Review Article

JRAD Journal of Research and Advancement in Dentistry

J Res Adv Dent 2016;6:1:23-31.

Amplifying Orthodontic Treatment with the Use of Lasers: A Review of Literature

Suresh Kangane[1*] Amit Prakash[2] Pravin Kumar Marure[3]

[1]Professor and Head, Department of Orthodontics, MIDSR Dental College and Hospital, Latur, Maharashtra, India.
[2]Associate Professor, Department of Orthodontics, Peoples College of Dental Science, Bhopal, India.
[3]Associate Professor, Department of Orthodontics, MIDSR Dental College and Hospital, Latur, Maharashtra, India.

ABSTRACT

Background: For many years research in LASER (Light Amplification by Stimulated Emission of Radiation) supported therapies in dental sciences is progressing steadily. There is no field of dentistry where development took place at such a tearing pace in recent years as in the field of laser dentistry. In the beginning it was only in some branches of this scientific field where significant therapeutic advantages compared to conventional forms of treatment could be reached, but by now this development already includes all branches of dentistry and integrates them into the spectrum of laser supported dental treatment. LASER technology represents an important help which may be used before, during and after, all the steps of orthodontic treatment such as etching, bonding pain control, accelerating tooth movement, debonding of ceramic brackets, welding, soft tissue surgery etc. When considering the use of lasers in clinical dentistry, the practitioner must use clinical experience, receive proper training, and have familiarity with the operating characteristics of each device. Because of the variable composition of human tissue and the differing ways in which laser energies are absorbed, no single laser is appropriate for all dental applications.

Keywords: LASER Technology, Etching, Bonding, Pain control, Accelerating tooth movement, Debonding.

INTRODUCTION

The word laser is an acronym for Light Amplification by Stimulated Emission of Radiation. Light is a form of energy that travels in a wave and exists as a particle, this particle is called a photon. The laser is in fact energy transformer. Different kinds of energy, such as light, kinetic of electrical energy, are transformed into a new kind of optical energy with special properties. This new kind of optical energy is completely artificial and cannot be found anywhere in nature. Based on this consideration, it can be stated that a laser transforms energy of "low quality" into a kind of energy which has "high quality" .Special materials with well-defined properties must be used to transform the energy during the simultaneous generation of light. These materials can be gases, Liquids, Semiconductor materials, glasses or artificial gemstones (crystals), and moving charged particles. Therefore, the systems will be classified as gas, dye, semiconductor, solid-state and free-electron laser.[1]

II. HISTORY

The laser was demonstrated for the first time in 1960 by Maiman after the pioneering theoretical work of Basov, Prokhorov and Townes.[2] Many other kinds of laser were invented soon after the solid ruby laser – the first uranium laser by IBM Laboratories (in November 1960), the first helium-neon laser by Bell Laboratories in 1961 (Javan et al)and the first semiconductor laser by Robert Hall at General Electric Laboratories in 1962; the first working neodymium-doped yttrium aluminium

Received: Oct. 8, 2016: **Accepted:** Dec. 2, 2016

*Correspondence Dr. Suresh Kangane.
Department of Orthodontics, MIDSR Dental College and Hospital, Latur, Maharashtra, India.
Email: drsureshkangane@rediffmail.com

garnet (Nd:YAG) laser and CO2 laser by Bell Laboratories in 1964, argon ion laser in 1964,chemical laser in 1965 and metal vapour laser in 1966. In each case, the 'name' of the laser was annotated with regard to the active medium (source of laser photons) used.[3]

Maiman, had exposed an extracted tooth to his ruby laser in 1960, the possibilities for laser use in dentistry did not occur until 1989, with the production of the American Dental Laser for commercial use.[4] This laser, using an active medium of Nd:YAG,emitted pulsed light and was developed and marketed by Terry Myers, an American dentist. Though low-powered and due to its emission wavelength, inappropriate for use ondental hard tissue, the availability of a dedicated laser for oral use gained popularity amongst dentists. This laser was first sold in the UK in 1990.In 1989, experimental work by Keller and Hibst, using a pulsed Erbium YAG (2,940 nm) laser, demonstrated its effectiveness in cutting enamel, dentine and bone. This laser became commercially available in the UK in 1995 and, shortly followed by a similar Er,Cr:YSGG (erbium chromium: yttrium scandium gallium garnet) laser in 1997, amounted to a laser armamentarium that would address the surgical needs of clinical dentistry in general practice.[5]

III. THE COMPONENT PARTS OF A TYPICAL LASER ARE[6]

A). Active medium: A material, either naturally occurring or man-made that when stimulated, emits laser light. This material may be a solid, liquid or gas. The first 'dental' laser used a crystal of neodymium doped yttrium Aluminium garnet (Nd:YAG) as its active medium.

B). Pumping mechanism: This represents a man-made source of primary energy that excites the active medium. This is usually a light source, either a flashlight or arc-light, but can be a diode laser unit or an electromagnetic coil.

C). Optical resonator: Laser light produced by the stimulated active medium is bounced back and forth through the axis of the laser cavity, using two mirrors placed at either end, thus amplifying the power. The distal mirror is totally reflective and the proximal mirror is partly transmissive, so that at a given energy density, laser light will escape to be transmitted to the target tissue.

IV. PROPERTIES OF LASER LIGHT

The laser light is distinguished from ordinary light by the following 2 properties: (1) Laser light is generated as only 1 colour, a property called monochromaticism. This colour can be either visible or invisible to the human eye, but is described as the measurement of the wavelength, which, for dental lasers, is expressed in nanometres (one billionth of a meter). (2) The waves of laser light are coherent for all lasers. Each wave is identical in physical size and shape. This monochromatic, coherent wave of light energy emerges from the laser device as a precise, collimated beam. These properties make the laser beam a uniquely efficient source of energy. Laser sources can emit light continuously or in pulsed fashion.[7]

V. LASER TYPES IN DENTISTRY

A wide variety of laser systems have been established in dentistry:

a). The helium – neon laser: The Helium- neon laser was not only the first gas laser, but also the first continuous-wave laser in the history of laser development.[3,8]

b). The argon ion laser: Ionized gases and vapours represent only a small segment of the range of media suitable for use in lasers. The idea of using ionized noble gases as laser media was realized technically by Gordon et al. Especially in dentistry, the Argon ion laser is used.[9]

c). The carbon dioxide laser: The Carbon dioxide laser is the most powerful gas laser. Its technical realization was achieved by Patel in 1964.[10]

d). The semiconductor laser: Laser activity in semiconductor crystal was first observed in 1962 by Hall et al and Holonyak et al. So-called semiconductor or diode lasers emit coherent radiation in the ultraviolet (UV), visible(VIS) and infrared (IR) spectral ranges. The first semiconductor lasers were pulsed and operated at low temperatures. They primarily include gallium – arsenide (GaAS) compounds.[11-14]

e). The neodymium: YAG laser: The Neodymium: YAG laser was developed in 1964 by Geusicand is the classical and most widely used solid- state laser. Emitting its strongest fundamental wave length at 1,064 nm, the Neodymium: YAG laser is characterized by a relatively simple set – up and the generation of high output powers, both in pulsed mode at high repetition rates (up to 10 kHz) and in continuous wave mode.[15,16]

f). The erbium family lasers: Since 1988 Erbium lasers are the mainly used laser systems in dentistry for cavity preparation. Two Erbium laser systems are preferred dentistry: first, the Erbium: YAG laser and second, the Erbium, chromium: YSGG laser.[17]

VI. LIGHT – TISSUE INTERACTION

When electromagnetic radiation hits biological tissue, different interactions occur as a function of various physical parameters. The processes occurring during the propagation of light in so- called turbid media can be divided into three cases: Reflections, Absorption and

Scattering. Laser-tissue interactions depend on the interplay of irradiation parameters: 1) wavelength or wavelength band of that particular laser source; 2) physical properties of the tissue irradiated with that particular wavelength or wavelength band; 3) irradiance or pulse energy; 4) continuous wave (CW) or pulsed irradiation; 5) laser beam size on the tissue; 6) irradiation duration or laser pulse length and repetition rate.[18]

VII. DIAGNOSTIC USES OF LASERS IN ORTHODONTICS

a). Three-dimensional laser scanning and reconstruction (holography): Three-dimensional (3D) laser scanners are increasingly being used in orthodontics to establish databases for normative populations and cross sectional growth changes and also to assess clinical outcomes in orthognathic surgical and nonsurgical treatments.[19-21]

b). Facial soft tissue analysis: The recent emphases on soft tissues as the limiting factor in treatment and on soft-tissue relationships in establishing the goals of treatment has made 3D analysis of soft tissues more important in diagnosis and treatment planning. It is equally important to be able to detect changes in the facial soft tissues produced by growth or treatment.[22]

c). Laser Doppler flowmetry: Pulpal responses to orthodontic forces or the orthopedic forces created by rapid maxillary expansion have previously been investigated by Laser Doppler flowmetry (LDF). LDF is also a reliable method for blood flow measurements after orthognathic surgery. Among patients who undergo a segmental maxillary osteotomy or Le fort I osteotomy, significant reduction in pulpal sensibility has been noted in teeth in the osteotomized segment or maxilla.[23]

d). Laser florescence (LF) for caries detection around brackets: The early detection and quantification of initial caries formed around orthodontic brackets is a possibility aiming to minimize the damage of caries lesions in orthodontic patients.[24] The LF device may be useful for assessing the severity, progression, and depth of white spot lesions during orthodontictreatment.[25]

VIII). HIGH INTENSITY LASER THERAPY IN ORTHODONTICS

a). Laser curing of light-cured materials (Argon laser):

Argon laser is promising for the polymerization of dental restorative materials because one of the argon laser's emission peaks (488 nm) matches well with the absorption peak of the photoinitiator, camphorquinone (CQ) in light-curing dental restorative materials. It was claimed that the argon laser can polymerize a light-cured orthodontic adhesive 4 times faster with the same or even higher bond strength and with less frequency of enamel fracture at debonding than with the conventional curing light.[26,27]

b). Enamel conditioning for bracket bonding with laser:

Proper conditioning of enamel surface is necessary for bonding of orthodontic attachments to teeth. Laser etching has become an alternative to acid etching of enamel. Laser etching is painless and does not involve either vibration or heat; also, the easy handling of the apparatus makes this treatment highly attractive for routine clinical use. Laser etching of enamel creates microcracks that are ideal for resin penetration. However, water spraying and air drying are not needed with laser etching, time can be saved, from a clinical standpoint, saving chair time also improves adhesion because it reduces the risk of salivary contamination. Different types of laser such as CO2, Er:YAG, Nd:YAG, and Er,Cr:YSGG have been used in orthodontics for enamel conditioning to bond brackets. Kim et al. and Lee et al, tested the effectiveness of Er:YAG laser in etching the enamel surface for orthodontic treatment and concluded that Er:YAG laser ablation can be an alternative tool to conventional acid etching.[28,29]

c). Bonding to porcelain crown:

Sometimes orthodontic attachments should be bonded to porcelain surfaces, a phenomenon which is most commonly seen in adult patients. Conventional acid etching is unable to produce sufficient bond strength of orthodontic brackets to porcelain surfaces. It has been demonstrated that the application of 9.6% hydrofluoric acid (HF) for 2 minutes provides suitable surface alterations for orthodontic bonding. However, the use of hydrofluoric acid can damage the surrounding teeth and soft tissues, if careful isolation of the operating area is not performed.[30]Li et al, prepared porcelain with 0.6, 0.9, and 1.2-W Nd:YAG lasers for bonding and concluded that this type of laser in combination with light cure composites created acceptable bond strength to porcelain. It appears that using an Nd:YAG laser not only eliminates the need to rough up the porcelain, it would also eliminate the potential gingival burns associated with HF acid and the need to repolish the porcelain at deband.[31]

d). Increasing the acid resistance of enamel to prevent formation of white spot lesions:

One of the most important problems during orthodontic treatment is the occurrence of enamel demineralization around orthodontic appliances. Fixed orthodontic appliances facilitate the adherence of food particles and make tooth brushing more difficult, resulting in increased amount of bacterial plaque around orthodontic attachments. The incidence of white spot lesions is significantly higher in orthodontic patients. In 1965 Sognnaes and Stern were the first to report that when the enamel was exposed to ruby laser irradiation, the resistance of enamel to acid attack was improved. There are several theories regarding the mechanisms by which laser irradiation enhances enamel resistance. These theories range from a surface melting through partial fusion and recrystalization of enamel prisms to changes in the enamel's organic matrix.[8]In 2001, Hossain et al. used an Er,Cr:YSGG laser to irradiate the enamel or dentin samples at 6 W (67.9 J/ cm2) or 5 W (56.6 J/cm2) pulse energy, respectively, with or without water mist. The results suggested that Er,Cr:YSGG laser irradiation appears to be effective for increasing acid resistance. In 2005 Qiao et al. irradiated the enamel and dentin samples with the Er,Cr:YSGG laser at 6 or 4 W for 6 seconds, respectively. They concluded that Er,Cr:YSGG laser irradiation is effective for increasing the acid resistance of dental hard tissue and does not cause thermal side effects.[32]

e). Ceramic bracket debonding:

Ceramic brackets were introduced in the mid 1980s to supply the demands of orthodontic patients for more aesthetic and invisible appliances. However, the low fracture toughness of ceramics may cause partial or complete bracket fracture during removal. This precludes reuse of the same bracket at a corrected position and may result in eye damage, ingestion or aspiration of bracket fragments.[33,34] Since the early 1990s, lasers have been used experimentally for debonding of ceramic brackets. The use of lasers eliminates problems such as enamel tear outs, bracket failures, and pain that are encountered during conventional ceramic bracket removal techniques. Additionally, lasers have the advantage of decreasing debonding force and operation time. In most previous studies, carbon dioxide lasers whose wavelength is more easily absorbed by the ceramic brackets had been preferred for debonding. Strobl et al. (1992) investigated the removal of polycrystalline and monocrystalline alumina brackets using carbon dioxide and YAG lasers. Their results showed that laser-aided debonding significantly reduced debonding force by thermal softening of the resin.[34]

f). Laser welding:

Today, most orthodontic appliances are fabricated by joining of different individual components together. However, in-office fusion of wires or other attachments to orthodontic appliances is still a common procedure for construction or repair of appliances during orthodontic treatment to achieve optimal treatment results. In orthodontics, as in other parts of dentistry, fusion can be achieved through soldering, brazing or welding. Laser welding method is also employed for joining metal frameworks. To weld dental alloys, Nd:YAG laser is mainly used.[35]Titanium alloys are commonly used in dentistry for crowns, bridges, partial denture frameworks, and also for orthodontic wires. These cannot be easily soldered by traditional torch-soldering or oven-soldering procedures. Laser welding is recently used in bracket manufacturing as an alternative to brazing. This technique eliminates the need to brazing alloy, reduces the risk of corrosion, and provides acceptable mechanical performance in association with a low risk of joint failure.[36]

Testing the cell reactions of osteoblasts, fibroblasts, and keratinocytes, found a good tolerance of electrical resistance and laser welding, while traditional silver solder was toxic for osteoblast differentiation, fibroblast viability, and keratinocyte growth.[37]

g). Laser minor surgery:

Laser surgery offers numerous advantages compared with traditional scalpel surgery. Softtissue excision is more precise with a laser than a scalpel. A laser coagulates blood vessels, seals lymphatic, and sterilizes the wound during ablation, maintaining a clear and clean surgical field. The use of soft-tissue lasers result in a shorter operative time and faster postoperative recuperation.[38]

Various applications of laser surgery in orthodontics are:

1). Gingival enlargements, gingival hyperplasia and reshaping gingival shape and contours:

Sometimes removal of excessive gingival tissues is necessary to provide optimal display of teeth. Gingivectomy may provide sufficient tooth display and appropriate tooth proportions. Recontouring gingival shape and contour can be readily accomplished in the orthodontist's office with a diode laser. Laser gingivectomy has advantages such as minimal bleeding and postoperative pain and no swelling. Correction of gingival hyperplasia can also be performed easily with the aid of laser light.[39]

2). Fibrotomy:

Fibrotomy (Pericision) is frequently indicated to provide long term stability of teeth with severe rotations before treatment. A gallium-aluminum-arsenide (Ga-Al-As) diode laser with an 808-nm wavelength and 0.4-mm fiber diameter was used. The laser circumferential supracrestal fiberotomy is an effective procedure to decrease relapse after tooth rotation, causing no apparent damage to the supporting periodontal structures.[40]

3). Frenectomy:

Frenectomy is usually indicated to prevent relapse after correction of midline diastema. When frenectomy is indicated, it is recommended to close the space between central incisors with orthodontic treatment prior to frenectomy. Otherwise, the formation of scar tissue prevents orthodontic space closure. Olivi et al. clinically evaluated the efficacy of Er,Cr:YSGG laser at a power setting of 1.5 W or less in 156 frenectomies. The reported very high patient acceptance and no postoperative adverse events.[41]Recently diode laser frenectomy without infiltrated anaesthesia was suggested by Kafas et al. They concluded that this procedure have optimum healing post-surgically.[42]

IX. LOW INTENSITY LASER THERAPY IN ORTHODONTICS

Low level laser therapy (LLLT) is also known as "soft laser therapy" and bio-stimulation. Low level laser therapy has been found to accelerate wound healing and reduce pain, possibly by stimulating oxidative phosphorylation in mitochondria and modulating inflammatory responses.[43]

a). Pain reduction:

Pain or discomfort is a common experience during fixed orthodontic treatment. To relieve pain, most orthodontists recommend their patients to use nonsteroidal anti-inflammatorydrugs (NSAIDs), to inhibit the formation of pain producing agents such as prostaglandins and thus reduce the pain. However, most drugs used for pain control can have negative effects on tooth movement if used chronically, due to their inhibitory effects on prostaglandins.

Considering the side effects of analgesics, researchers have looked for other new, but safer approaches, such as LLLT to reduce pain from orthodontic procedures.[44] Although only a few studies have dealt with the response of orthodontic patients to LLLT, all concluded that LLLT reduces pain during orthodontic treatment. Overall, based on the efficacy of LLLT to control pain in orthodontic treatment, LLLT could be recommended for pain control during fixed orthodontic appliance therapy.[45]

b). Accelerating tooth movement:

Cruz et al, demonstrated clinically that LLLT accelerates the orthodontic tooth movement in humans. They conducted an experiment on 11 young patients who required tooth movement for extraction space closure. They were irradiated with LLLT of 780 nm wavelength (for 10 s at 20 mW; 5 J/cm2) on one side of the maxilla for 4 days in a month and were not irradiated on the opposite side, which acted as the control. The results showed that the experimental side demonstrated significantly more rapid progression of space closure than the control side.[46]

Fujita et al, and Yamaguchi et al, reported that LLLT stimulated the velocity of tooth movement via RANK and c-Fms gene expressions in vitro. This was confirmed that LLLT accelerates the process of bone remodeling by stimulating MMP-9, cathepsin K, and integrin subunits of a(v)b3 expression during orthodontic tooth movement in rats.[47,48]

c). Distraction osteogenesis:

Distraction osteogenesis is a method to induce new bone formation and investing soft tissue under the influence of tensional stress at osteotomized sites of a healing bone. This method was used successfully by Alizarow in the 1950s to lengthen the bony segments of the limbs, and now is widely used in dentistry for correcting deficient growth of the maxilla and mandible in patients with congenital problems such as cleft lip/palate and hemifacial microsomia.

Miloro et al, evaluated the effect of LLLT during mandibular distraction osteogenesis and concluded that LLL accelerates the process of bone regeneration during the consolidation phase after distraction osteogenesis.[49] The results of a study by Hübler et al, showed that LLLT had a positive effect on the percentage of newly formed bone, on the chemical composition according to the Ca-to-P ratios, and on the crystallinity and crystalline structure at the distraction osteogenesissites.[50]

d). Maxillary expansion:

Maxillary expansion may be required in patients who have deficient maxillary width. This treatment also helps to remove crowding and align the teeth. Saito and Shimizu, studied the effects of LLLT on the expansion of mid-palatal sutures in rats, comparing the bone regeneration obtained with and without laser treatment.[51]Their results showed that the therapeutic effects of laser are dependent on the total dosage, the frequency, and the duration of the treatment. Studies have showed that LLLT had a significant effect on the increase of mandibular length in rats and might be helpful in the correction of class II malocclusions. However, further studies are required to confirm these results.[52]

e). Retention & relapse:

Teeth that have moved by orthodontic forces tend to return to their original positions, a phenomenon referred to as relapse. Generally, occlusion instability occurs because of the following reasons: changes related to growth, Inherent instability of the occlusion due to soft tissue pressure and the changes related to fibrous system of PDL and gingival. Kim et al, investigated the effectiveness of LLLT on orthodontically rotated teeth in beagles. A Ga-Al-As diode laser was used. The biostimulation mode (pulsed wave, 10 Hz, 763 mW, 4.63–6.47 J/cm2) was used for irradiation, with the fiber tip held 2–3 mm away from the gingiva. They concluded that LLLT of orthodontically rotated teeth without retainers increased the rotational relapse of the teeth compared with the control group.[40]

CONCLUSION

When considering the use of lasers in clinical dentistry, the practitioner must use clinical experience, receive proper training, and have familiarity with the operating characteristics of each device. Because of the variable composition of human tissue and the differing ways in which laser energies are absorbed, no single laser is appropriate for all dental applications.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

REFERENCES

1. Meister, J.. Basic Research, In: Proceedings of the 1st International Workshop of EvidenceBased Dentistry on Lasers in Dentistry, Gutknecht N,Quintessence publisher, Berlin 2007,pp 3-27.
2. Schawlow, AL., Townes, CH.Infrared and Optical Masers .Phys, Rev 1958;112.
3. Javan, A., Bennett Jr., W.R.,& Herriott, D.R. Population inversion and continuousoptical maser oscillation in a gas discharge containing a He-Ne mixture. Phys Rev Let 1961;6(3). 106-110.
4. Maiman, TH. Stimulated optical radiation in ruby masers. Nature 1960; 187: 493–494.
5. Hibst R.,& Keller, U. Experimental studies of the application of the Er YAG laser ondental hard substances: 1. Measurement of ablation rate. Lasers Surg Med 1989; 9: 338–344.
6. Parker, S.Verifiable CPD paper: introduction, history of lasers and laser light production, Br Dent J 2007;202, 21 – 31.
7. Meserendino, LJ., Pick ,RM. Lasers in Dentistry, Chicago, Ill: Quintessence 1995.
8. Wigdor, HA., Walsh, JT., Featherstone, JDB., Visuri, SR., Fried, D., & Waldvogel JL. Lasers in dentistry. Laser Surg Med 1995;16:103-33.
9. Gordon, E. I., Labuda, E.F., & Bridges, W.B. Continuous visible laser action in singly ionized argon, Krypton and exenon. Appl Opt Lett 1964;4(10) , 178.
10. Patel, C.K. N. Interpretation of CO2 optical maser experiments. Phys Rev Lett 1964;12(21), 588-590.
11. Hall, R. N., Fenner, G.E., Kingsley, J.D., Soltys, T.J.,& Carlson, R. O. Coherent light emission from GaAs junctions. Phys Rev Lett 1962;9(9). 366.
12. HolonyakJr., N.,& Bevacqua. S. F. Coherent (visible) light emission form Ga (As1-x Px) junctions. Appl Phys Lett 1962;1(4), 82-83.
13. Aoki, A., Sasaki, K. M., Watanabe, H., Ishikawa, I. Laser in nonsurgical periodontal therapy. Periodontal 2000 2004;36, 59-97.
14. Kimura, Y., Wilder-Smith, P., & Matsumoto, K. Lasers in endodontics: A review. Int Endod J 2000;33:173-85.
15. Geusic, J. E., Marcos, H.M., & Van Uitert, L. G. Laser Dscillations in Nd- doped yttrium alum aluminium, yttrium gallium and gadolinium garnets. Appl Phys Lett 1964;4 (101), 182-184.
16. Geusic, J.E. The continuous Nd: YAGlaser . IEEE J Quant Electron 1966;2(4), 105.
17. Paghdiwala, A. F. Application of the erbim: YAG laser on hard dental tissues: measurement of the termperature changes and depth of cut. In: Laser research in medicine, surgery and dentistry 1988;88:64:192-201.
18. Cilesiz ,I. Laser-Tissue Interaction. Marcel Dekker, Inc., New York, NY, USA 2000.
19. Yamada, T., Mori, Y., Katsuhiro, M., Katsuaki, M., &Tsukamoto Y.Three-dimensional analysis of facial morphology in normal Japanese children as control data for cleft surgery, Cleft Palate .Craniofac J 2002;39: 517–526.
20. Nute SJ, Moss JP. Three-dimensional facial facial growth studied by optical surface scanning.JOrthod 2000;27: 31–38.
21. Moss JP, S.F. Ismail and R.J. Hennessy. Three-dimensional assessment of treatment outcomes on the face, Orthod Craniofac 2003;126–131.
22. Kau, CH., Knox, J., Zhurov, AI.,& Richmond, S. Validity and reliability of a portable 3D optical

scanning device for field studies. In: Proceedings of the 7th EuropeanCraniofacial Congress. Bologna: Monduzzi Editore-International Proceedings Division 2004.

23. Emshoff, R., Kranewitter R., Brunold S, Laimer K, & Norer, B. Characteristics of pulpal blood flow levels associated with non-segmented and segmented Le Fort I osteotomy. Oral Surg Oral Med Oral Pathol Oral RadiolEndod, 2008;105: 379–384.

24. Staudt ,CB., Lussi, A., Jacquet, J., & Kiliaridis, S.White spot lesions around brackets: in vitro detection by laser fluorescence. Eur J Oral Sci 2004;112:237–243.

25. Benham, AW., Campbell, PM., Buschang, PH. Effectiveness of pit and fissure sealants in reducing white spot lesions during orthodontic treatment. A pilot study. Angle Orthod2009; 79(2):338-45.

26. Talbot, TQ.,Blankenau RJ, Zobitz, ME., Weaver, AL., Lohse, CM., & Rebellato J. Effect of argon laser irradiation on shear bond strength of orthodontic brackets: an in vitro study. Am J Orthod Dentofacial Orthop 2000;118:274-9.

27. Lalani N, Foley TF, Voth R, Banting D, Mamandras A. Polymerization with the argon laser: curing time and shear bond strength. Angle Orthod 2000;70:28-33.

28. Klein, AL., Rodrigues LK, Eduardo CP, Nobre dos Santos M,&Cury, JA.Caries inhibition around composite restorations by pulsed carbon dioxide laser application. Eur J Oral Sci 2005; 113: 239-44.

29. Lee BS, Hsieh TT, Lee YL, Lan WH, Hsu YJ, Wen PH, Lin CP. Bond strength of orthodontic bracket after acid-etched, Er:YAG laser-irradiated and combined treatment on enamel surface. Angle Orthod 2005;73:565–570.

30. Zachrisson, BU., Buyukyilmaz, T. Bonding in orthodontics. In: Graber TM, Vanarsdall RL, Vig KWL. Orthodontics: Current principles & techniques, 4th ed. St. Louis: Mosby 2005;596-600.

31. Li R, Ren Y, Han J. Effects of pulsed Nd:YAG laser irradiation on shear bond strength of composite resin bonded to porcelain. Hua Xi Kou Qiang Yi XueZaZhi2000;18:377– 379.

32. Hossain M, Kimura Y, Nakamura Y, Yamada Y, Kinoshita JI, & Matsumoto K. A study on acquired acid resistance of enamel and dentin irradiated by Er,Cr:YSGG laser. J Clin Laser Med Surg 2001;19:159-63.

33. Chen ,HY., Su MZ., Chang HF, Chen YJ, Lan WH, Lin CP. Effects of different debonding techniques on the debonding forces and failure modes of ceramic brackets in simulated clinical set-ups. Am J Orthod Dentofacial Orthop 2007;132(5): 680-686.

34. Strobl, K., Bahns, TL.,Willham, L., Bishara SE, Stwalley WC. Laser-aided debonding of orthodontic ceramic brackets. Am J Orthod Dentofacial Orthop 1992;101:152–158.

35. Watanabe I , Baba N , Chang J , Chiu Y.Nd:YAG laser penetration into cast titanium and gold alloy with different surface preparations . Journal of Oral Rehabilitation 2006;33 : 443 – 446.

36. Eliades, T. Orthodontic materials research and applications: part 2. Current status and projected future developments in materials and biocompatibility. Am J Orthod Dentofacial Orthop 2007;131(2): 253-262.

37. Sestini, S., Notarantonio, L., Cerboni B, Alessandrini C, Fimiani M, Nannelli P, Pelagalli A, & Giorgetti, R. In vitro toxicity evaluation of silver soldering, electrical resistance, and laser welding of orthodontic wires. Eur J Orthod 2006;Dec;28(6):567-72.

38. Sarver, DM.,&Yanosky M. Principles of cosmetic dentistry in orthodontics: part 2. Soft tissue laser technology and cosmetic gingival contouring. Am J Orthod Dentofacial Orthop 2005;127:85–90.

39. Lioubavina-Hack N. Lasers in dentistry. The use of lasers in periodontology. Ned TijdschrTandheelkd2002;109:286–292.

40. Kim SJ, Paek JH, Park KH, Kang SG, Park YG. Laser-aided circumferential supracrestal fiberotomy and low-level laser therapy effects on relapse of rotated teeth in beagles. Angle Orthod 2010;80(2):385-90.

41. Olivi G, Chaumanet G, Genovese MD, Beneduce C, Andreana S. Er,Cr:YSGG laser labial frenectomy: a clinical retrospective evaluation of 156 consecutive cases. Gen Dent 2010;58(3):e126-33.

42. Kafas, P., Stavrianos, C., Jerjes, W., Upile, T., Vourvachis, M., Theodoridis, M.& Stavrianou, I. Upper-lip laser frenectomy without infiltrated anaesthesia in a paediatric patient: a case report. Cases J 2009;20;2:7138.

43. Walsh LJ, Goharkhay K, Verheyen P, Moritz A.Low Level Laser Therapy, In: Oral Laser Application, Mortiz A, ,Quintessenz Publisher,Berlin,Germany 2006, PP,521-539.

44. Xiaoting, L., Yin, T., &Yangxi, C. Interventions for pain during fixed orthodontic appliance therapy. Angle Orthodontist 2010;80: 925-32.

45. Youssef, M., Ashkar,S., Hamade, E., Gutknecht, N., Lampert, F.,& Mir, M. The effect of low-level laser therapy during orthodontic movement: a preliminary study. Lasers Med Sci 2008; 23(1):27–33.

46. Cruz, DR., Kohara, EK.,Ribeiro, MS., &Wetter NU. Effects of low-intensity laser therapy on the orthodontic movement velocity of human teeth: a preliminary study. Lasers SurgMed 2004;35: 117–120.

47. Fujita, S., Yamaguchi, M., Utsunomiya T, Yamamoto, H.,& Kasai, K. Low-energy laser stimulates tooth movement velocity via expression of RANK and RANKL. Orthod Craniofac Res 2008;11:143–155.

48. Yamaguchi, M. Low-energy laser irradiation stimulates the tooth movement velocity via expression of M-CSF and c-fms. Orthodontic Waves 2007; 66: 139–148

49. Miloro M, Miller JJ, Stoner JA. Low-level laser effect on mandibular distraction osteogenesis.J Oral MaxillofacSurg 2007;65(2):168-76.

50. Hübler, R., Blando, E., Gaião, L., Kreisner, PE, Post, LK., Xavier, CB.,& de Oliveira MG. Effects of low-level laser therapy on bone formed after distraction osteogenesis. Lasers Med Sci 2010;25(2):213-9.

51. Saito, S., &Shimizu,N. Stimulatory effects of low-power laser irradiation on bone regeneration in midpalatal suture during expansion in the rat. Am J OrthodDentofacial Orthop 1997;111(5):525–532.

52. Seifi, M., Shafeei, HA.,Daneshdoost, S. Effects of two types of low-level laser wave lengths (850 and 630 nm) on the orthodontic tooth movements in rabbits. Lasers Med Sci 2007;22:261–264.