Review / Derleme

Dental Lasers and Application Fields in Endodontics

Endodontide Dental Lazerler ve Uygulama Alanları

Emrah Çetin, Hicran Dönmez Özkan, Senem Gökçen Yiğit Özer

Adnan Menderes University Faculty of Dentistry, Department of Endodontics, Aydın, Turkey

Abstract

Since the first laser application in endodontics by Weichman in 1971, search for new laser devices is being proposed with the rapid development of laser technology. The purpose of this article is to update the information on laser application fields in endodontics and give information regarding the advantages and limitations of the laser devices.

Öz

1971'de Weichman tarafından endodonti alanında ilk lazer uygulanmasının ardından, lazer teknolojisinin hızlı gelişimi ile yeni lazer cihazları ile ilgili çalışmalar hız kazanmıştır. Bu makalenin amacı, endodontide lazer uygulama alanlarıyla ilgili bilgileri güncellemek ve lazer cihazlarının avantaj ve kısıtlamaları hakkında bilgi vermektir.

Keywords
Endodontics, laser, dentine sensivity, root canal disinfection

Anahtar Kelimeler
Endodonti, lazer, dentin hassasiyeti, kök kanal dezenfeksiyonu

Received/Geliş Tarihi : 29.09.2016
Accepted/Kabul Tarihi : 20.11.2016

doi:10.4274/meandros.2995

Address for Correspondence/Yazışma Adresi:
Emrah Çetin MD,
Adnan Menderes University Faculty of Dentistry,
Department of Endodontics, Aydın, Turkey
Phone : +90 256 213 39 39
E-mail : dt.emrahcetin@gmail.com

Introduction

LASER (Light Amplification by Stimulated Emission of Radiation) was developed in 1960 by a scientist working for the Hughes Aircraft Corporation, Theodore Maiman, who proposed its mechanism based on the emitted beam coming from a ruby crystal (1).

Lasers were tested for dental use first between 1970-1980, and laser devices such as carbon dioxide (CO_2) and neodymium:doped yttrium aluminum garnet (Nd:YAG) were considered suitable for hard dental tissues, while lasers were already in use for soft-tissue procedures in the middle of 1970s. Since then, many type of laser devices and applications have been used in dentistry, and new laser models and applications are still being created (2).

The most common dental lasers in use today are erbium, Nd:YAG, diode, erbium, chromium doped: yttrium, scandium, gallium and garnet (Cr:YSGG), and CO_2. Naturally, different types of lasers possess specific biological effects, are used in different procedures and, thus, are coupled with specific applicators.

Nd:YAG Lasers

Marketed solely for dental use, these are the first true pulse lasers with a near infrared wavelength of 1064 nm (3). Primarily used for periodontal treatments since their proclivity for pigmented tissue allows for effective debridement and disinfection of periodontal pockets (4).

Diode Lasers

Their portable size and affordable prices made Diode lasers quite popular. Their invisible near infrared wavelengths from 805-1064 nm allows them to be used only on soft tissues. Although they are used in laser assisted tooth whitening technology (5), soft tissue procedures such as gingivectomy, biopsy, impression troughing, and frenectomy are quite practical while coupled with their bactericidal capabilities.

CO_2 Lasers

Their main uses are preparation, incision and remodeling of soft tissues such as incisional and excisional biopsies, frenectomy, gingivectomy, pre and prosthetic procedures, which can also be done with excellent hemostasis. Blocking of nerve endings and eliminating the need for sutures often offers the patient a comfortable post-operative experience (6).

Er:YAG and Er, Cr:YSGG Lasers

Erbium lasers [erbium, Cr:YSGG and erbium:doped yttrium aluminum garnet (Er:YAG)] can be used both on soft and hard tissues owing to their wide absorption scale that works for both apatite crystals based on maximum absorption by water content of soft and hard tissue (7). Especially, erbium, Cr:YSGG laser performs best in all-tissue procedures (soft-tissue, enamel, dentine and bone preparations).

Lasers in Dentin Hypersensitivity Treatment

One of the most painful and the least treated conditions in dentistry is dentinal hypersensitivity (DH), which affects one in six people (8). Lasers were used to eliminate DH first in 1985 (9); however, DH is so complicated that researchers have been carried out many investigations on its mechanism of action, advantages, and unclear points (10). Researchers hypothesized many theories while trying to explain its mechanism; the most popular one is the hydrodynamic theory of Brännström et al. (11). Who postulated that abrupt fluid transfer in the dentinal tubules stimulate mechanosensitive nerve ends close to the odontobastic layer (12,13).

According to hydrodynamic DH mechanism, A-δ nerve fibers located in the dentinal tubules are activated by the hydrodynamic interactions, which enable the communication with open or clogged dentinal tubules (14).

The lasers used for the treatment of dentine hypersensitivity are divided into two groups:

1- Low output power (low-level) lasers are [helium-neon (He-Ne) and gallium-aluminumarsenide (diode) lasers (GaAlAs)],

2- Middle output power lasers are [CO_2 laser, neodymium- or erbium-doped yttrium aluminum garnet (Nd:YAG, Er:YAG lasers) and erbium, chromium doped: yttrium, scandium, gallium and garnet (erbium, Cr:YSGG) lasers] (15).

Helium-Neon Laser

The mechanism here is not known for most cases. According to the results of few physiological studies, peripheral A-delta or C-fiber nociceptors are not induced by He-Ne laser irradiation; however, He-Ne laser irradiation affects the nature of the stimuli. Effectivity of the treatment when He-Ne laser are used falls between 5.2% and 100% (14-16).

GaAlAs Laser

Low output power lasers such as GaAlAs lasers creates an analgesic effect related to depressed nerve transmission. Studies showed blocking depolarization in C-fiber afferents when GaAlAs laser were used at 830 nm (14). Rates for treatment effectiveness change between 53.3% and 94.2% for the GaAlAs laser at 1-month follow-up (14).

CO_2 Laser: Moritz et al. (17) first used this laser for the treatment of dentine hypersensitivity. Output powers of 1 to 2 W with CW or pulse mode can be advised. Using the CO_2 laser at moderate energy densities, in the first place sealing of dentinal tubules is achieved, in addition to the reduction of permeability (14,15).

Nd:YAG Laser: While using Nd:YAG laser irradiation, it is recommended to use black ink as an absorption enhancer to prevent deep penetration of the Nd:YAG laser beam through the enamel and dentin and excessive effects in the pulp. The mechanism of Nd:YAG laser effects on dentine hypersensitivity could be the result of laser-induced occlusion or narrowing of dentinal tubules as well as direct nerve analgesia (18). Nd:YAG and CO_2 lasers cause occlusion of dentinal tubules effectively (14,15).

Er:YAG Laser: While endodontic and periodontologic applications are available, such lasers are mainly used in caries treatment. Laser tip in this laser system may damage both type of tissues if the tip is not used quickly across the surface of gingiva and teeth (15). Elimination of DH after 6 months when Er:YAG laser is used ranges between 38.2%-47% (14,18). Although lasers can seal dentinal tubules, exert nerve analgesia (19), when compared to widely used treatment procedures of DH, treatment with laser does not prove superior due to economic cost and complexities in its use and hypersensitivity bounce back in time (20,21). Additionally, it is not clear how DH can be eliminated by laser applications (20), for instance subjects of control groups in a clinical study showed similar reactions to those of patients treated with lasers (14). According to a result of a systematic study it was shown that laser therapy can lessen pain originated from DH, but it is not clear how this phenomenon takes place (21,22).

The Use of Laser in Determining the Pulp Vitality

Vitality tests indicate vitality of the sensory fibers within pulp (23); however, up to 16% of test results were proved to be false positive (24). It can be explained with the resistance of neurons including sensory fibers against degenerative processes of inflammation even though the surrounding connective tissues are necrotic or degenerated (25). On the other hand, teeth with calcific metamorphosis (26), cases of recent trauma and teeth with ongoing root development (27-29) may result in a false-negative response (i.e., no response).

Although vitality tests work based on the nerve response in pulp, condition of the sensory fibers does not define the vitality of pulp. Pulp vitality is rather determined by the condition of the vascular supply of pulp (30-32) which enters pulp through the apical and accessory foramina. Bracnhes of this vascular network connects its arterioles and venules under the odontoblast layer and venules leave pulp using the same apical foramen (33,34). In order to test the condition of vascular supply of pulp, blood flow was determined using different methods suh as clearence of isotopes (35), desaturation of hydrogen (36) and labelled particles (37). A noninvasive method, Dual-wavelength spectrophotometry (DWS), is also used to test pulpal blood flow. Oxygen saturation level in vascular supply of pulp is evaluated by a spectrometer that uses simultaneously released beams (760 and 850 nm) (38,39). Devital or degenerative status of pulp can be detected using this instrument (38). Teeth without pulp, with fixed pulp, and teeth filled with blood rich in oxygen were tested (39) to investigate the validity of DWS and its derivative technique Pulse oximetry which is commonly used to measure oxygen saturation during the administration of intravenous anesthesia (39) performed for sedation and analgesia (40). Pulse oximetry is a modification of Beer's law that postulates the absorption of light by a solute is related to its concentration at a given wavelength (41). This technique also uses the properties of hemoglobin in the red and infrared range. This means that oxyhemoglobin absorbs more light in the infrared range than deoxyhemoglobin, and deoxyhemoglobin absorbs more in the red light range. Another technique that employs laser is laser doppler flowmetry (LDF), is an accurate, noninvasive, reproducible, reliable method (42-45) of assessing blood flow in microvascular systems with a diode. When diode is used an infrared light beam through the crown and pulp chamber. Moving red cells and static tissues cause this light beam to scatter around (46). The frequency of this light beam shifts when it passes through the moving red blood cells; however, it remains steady when the beam passes through static tissues (46,47). However, the LDF technique possesses a draw back in itself- it takes about an hour to produce recordings, and this makes it impractical for dental practices. For this reason, the time frame of this technique should be shortened to a few minutes.

Laser Applications in Endodontic Surgery

Root apex resection is performed when root canal treatment fails and orthograde retreatment is not possible. In its procedure, apex is cut and removed. When a laser is chosen for the surgery, it provides a clean visual of the operative area without blood contamination owing to the ability of the laser to vaporise the tissues, to coagulate and to seal small blood vessels. It is thought that laser irradiated dentin surfaces are sterile and sealed. With Er:YAG lasers hard tissues can be prepared without significant thermal or structural damage (48).

Laser Applications in the Removal of the Root Canal Filling Material and Medicaments

Smear layer may cover dentinal tubules and thus it is thought that smear layer may help to seal dentin and decrease microleakage. However, smear layer may also contain microotganisms and their by products (49). Therefore, removal of smear layer should be preferred and it is possible to seal dentin tubules by laser irradiation while removing its smear layer (50). On the other hand, irradiation with CO_2 laser removed smear plugs in an *in vitro* study where increased dentin permeability was observed in the end (51).

Takeda et al. (52) showed that irrigation with 17% EDTA, 6% phosphoric acid and 6% citric acid was not able to remove the entire smear from the root-canal system. Acidic solutions cause erosion and widening of tubules. CO_2 laser was useful to remove smear, and Er:YAG laser was proved to be more effective. However, dentin permeability was promoted by Er:YAG laser irradiation (53), and using sodium hypochlorite irrigation afterwards also fortifies this effect.

Disinfection of the Root Canal System

Irrigation of the Root Canal System by Laser Activation (LAI): Photon-Induced Photoacoustic Streaming (PIPS)

Lasers help to clean and disinfect root canals system while eliminating highly resistant species such as *E. faecalis* (54-56). The most effective laser in canal disinfection is Er:YAG laser since it has the highest absorption level in water (57). Laser energy could be used to activate the irrigant solutions in various ways, e.g. irrigant solutions get activated at a molecular level as in photo-activated disinfection (PAD) or at a bulk flow level as in laser-activated irrigation (LAI). It was reported by Seal et al. (58) that the PAD was bactericidal to *S. intermedius* biofilms in root canals owing to the combined use of a photosensitizing agent and a low-power laser; however, bacteria were not eliminated totally while 3% NaOCl was able to eradicate all. To examine the capacity of lasers to activate irrigants inside root canal systems was first reported by George et al. (59) *in vitro* study. It was suggested by Blanken et al. (60) that the laser generates expansion and successive implosion of irrigants, in addition to causing a movement of fluids by a secondary cavitation effect. The LAI and passive ultrasonic irrigation were compared and the laser technique gave results which were comparable to the ultrasound technique that used in longer irrigation times (61,62). Debriding and cleaning efficacy of irrigation was enhanced by a new erbium laser technique coupled with a photon-induced photoacoustic streaming (PIPS) having a newly designed tapered tip with specific minimally ablative laser (63).

PIPS is a type of LAI system that works indirectly by activating irrigants without thermal effects. The mechanism of action of PIPS is to create a strong photoacoustic shockwave that streams irrigants three dimensionally throughout the root canal system.

Photon-Induced Photoacoustic Streaming Protocol

While avoiding to insert into the root canal, the tip of PIPS is placed only in the pulp chamber, and held constant throughout the activation process. A nonstop flow of the solution from the dental irrigating syringe is required while the laser is activated. It is crucial that pulp chamber must be kept flooded with enough irrigating solution in order to keep the PIPS tip submerged. The laser activation period for PIPS should be in 30 s cycles. The present protocol is six cycle of 30 s laser activation with three [X3] 30 s off (rest phase) between activation while using NaOCl. As soon as the 3-30 s cycles of LAI is completed with NaOCl, the canals are irrigated for an additional 30 s using PIPS with water, and only then the pulp chamber is emptied, and 17% EDTA is used with PIPS and continuous flow for an additional 30 s. The last step in the PIPS protocol is laser activation with an additional 30 s of water to provide root canal system ready for the final step, obturation (64).

Tooth Bleaching

Patients' awareness of options available for changing the color of natural dentition has caused an increase in the public demand. The known indications are superficial stains, penetration, absorbed stains, and age-related stains. Patients who prefer conservative treatment to improve appearance, color change related to pulp trauma and necrosis, and interproximal discolorations (65,66) are also seen everywhere nowadays.

The whitening efficacy of LED and diode laser irradiation was compared by Wetter et al. (67), using the two agents Opalescence Xtra and HP Whiteness. The results of the comparison indicated that significant differences in the chroma value were obtained for the two whitening agents and for the different light sources. Under the conditions of lightness, the togetherness of laser and Whiteness HP bleaching gel showed significantly better results than the cases in which the same agent was used alone or in combination with LED (68).

As a result laser bleaching is a power bleaching technique that produces quickly results without the long-term commitment of wearing trays.

Conclusions

Dental treatments using lasers are preferred more often every day and lasers provide results in shorter time than the conventional treatment methods and have more effective results in some conditions and cases. Contrary, the most significant disadvantages of lasers appear as their cost and maintanence. Further studies are required to obtain long-term results of therapies done by lasers.

Ethics

Informed Consent: Consent form was filled out by all participants. Peer-review: Externaliy and internaliy peer-reviewed.

Authorship Contributions

Concept: S.G.Y.Ö., E.Ç., Design: S.G.Y.Ö., E.Ç., Data Collection or Processing: H.D.Ö., Analysis or Interpretation: E.Ç., H.D.Ö., S.G.Y.Ö., Literature Search: E.Ç., Writing: S.G.Y.Ö., E.Ç.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study received no financial support.

References

1. Myers TD. Lasers in dentistry. J J Am Dent Assoc 1991; 122: 46-50.
2. Miller M, Truhe T. Lasers in dentistry; an overview. J Am Dent Assoc 1993; 124: 32-5.
3. Anic I, Tachibana H, Maumoto K, Qi P. Permeability, morphologic and temperature changes of canal dentine walls induced by Nd: YAG, CO_2 and Argon lasers. Int Endod J 1996; 29: 13-22.
4. American Academy of Periodontology. The American Academy of Periodontology statement regarding gingival curettage. J Periodontol 2002; 73: 1229-30.
5. Judy MM, Matthews JL, Aronoff BL, Hults DF. Soft tissue studies with 805 nm diode laser radiation: thermal effects with contact tips and comparison with effects of 1064 nm Nd: YAG laser radiation. Lasers Surg Med 1993; 13: 528-36.
6. Anic I, Dzubur A, Vidovic D, Tudja M. Temperature and surface changes of dentine and cementum induced by CO_2 laser exposure. Int Endod J 1993; 26: 284-93.
7. Zakariasen KL, Dederich DN. Dental Lasers and science. J Can Dent Assoc 1991; 57: 570-3.
8. Gerschman JA, Ruben J, Gerbart-Eaglenont J. Low level laser therapy for dentinat tooth hypersensitivity. Aust Dent J 1994; 39: 353-7.
9. Matsumoto K, Funai H, Shirasuka T, Wakabayashi H. Effects of Nd:YAG-laser in treatment of cervical hypersensitive dentine. Jpn J Conserv Dent 1985; 28: 760-5.
10. Rosenthal MW. Historic review of the management of tooth hypersensitivity. Dent Clin North Am 1990; 34: 403-27.
11. Brännström M, Linden LA, Aström A. The hydrodynamics of dental tubule and pulp fluid. Caries Res 1967; 1: 310-7.
12. Cohen SP, Burns RC. Pathways of the pulp. 8th Edition, Mosby, 2002: 36, 593.
13. Trushkowsky R, Oquendo A. Treatment of dentine hypersensitivity. Dent Clin North Am 2011; 55: 599-608.
14. Kimura Y, Wilder-Smith P, Yonaga K, Matsumoto K. Treatment of dentine hypersensitivity by lasers: a review. J Clin Periodontol 2000; 27: 715-21.
15. Matsumoto K, Kimura Y. Laser Therapy of Dentin Hypersensitivity. J Oral Laser Application 2007; 7: 7-25.
16. Ladalardo TC, Pinheiro A, Campos RA, Brugnera Junior A, Zanin F, Albernaz PL, et al. Laser therapy in the treatment of dentine hypersensitivity. Braz Dent J 2004; 15: 144-50.
17. Moritz A, Gutknecht N, Schoop U, Goharkhay K, Ebrahim D, Wernisch J, et al. The advantage of CO_2- treated dental necks, in comparison with a standard method: Results of an in vivo study. J Clin Laser Med Surg 1996; 14: 27-32.
18. Lan WH, Liu HC. Sealing of human dentinal tubules by Nd:YAG laser. Journal of Clinical Laser Medicine & Surgery 1995; 13: 329-33.
19. Grag N, Grag A. Text book of endodontics. 1st Edition, 2007: 421.
20. Sgolastra F, Petrucci A, Gatto R, Monaco A. Effectiveness of laser in dentinal hypersensitivity treatment: a systematic review. J Endod 2011; 37: 297-303.

21. Orchardson R, Gillam DR. Managing dentin hypersensitivity. J Am Dent Assoc 2006; 137: 990-8; quiz 1028-9.
22. Orchardson R, Gangarosa LP, Holland GR, Pashley DH, Trowbridge HO, Ashley FP, et al. Dentine hypersensitivity into the 21st century. Arch Oral Biol 1994; 39 (Suppl): 113S-9S.
23. Cohen S, Burns RC, eds. Pathways of the pulp. 8th ed. St. Louis: Mosby; 2002.
24. Petersson K, Soderstrom C, Kiani-Anaraki M, Levy G. Evaluation of the ability of thermal and electrical tests to register pulp vitality. Endod Dent Traumatol 1999; 15: 127-31.
25. Radhakrishnan S, Munshi AK, Hegde AM. Pulse oximetry: a diagnostic instrument in pulpal vitality testing. J Clin Pediatr Dent 2002; 26: 141-5.
26. Noblett WC, Wilcox LR, Scamman F, Johnson WT, Diaz-Arnold A. Detection of pulpal circulation in vitro by pulse oximetry. J Endod 1996; 22: 1-5.
27. Klein H. Pulp responses to an electric pulp stimulator in the developing permanent anterior dentition. ASDC J Dent Child 1978; 45: 199-202.
28. Andreasen FM, Zhijie Y, Thomsen BL, Andersen PK. Occurrence of pulp canal obliteration after luxation injuries in the permanent dentition. Endod Dent Traumatol 1987; 3:103-15.
29. Andreasen FM. Histological and bacteriological study of pulps extirpated after luxation injuries. Endod Dent Traumatol 1988; 4: 170-81.
30. Bhaskar SN, Rappaport HM. Dental vitality tests and pulp status. J Am Dent Assoc 1973; 86: 409-11.
31. Chambers IG. The role and methods of pulp testing in oral diagnosis: a review. Int Endod J 1982; 15: 1-15.
32. Sasano T, Onodera D, Hashimoto K, Iikubo M, Satoh-Kuriwada S, Shoji N, et al. Possible application of transmitted laser light for the assessment of human pulp vitality. Part 2. Increased laser power for enhanced detection of pulpal blood flow. Dent Traumatol 2005; 21: 37-41.
33. Rowe AH, Pitt Ford TR. The assessment of pulpal vitality. Int Endod J 1990; 23: 77-83.
34. Nanci A, Ten Cate AR. Ten Cate's Oral histology: development, structure, and function. 6th ed. St. Louis: Mosby; 2003.
35. Edwall L, Kindlova M. The effect of sympathetic nerve stimulation on the rate of disappearance of tracers from various oral tissues. Acta Odontol Scand 1971; 29: 387-400.
36. Tonder KH, Aukland K. Blood flow in the dental pulp in dogs measured by local H2 gas desaturation technique. Arch Oral Biol 1975; 20: 73-9.
37. Kim S. Regulation of pulpal blood flow. J Dent Res 1985; 64: 590-6.
38. Nissan R, Trope M, Zhang CD, Chance B. Dual wavelength spectrophotometry as a diagnostic test of the pulp chamber contents. Oral Surg Oral Med Oral Pathol 1992; 74: 508-14.
39. Schnapp LM, Cohen NH. Pulse oximetry. Uses and abuses. Chest 1990; 98: 1244-50.
40. Schmitt JM, Webber RL, Walker EC. Optical determination of dental pulp vitality. IEEE Trans Biomed Eng 1991; 38: 346-52.
41. Gopikrishna V, Tinagupta K, Kandaswamy D. Comparison of electrical, thermal, and pulse oximetry methods for assessing pulp vitality in recently traumatized teeth. J Endod 2007; 33: 531-5.
42. Gazelius B, Olgart L, Edwall B, Edwall L. Non-invasive recording of blood flow in human dental pulp. Endod Dent Traumatol 1986; 2: 219-21.
43. Olgart L, Gazelius B, Lindh-Stromberg U. Laser Doppler flowmetry in assessing vitality in luxated permanent teeth. Int Endod J 1988; 21: 300-6.
44. Ingolfsson AE, Tronstad L, Riva CE. Reliability of laser Doppler flowmetry in testing vitality of human teeth. Endod Dent Traumatol 1994; 10: 185-7.
45. Yanpiset K, Vongsavan N, Sigurdsson A, Trope M. Efficacy of laser Doppler flowmetry for the diagnosis of revascularization of reimplanted immature dog teeth. Dent Traumatol 2001; 17: 63-70.
46. Pettersson H, Öberg PA. Pulp blood flow assessment in human teeth by laser Doppler flowmetry. Lasers in Orthopedic, Dental, and Veterinary Medicine. 1991; (SPIE)1424: 116-9.
47. Wilder-Smith PE. A new method for the non-invasive measurement of pulpal blood flow. Int Endod J 1988; 21: 307-12.
48. Kimura Y, Wilder-Smith P, Matsumoto K. Lasers in endodontics: a review. Int Endod J 2000; 33: 173-85.
49. Fogel HM, Pashley DH. Dentin permeability: effects of endodontic procedure on root slabs. J Endod 1990; 16: 442-5.
50. Weichman JA, Johnson FM. Laser use in endodontics. A preliminary investigation. Oral Surg 1971; 31: 416-20.
51. Pashley EL, Horner JA, Liu M, Kim S, Pashley DH. Effects of CO_2 laser energy on dentin permeability. J Endod 1992; 18: 257-62.
52. Takeda FH, Harashima T, Kimura Y, Matsumoto K. Comparative study about the removal of smear layer by three types of laser devices. J Clin Laser Med Surg 1998; 16: 117-22.
53. Pecora JD, Brugnera-Junior A, Cussioli AL, Zanin F, Silva R. Evaluation of dentin root canal permeability after instrumentation and Er: YAG laser application. Lasers Surg Med 2000; 26: 277-81.
54. Schoop U, Moritz A, Kluger W, Patruta S, Goharkhay K, Sperr W, et al. The Er:YAG laser in endodontics: results of an in vitro study. Lasers Surg Med 2002; 30: 360-4.
55. Gordon W, Atabakhsh VA, Meza F, Doms A, Nissan R, Rizoiu I, et al. The antimicrobial efficacy of the erbium, chromium: yttrium-scandiumgallium-garnet laser with radial emitting tips on root canal dentin walls infected with Enterococcus faecalis. J Am Dent Assoc 2007; 138: 992-1002.
56. Wang Q, Zhang C, Yin X. Evaluation of the bactericidal effect of Er, Cr: YSGG, and Nd: YAG lasers in experimentally infected root canals. J Endod 2007; 33: 830-2.
57. Coluzzi DJ. Fundamentals of dental lasers: science and instruments. Dent Clin North Am 2004; 48: 751-70.
58. Seal GJ, Ng YL, Spratt D, Bhatti M, Gulabivala K. An in vitro comparison of the bactericidal efficacy of lethal photo - sensitization or sodium hyphochlorite irrigation on Streptococcus intermedius biofilms in root canals. Int Endod J 2002; 35: 268-74.

59. George R, Meyers IA, Walsh LJ. Laser activation of endodontic irrigants with improved conical laser fiber tips for removing smear layer in the apical third of the root canal. J Endod 2008; 34: 1524-7.
60. Blanken J, De Moor RJ, Meire M, Verdaasdonk R. Laser induced explosive vapor and cavitation resulting in effective irrigation of the root canal. Part 1: a visualization study. Lasers Surg Med 2009; 41: 514-9.
61. De Groot SD, Verhaagen B, Versluis M, Wu MK, Wesselink PR, van der Sluis LW. Laser-activated irrigation within root canals: cleaning efficacy and flow visualization. Int Endod J 2009; 42: 1077-83.
62. De Moor RJ, Blanken J, Meire M, Verdaasdonk R. Laser induced explosive vapor and cavitation resulting in effective irrigation of the root canal. Part 2: evaluation of the efficacy. Lasers Surg Med 2009; 41: 520-3.
63. DiVito E, Peters OA, Olivi G. Effectiveness of the erbium: YAG laser and new design radial and stripped tips in removing the smear layer after root canal instrumentation. Lasers Med Sci 2012; 27: 273-80.
64. Basrani B. Irrigation in endodontic treatments. Alpha Omegan 2011; 104: 18-25.
65. Dostalova T, Jelinkova H, Housova D, Sulc J, Nemec M, Miyagi M, et al. Diode-laser activated bleaching. Braz Dent J 2004; 15: SI3-8.
66. Sun G. The role of lasers in cosmetic dentistry. Dent Clin North Am 2000; 44: 831-49.
67. Wetter NU, Barrose MC, Pelino JE. Dental bleaching efficacy with diode laser and LED irradiation: an in vitro study. Lasers Surg Med 2004; 35: 254-8.
68. Zhang C, Wang X, Kinoshita J, Zhao B, Toko T, Kimura Y, et al. Effects of KTP laser irradiation, diode laser, and LED on tooth bleaching: a comparative study. Photomed Laser Surg 2007; 25: 91-5.