Nanotechnology In Orthodontics – A Short Review

Dr. Krithika. A*, Dr. S. Kishore kumar

Asst. Professor, Srm Kattankulathur Dental College and Hospital, Chennai

Abstract:

Nanotechnology deals with the physical, chemical, and biological properties of structures and their components at nanoscale dimensions. It is based on the concept of creating functional structures by controlling atoms and molecules on a one-by-one basis. The use of this technology will allow many developments in the health sciences sas well as in materials science, bio-technology, electronic and computer technology, aviation, and space exploration. With developments in materials science and biotechnology, nanotechnology is especially anticipated to provide advances in dentistry and innovations in oral health-related diagnostic and therapeutic methods.

INTRODUCTION:

Nanotechnology is about manipulating matter, atom by atom. The word nano is a Greek word, meaning dwarf. It is used as a prefix in the metric system and denotes a factor of 10^{-9} or 0.000000001. Research is undergoing for the provision of better tools for diagnosis and management of medical conditions with the aid of nanotechnology. It is defined as the multidisciplinary science of the creation of materials, devices, and systems at the nanoscale level. The concept of nanotechnology is unique and exciting as their size is smaller than the critical lengths defining many physical events.

According to the definition of the National Nanotechnology Initiative, "Nanotechnology is the direct manipulation of materials at the nanoscale". This term defines a technology that enables almost complete control of the structure of matter at nanoscale dimensions. In general, nanotechnology is translated as "the science of the small".

Nanodentistry is an emerging field with a new generation of technologically advanced clinical tools and devices for oral health care. There is a hope that nanotechnology will likewise bring tangible benefits to dentistry, from the bench to the clinical level. Nanotechnology has been applied in dentistry since 1970s with the beginning of the era of microfills. Nanobionmaterials has been employed in dentistry which helps in maintenance of comprehensive oral health care.

HISTORY

The term nanotechnology was coined by **Prof. Kerie E. Drexler**, a researcher and writer of nanotechnology. Richard Zsigmondy studied nanomaterials in the early 20th century, and later discoveries culminated in ideas presented by Nobel Prize winning physicist Richard Feynman in a lecture called "Plenty of Room at the Bottom" in 1959, in which he explored the implications of matter manipulation. The word "nanotechnology" was introduced for the first time into a scientific world by **N. Taniguchi** at the International conference on industrial production in Tokyo in 1974 in order to describe the superthin processing of materials with nanometer accuracy and the creation of nano-sized mechanisms.

The concept and origin of nanotechnology was in 1959 by Richard Feynman who is an the American physicist and Nobel Laureate.

CLASSIFICATION OF NANOMATERIALS

Siegel has classified nanomaterials as

- zero dimensional,
- one dimensional,
- two dimensional and
- three dimensional nanostructures.

Nanostructures can be described as: Nanoparticles, Nanopores, Nanotubes, Nanorods, Nanospheres, Nanofibres, Nanoshells, Dendrimers & dendritic copolymers.

NANOPARTICLES

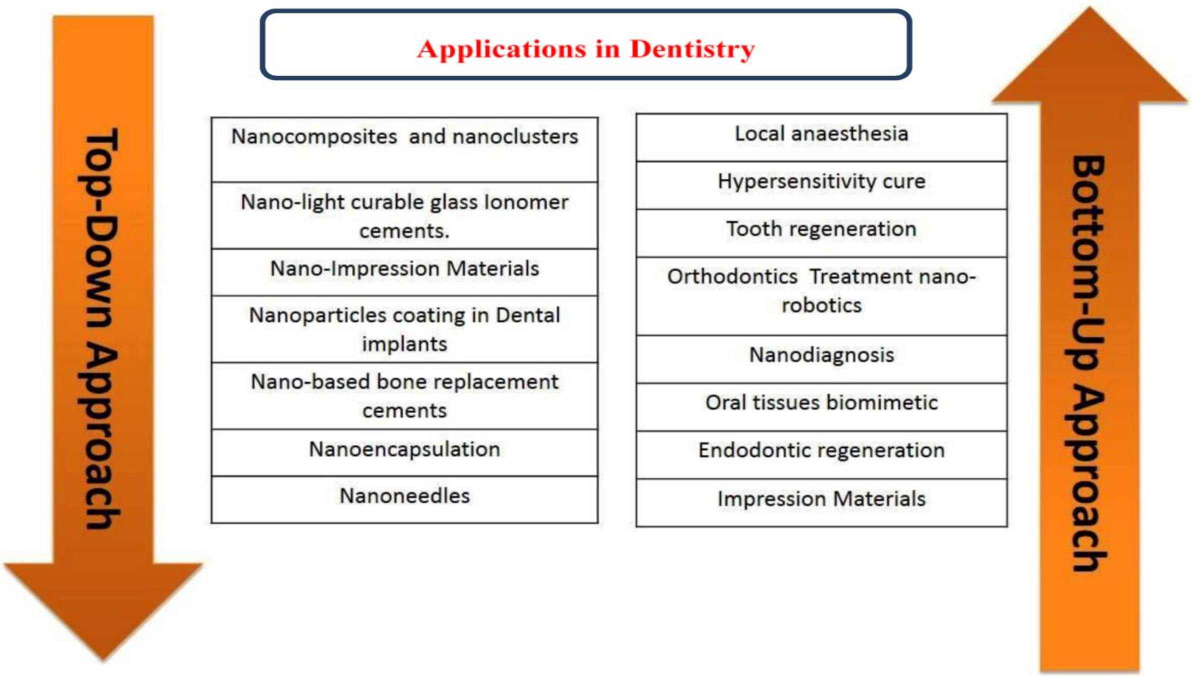
British Standards Institution defines Nanoparticles as those particles in which all the fields or diameters are in the nanoscale range. Nanoparticles are generally classified based on their dimensions, morphology, composition, uniformity, and agglomeration. Nanoparticles can be described as Nano pores, Nanotubes, Quantum dots, Nano shells, Dendrimers, Liposomes, Nano rods, Fullerenes, Nano spheres, Nanowires, Nano belts, Nano rings and Nano capsules.

Nanoparticles application as antimicrobial agent

Nitrogen doped Titanium dioxide (TiO_2), Silver (Ag), Gold (Au) , Silica (SiO_2) Copper (Cu/CuO) and ZnO nanoparticles have been coated on either brackets or added to cements and bonding agents to reduce the demineralization produced as a result of orthodontic treatment.

TECHNIQUES IN NANOTECHNOLOGY:

Nanotechnology has been approached in two ways: from the “top-down” or the “bottom-up” approach.



NANO-INDENTATION AND ATOMIC FORCE MICROSCOPY

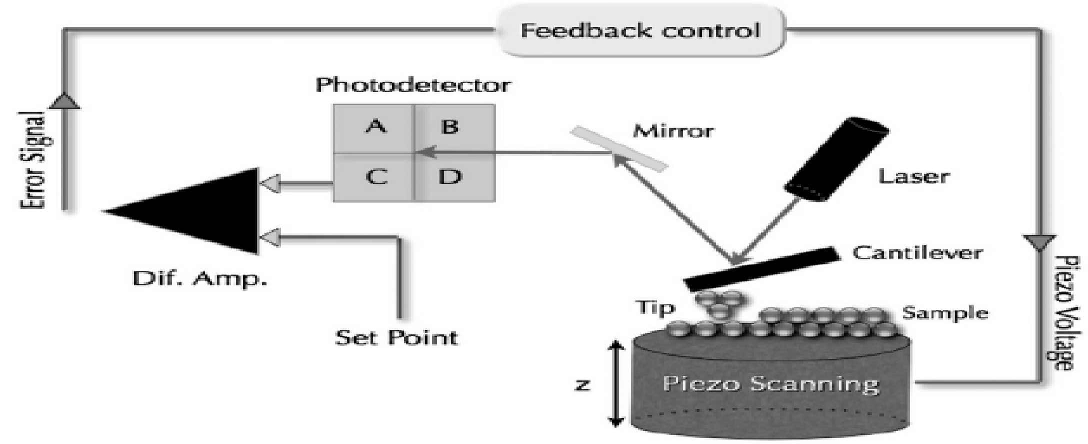


Figure 1. Atomic force microscope (AFM) diagram of operation: The AFM consists of a cantilever, the end of which is fitted with a tip, typically composed of silicon or silicon nitride, which has a radius of curvature on the order of nanometers. Attraction and repulsion forces between the tip and the sample depend on Van der Waals forces, which cause a deflection of the cantilever (the elastic constant of which is known), in accordance with Hooke's Law. The deflection is measured using a laser light reflected from the top of the micro-lever, which will be detected by a four-quadrant photodiode. A feedback loop adjusts the distance between the tip and the sample in order to keep the force acting between them constant, which in turn allows for perfect scanning of all the surface asperities. The sample is placed on a piezo-electric tube that can move it perpendicularly (z direction) to maintain a constant force in the plane (x and y directions) to analyze the surface. The resulting map (x, y) represents the topography of the surface sample.

The invention of scanning tunneling microscope (STM) by **Binnig and Rohrer**[3] in 1981, is by which the individual atoms were easily identified for the first time.

Gerd Binnig (left) and Heinrich Rohrer (right) won the 1986 Nobel Prize in Physics for their 1981 invention of the scanning tunneling microscope.

The surface characteristics which includes the roughness and surface free energy (SFE), of the brackets play a significant role in reducing friction and plaque formation. Nanoscale surface characteristics of bio-materials were evaluated using an nanoindenter coupled with atomic force microscope. Mechanical properties such as hardness, elastic modulus, yield strength, fracture toughness, were also evaluated by nano indentation studies.

Atomic force microscopy (AFM) or scanning force microscopy (SFM) which was developed subsequent to the invention of the scanning tunneling microscope (STM), is a very high resolution type of scanning probe microscopy, with demonstrated resolution more than 1000 times better than the optical diffraction limit.

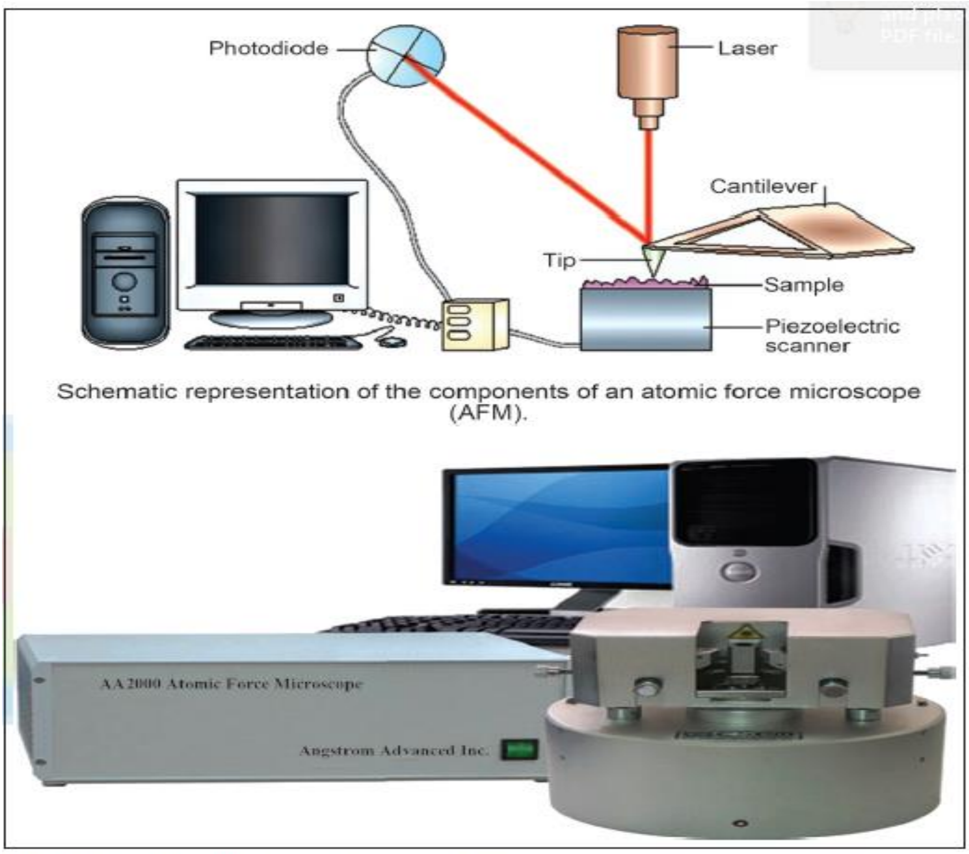


Figure 2: Atomic force microscope

NANO-COATED ARCHWIRES AND FRICTION:

Nanoparticles have been used as a component of dry lubricants for minimizing frictional forces between the orthodontic wire and brackets, thus enhancing tooth movement. Inorganic fullerene-like nanoparticlcs of tungsten sulflide (IF-WS2) are examples of dry lubricants which have been used as selflubricating coatings for orthodontic stainless steel wires. The other alternatives are to vary the wire size and shape, altering the bracket design or coating the wire surfaces with different materials which may aid in conquering sliding resistance. These coatings have been applied either on bracket surface, or S.S. or NiTi wires.

HOLLOW WIRES

Hollow wires are wires coated with NiTi/Ni-TiO2 composite nanoparticles via the synthesis method called ultrasonic spray pyrolysis (USP). This wire could potentially have the shape-memory and superelasticity properties, while possibly reducing the material needed for the wire production.

SHAPE MEMORY POLYMERS

Shape memory polymers (SMPs) are materials that have the ability to memorize a macroscopic or equilibrium shape and then be manipulated and fixed to a temporary or dormant shape under specific conditions of temperature and stress. They relax to their original, stress-free condition and equilibrium shape under thermal, electrical, or environmental conditions. This relaxation is associated with elastic deformation stored during prior manipulation. The relaxation of SMP can be accompanied by an adequate force, useful for an orthodontic tooth movement, or macroscopic shape change, which is useful in ligation. As SMP's can have two shapes, these devices meet needs unattainable with current orthodontic materials allowing for easier and more comfortable procedure for the orthodontist to insert into the mouth of the patient. Once placed in the mouth, these polymers are activated by the body temperature or photoactive nanoparticles which brings about tooth movement. The SMP orthodontic wires provide lighter, more constant forces reducing pain for the patients.

BIO MEMS/NEMS FOR ORTHODONTIC TOOTH MOVEMENT AND MAXILLARY EXPANSION

Microelectromechanical systems (MEMS) devices are manufactured using microfabrication techniques. They often have moving components that allow a physical or analytical function to be performed by the device in addition to their electrical functions. The biological MEMS (bioMEMS) are made up of micromachined elements for applications to biological systems. Implantable bioMEMS have been used as biosensors for in vivo diagnostics of diseases and as drug delivery microchips.

Orthodontic tooth movement can be enhanced by means of electricity. Animal experiments indicated that when 15-20 microamperes of low direct current (dc) was applied to the alveolar bone, osteoblasts and periodontal ligament cells demonstrated increased concentrations of the second messengers cAMP (adenosine-30 ,50 -cyclic monophosphate) and cGMP (cyclic guanosine monophosphate). These findings suggest that electric stimulation enhanced cellular enzymatic phosphorylation activities, leading to synthetic and secretory processes associated with accelerated bone remodeling.

NANO LIPUS DEVICES

Ultrasound (US) is a form of mechanical energy that is transmitted as an acoustic pressure wave at frequencies above the limit of human hearing through and into biological tissues as a diagnostic tool. Low–intensity pulsed US (LIPUS) is effective in liberating preformed fibroblast growth factors from a macrophage-like cell line (U937), and it enhances angiogenesis during wound healing. Also, LIPUS enhances bone growth into titanium porous–coated implants and bone healing after fracture and mandibular distraction osteogenesis.

ORTHODONTIC NANOROBOTS

The orthodontic nanorobots can be used in future to alter the periodontal tissues, including gums, periodontal ligament, cementum and alveolar bone, allowing a rapid and painless straightening, rotating or vertical positioning.

NANOMECHANICAL SENSORS FOR ORTHODONTIC FORCES AND MOMENTS MEASUREMENT

Both modulus of elasticity and geometry are important in determining wire stiffness according to the following equation:

K (stiffness) = E * I (E is the modulus of elasticity and I is the area moment of inertia).
For round wire, d is the diameter of the round wire,

$$I = \pi d^4/64$$

For rectangular wire (Figure 12.5). Dimensions of the rectangular wire where (b) is the wire base in the in-out direction; and (h) is the wire height in the up-down direction

$$I = b(h^3)/12$$

NANO-ORTHODONTIC BRACKETS

The nanosilver-coated orthodontic bracket is a new type of bracket for use in human teeth to reduce the areas of tooth decay and demineralization during orthodontic treatment with the advantages of the antibacterial properties of nanosilver.

INTEGRATED SIX-DEGREE-OF-FREEDOM SENSING FOR ORTHODONTIC SMART BRACKETS

J. Bartholomeyczik et al[14] (2006), reported for the first time, an orthodontic smart bracket capable of detecting all six externally applied force and moment components. By measuring the stresses in the plane of a sensor chip inside the bracket, it is possible to extract the forces and moments externally applied to the bracket. The stress sensing device consists of an integrated CMOS circuit packaged within a bracket demonstrator for application in orthodontics. By measuring 64 stress signals within the chip plane the sensor is capable of extracting all six components of the force and moment at the interface between the orthodontic bracket and the base onto which it is mounted.

The combination of an orthodontic bracket with an integrated CMOS-based stress sensor system is the principle of the smart bracket concept. The integrated stress sensor system comprises diffused silicon resistors capable of measuring mechanical stress in the surface of the sensor die exploiting the piezoresistive effect in silicon. Such devices are capable of simultaneously measuring the in plane stress components. By applying external forces and moments to the arch wire, a characteristic stress distribution will appear in the surface of the sensor die caused by the mechanical deformation of the bracket body.

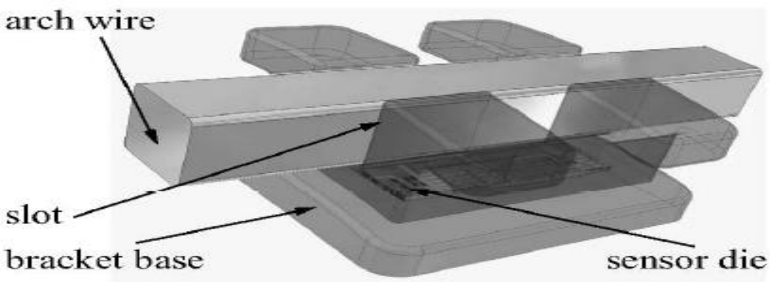


Figure 1: Illustration of the smart bracket concept with an integrated stress sensor system embedded in an orthodontic bracket.

Lapatki et al[58], (2007) demonstrated *the* feasibility of this approach using finite-element (FE) simulations and a 2.5 times enlarged real smart bracket model. A true-scale smart bracket was built using a stress-sensor chip (having a surface area of 2 × 2.5 mm^2) and a conventional bracket slot. This bracket was calibrated on a biomechanical system for 3D application and measurement of forces and moments, then its measurement accuracy was evaluated.

ADVANTAGES OF SMART BRACKETS

All six components of the force-moment system can be quantitatively determined, albeit with limited success in
terms of bucco-lingual forces.
1) Measurements can be taken on each tooth simultaneously and on all teeth included in the appliance.
2) The forces and moments can be measured without manipulation, that is deactivation, of the fixed appliance.
3) Measurements are taken at the specific location where the load is transmitted to the tooth, thus accounting for the friction between the bracket and wire. The negative effect on the highly-variable measurement accuracy caused by friction between the bracket and wire is thus eliminated.

CONCLUSION

The future in orthodontic treatment will rely primarily on the application of nanotechnology should all aforementioned technologies are proven to reproduce similar results under different conditions. Also, the application of nanotechnology in orthodontics should not lead to un-affordable cost to the orthodontist as well as the patient. To achieve quality patient care, reproducibility of results as well as cost effectiveness, research on the use of nanotechnology in orthodontics needs to be channelized in the direction of, processes for the creation of the materials, fabrication of the devices and / appliances, clinical implementation and analysis of these materials, devices and appliances.

REFERENCES

[1] Theodore Eliades et al, Orthodontic materials research and applications: Part 1. Current status and projected future developments in bonding and adhesives, Am J Orthod Dentofacial Orthop 2006;130:445-51)

[2] Marcos D´ıaz, Flora Barba, MiriamMiranda, Francisco Guiti ´an, Ram´on Torrecillas,3 and Jos´e S. Moya, Synthesis and Antimicrobial Activity of

[3] a Silver-Hydroxyapatite Nanocomposite, 2009

[4] Vincenzo D'Anto`; Roberto Rongo; Gianluca Ametrano; Gianrico Spagnuoloa; Paolo Manzo; Roberto Martina; Sergio Paduano; Rosa Valletta, Evaluation of surface roughness of orthodontic wires by means of atomic force microscopy, Angle Orthod. 2012;82:922–928.

[5] Juan Liao et al, Antibacterial titanium plate deposited by silver nanoparticles exhibits cell compatibility, International Journal of Nanomedicine 2010

[6] C. Bourauel, D. Drescher and M. Thier, An experimental apparatus for the simulation of three-dimensional movements in orthodontics, J, Biomed. Eng. 1992, Vol. 14. September

[7] Christoph Bourauel, Dirk Vollmer, Andreas Jäger, Application of Bone Remodeling Theories in the Simulation of Orthodontic Tooth Movements, Journal of Orofacial Orthopedics, 2000

[8] Suresh Mitthra et al, Nanorobots – A Small Wonder, *BIOSCIENCES BIOTECHNOLOGY RESEARCH ASIA*, December 2016. Vol. 13(4), 2131-2134

[9] Andrei M Popov et al, Biocompatibility and applications of carbon nanotubes in medical nanorobots, International Journal of Nanomedicine 2007:

[10] Santiago Arango et al, Coating and Surface Treatments on Orthodontic Metallic Materials, *Coatings* 2013.

[11] *Romanian Journal of Oral Rehabilitation,* Vol. 3, No. 4, December 2011, Ana-Maria Dumitrescu, Cristina, DENTAL NANOROBOTS SMALL INSTRUMENTS WITH LARGE POTENTIAL

[12] *Fan-Gang Tseng et al,* An elastomeric tactile sensor employing dielectric constant variation and applicable to orthodontia, 2004

[13] Mallanagouda Patil, Dhoom Singh Mehta, and Sowjanya Guvva et al, Future impact of nanotechnology on medicine and dentistry, 2005

[14] Lakshmi sree et al, Nanotechnology in Dentistry – A Review, *International Journal of Dental Science and Research, 2013, Vol. 1, No. 2, 40-44.*

[15] J. Bartholomeyczik et al, INTEGRATED SIX-DEGREE-OF-FREEDOM SENSING FOR ORTHODONTIC SMART BRACKETS, MEMS 2006, Istanbul, Turkey, 22-26 January 2006.

[16] Bernd G. Lapatki, Oliver Paul, J Orofac Orthop 2007;68:377–96, Smart Brackets for 3D-Force-Moment Measurements in Orthodontic Research and Therapy – Developmental Status and Prospects

[17] Manufacturing Technology For Medical Nanorobots, *APNF Asia Pacific Nanotechnology Forum News Journal Vol 6, No. 1, January 2007*

[18] Zohaib Khurshid et al, Advances in Nanotechnology for Restorative Dentistry, *Materials* 2015, *8*, 717-731

[19] Dirk Friedrich et al, Journal of Biomechanics 32 (1999) , Measuring system for in vivo recording of force systems in orthodontic treatment - concept and analysis of accuracy

[20] Julian Bartholomeyczik et al, Multidimensional CMOS In-Plane Stress Sensor, IEEE SENSORS JOURNAL, VOL. 5, NO. 5, OCTOBER 2005

[21] T. Hosseinzadeh-Nik et al, Bond strength of a nano-composite used for bonding ceramic orthodontic brackets, Materials and Design (2013)

[22] Devika.G.Umalkar et al, Applications of nanotechnology in clinical orthodontics, A Review - International Journal of Contemporary Orthodontics, 2016

[23] *Archana Bhardwaj et al,* Nanotechnology in dentistry: Present and future, *Journal of International Oral Health 2014; 6(1):121-126*

[24] S A P Rasheed, et al, Nanotechnology and Its Applications in Dentistry, International Journal of Advanced Health Sciences ,Vol 2 Issue 9, January 2016.

[25] K. Rajasundari and K. Ilamurugu, Nanotechnology and Its Applications in Medical Diagnosis, *J. Basic. Appl. Chem.*, 1(2)26-32, 2011

[26] Dayanne Lopes da Silva et al, Infrared spectroscopy, nano-mechanical properties, and scratch resistance of esthetic orthodontic coated archwires, Angle Orthod. 2015;85:777–783.

[27] Tancan Uysal et al, Are nano-composites and nano-ionomers suitable for orthodontic bracket bonding? *European Journal of Orthodontics* 32 (2010) 78–82

[28] SNEHA SUNDAR RAJAN et al, NANODENTISTRY, Indian J.Sci.Res. 4(2) : 233-238, 2013

[29] Enan et al, Microleakage under orthodontic bands cemented with nano-hydroxyapatite-modified glass ionomer, Angle Orthod. 2013;83:981–986.
[30] Ritika Arora et al, Nanotechnology in Dentistry - Hope or Hype, OHDM - Vol. 13 - No. 4 - December, 2014
[31] Dr. Mehra P et al, A Nanorobotics - The Changing Face of Dentistry, International Journal of Science and Research (IJSR)2013.
[32] Surendiran et al, Novel applications of nanotechnology in medicine, Indian J Med Res 130, December 2009.
[33] KH Awan et al, Nanotechnology and its role in dentistry: A review, *Hard Tissue 2014 Jun 14;3(1):10.*
[34] Neetha J. Shetty et al, Nanorobots: Future in dentistry, The SaudiDentalJournal(2013) 25, 49–52
[35] Karthikeyan subramani et al, Nanobiomaterials in clinical dentistry, 2013
[36] *Shibli S Syed et al,* A Novel Method of Coating Orthodontic Archwires with Nanoparticles, *Journal of International Oral Health 2015; 7(5):30-33*
[37] Single gorav et al, Nanodentistry - the future ahead, BFUDJ, Volume 1, Number 1, July 2010.
[38] Deepak Ranjan Dalai et al, Futuristic Application of Nano-Robots in Dentistry, International Journal of Advanced Health Sciences, July 2014
[39] Sandesh.S.Pai et al, evaluation of a new nano-filled bonding agent for bonding orthodontic brackets as compared to a conventional bonding agent, an in-vitro study, J Ind Orthod Soc 2012.
[40] Javed chalipa et al, evaluation of shear bond strength of orthodontic brackets bonded with nano-filled composites,
[41] *Journal of Dentistry, Tehran University of Medical Sciences, Tehran, Iran (2013; Vol. 10, No.5.*
[42] Paresh Chandra Ray et al, Toxicity and Environmental Risks of Nanomaterials: Challenges and Future Needs, *J Environ Sci Health C Environ Carcinog Ecotoxicol Rev*. 2009 January
[43] Sandhya Maheshwari et al, Nano–orthodontics revolutionizing oral health care, http://www.indjos.com on Sunday, April 23, 2017
[44] Adriano Cavalcanti et al, Nanorobot Hardware Architecture for Medical Defense, *Sensors* 2008, *8*, 2932-2958
[45] Dr.V.Sujatha et al, nanorobotics – A Futuristic Approach, SRM University Journal of dental sciences, volume-1, issue 1, june 2010.
[46] Bhavna Jha Kukreja, ROBOTIC DENTISTRY-THE FUTURE IS AT THE HORIZON, JOURNAL OF PHARMACEUTICAL AND BIOMEDICAL SCIENCES, 2012
[47] Adith Venugopal et al, Incorporation of silver nanoparticles on the surface of orthodontic microimplants to achieve antimicrobial properties, Korean J Orthod 2017;47(1):3-10
[48] Rajshri M Navalakhe et al, Application of Nanotechnology in biomedicine, Indian journal of experimental biology, Vol 75, Feb 2007
[49] Sanjeev kumar verma et al, A critical review of the implication of Nanotechnology in modern dental practice, Natl J Maxillofac Surgery, Vol 1, Issue 1, jun 2010.
[50] SARAVANA KUMAR ET AL, Nanotechnology in dentistry, Ind J Dent Res 17(2): 62-65, 2006
[51] Panchali Batra et al, Nanoparticles and their Applications in Orthodontics,

Adv Dent & Oral Health, 2016

[52] T. S. V. Satyanarayana, Rathika Rai, Nanotechnology: The future, Journal of Interdisciplinary Dentistry / Jul-Dec 2011 / Vol-1 / Issue-2

[53] Cyril Ng, Lung Kit, Where will Nanotechnology Take Us in the 21st Century?, Young Scientists Journal, 2008

[54] Dr. Deepti Govindankutty, Applications of nanotechnology in orthodontics and its future implications: A review, International Journal of Applied Dental Sciences 2015; 1(4): 166-171

[55] Surya Singh and Hari Singh Nalwa, Nanotechnology and Health Safety – Toxicity and Risk Assessments of Nanostructured Materials on Human Health, Journal of Nanoscience and Nanotechnology, Vol.7, 3048–3070, 2007

[56] Dr. Umesh Y. Pai et al, Applications of Nanotechnology in Dentistry, *Journal of International Medicine and Dentistry 2015; 2(3): 186-203*

[57] Jiirg Schwizer, Wan Ho Song, Michael Mayer, Oliver Brand, and Henry Baltes et al, Packaging test chip for flip-chip and wire bonding process characterization, The 12th International Conference on Solid State Sensors, Actuators and Microsyslems, Boslon. June 8-12, 2003

[58] Dr Suhail Majid Jan et al, Role of Nanotechnology in Dentistry, Sch. J. App. Med. Sci., 2014; 2(2D):785-789

[59] Viorel Marin Rusu et al, Size-controlled hydroxyapatite nanoparticles as self-organized organic–inorganic composite materials, Biomaterials 26 (2005) 5414–5426

[60] B. Lapatki, O. Paul, Smart Brackets for 3D-Force-Moment Measurements in Orthodontic Research and Therapy-Developmental Status and Prospects, 2007 *J Orofac Orthop*, pages: 377 – 396

[61] B.G. Lapatki, J. Bartholomeyczik, P. Ruther, I.E. Jonas, and O. Paul, Smart Bracket for Multi-dimensional Force and Moment Measurement, Journal of Dental Research 86(1):73-8 · February 2007

[62] *P. Gieschke, J. Held, M. Doelle, J. Bartholomeyczik, P. Ruther, and O. Paul,* SMART BRUSH BASED ON A HIGH DENSITY CMOS STRESS SENSOR ARRAY AND SU-8 MICROPOSTS, MEMS 2007, Kobe, Japan, 21-25 January 2007.

[63] S. Rues , B.Panchaphongsaphak , P.Gieschke , O.Paul , B.G.Lapatki, An analysis of the measurement principle of smart brackets for 3D force and moment monitoring in orthodontics, Journal of Biomechanics 44 (2011) 1892–1900.