. [9, 10]
- ✓ Impact of dissolved ions: Metal ions that are taken up by bacterial cells have a direct effect on the carboxyl (-COOH), amino (-NH), and mercapto (-SH) functional groups of proteins and nucleic acids. This interaction damages enzyme activity, alters the structure of the cell, interferes with regular physiological functions, and eventually inhibits microorganisms. [11–14]

Notwithstanding NPs' strong antibacterial action, there are still restrictions on their use, such as toxicity, uneven antibacterial concentrations against microbiofilm, and potentially unfavorable impacts on human health.

- *Effect of Nanoparticles*

One of the most difficult challenges in orthodontic treatment with fixed equipment is controlling enamel demineralization around the brackets, which is estimated to happen in 50% of patients. Decalcification marks, which are early forms of enamel caries that, within specific bounds, have the capacity to remineralize in the presence of fluoride, appear on the surface of teeth as early as four weeks after the placement of bands or brackets following the use of permanent appliances. This is one of the reasons that numerous authors [15,16] recommend frequent local fluoride treatments in addition to good oral hygiene during orthodontic treatment.

By adding nanoparticles to resin, it may be possible to create materials for bracket adhesive fixation that have superior mechanical qualities and better flowability than microfilled materials. Additionally, the ion-releasing materials' properties may change as a result of this process [17, 18]. As nanotechnology has advanced, nanoparticles (NPs) have been used in orthodontic materials to reduce the buildup of tooth plaque because of their superior antibacterial qualities. 19.

Sodagar et al. showed that all experimental groups reduced the amount of live germs in comparison to the control group. The 5% Ag/hydroxyapatite nano-fillers demonstrated a shear bond strength of 20 and strong antibacterial properties. The antibacterial property was enhanced by the inclusion of CuO NPs without compromising shear bond strength 21. Conversely, the inclusion of TiO2 NPs reduced the shear bond strength 22 while improving antibacterial activity. Because of their exceptional ability to release fluoride ions, resin-modified GICs have found extensive application in orthodontic equipment [23, 24].

When added independently to RMGICs, monolayer-protected metal clusters (MPC), dimethylaminohexadecyl methacrylate (DMAHDM), AgNPs, and amorphous calcium phosphate nanoparticles (NACP) all produced the best antibacterial outcomes. 22–25 A brand-new, multipurpose orthodontic cement with a potent antibacterial effect was created to prevent bacteria from growing on the cement and nearby, away from the brackets.

➢ *Elastomeric Ligature in Orthodontics*

Elastomeric ligatures can be used as a framework for distributing anti-inflammatory or anti-cariogenic nanoparticles. A study26 used silver nitrate salts as metal-ion precursors and an extract of the plant Hetheroteca inuloides (H. inuloides) as a bioreductant to create silver nanoparticles (AgNPs) in situ on orthodontic elastomeric modules (OEM) in a simple and environmentally friendly manner.

The generated AgNPs were examined using scanning electron microscopy-energy-dispersive spectroscopy (SEM-EDS), transmission electron microscopy (TEM), and UV-visible spectroscopy. The surface plasmon resonance peak found at 472 nm confirmed the formation of AgNPs. SEM and TEM images demonstrate the particles' quasi-spherical shape. The EDS examination confirmed that elemental silver was present in the AgNPs. The antibacterial properties of OEM containing AgNPs were evaluated against clinical isolates of Lactobacillus casei, Staphylococcus aureus, Streptococcus mutans, and Escherichia coli using agar diffusion assays. The physical characteristics were evaluated using universal testing equipment. OEM with AgNPs showed inhibitory halos for all microorganisms in comparison to OEM control. In comparison to the control group, properties such as the capacity to combat dental biofilm and reduce enamel demineralization rose.According to the results, the material might be able to combat dental biofilm, which would slow down the demineralization of dental enamel and ensure that patients receiving orthodontic treatment would benefit from it. 26

➢ *Orthodontic Power Chains*

Since their invention in the late 1960s, power chains have been utilized on a regular basis in all orthodontic offices. Typically, polymeric materials like polyesters and polyethers, which are created through the process of polymerization, make up these power chains. They improve space closure in extraction scenarios and show a high degree of adaptability. Clinical benefits of these chains include their affordability, ease of use, and adaptability to each patient. Power chains, on the other hand, have drawbacks. It is well known that their mechanical efficacy is time-limited, necessitating frequent replacement.27 The physical properties of power cables were attempted to be improved using a surface treatment called nanoimprinting in an attempt to mitigate this effect.

The procedure entails creating nanostructures, or nanopillars, on the surface of the chains. The process involves forming nanopillars, or nanostructures, on the chains' surface. Since this treatment changes the material from hydrophilic to hydrophobic and mitigates the drawbacks of these orthodontic auxiliaries, the results appear promising.28

➢ *Orthodontic Bands*

When undergoing fixed orthodontic treatment Dental bands must be inserted for orthodontic motions to occur. These auxiliaries, however, have the potential to retain bacterial plaque, particularly in the hard-to-clean posterior teeth. It has been shown that prolonged plaque buildup around orthodontic brackets and bands causes a quick change in the bacterial flora, favoring acidogenic bacteria like S. mutans and Lactobacilli. These bacteria raise the risk of cavities, white spot lesions, and demineralization of the enamel.29 In order to decrease the occurrence of cavities and white spot lesions while maintaining the adhesion characteristics, technology has made it feasible to incorporate antimicrobial agents into dental resins and cement.

Various manufacturers attempted to lower the acidity of the oral environment and lower the metabolism of bacteria by incorporating fluorides, zinc oxide, and chlorhexidine.30

To prevent white spots from appearing, band cements with antimicrobial properties, such as antibacterial release materials, such as silver nanoparticles, have been created. These resins were shown to be biocompatible in the majority of situations and may have mechanical qualities similar to controls.31

➢ *Nanoparticles in Orthodontic Archwires*

By lowering the frictional forces between the orthodontic wire and brackets, it would be feasible to enhance the desired tooth movement and shorten the course of therapy. Since nanoparticles are dry lubricants, they can reduce the friction between two sliding surfaces without the use of a liquid medium. Inorganic fullerene-like tungsten sulfide nanoparticle (IF-WS2) self-lubricating coatings for orthodontic stainless steel wires are one example. Through friction experiments, the performance of coated and uncoated wires was simulated using an Instron machine. Scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) examinations of the coated wires showed a discernible impregnation of IF-WS2 nanoparticles in the Ni-P matrix. 32 Cobalt and IF-WS2 nanoparticles can be coated on NiTi substrates using the electrodeposition process.. There was 66% less friction in coated substrates as compared to the untreated substrates.

However, the drawback of adding nickel to this kind of coating could be allergic reactions in individuals who are nickel sensitive. Thus, it is necessary to evaluate the biocompatibility of such NiP coatings on NiTi and stainless steel wires using animal models and additional human experiments.

- *Nanoproperties in Micro-Implants*

The usage of micro-implants for absolute anchoring is growing as a result of the quick development of orthopaedic and orthodontic technology. Bacterial infections can cause poor osteointegration and healing in Ti-based implants, which can lead to implant failure or the need for repeated surgery 33. Nanoparticles were applied to the micro-implants to lower bacterial infections and boost implant success rates. In Qiang's study, the antibacterial qualities of Ag NP/silk sericin-coated Ti surfaces were shown to prevent bacterial cell adhesion as well as early-stage biofilm formation and indicated a negligible level of cytotoxicity in L929 mouse fibroblast cells. Venugopal discovered that titanium micro-implants modified with AgNP-coated biopolymers exhibited excellent antibacterial properties 34.

- *Smart Brackets with Nanomechanical Sensors*

Quantitative understanding of the three-dimensional (3D) force moment systems utilized for orthodontic tooth movement is essential for predicting the movement route of the teeth and reducing traumatic side effects. A smart bracket with an integrated sensor system for 3D force and moment measurement was recently proposed. By creating and incorporating nanomechanical sensors into the base of orthodontic brackets, real-time feedback about the applied orthodontic forces can be acquired. With this real-time input, the orthodontist may efficiently move teeth with minimal negative effects by modifying the applied force to be within a biological range.

The invention of a "smart" bracket for multidimensional force and moment management was reported by Lapaki et al. [35, 36]. They described a large-scale prototype bracket that used a microsystem chip housed within small, low-profile, contemporary bracket systems with reduced dimensions in order to facilitate clinical testing of this technology.

- *The use of Shape Memory Nanocomposite Polymer in Orthodontics*

Over the past ten years, there has been an increase in the popularity of creating visually appealing orthodontic wires to match tooth-colored brackets. Potential areas of study include polymers with shape memory. These are a family of stimuli-responsive materials that can remember a preprogrammed shape that was imprinted during synthesis and revert to its original shape when exposed to a stimulus such as heat, light, or a magnetic field. [37, 38] The thermal conductivity of shape-memory nanocomposite polymers can be enhanced by the use of nanoparticles. [39, 40] Additionally, these wires can be manufactured at elastic stiffness levels that are therapeutically relevant. Warmth within the body can activate these polymers when they are in the mouth, and light can activate the photoactive nanoparticles, which in turn can change the movement of teeth. Intriguing opportunities for the field of orthodontic biomaterials may arise from future research on shape-memory nanocomposite polymers to produce aesthetically pleasing orthodontic wires.

- *Nanoelectromechanical Systems for Orthodontic Tooth Movement*

Nanoelectromechanical systems (NEMS) are devices that integrate mechanical and electrical functions at the nanoscale level. There is proof that increasing the mechanical forces with electricity can increase the mobility of orthodontic teeth. [41, 42] Studies on animals have shown that when 15-20 µA of low direct current (dc) was applied to the alveolar bone by changing the bioelectric potential, osteoblasts and periodontal ligament cells displayed increased amounts of the second messengers cAMP and cGMP. These findings showed that electric stimulation enhanced cellular enzymatic phosphorylation activities, leading to secretory and synthetic processes associated with accelerated bone remodeling. The intraoral source of energy is a major problem that has to be fixed, though.

In order to facilitate orthodontic tooth movement, it has recently been suggested that power can be produced using microfabricated biocatalytic fuel cells, also known as enzyme batteries. 43 When applied to the gingiva close to the alveolar bone, an enzymatic microbattery may serve as a potential electrical power source to speed up orthodontic tooth movement. Soft-tissue biocompatibility and the effect of foods with different pH and temperature ranges on the output of such a microfabricated enzyme battery are among the issues that still need to be addressed. The NEMS-based method is expected to be utilized in the coming years to develop strong, biocompatible biofuel cells that can be safely inserted in the alveolus of the maxilla or mandible or in the palate to enhance orthodontic tooth movement.

III. TOXICITY

The toxicity of antimicrobial nanoparticles depends on a wide range of factors, such as dosage, types, particle size, dispersion, duration of action, interaction with other components, and so forth. Due to their small size, NPs can readily enter the body and accumulate in organs, resulting in symptoms of poisoning. There is currently no research that examines the cytotoxicity of NPs to people. Furthermore, although several research have looked at the antibacterial toxicity of different NPs, there are no reliable indicators to standardize the toxicity of antibacterial NPs [44,45]. Therefore, it is difficult to compare the toxicity of different NPs. Examining the toxicity of antimicrobial nanoparticles in the same oral environment is worthwhile.

IV. CONCLUSION

Even if the application of nanotechnology in dentistry is limited to currently available materials, rapidly progressing research will ensure that breakthroughs that seem unimaginable today are possible in the future. The use of nanotechnology's advantages will enable future developments in oral health. Advanced restorative materials, novel diagnostic and therapeutic techniques, and pharmaceutical approaches will all enhance dental care.

REFERENCES

[1]. Mizrahi E. Enamel demineralization following orthodontic treatment. Am J Orthod 1982;82:62-7.

[2]. Ogaard B, R¢lla G, Arends J, ten Cate JM. Orthodontic appliances and enamel demineraliztion, part 2 prevention and treatment of lesions. Am J Orthod Dentofac Orthop 1988;94:123-8.

[3]. Gorelick L, Geiger AM, Gwinnett AJ. Incidence of white spot formation after bonding and banding. Am J Orthod 1982;81:93-8.

[4]. Shannon IL. Prevention of decalcification in orthodontic patients. J Clin Orthod 1981;15:694-705.

[5]. ~rtun J, Brobakken BO. Prevalence of carious white spots after orthodontic treatment with mnltiband appliances. Eur J Orthod 1986;8:229-34.

[6]. O'Reilly MM, Featherstone JDB. Demineralization and remineralization around orthodontic appliances: an in vivo study. Am J Orthod Dentofac Orthop 1987;92:33-40.

[7]. Ogaard B, R¢lla G, Arends J, ten Cate JM. Orthodontic appliances and enamel demineralization, part 1: lesion development. Am J Orthod Dentofac Orthop 1988;94:68-73.

[8]. Gracco, A.; Siviero, L.; Dandrea, M.; Crivellin, G. Use of nanotechnology for the superlubrication of orthodontic wires. In Nanobiomaterials in Dentistry: Applications of Nanobiomaterials; Elsevier Inc.: Amsterdam, The Netherlands, 2016; Volume 11, pp. 241–267. [**Google Scholar**.

[9]. Peng Z, Ni J, Zheng K, Shen Y, Wang X, He G, et al. Dual effects and mechanism of TiO2 nanotube arrays in reducing bacterial colonization and enhancing C3H10T1/2 cell adhesion. Int J Nanomed. 2013;8:3093–105.

[10]. Li Y, Zhang W, Niu J, Chen Y. Mechanism of photogenerated reactive oxygen species and correlation with the antibacterial properties of engineered metal-oxide nanoparticles. ACS Nano. 2012;6(6):5164–73.

[11]. Wang L, Hu C, Shao L. The antimicrobial activity of nanoparticles: present situation and prospects for the future. Int J Nanomed. 2017;12:1227–49.

[12]. Kim JS, Kuk E, Yu KN, Kim JH, Park SJ, Lee HJ, et al. Antimicrobial effects of silver nanoparticles. Nanomedicine. 2007;3(1):95–101.

[13]. Liao C, Li Y, Tjong SC. Bactericidal and cytotoxic properties of silver nanoparticles. Int J Mol Sci. 2019;20(2):449–9.

[14]. Yin IX, Zhang J, Zhao IS, Mei ML, Li Q, Chu CH. The antibacterial mechanism of silver nanoparticles and its application in dentistry. Int J Nanomed. 2020;15:2555–62

[15]. Geiger AM, Gorelick L, Gwinnett A J, Griswold PG. The effect of a fluoride program on white spot formation during orthodontic treatment. Am J Orthod Dentofac Orthop 1988;93:29-37.

[16]. Buonoure GM, Vezin JC. Orthodontic fluoride protection. J Clin Orthod 1980;14:321-35.

[17]. Wiegand A, Buchalla W, Attin T (2007) Review on fluoridereleasing restorative materials-fluoride release and uptake characteristics, antibacterial activity and influence on caries formation. Dent Mater 23(3):343–362

[18]. Mitra SB, Dong WU, Holmes BN (2003) An application of nanotechnology in advanced dental materials. J Am Dent Assoc 134:1382–1390

[19]. Application of antibacterial nanoparticles in orthodontic materials : Zhang Yun , Du Qin , Fei Wei and Li Xiaobing

[20]. Sodagar, A.; Akhavan, A. Evaluation of the antibacterial activity of a conventional orthodontic composite containing silver/hydroxyapatite nanoparticles. Prog. Orthod. 2016, 17, 40. [CrossRef] [PubMed]

[21]. Toodehzaeim, M.H.; Zandi, H. The Effect of CuO Nanoparticles on Antimicrobial Effects and Shear Bond Strength of Orthodontic Adhesives. J. Dent. (Shiraz) 2018, 19, 1–5.

[22]. Sodagar, A.; Akhoundi, M.S.A. Effect of TiO2 nanoparticles incorporation on antibacterial properties and shear bond strength of dental composite used in Orthodontics. Dent. Press J. Orthod. 2017, 22, 67–74. [CrossRef] [PubMed]

[23]. Ma, Y.; Zhang, N. Novel multifunctional dental cement to prevent enamel demineralization near orthodontic brackets. J. Dent. 2017, 64, 58–67. [CrossRef]

[24]. Zhang, N.; Weir, M.D. Orthodontic cement with protein-repellent and antibacterial properties and the release of calcium and phosphate ions. J. Dent. 2016, 50, 51–59. [CrossRef] [PubMed]

[25]. Zhang, N.; Chen, C. Antibacterial and protein-repellent orthodontic cement to combat biofilms and white spot lesions. J. Dent. 2015.

[26]. Biosynthesis of Silver Nanoparticles on Orthodontic Elastomeric Modules: Evaluation of Mechanical and Antibacterial Properties.

[27]. Leung M.T.-C., Lee T.C.-K., Rabie A.B.M., Wong R.W.-K. 2008. Use of Miniscrews and Miniplates in Orthodontics. J. Oral Maxillofac. Surg.;66:1461–1466.

[28]. Cheng H.C., Chen M.S., Peng B.Y., Lin W.T., Shen Y.-K., Wang Y.H. 2017. Surface Treatment on Physical Properties and Biocompatibility of Orthodontic Power Chains. BioMed Res. Int.;2017:6343724.

[29]. Maxfield B.J., Hamdan A.M., Tüfekçi E., Shroff B., Best A.M., Lindauer S.J. 2012. Development of white spot lesions during orthodontic treatment: Perceptions of patients, parents, orthodontists, and general dentists. Am. J. Orthod. Dentofac. Orthop.;141:337–344.

ISSN No:-2456-2165

[30]. Prabha R.D., Kandasamy R., Sivaraman U.S., Nandkumar M.A., Nair P.D. Antibacterial nanosilver coated orthodontic bands with potential implications in dentistry. Indian J. Med. Res. 2016;144:580–586.
[31]. Moreira D.M., Oei J., Rawls H.R., Wagner J., Chu L., Li Y., Zhang W., 2015. Whang K. A novel antimicrobial orthodontic band cement with in situ–generated silver nanoparticles. Angle
[32]. Applications of nanotechnology in orthodontics and its future implications: A review Dr. Deepti Govindankutty of WS2 as potential solid-state lubricants. Nat. Cell Biol. 1997, 387, 791–793.
[33]. Qiang WP, He XD, Zhang K, Cheng YF, Lu ZS, Li CM, et al. Mussel adhesive mimetic silk sericin repared by enzymatic oxidation for the construction of antibacterial coatings. ACS Biomater Sci Eng. 2021;7(7):3379–88.
[34]. Venugopal A, Muthuchamy N, Tejani H, Gopalan AI, Lee KP, Lee HJ, et al. Incorporation of silver nanoparticles
[35]. Lapatki BG, Paul O. Smart backets for 3D-force-moment ~ 171 ~ International Journal of Applied Dental Sciences measurement in orthodontic research and therapydevelopmental status and prospects. J Orofac Orthop. 2007; 68(5)377-396.
[36]. Lapaiki HG, Bartholomeyczik J, Ruther P, Jonas IE, Paul O. Smart bracket for multi-dimensional force and moment measurement. J Dent Res. 2007; 86(1):73-78.
[37]. S.I. Gunes, S.C. Jana, Shape memory polymers and their nanocomposites: a review of science and technology of new multifunctional materials, J. Nanosci. Nanotechnol. 8 (4) (2008) 16161637
[38]. M.A.C. Stuart, et al., Emerging applications of stimuli-responsive polymer materials, Nat. Mater. 9 (2010) 101113.
[39]. Q. Meng, J. Hu, A review of shape memory polymer composites and blends, Compos., A: Appl. Sci. Manuf. 40 (11) (2009) 16611672.
[40]. J. Leng, et al., Shape-memory polymers and their composites: stimulus methods and applications, Prog. Mater. Sci. 56 (7) (2011) 10771135
[41]. Z. Davidovitch, et al., Electric currents, bone remodeling, and orthodontic tooth movement. II. Increase in rate of tooth movement and periodontal cyclic nucleotide levels by combined force and electric current, Am. J. Orthod. 77 (1) (1980) 3347. References 297
[42]. Z. Davidovitch, et al., Electric currents, bone remodeling, and orthodontic tooth movement. I. The effect of electric currents on periodontal cyclic nucleotides, Am. J. Orthod. 77 (1) (1980) 1432.
[43]. J. Kolahi, M. Abrishami, Z. Davidovitch, Microfabricated biocatalytic fuel cells: a new approach to accelerating the orthodontic tooth movement, Med. Hypotheses 73 (3) (2009) 340341.
[44]. Shrestha, A.; Hamblin, M.R. Photoactivated rose bengal functionalized chitosan nanoparticles produce antibacterial/biofilm activity and stabilize dentin-collagen. Nanomedicine 2014, 10, 491–501. [CrossRef]43, 1529–1538. [CrossRef] [PubMed]
[45]. Chen, R.; Han, Z. Antibacterial activity, cytotoxicity and mechanical behavior of nano-enhanced denture base resin with different kinds of inorganic antibacterial agents. Dent. Mater. J. 2017, 36, 693–699. [CrossRef] [PubMed]