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Applications of nanotechnology in orthodontics and its future implications: A review

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Abstract
Nanotechnology is manipulating matter at nanometer level. This concept can be applied to the field of medicine and dentistry with the terms Nanomedicine and Nanodentistry being used respectively. Nanotechnology holds promise in many areas like advanced diagnostics, targeted drug delivery and biosensors. It has several applications in dentistry as well, from diagnosis of pathological conditions to local anaesthesia, orthodontic tooth movement and periodontics. Biomaterials science has also greatly benefited by this technology. This review provides an early glimpse on the impact and future implication of nanotechnology in orthodontics.

Keywords: Nanotechnology, Nanodentistry, Orthodontics, Biomaterials.

Introduction
The term “Nano” is derived from Greek word meaning “dwarf”. A nanometer is 10^{-9} or one billionth of a meter. Nanotechnology is about manipulating matter, atom by atom [1-4]. The concept and origin of nanotechnology has been attributed to the American physicist and Nobel Laureate Richard Feynman in 1959 [5-6]. This was made possible by Eric Drexler in the mid-1980s when he emphasized the potential of molecular nanotechnology [7-8]. It is defined as the multidisciplinary science of the creation of materials, devices, and systems at the nanoscale level. What makes the concept of nanotechnology unique and exciting is that their size is smaller than the critical lengths defining many physical events.
Three approaches followed in production of nanoparticles are- Bottom up approach, Top down approach and Functional approach [9]. The functional approach has the objective to produce a nanoparticle with a specific functionality. Science and technology has witnessed the fabrication of several nanoparticles that we come a use in our day to day lives, many a times not realizing it is part of the future revolution. These nanoparticles are nano pores, nanotubes, quantum dots, nanoshells, dendrimers, liposomes, nanorods, fullerenes, nanospheres, nanowires, nanobelts, nanorings, nanocapsules etc [10]. This list is by no means exhaustive.

Nanotechnology in dentistry
Nanodentistry is the science and technology of maintaining near-perfect oral health through the use of nanomaterials including tissue engineering and nanorobotics. New potential treatment opportunities in dentistry may include local anesthesia, permanent hypersensitivity cure, nanorobotic dentifrice, treatment of oral cancer etc.

Nanotechnology in Orthodontics
Nano indentation and atomic force microscopy studies on orthodontic brackets and arch wires the surface characteristics i.e roughness and surface free energy (SFE), of the brackets play a significant role in reducing friction and plaque formation. A nanoindenter coupled with atomic force microscope (AFM) is used to evaluate nanoscale surface characteristics of bio-materials. They have also been used to evaluate mechanical properties such as hardness, elastic modulus, yield strength, fracture toughness, scratch hardness and wear properties by nano indentation studies.
Atomic force microscopy (AFM) or scanning force microscopy (SFM) which was developed subsequently to 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 [11]. The AFM consists of a cantilever, the end of which is fitted with a tip, typically composed of silicon or silicon nitride and 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, in accordance with Hooke's Law. The deflection is measured using a laser light reflected from the top of the micro-lever, and 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 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.

A typical AFM can provide resolutions of 1 nm laterally and 0.07 nm (sub-angstrom) vertically [12]. AFM has been utilized to look at the nanoscale dimension of the orthodontic armamentarium and the changes taking place during the course of treatment in various studies [13-16].

D'Antò *et al* [17] compared the surface roughness of stainless-steel (SS), β-titanium (β-Ti), and nickel-titanium (NiTi) wires using AFM. The investigation showed that AFM had many advantages, such as the production of topographical three-dimensional images in real space with a very high resolution (~10 A). The most important drawback of AFM is the small scan size, which, in association with the slow velocity of scanning, often impedes a complete analysis of the sample [18].

2. Nanocoatings in archwires

Minimizing the frictional forces between the orthodontic wire and brackets has the potential to increase the desired tooth movement and therefore result in less treatment time. Nanoparticles have been used as a component of dry lubricants in recent years. Dry lubricants are solid phase materials capable to reduce friction between two surfaces sliding against each other without the need for a liquid media. Inorganic fullerene-like nanoparticlcs of tungsten sulflide (IF-WS2), which are potent dry lubricants have been used as self-lubricating coatings for orthodontic stainless steel wires.

Redlich *et al* [19] coated stainless steel wire with nickel–phosphorous electroless film impregnated with inorganic fullerene-like nanoparticles of tungsten disulfide (IF-WS2) by inserting stainless steel (SS) wires into electroless solutions of nickel–phosphorus (Ni–P) and IF-WS2. Friction tests simulating archwire functioning of the coated and uncoated wires were carried out by an Instron machine and SEM/EDS analysis of the coated wires showed clear impregnation of the IF-WS2 nanoparticles in the Ni–P matrix. The friction forces measured on the coated wire were reduced by up to 54%.

3. Nanoparticle in Orthodontic adhesive

Polymer nanocomposites are a new class of materials that contain nano fillers that are 0.005‐ 0.01 microns in size. To make filler particles of the mechanically strong composites of today (such as macrofills, hybrids and microhybrids), one starts from dense, large particles like mined quartz, melt glasses, ceramics and comminute them to small particle size [20]. Due to the reduced dimension of the particles and a wide size distribution, an increased filler load can be achieved that reduces polymerization shrinkage [21] and also increases mechanical properties such as tensile and compressive strength and resistance to fracture. Geraldeli and Perdigao [22] reported that nano-composites had a good marginal seal to enamel and dentine compared with total-etch adhesives.

The advantages of nanocomposite materials include excellent optical properties, easy handling characteristics and superior polishiability [23]. Also, nanofillers can decrease surface roughness of orthodontic adhesives, which is one of the most significant factors for bacterial adhesion [24-25].

In recent times a nanoionomer which is resin-moditied GIC (Ketac ™ N1OO Light Curing Nano ionomer) has been introduced to operative dentistry [26-27]. This light curing nanoionomer is composed of nanofillers fluoroaluminosilicate glass, and nanofiller ‘clusters’ combined to improve mechanical properties and high fluoride release.

Uysal *et al* [28] tested nano-composite (Filtek Supreme Plus Universal) and a nano-ionomer (Ketac ™ N100 Light Curing Nano-Ionomer) restorative to determine their shear bond strength (SBS) and failure site locations in comparison with a conventional light-cure orthodontic bonding adhesive (Transbond XT). The results suggest that Nano-composites and nano-ionomers may be suitable for bonding since they achieve the previously suggested SBS ranges for clinical acceptability.But they are inferior to a conventional orthodontic composite. Bishara and Ajlouni [29] compared the shear bond strength of a nano‐ hybrid restorative material, Grandio (Voco, Germany), and traditional adhesive material (Transbond XT; 3M Unitek) when bonding orthodontic brackets and concluded that nano‐ filled composite materials can potentially be used to bond orthodontic brackets to teeth if its consistency can be made more flowable to readily adhere to the bracket base.

4. Nanoparticle delivery from elastomeric ligature

Elastomeric ligatures can serve as a carrier scaffold for delivery of nanoparticles that can be anticariogenic, antiinflammatory and antibiotic drug molecules embedded in the elastomeric matrix. The release of anticariogenic fluoride from elastomeric ligatures has been reported in the literature previously [30-32]. The studies conclude that the fluoride release is characterized by an initial burst of fluoride during the first few days followed by a logarithmic decrease. For optimum clinical benefit, the fluoride ties should be replaced monthly.

5. Shape memory polymers in orthodontics

Over the past decade there has been an increased interest in manufacturing esthetic orthodontic wires to complement tooth coloured brackets. Shape-memory esthetic polymer is an area of potential research. Shape memory polymers (SMPs) are materials that have the ability to memorize a macroscopic or equilibrium shape and then be manipulated and fixedto a temporary or dormant shape under specific conditions of temperature and stress. They can later relax to the original, stress-free condition under thermal, electrical, or environmental condition. This relaxation is associated with elastic deformation stored during prior manipulation. The return of the SMP toward its equilibrium shape can be accompanied by an adequate and prescribed force, useful for an orthodontic tooth movement, or macroscopic shape change, which is useful for ligation mechanisms. Due to the SMP’s ability to 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 [33-34].

Once placed in the mouth, these polymers can be activated by the body temperature or photoactive nanoparticles activated by light and thusbring about tooth movement. The SMP orthodontic wires can provide improvements over traditional orthodontic materials as they will provide lighter, more constant forces which in turn may cause less pain for the patients. In addition, the SMP materials are clear, colourable, and stain resistant, providing the patient a more aesthetically appealing appliance during treatment. The high percent elongation of the SMP appliance (up to about 300%) allows for the application of continuous forces over a long range of tooth movement and hence, results in fewer visits for the patient [35-36]. Future research directions in shape—memory nanocomposite polymers to produce esthetic orthodontic wires can be of interesting potential in orthodontic biomaterial research.

5. Control of oral Biofilms during orthodontic treatment

NPs present a greater surface-to-volume ratio (per unit mass) when compared with non nanoscale particles, interacting more closely with microbial membranes and provide considerably larger surface area for antimicrobial activity. Metal NPs in the size range of 1-10 nm have particularly shown the greatest biocidal activity against bacteria [37]. Silver has a long history of use in medicine as an antimicrobial agent [38]. The antibacterial properties of NPs have been used through the mechanism of combining dental materials with NPs or coating surfaces with NPs to prevent microbial adhesion, with the aim of reducing biofilm formation [39-40]. Resin composites containing silver ion-implanted fillers that release silver ions have been found to have antibacterial effects on oral streptococci [41].

S J Ahn [42] *et al* compared an experimental composite adhesive (ECAs) containing silica nanofillers and silver nanoparticles with two conventional composite adhesives and resin modified glass ionomer [RMGI]) to study surface characteristics, physical properties and antibacterial activities against cariogenic streptococci. The results suggest that ECAs had rougher surfaces than conventional adhesives due to the addition of silver nanoparticles. Bacterial adhesion to ECAs was less than to conventional adhesives, which was not influenced by saliva coating. Bacterial suspension containing ECAs showed slower bacterial growth than those containing conventional adhesives. There was no significant difference in shear bond strength and bond failure interface between ECAs and conventional adhesives. This study suggested that ECAs can help prevent enamel demineralization around brackets without compromising physical properties.

6. Bio MEMS/NEMS for orthodontic tooth movement and maxillary expansion

Biomedical Microclectromechanical systems (Bio MEMS) can be defined as the science and technology of operating at the microscale for biological and biomedical applications, which may or may not include any electronic or mechanical functions. They are made up of micromachined elements usually on silicon substrates, including gears, motors and actuators with linear and rotary motion for applications to biological systems. Implantable bioMEMS have been used as biosensors for in vivo diagnosis of diseases and drug delivery microchips [43-45]. Nanoelectromechanical systems (NEMS) are devices integrating electrical and mechanical functionality on the nanoscale level.

Evidence suggests that orthodontic tooth movement can be enhanced by supplementing the mechanical forces with electricity [46-47]. Animal experiments indicated that when 15—20 micro- amperes of low direct current (dc) was applied to the alveolar bone by modifying the bioelectric potential, osteoblasts and periodontal ligament cells demonstrated increased concentrations of the second messengers cAMP and cGMP. These findings suggest that electric stimulation enhanced cellular enzymatic phosphorylation activities, leading to synthetic and secretory processes associated with accelerated bone remodeling. However, the intraoral source of electricity is a major problem that has to be addressed.

It has been proposed that microfabricated biocatalytic fuel cells (enzyme batteries) can be used to generate electricity to aid orthodontic tooth movement. An enzymatic microbattery when placed on the gingiva near the alveolar bone might be a possible electrical power source for accelerating orthodontic tooth movement. It is proposed that this device uses organic compound (glucose) as the fuel and is noninvasive and non-osseointegrated. The enzyme battery can be fabricated with the combination of two enzyme electrodes and biocatalysts such as glucose oxidase or formate dehydrogenase to generate electricity. However, there are several issues like soft tissue biocompatibility, effect of food with different temperature and pH range on the output of such microfabricated enzyme battery that need to be addressed. The use of microenzyme batteries has issues like enzyme stability, electron transfer rate and enzyme loading which result in shorter lifetime and poor power density. Many nanostructured materials, such as mesoporous media, nanoparticles, nanofibers, and nanotubes, have been demonstrated as efficient hosts of enzyme immobilization. When nanostructure of conductive materials is used, the large surface area of these nanomaterials can increase the enzyme loading and facilitate reaction kinetics, and thus improve the power density of the biofuel cells [48]. It is expected that the MEMS/NEMs based system will be applied over the next few years to develop biocompatible powerful biofuel cells, which can be safely implanted in the alveolus of the maxilla or mandible to enhance orthodontic tooth movement.

7. Temporary anchorage devices

Currently, TADs are manufactured with smooth titanium surfaces because complete osseointegration is a disadvantage that complicates their removal. On the other hand, lack of osseointegration is also one of the factors for the failure of TADs [49-50]. Therefore it is postulated that the balance lies in the fabrication of an ideal surface that could stimulate initial ossointegration and facilitate its removal once the TAD is no longer needed. Biocompatible coatings like Titanium nanotubes should be studied to evaluate if the nanotubular layer can enhance initial osseointegration and can serve as an interfacial layer between the newly formed bone and the TAD.

8. Nano LIPUS devices

Ultrasound (US) is a form of mechanical energy that is transmitted through and into biological tissues as an acoustic pressure wave at frequencies above the limit of human hearing, is used widely in medicine as a therapeutic, operative, and diagnostic tool [51-52]. Low–intensity pulsed US (LIPUS) has been reported to be effective in liberating preformed fibroblast growth factors from a macrophage-like cell line (U937), and it enhances angiogenesis during wound healing [53]. Also, LIPUS has been reported to enhance bone growth into titanium porous–coated implants [54] and bone healing after fracture [55-56] and after mandibular distraction osteogenesis [57]. The specific mechanisms by which US stimulation works on bone cell activities are still unknown.

El-Bialy *et al* [58] applied LIPUS on the temporomandibular joint (TMJ) region of growing rabbits and baboon monkeys for

20 minutes daily. Their results show a significant increase in mandibular cartilaginous growth, especially under chronic mandibular advancement [59]. In another study by Oyonartea *et al* [60] experimental rats were stimulated with LIPUS in the TMJ region unilaterally, for 10 or 20 minutes for 20 days. The results showed that LIPUS application may affect mandibular growth pattern in rats acting at the cartilage and bone level.

Another application of this technique is to reduce root resorption during orthodontic treatment. Based on their observation that LIPUS can promote dental tissue formation in rabbits, el-Bialy *et al* [61] concluded that it may be used to treat root resorption. Similar results were found by Liu *et al* [62]

The initial devices were bulky but with nanotechnology nano LIPUS device can be made with system on a chip design. The wireless design of the ultrasound transducer means the miniscule device will be able to fit comfortably inside a patient's mouth while packed in biocompatible materials. The unit will be easily mounted on a bracket or even a plastic removable crown. An energy sensor can also be used that will ensure the LIPUS power is reaching the target area of the teeth roots within the bone.

9. Smart brackets with nanomechanical sensors

Quantitative knowledge of the three dimensional (3D) force-moment systems applied for orthodontic tooth movement is of utmost importance for the predictability of the course of tooth movement as well as the reduction of traumatic side effects. The concept of a smart bracket with integrated sensor system for 3D force and moment measurement has recently been published. Nanomechanical sensors can be fabricated and be incorporated into the base of orthodontic brackets in order to provide real-time feedback about the applied orthodontic forces. This real-time feedback allows the orthodontist to adjust the applied force to be within a biological range to efficiently move teeth with minimal side effects.

Lapaki *et al* [63-64] reported on the introduction of a 'smart" bracket for multidimensional force and moment control. They reported on a large-scale prototype bracket that utilized microsystem chip encapsulated into small low profile contemporary bracket systems with reduced dimensions to allow clinical testing of this technology.

Conclusion

Although application of nanotechnology in orthodontics is considered to be in its infancy, there is a huge potential in research in this area including nanodesigned orthodontic bonding material, possible nanovector for gene delivery for mandibular growth stimulation, and nano-LIPUS devices. In a fast growing world of nanotechnology, the hope would be to get these technologies into clinical application sooner or later. In conclusion, the future in orthodonic treatment will benefit greatly through nanotechnology should all the current attempts succeed to its clinical application at a reasonable cost to the orthodontist and patients.

References

1. NTaniguchi. On the Basic Concept of Nano Technology, Proc ICPE Tokyo 1974; 21:8-23.
2. Schleyer TL. Nanodentistry. Fact or Fiction? J Am Dent Assoc 2000; 131:1567-1568.
3. Whitesides GM, Love JC. The art of building small. Scientific American 2001; 285:33-41.
4. Kaehler T. Nanotechnology: Basic concepts and definitions. Clin Chem 1994; 40:1797-1799.
5. Park B. Current and Future Applications of Nanotechnology. The Royal Society of Chemistry, Cambridge, UK., 2007.
6. Feynman RP. There's Plenty of Room at the Bottom. Eng. Sci. 1960, 1961; 23:22-36.
7. Drexler KE. Engines of creation, the coming era of nanotechnology. Anchor press, New York, 1980.
8. Drexler KE. Molecular Engineering: An Approach to the Development of General Capabilities for Molecular Manipulation. Proc Natl Acad Sci 1981; 78:5275-5278.
9. Rodgers P. Nanoelectronics. Nature Nanotech, 2006.
10. Freitas RA Jr: Nanomedicine, Basic Capabilities, Georgetown, TX: Landes Bioscience, 1999; I:345-350.
11. Binning G, Quate C, Gerber C. Atomic force microscope. Phys Rev. Lett 1986; 12:930.
12. Kusy RP, Whitley JQ. Effects of surface roughness on the coeficients of friction in model orthodontic systems. J Biomech. 1990; 23(9)913-925.
13. Bourauel C, Fries T, Drescher D, Plietsch R. Surface roughness of orthodontic wires via atomic force microscopy, laser specular reflectance, and profilometry. Eur J Orthod. 1998; 20:79-92.
14. Silikas N, Lennie AR, England KER, Watts DC. AFM as a tool in dental research. Microsc Analysis 2001; 82:19-21.
15. Lee GJ, Park KH, Park YG, Park HK. A quantitative AFM analysis of nano-scale surface roughness in various orthodontic brackets. Micron 2010; 41:775-782.
16. Kakaboura A, Fragouli M, Rahiotis C, Silikas N. Evaluation of surface characteristics of dental composites using profilometry, scanning electron, atomic force microscopy and gloss-meter. J Mater Sci Mater Med 2007; 18:155-163.
17. Antò VD, Rongo R, Ametrano G, Spagnuolo G, Manzo P, Martina R *et al*. Evaluation of surface roughness of orthodontic wires by means of atomic force microscopy. Angle Orthod 2012; 82(5):922-928.
18. Braga PC, Ricci D. Atomic Force Microscopy: Biomedical Methods and Applications. Humana Press. Totowa, NJ, 2004.
19. Redlich M, Katz A, Rapoport L, Wagnerb HD, Feldmanb Y. Improved orthodontic stainless steel wires coated with inorganic fullerene-like nanoparticles of WS2 impregnated in electroless nickel–phosphorous film. Dent Mater 2008; 24:1640-1646.
20. Mitra SB, Dong WU, Holmes BN. An application of nanotechnology in advanced dental materials. J Am Dent Assoc. 2003; 134:1382-90.
21. Moszner N, Salz U. New developments of polymeric dental composites. Program Polymer Science 2001; 26:535-576.
22. Geraldeli S, Perdigao J. Microleakage of a new restorative system in posterior teeth. Journal of Dental Research (special issue A): 126 (Abstract), 2003.
23. Lee YK, Lim BS, Rhee SH, Yang HC, Powers JM. Changes of optical properties of dental nano-filled resin composites after curing and thermocycling. J Biomed Mater Res 2004; 71B:16-21.
24. Quirynen M, Bollen CM. The influence of surface roughness and surface free-energy on supra- and subgingival plaque formation in man. J Clin Periodontol. 1995; 22:1-14.
25. Quirynen M, Marechal M, Busscher HJ, Weerkamp AH, Darius PL, van Steenberghe D. The influence of surface free energy and surface roughness on early plaque formation, an in vivo study in man. J Clin Periodontol.

1990; 17:138-44.
26. Killian CM, Croll TP. Nano-ionomer tooth repair in pediatric denistry, Pediatr. Dent 2010; 32(7):330-535.
27. Kotmaj V. Influence of different conditioning methods on shear bond strength of novel light curing nano-ionomer restorative to enamel and dentin. Lawers Med. Sci 20I0; 25:861-866.
28. Uysal T, Yagci A, Uysal B, Akdogan G. Are the nano‑ composites and nano‑ ionomers suitable for orthodontic bracket bonding? Eur J Orthod. 2010; 32:78-82.
29. Bishara SE, Ajlouni R, Soliman MM, Oonsombat C, Laffoon JF, Warren J. Evaluation of a new nano‑ filled restorative material for bonding orthodontic brackets. World J Orthod 2007; 8:8-12.
30. Wiltshire WA. determination of fluoride from fluoride-releasing elastomeric ligature ties. Am. J Orthod Deniofacial thop. 1996; 110(4):383-387.
31. Wiltshire WA. *In vitro* and *in vivo* fluride release from orthodonic elastoomerc ligature ties. Am. J Orthod Dentofac Orthop. 1999; 115(3):288-292.
32. Miura KK. Aniticariogenic effect of fluoride-releasing elastomers in orthodontic patients. Braz. Oral. Res 2097; 21-(3)228-233.
33. Gunes S, Jana C. Shape memory polymers and their nanocomposites: a review of science and technology of new multifunctional materials. J Nanosci Nanotechnol. 2008; 8(4):1616-1637.
34. Stuart MA, Huck WT, Genzer J, Muller M, Ober C, Stanm M. Emerging applications of stimuli-responsive polymer materials. Nat. Mater. 2010; 9:110-113.
35. Meng Q, Hu J. A review of shape memory polymer composites and blends. Compos A Appl. Sci. ManuI. 2009; 40(11):1661-1672.
36. Leng J, Lan X, Liu Y, Du S. Shape-memory polymers and their composites: stimulus methods and applications. Prog. Mater. Sci. 2011; 56(7):1077-1135.=
37. Allaker RP. The use of nanoparticles to control oral biofilm formation. J Dent Res 2010; 89:1175-86.
38. Hill WR, Pillsobury DM. The pharmacology of silver. Baltimore: The Williams & Wilkins Co, 1939.
39. Hannig M, Kriener L, Hoth-Hannig W, Becker-Willinger C, Schmidt H. Influence of nanocomposite surface coating on biofilm formation in situ. J Nanosci Nanotechnol. 2007; 7:4642-8.
40. Monteiro DR, Gorup LF, Takamiya AS, Ruvollo-Filho AC, De Camargo ER, Barbosa DB. The growing importance of materials that prevent microbial adhesion: antimicrobial effect of medical devices containing silver. Int J Antimicrob Agents. 2009; 34:103-10.
41. Yamamoto K, Ohashi S, Aono M, Kokubo T, Yamada I, Yamauchi J. Antibacterial activity of silver ions implanted in SiO2 filler on oral streptococci. Dent Mater 1996; 12:227-9.
42. Ahn SJ, Lee SJ, Kook JK, Lim BS. Experimental antimicrobial orthodontic adhesives using nanofillers and silver nanoparticles. Dent Mater 2009; 25(2):206-13.
43. NuxoII EE, Siegel RA. Bio MEMS devices for delivery. IEEE Eng. Med. Biol. Mag 2009; 28(1):31-39.
44. Xu B. Bio MEMS enabled drug delivery, Nanomedicine 2005; 1(2):176-177.
45. Gourley PL. Brief overview of BioMicroNano technologies. Biotechnol. Prog. 2005; 21(1):2-10.
46. Davidovitch Z, Finkelson MD, Steigman S, Shanfrid JL, Montgomery PC, Korostoff E *et al.* Electric currents, bone remodeling and orthodontic tooth movement. II. lncrease in rate of tooth movement and periodontal cyclic nucleotide level by combined force and electric current. Am J Orthod. 1980; 77:33-47.
47. Davidovitch Z, Finkelson MD, Steigman S, Shanfrid JL, Montgomery PC, Korostoff E *et al.* Electric currents, bone remodeling, and orthodoniic tooth movement I. The effect ot electric currents on periodontal cyclic nucleotides. Am J Orthod. I980; 77:14-32.
48. Kolahi J, Abrishami M, Davidovitch Z. Microfabricated biocatalytic fuel cells: A new approach to accelerating the orthodontic tooth movement. Med Hypotheses 2009; 73:340-341.
49. Miyawaki S, Koyama I, Inoue M, Mishim K, Sugahara T, Takano-Yamamoto T *et al.* Factors associated with the stability of titanium screws placed in the posterior region for orthodontic anchorage. Am J Orthod. Dentofacial Orthop. 2003; 124(4):373-378.
50. Kuroda S, Sugawara Y, Deguchi T, Kyung HM, Takano-Yamamoto T. Clinical use of minis- crew implants as orthodontic anchorage: success ratcs and postoperative discomfort. Am J Orthod. Dentofac Orthop. 2007; 131(1):9-15.
51. Maylia E, Nokes LD. The use of ultrasonics in orthopaedics-a review. Technol Health Care 1999; 7:1-28.
52. Ziskin MC. Applications of ultrasound in medicine—comparison with other modalities. In: Rapacholi MH, Grandolfo M, Rindi A, eds. Ultrasound: Medical Applications, Biological Effects, and Hazard Potential. New York, NY: Plenum Press; 1987, 49-59.
53. Young SR, Dyson M. The effect of therapeutic ultrasound on angiogenesis. Ultrasound Med Biol. 1990; 16:261-269.
54. Tanzer ME, Harvey A, Kay P, Morton, Bobyn JD. Effect of noninvasive low intensity ultrasound on bone growth into porouscoated implants. J Bone Joint Surg. 1996; 14:901-906.
55. Abramovich A. Effect of ultrasound on the tibia of the young rat. J Dent Res. 1970; 49:1182.
56. Heckman JD, JB Ryaby J, McCabe JJ, Frey Kilcoyne RF. Acceleration of tibial fracture-healing by non-invasive, low-intensity pulsed ultrasound. J Bone Joint Surg. 1994; 76:26-34.
57. El-Bialy TH, Royston TJ, Magin RL, Evans CA, Zaki AM, Frizzell LA. The effect of pulsed ultrasound on mandibular distraction. Ann Biomed Eng. 2002; 30(10):1251-1261.
58. El-Bialy T, El-Shamy I, Graber TM. Growth modification of the rabbit mandible using therapeutic ultrasound: is it possible to enhance functional appliance results? Angle Orthod. 2003; 73:631-639.
59. El-Bialy T, Hassan A, Albaghdadi T, Fouad HA, Maimani AR. Growth modification of the mandible with ultrasound in baboons: a preliminary report. Am J Orthod Dentofacial Orthop. 2006; 130:435.e7-14.
60. Oyonarte R, MZa´rate, odriguez FR. Low-intensity pulsed ultrasound stimulation of condylar growth in rats. Angle Orthod 2009; 79(5):964-970.
61. El-Bialy TH, El-Moneim Zaki A, Evans CA. Effect of ultrasound on rabbit mandibular incisor formation and eruption after mandibular osteodistraction. Am J Orthod Dentofacial Orthop. 2003; 124:427-434.
62. Liu Z, Xu J, Eb L, Wang D. Ultrasound enhances the healing of orthodontically induced root resorption in rats. Angle Orthod: 2012; 82(1):48-55.
63. Lapatki BG, Paul O. Smart backets for 3D-force-moment

measurement in orthodontic research and therapy-developmental status and prospects. J Orofac Orthop. 2007; 68(5)377-396.

64. 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.