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REVIEW ARTICLE/**REVIEW**

Current Applications of Lasers in Endodontics

Applicazioni del Laser in Endodonzia

KEYWORDS
Endodontics, Laser Applications, Pulp, Root Canal System, Disinfection

PAROLE CHIAVE
Endodonzia, applicazioni del laser, polpa, sistema canalare, disinfettare

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Received 2019, March 17

Accepted 2019, May 10

Abstract

The use of lasers within the scope of endodontic practice and research has increased significantly in the past few years. Lasers are generally classified according to their physical constructions and special wavelengths, which have impacts on their enhanced clinical usage. Lasers according to their physical constructions are divided into three groups. The first type is the solid state laser, so named because the medium, undergoing lasing, is in a solid form. Ruby laser is the prototype of all solid state lasers. By forming crystalline materials that are doped with rare earth elements a wide range of solid state lasers can be produced. Some of the most common types of solid state lasers use the YAG (Yttrium Aluminium Garnet) crystal (Holmium:YAG, Thulium:YAG Neodymium:YAG and Erbium:YAG) and the YSGG (Yttrium Scandium Gallium Garnet) crystal (Er,Cr:YSGG) as their base. The second major family of lasers are the gas lasers. In this group the lasing material that is ionized can be Argon gas, Carbon dioxide gas, Nitrogen gas or a Helium-Neon (He:Ne) gas mixture. The third family of lasers are the Diode lasers, which produce wavelengths in the visible spectrum. The most frequently used lasers in endodontics are: Neodymium:YAG (Nd:YAG), Diode Laser, Erbium:YAG (Er:YAG), Erbium Chromium:YSGG (Er,Cr:YSGG) and He:Ne laser. This paper reviews the most common applications of lasers in endodontics that include Laser Doppler Flowmetry (LDF), treatment of dentinal hypersensitivity, pulpotomy and pulp capping and root canal disinfection through laser activated irrigation and photo-activated root canal disinfection (PAD).

L'uso dei laser nell'ambito della pratica e della ricerca endodontica è aumentato significativamente negli ultimi anni. I laser sono generalmente classificati in base alla loro costruzione fisica e alle lunghezze d'onda utilizzate che hanno avuto un impatto importante sul miglioramento del loro utilizzo clinico. I laser, in base alle loro caratteristiche fisiche, sono divisi in tre gruppi. Il primo tipo è il laser a stato solido, così chiamato perché il mezzo sottoposto a lasing è in una forma solida; il laser a rubino è il prototipo di tutti quelli allo stato solido: formando materiali cristallini che sono drogati con elementi di terre rare si può produrre una vasta gamma di laser a stato solido. Alcuni dei tipi più comuni di laser a stato solido utilizzano il cristallo YAG (Yttrium Aluminum Garnet) (Holmium:YAG, Thulium:YAG Neodymium:YAG and Erbium:YAG) e il cristallo YSGG (Yttrium Scandium Gallio Granato) (Er, Cr: YSGG) come base. La seconda grande famiglia sono i laser a gas: in questo gruppo il materiale lasing che è ionizzato può essere gas Argon, gas di anidride carbonica, gas azoto o una miscela di gas Elio-Neon (He:Ne). La terza famiglia sono i laser a diodi, che producono lunghezze d'onda nello spettro visibile. I laser più frequentemente utilizzati in endodonzia sono: Neodimio:YAG (Nd:YAG), Laser a diodi, Erbio:YAG (Er: YAG), Erbio Cromo:YSGG (Er,Cr:YSGG) e He:Ne laser.
Questo articolo si propone di esaminare le più comuni applicazioni del laser in endodonzia che includono la flussimetria laser doppler Flowmetry, il trattamento dell'ipersensibilità dentinale, la pulpectomia e l'incappucciamento della polpa e la disinfezione del canale radicolare mediante irrigazione attivata mediante laser e disinfezione canalare fotoattivata (PAD).

Introduction

In the past three decades, several important researches have attempted to find and apply new technologies to improve endodontic treatments. Among these investigations studies on lasers with different wavelengths have been of great importance. Light Amplification by Stimulated Emission of Radiation (LASER) uses amplified lights to remove or treat soft and hard tissues in oral cavity. Lasers are generally classified according to their physical constructions and special

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Peer review under responsibility of Società Italiana di Endodonzia
10.32067/GIE.2019.33.02.01

wavelengths, which have impacts on their enhanced clinical usage. Lasers according to their physical constructions are divided into three groups. The first type is the solid-state laser, so named because the medium, undergoing lasing, is in a solid form. Ruby laser is the prototype of all solid-state lasers: by forming crystalline materials, which are doped with rare earth elements, a wide range of solid-state lasers can be produced. Some of the most common types of solid state lasers use the YAG (Yttrium Aluminium Garnet) crystal (Holmium:YAG, Thulium:YAG Neodymium:YAG and Erbium:YAG) and the YSGG (Yttrium Scandium Gallium Garnet) crystal (Er,Cr:YSGG) as their base. The second major family of lasers are the gas lasers. In this group the lasing material ionized can be Argon gas, Carbon dioxide gas, Nitrogen gas or a Helium-Neon (He:Ne) gas mixture. The third family of lasers are the Diode lasers, which produce wavelengths in the visible spectrum.

The laser amplified focused light energy has the potential to interact with the biological dental tissues and structures in order to penetrate the surface of the tooth and access to the pulp cavity, clean, disinfect and shape the root canal system and finally help to fill it in three dimensions. The most frequently used lasers in endodontics are: Neodymium:YAG (Nd:YAG), Diode Laser, Erbium:YAG (Er:YAG), Erbium Chromium:YSGG (Er,Cr:YSGG) and He:Ne laser.

A position paper from the American Association of Endodontists states that the application of lasers to disinfect the root canal is more promising than in instrumentation and shaping of it (1).

This paper aims to review the most common applications of lasers in endodontics that include Laser Doppler Flowmetry (LDF), treatment of dentinal hypersensitivity, pulpotomy and pulp capping and root canal disinfection through laser activated irrigation and photo-activated root canal disinfection (PAD).

Laser Doppler Flowmetry (LDF)

This technology was first developed to assess blood flow in microvascular systems such as the retina or skin. It was adapted by Gazelius and Olgaret in 1986 for use on human teeth in order to measure pulpal blood flow (2). This diagnostic tool was especially deemed appropriate to determine pulpal vitality (blood flow) subsequent to tooth trauma when traditional clinical findings were inconclusive. In this technique laser light is scattered by moving blood cells and undergoes a frequency shift according to the Doppler principle. The light is detected and processed to produce a signal that shows the function of the red cell flux (volume of cells X cell velocity) (3). In an additional contemporary application it may become useful in detecting revascularization much earlier than standard sensitivity tests (4). Furthermore it may be useful in detecting transient ischemic episodes and identifying teeth at risk of developing adverse sequelae. An accurate LDF reading can be established at the 12-week follow-up appointment of replanted and splinted avulsed permanent maxillary incisors when the potential for revascularization is diagnosed. However, this finding is based on the clinical and radiographic parameters of vital and non-vital teeth and may not be interpreted as representing the histologic condition of the pulp (5). Ikawa et al. in 2003 stated that age related changes in human pulpal blood flow could be measured by LDF as their findings indicated that the hemodynamic of the human pulp is reduced with age (6). However, LDF has some limitations, as it is expensive, not readily available and requires skill in its application in teeth with large restorations, when the laser light may not reach pulp and measure the true blood flow. The LDF process uses the He-Ne laser at different wavelengths; for example, Morikawa et al. used the He-Ne Laser with 632 nm wave length (7) while Odor et al. used the He-Ne laser at 810 and 633 nm wavelengths. At 810 nm good sensitivity was experienced, as disease or non-vitality could be detected well but with poor specificity, which meant their absence could not be assessed as well (3). At 633 nm Evans et al. claimed equal specificity and sensitivity following using LDF (8). When assessing pulpal vitality with the

LDF a major portion of the signal comes from tissues other than the pulp. The results may be inconsistent in pulp blood flow measurements without taking precautions (such as dental-dam application) (9). Akpinar et al. also indicated the significant effect of gingiva on LDF flow measurements. Indeed they reported that the contribution of labial gingiva to laser Doppler blood flow measurements was more than that of palatal gingiva (10).

Treatment of dentinal hypersensitivity

According to hydrodynamic theory that was postulated by Brännström dentine hypersensitivity occurs when open dentinal tubules are exposed, resulting in a painful sensation due to an intensification of the dentinal permeability. Treatment, therefore, should be based on a decrease of this permeability, achieved by the obliteration or blocking of dentinal tubules (11). Grossman in 1935 mentioned seven original prerequisites for successful treatment of dentinal hypersensitivity using various substances (12), including: non irritating to pulp, relatively painless on application, easily applied, rapid in action, effective for a long time, without staining effects and consistently effective. Several recent studies have compared the effects of the Nd:YAG and Er:YAG lasers in the management of dentinal hypersensitivity (13-17). Lan et al. on the basis of a morphologic study of Nd:YAG laser usage in treatment of dentinal hypersensitivity stated that dentine surface after Nd:YAG laser treatment showed no protrusive rods, in contrast with the presence of numerous rods before laser irradiation. Protrusive rods are a sign of open dentinal tubules and the data obtained supported the hypothesis that Nd:YAG laser irradiation at specifications of 30 mJ, 10 pulses per second and 2 min. is effective in sealing exposed dentinal tubules (13).

Lee et al. indicated that a highly biocompatible material such as bioglass could be melted by laser irradiation to achieve better sealing depth for dentinal tubules (14). The melted bioglass, when bonded to the dentin in a physiological environment, may offer a prolonged therapeutic effect. However the melting point of a modified bioglass composite should be reduced and its use plus Nd:YAG laser has the potential in clinical use to manage dentin hypersensitivity (14). Al-Azzawi and Dayem found no significant difference in the occluding effect of Nd:YAG laser and a tooth paste (15). However the occluding effect of Nd:YAG laser occurs within seconds where as that of the toothpaste takes at least 3 weeks (15). Birang et al. concluded that Nd:YAG laser is more effective than Er:YAG laser in reduction of patients' pain in dentine hypersensitivity management and the effects seemed to last for at least six months (16). Wan-Hong et al. proposed that the mechanism of the Nd:YAG laser effect on dentin is given by thermal energy absorption in dentine that melts the hydroxyl apatite crystals of dentine partly or completely, which results in dentinal tubule occlusion (17). The sealing depth through this process was estimated 4 microns (17).

Aranha *et al.* stated that the Er:YAG at 60 mJ, 2 HZ and the Nd:YAG laser at 1.5 W, 15 HZ are useful for decreasing dentine permeability (18), while Stabholz et al. using Er:YAG laser at different energy levelsì did not find any melting or sealing/occluding of dentinal tubules (19). The authors believed that any reduction in dentine hypersensitivity due to Er:YAG laser irradiation cannot be attributed to occlusion or narrowing of dentinal tubules (19). Two major types of lasers that have been commonly used for the purpose of dentine hypersensitivity treatment are He-Ne and GaAlAs (Gallium/Aluminium/Arsenide) with low output power and the CO_2 and Nd:YAG with medium output power. The mechanism of action for these lasers, known as *desensitization,* is mostly unknown and may be different for each laser type. A low power He-Ne laser may affect the action potential of A-delta and C nociceptor fibers without destroying them, while GaAlAr lasers may block depolarization of the nociceptors (20, 21).

Pulp capping and pulpotomy

Pulp capping represents the boundary between conservative pulpal management and a root canal procedure. Between 1985 and 1987 Melcer et al. suggested that the CO_2 laser could be used for direct pulp capping (2, 22). They also described successful pulp retention after direct capping of inflamed pulps with laser (24). CO_2 laser-assisted pulp capping is an easy, safe and fast method to achieve haemostasis, along with disinfection and coagulation of exposed pulp tissues. The laser beam is applied in a contact free mode using a He-Ne laser to facilitate targeting. Irradiation starts immediately after the exposure of vital pulp and the area is repeatedly irradiated at a power setting of 1 W for 0.1 s with a 1-s interval until haemostasis occurs and the aperture is completely sealed. The lased pulp is then dressed with calcium hydroxide and the cavities filled with glass-ionomer cement. The long-term results of Moritz et al. indicated a success rate of 93%, two years after super pulsed CO_2 laser-assisted pulp capping (25). Suzuki et al. showed that CO_2 laser is effective for pulp capping procedures; however a longer observation time would be required to determine the presence of dentine bridge formation (26).

Er:YAG and Nd:YAG lasers have been successful in pulp capping procedures in several different studies, demonstrating good healing capacity with the formation of a dentine bridge and reparative dentine (27, 28). Docimo compared the effectiveness of the three techniques for pulp capping of deeply decayed permanent teeth, reporting a success rate of 63% for traditional methods, 83% for Er,Cr: YSGG laser-assisted techniques and 75% for Erbium:YAG laser-assisted pulp capping after four years of assessment (29). Therefore, laser technology has been shown to be effective in improving the prognosis of pulp capping procedures even on teeth affected by deep caries (29).

Pulpotomy is defined as the surgical removal of the coronal pulp in attempt to maintain the health of remaining pulp (25, 26). The first report on laser pulpotomy was provided in 1995 by Shoji et al. followed by the study from Figueiredo et al (30, 31). CO_2 laser was used for pulpotomy in dogs and the presence of secondary dentine and a regular odontoblast layer in the tissues of underlying ablated area was observed (32-34). Kimura et al. in a preliminary report on laser pulpotomy stated that the effects on pulp tissues during a pulpotomy procedure by Er:YAG laser irradiation are minimal if appropriate parameters are selected and that it represents a potential therapy for pulp retention in human teeth (35). However, Huth et al. determined a success rate of 78% for Erbium:YAG laser-assisted pulpotomies, 85% for formocresol, 53% for $Ca(OH)_2$ and 86% success rate for ferric sulfate mediated pulpotomies (36). These investigators have also indicated that the validity of this study revealing new data concerning the controlled use of Er:YAG laser for pulpotomies is limited and recommended future studies with a sufficient number of patients and standard parameters of evaluations (36).

The CO_2 laser is not only an effective tool for direct pulp capping but also for the pulpotomy of primary teeth. A success rate of 91 to 98% has been reported for CO_2 laser pulpotomy of primary teeth by Pescheck and Moritz in 2002 (34).

Root canal disinfection and laser-activated irrigation

Presently, Er:YAG, Nd:YAG, ER,CR:YSGG, CO_2 laser and diode laser have been shown to be efficient and effective for the purpose of root canal disinfection and smear layer removal (37). The effects produced by laser light on living cells tissues or organisms may be due to photothermal, photochemical, photoablative or photomechanical actions. High power (Class 4) lasers have been well recognized for their photothermal (heat based) destructive effects on bacteria and this has led to the development of techniques for disinfecting root canal system. These lasers typically use pulsed modes of operation for endodontic root canal disinfection, to reduce the risk of thermal injury to the periodontal ligament cells (37, 38). Undesirable surface effects within the radicular dentine such

as carbonisation and cratering remain a concern with certain laser types such as the Nd:YAG and carbon-dioxide laser; therefore strict protocols must be followed to minimise such effects and any associated thermal stress within the radicular dentin when such lasers are used for root canal disinfection (39).
Folwaczny et al. evaluated the antibacterial effects of pulsed Nd:YAG laser irradiation at different energy settings in root canals without using photosensitizing dye and determined that laser radiation has antimicrobial effects in root canals (40). The results of a similar study by Piccolomini et al. showed an antibacterial effect of Diodium Nd:YAG laser depending on the radiation frequency. However, through their study 5.25% NaOCl was more effective than either laser application (41). An *in vivo* study evaluating the therapeutic effect of Nd:YAG laser in persistent lesions supported the use of laser, since it created an unfavourable environment for the continuing development of microorganisms (42). Gutknecht et al. investigated the antibacterial depth effect of the continuous wave of a 980-nm diode laser irradiation in bovine dentine, showing that laser can eliminate bacteria deep into the dentine (43).
Laser-activated irrigation (LAI) or the Photon-Initiated Photoacoustic Streaming (PIPS) is one of the most prominent applications of laser in the scope of endodontic treatments (44). A research by De Moor et al. has come to the conclusion that LAI techniques using erbium lasers (Er:YAG or Er,Cr:YSGG) for 20 seconds (4×5 seconds) are as efficient as Passive Ultrasonic Irrigation with the intermittent flush technique (3×20 seconds) (45).
Another article has shown that the impact of alkaline solutions of NaOCl and EDTA in endodontics can be highly improved when these are agitated by ultrasonic source of energy or pulsed lasers (46). It creates fluid motion which improves the contact of the irrigant solutions with areas of the root canal walls that cannot be obtained by rotary instruments (46). They also increase the temperature of these irrigants that results in better chemical actions on soft and hard tissues (46).
The effective absorption of the laser light by sodium hypochlorite leads to vaporization of this irrigating solution resulting in formation of vapor bubbles that causes secondary cavitation effects (44). In this procedure the Er:YAG laser creates photoacustic shock-waves within the irrigant inside the root canal system (44). Perin et al. evaluated both Er:YAG laser (7 HZ, 100 mJ, 80 pulses/canal, 11 sec) and 1% NaOCl irrigations capacity against intra-canal microbiota and found its effectiveness to eliminate these microorganisms (47). Vezzani et al. evaluated the degree of disinfection of the Er:YAG laser in root canals contaminated with five intracanal microorganisms at different frequencies and concluded that all the groups showed statistically similar results and no method totally eliminated microorganisms (48). Radatti et al. evaluated the efficacy of an Erbium,-Chromium:Yttrium,Scandium, Gallium,Garnet (Er,Cr:YSGG) laser powered hydrokinetic system (HKS) versus that of rotary instrumentation for root canal debridement. According to their results the debridement efficacy of the HKS with distilled water irrigation was unacceptable with 5.25 percent NaOCl irrigation and it was similar to that of rotary instrumentation. If the HKS was to be used for debridement, then NaOCl irrigation must be used for predictable tissue removal (49). Jha et al. stated both laser and rotary instrumentations are unable to eliminate root canal infections (50). Currently, great emphasis in terms of elimination of root canal infection is focused upon mechanical preparation and ultrasonic and laser activation methods in conjunction with using appropriate irrigation solutions (51, 52).
Takeda et al. in a comparative study of the removal of smear layer using three intracanal irrigants and two types of lasers concluded that the CO_2 laser was useful in removing and melting the smear layer on the instrumented root canal walls and that the Er:YAG laser was the most effective in removing the smear layer from the root canal wall (53). Wang et al. stated that the diode laser irradiation significantly removed the smear layer, resulting in less apical leakage after obturation in compar-

ison to non-laser irradiated root canals (54). Confocal laser scanning microscopy (CLSM) and scanning electron microscope (SEM) three-dimensional images from samples irradiated using Er:YAG laser with different parameters revealed that the root canal walls were not smooth and the root canal dentine surface was ablated. No debris was observed at the dentine surface and strong melting and recrystallization or unusually flat surfaces with open dentinal tubules were obtained. So Er:YAG laser can induce different modifications of root canal surface (55).
Irradiation of dentine with Nd:YAG laser removes smear layer and promotes its fusion and recrystallization, thus decreasing permeability. Santos et al. reported that the increase of power and frequency of the laser produced typical structures that characterize the irradiation of dentine by Nd:YAG laser, such as globular formations, melting and glazing ebullitions. Furthermore, the removal of smear layer increased the number of visible dentinal tubules openings (56). Altundasar et al. evaluated the ultra-morphological and histochemical changes of dentinal walls after ER-,CR:YSGG laser irradiation. SEM observations revealed partial or total removal of the smear layer associated with few small regions of thermal injury, including carbonization and partial melting. Energy dispersive X-ray analysis (SEM-EDX) of affected dentine showed no significant difference between the Ca/P ratios of the tested groups, suggesting absence of changes at a molecular level (57).
Da Costa Ribeiro et al. evaluated the morphological and thermographic effect of 810 nm diode laser irradiation on root canal walls (58).
The SEM images of affected root canal walls revealed closed dentinal tubules especially at the apical regions and the maximum temperature rise at these apical regions, which was assessed by an infrared thermographic camera, was 8.6 °C, thus suggesting that the diode laser can be used in root canal procedures and is safe for periodontal tissues (58). The results of Ishizaki et al. suggested that the temperature rise during Er,Cr:YSGG laser irradiation is minimal to damage to the periodontal and bone tissues (59).

Photo-activated disinfection (PAD) of root canals

In case that persistent bacteria exists within the root canal system, inadequate debridement and disinfection may result in post treatment endodontic diseases (60). Different mechanical instrumentation methods are not able to eliminate the microorganisms inside the root canal system, sufficiently. A wide range of chemical irrigating solutions has been introduced to increase reduction of the microbial load within the root canal system. New technologies and substances have also been proposed to improve root canal disinfection either by replacing contemporary chemo-mechanical procedures or by increasing their effects (61-63).
PAD is an alternative approach to microbial killing in the root canal system by laser light, which involves the use of low-power lasers such as a visible red diode laser with an output power of up to 100 mw, over 60-120 seconds (64). PAD drives photochemical reactions, particularly the production of singlet oxygen, free radicals and other reactive oxygen species from photosensitiser dyes such as Tolunium chloride to kill intracanal bacteria including the resistant *E. faecalis* that is estimated to be the main cause of persistent apical periodontitis following root canal procedures. For maximum effect within the root canal system, the laser energy should be delivered using a photodynamic diffuser tip that gives a cylindrical emission pattern, corresponding to the shape of the root canal system. The appliction of PAD in contemporary root canal procedures relates to its potential for one step high level disinfection of the root canal space as a prelude to single-visit procedures or as a treatment for refractory root canal infections. The low level laser energy of PAD has advantages in that its bactericidal effect could be achieved without damaging the host tissues and with little optical danger to both the operator and patient (64).
Currently several authors recommend

Photo Dynamic Therapy (PDT) as a promising effective disinfection supplement to standard intracanal cleaning and shaping for clinical treatment of periapical lesions, especially in cases undergoing single visit root canal treatment or retreatment (65-67). In fact, both *in vivo* and *ex vivo* studies have shown that PDT is a promising technology to reduce bacterial load or bacterial concentration in the patients undergoing root canal treatment and also in extracted infected teeth (68-70). Although the application of PAD has significant advantages, potential adverse side effects have been reported regarding that (70). Tooth discoloration has been reported to be an adverse effect since the use of methylene blue (MB) as a photosensitizer may intensify discoloration (70-72). Several chemical compounds like 2.5% NaOCl used during cleaning and shaping of the root canals have been reported to be effective in preventing tooth staining caused by the application of MB during PAD (73). Some other authors have reported that MB, when used in concentrations of 100 microgr/mL, minimizes the chances of tooth discoloration (74).
Smear layer formation may decrease the bond strength of root filling materials to dentine by occluding the dentinal tubules (75). According to Souza et al. the use of ultrasonics improves the efficiency of 17% EDTA and QMix to remove the PS from all parts of the root canal walls, following PDT (76).
The species of microorganisms in the root canal system and their growth mode has been reported to influence their sensitivity to PDT in a dose-dependent form (77). Regarding the dose of energy, the highest power observed refers to laser (74-78), probably because of concentration in a small area of high energy dose originated from the light (79). This area of concern should also be carefully analysed, since temperature increase may create trauma to surrounding tissues and causes irreversible defects (80). The use of LED may be suggested, considering its capacity of not changing the temperature together to its high-dose energy supply. One of the advantages of PDT is the absence of thermal side effects in the periradicular tissues (81). The action of PDT is based on photochemical events and not thermal effects, in contrast with many laser therapy techniques (52).

Additional uses of lasers

Several studies report on the use of Er:YAG laser for the purpose of access cavity and root canal preparation, through a photo ablative action similar to that of cavity preparation. The Er:YAG laser has the ability to open the dentinal tubules and remove the smear layer, so that the root canal sealers can easily penetrate the canal walls during obturation, thereby establishing an optimal seal (25).
Histologic and SEM examination of root canal walls after preparation with special Er:YAG laser microprobes by Kesler et al. in 2002 showed that they are effective in enlarging, shaping and cleaning straight root canals (82). Mazeki et al. in 2003 evaluated the effectiveness of Er:YAG laser irradiation for preparation of root canal orifices in extracted human teeth. SEM observations showed that irradiated surfaces were slightly rough, but essentially free from debris and smear layer. Orifices were successfully prepared and no ledge formation or perforations were observed (83). Kimura et al. in 2002 had stated that the roughness and irregularities of root canal walls prepared by Er:YAG laser do not affect apical leakage after obturation compared with leakage in canals prepared using the traditional methods (84). Lee et al. assessed the thermal effect and morphological changes induced by Er:YAG laser using two kinds of fiber tips to enlarge the root canals and identified that the cone shaped fiber tip of Er:YAG laser produced fewer thermal effects and morphological changes as compared to the flat fiber tip (85). Furthermore, Kimura and Yonaga determined that there were minimal effects of ER:YAG laser irradiations on periodontal and periapical tissues of the related root canal prepared teeth (86). Biedma et al. mentioned that Er:YAG laser combined with rotary and manual techniques may improve the cleanliness of root canals (87). Nd:YAG laser irradiation was

also an effective tool for softening and removal of gutta-percha and root canal obturation materials (88, 89). Moshonov et al. stated that a new Nd:YAP laser with a wavelength that is in the infrared region is absorbed in water better than Nd:YAG and may improve the cleanliness of the root canal walls (90).
Since 2005 evaluation of the efficacy of a Erbium laser family called Er,Cr:YSGG laser for the purpose of cleaning and shaping the root canal system has been subject of several studies (91-93).. Hossain et al. compared the efficacy of Er,Cr:YSGG laser with the efficacy of hand instrumentation methods and observed a significant decrease in smear layer or debris in laser prepared canals but canal preparations with the laser device sometimes resulted in ledges, zips, perforations or over instrumentation (91). Matsuka et al. in a morphological study of the Er,Cr:YSGG laser for root canal preparation in mandibular incisors with curved root canals noticed step-like appearances of irradiated walls and openings of dentinal tubules and only root canals having curvatures, less than 10 degrees could be prepared using this technique (92). Jahan et al. in another study stated that because of ledge, zip or perforations observed in the canals prepared by Er,Cr:YSSGG laser further development in this laser device and technique is required to ensure its success in root canal preparation, especially in curved canals (93). Today the results of many research studies on NiTi mechanical instruments recommend these techniques for the purpose of cleaning and shaping the root canal systems (94, 95).
During contemporary root canal obturation, a laser can be used as a heat source to soften gutta-percha in root canals. Park et al. evaluated the effect of Nd:YAG laser irradiation on the apical leakage of obturated root canals using an electrochemical method (96). Their results indicated that laser irradiation following root canal preparation reduces apical leakage following obturation (96, 97). Maden et al. found no difference in the apical leakage of root canals obturated with Nd:YAG laser-softened gutta-percha, system-B and lateral compaction techniques (98). However, the temperature elevation following laser softening of gutta-percha was a concern (98). Nd:YAG laser irradiation has also been recognized to be an effective tool for softening and removal of gutta-percha and root canal obturation materials (98).
Anic et al. measured dentinal heat transmission induced by three different laser softened gutta-percha obturation techniques using a thermovision camera (99). Argon laser produced a rise in temperature of 12.9 °C, the CO_2 laser produced a rise in temperature of 10.3 °C, while the Nd:YAG laser caused the highest temperature elevation of +14.4 °C (99).

Bleaching of root-treated discoloured teeth

Tooth discoloration subsequent to root canal treatment is a common, aesthetic problem particularly in anterior teeth (100). According to Nicholls, the main causes of intrinsic tooth discoloration related to endodontic treatment are decomposition of necrotic pulp tissue, hemorrhage into the pulp chamber, intracanal drugs and filling materials (101). Gutta-percha and different types of sealers if not removed from the pulp chamber after obturation may cause mild to severe discoloration of the tooth. Laser-assisted bleaching technique has been shown to be an efficient method to treat resistant discolorations in less than one hour (102).

Conclusions

Given the numerous applications of lasers described in the present article in the field of the Endodontics, currently most important focus of this technology is on antimicrobial and disinfection efficiency via either PAD or laser-activated irrigation of the root canal systems. The ability of laser as a diagnostic tool as the Laser Doppler Flowmetry, treatment of dentinal hypersensitivity, pulp capping and pulpotomy has been ruled out in the past. In the area of access cavity and root canal preparation today it is believed that mechanical instrumentation is preferable to laser-assisted procedures. Different types of lasers have been found to be effective to treat severe tooth discolorations, if both their manual and safety issues are carefully considered by the clinicians. More studies are needed regarding the role of lasers in obturation of the root canal systems.

Clinical Relevance

The use of lasers within the scope of endodontic practice and research has increased significantly in the past few years. The most common applications of lasers in endodontics include treatment of dentinal hypersensitivity and root canal disinfection through laser-activated irrigation and photo-activated root canal disinfection.

Conflict of Interest

The author declares there is no conflict of interests.

References

1. AAE Position Statement on Use Lasers in Dentistry, American Association of Endodontists; 2012. Available from: http://www.aae.org
2. Olgaret L, Gazelius G, Lindh-Strömberg U. Non-invasive recording of blood flow in human dental pulp. Int Endod J 1988;2:300-306.
3. Odor TM, Pittford TR. Effect of wave length and band width on the clinical reliability of laser Doppler recordings. Dent Traumatol 1996;6:265-3.
4. Strobl H, Gojer G, Norer B, Emshoff R. Assessing revascularization of avulsed permanent maxillary incisors by laser Doppler flowmetry. J Am Dent Assoc 2003; 12:1597-603.
5. Ritter AL, Ritter AV, Murrah V, Sigurdson A, Trope M. Revascularization of replanted immature dogteeth after treatment with Minocycline and Doxycycline assessed by laser Dopple flowmetry, radiography and histology. Dent Traumatol 2004;20:75-84.
6. Ikawa M, Komatsu H, Ikawa K, Mayanagi H, Shimauchi H. Age related changes in the human pulpal blood measured by laser Doppler flowmetry. Dent Traumatol 2003;1:36-40.
7. Morikawa S, Johnson CC, Lanz O. Laser Doppler measurements of localized pulsatil fluid Velocity. IEEE Trans Biomed Eng 1971;6:416-20.
8. Evans D, Reid J, Strang R, Stirrups D. A comparison of Laser Doppler Flowmetry with other methods of assessing the vitality of traumatized anterior teeth Dent Traumatol 1999;6:284-90.
9. Polat S, Akpinar KE, Polat NT. The sources of laser Doppler blood Flow signals recorded from vital and root canal treated teeth. Arch Oral Biol 2004;1:53-7.
10. Akpinar KE, Er K. Effect of gingival on laser Doppler pulpal blood flow measurements. J Endod 2004;3:138-40.
11. Brännström MA. Hydrodynamic mechanism in the transmission of pain-producing stimuli through the dentin.̀ in: Anderson DJ (Ed.) Sensory mechanisms in dentine. Pergamon Press, London; 1963:73-79.
12. Grossman LI. The treatment of hypersensitive dentin. J Amer Dent Assoc1935; 22:592-6.
13. Lan WH, Lee BS, Liu HC, Lin CP. Morphologic study of Nd:YAG laser usage in treatment of dentinal hypersensitivity. J Endod 2004;30: 131-4.
14. Lee BS, Chang CW, Chen WP, Lan WH, Lin CS. In vitro study of dentin hypersensitivity treated by Nd:YAG laser and bioglass. J Dent Mater 2005;21:511-9.
15. Al-Azzawi LM, Dayem RN. A comparison between the occluding effects of the NdYAG laser and the desensitising agent sensodyne on permeation through exposed dentinal tubules of endodontically treated teeth: an in vitro study. Arch Oral Biol 2006;7:535-40.
16. Birang R, Poursamimi J, Gutknecht N, Lampert F, Mir M. Comparative evaluation of the effects of Nd:YAG laser in dentin hypersensitivity treatment. J Lasers Med Sci 2007;1:2-7.
17. Wan-Hong L, Lee BS, Liu HC, Lin CP. Morphologic study of Nd:YAG Laser usage in treatment of dentinal hypersensitivity. JEndod 2004;30:131-4.
18. Aranha AC, Domingues FB, Franco VO, Gutknecht N, Eduardo CP. Effects of Er:YAG and Nd:YAG lasers on dentin permeability in root surfaces: a preliminary in vitro study. J Photomed Laser Surg 2005;5:504-8.
19. Stabholz AY, Moshonov J. The effect of Er:YAG laser irradiation with and with out water spray on root surfaces of human extracted teeth. Abstract presented at the 8th International congress on Lasers in dentistry, Yokohama, Japan.2002.
20. Jarvis D, Tanelian DL, MacIver B. Electrophysiologic recording and thermodynamic modeling demonstrate that helium-neon laser irradiation does not affect peripheral A-Delta or C-fiber nociceptors. Pain 1990; 43:235-42.
21. Wakabayashi H, Hamba M, Hamba M, Matsumoto K, Tachibana H. Electro physiological study of irradiation of semiconductor laser on the activity of the trigeminal subnucleus caudal neurons. Journal of Japanese Society for Laser Dentistry1992;3:65-74.
22. Melcer J, Chaumette MT, Melcer F, Zeboulon S. Experimental research on the preparation of dentin-pulp tissue of teeth exposed to CO2 laser beams in dogs. CR Soc Biol 1985;179:577-85.
23. Melcer J, Chaumette MT, Melcer F. Dental pulp exposed to the CO2 laser beam. Lasers Surg Med 1987;7:347-52.
24. Melcer J. Latest treatment in dentistry by means of the CO2 laser beam. Lasers Surg Med 1986;6:396-98.
25. Moritz A, Beer F, Walsh LJ. Oral laser application. Berlin Quintessence 2006.
26. Suzuki M, Katsumi A, Watanabe R, Shirono M, Katoh Y. Effects of an experimentally developed adhesive resin system and CO2 laser irradiation on direct pulp capping.Oper Dent. 2005;30:702-18.
27. Santucci PJ. Dycal versus Nd:YAG laser and vitrebond for direct pulp

capping in permanent teeth. J Clin Laser Med Surg 1999;17:69-75.
28. Jayawardena JA, Kato J, Moriya K, Takagi Y. Pulpal response to exposure with Er:YAG laser. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2001;91:222-29.
29. Olivi G, Genovese MD, Maturo P, Docimo R. Pulp capping: advantages of using laser technology. Eur J Paediatr Dent2007;2: 89-95.
30. Shoji S, Nakamura M, Horiuchi H. Histological changes in dental pulps irradiated by CO2 laser: A preliminary report on laser pulpotomy. J Endod 1985;9:379-84.
31. Figueiredo JA, Chavantes MC. Pulpotomies with CO2 laser in dogs. Proceedings of the International Society for Optical Engineering 1995:15-19.
32. Wilder-Smith PE, Dang J, Kurosaki T. CO2 laser treatment of traumatic pulpal exposures in dogs. Laser Surg Med1997;5:432-37.
33. Dang J, Wilder-Smith P,George M, Peavy DWM. Clinical preconditions and treatment modality: effects on pulp surgery outcome. Lasers Surg Med 1998;22:25-29.
34. Pescheck A, Pescheck B, Moritz A. Pulpotomy of primary Molars with the use of a CO2 laser: Results of a long-term in vivo study. J Oral Laser Appl 2002;2:165-9.
35. Kimura Y,Yokoyama K, Watanabe H, Wang X, Matsumoto K. Histopathological changes in dental pulp irradiated by Er:YAG Laser:a preliminary report on laser pulpotomy. Clin Laser Med Surg 2003;6:345-50.
36. Huth KC, Paschos E, Hajek-Al-Khatar N, Hollweck R, Crispin A, Hickel R, Folwaczny M. Effectiveness of 4 pulpotomy techniques-randomized controlled trial. J Dent Res 2005;12:1144-8.
37. Walsh LJ. Pulpal safety parameters for irradiation of dental hard tissues with carbon dioxide lasers. Aust Endod Newsletter 1993;19:21-25.
38. Walsh LJ. The current status of low level laser therapy in dentistry. Part 2. Hard tissue Applications. Aust Dent J 1997;42:302-6.
39. Turkmen C, Gunday M, Karaçorlu M, Başaran B. Effect of CO2, Nd:YAG and ArF excimer lasers on dentin morphology and pulp chamber temperature: an in vitro study.J Endod 2000;26:644-48.
40. Folwaczny M, Mehl A, Jordan C, Hickel R. Antibacterial effects of pulsed Nd:YAG laser radiation at different energy settings in root canals. J Endodon 2002;28:24-9.
41. Piccolomini R, Arcangelo C. Bacteriologic evaluateon of the effect of Nd:YAG laserirradiation in experimental infected root canals. J Endod 2002;28:276-8.
42. Ricardo AL, Britto ML, Genovese WJ. In vivo study of the Nd:YAP laser in persistent periapical lesion. J Photomed Laser Surg 2005;23:582-5.
43. Gutknecht N, Franzen R, Schippers M, ampert F. Bactericidal effect of a 980 nm diode laser in root canal wall dentin of bovine teeth. J Clin Laser Med Surg 2004;22:9-13.
44. Plotino G, Cortese T, Grande NM, Leonardi DP, Giorgio DG, Testarelli L, Gambarini G. New technologies to improve root canal disinfection. Brazilian Dental Journal 2016;27:3-8.
45. De Moor RJ, Meire M, Goharkhay K, Moritz A, Vanobbergen J. Efficacy of Ultrasonic versus Laser-activated Irrigation to Remove Artificial placed dentin Debris Plug. J Endod 2010;36:1580-4.
46. Walsh LJ, George R. Activation of Alkaline Irrigation Fluids in Endodontics. Materials 2017;10:1214-24.
47. Perin FM ,Franca Sc, Silva-Sousa YT, Alfredo E, Saquy PC, Estrela C, Sousa-Neto MD. Evaluation of the antimicrobial effect of Er:YAG Laser irradiation versus 1% sodium hypochlorite irrigation for root canal disinfection. Aust Endod J 2004;30:20-2.
48. Vezzani MS, Pietro R Silva-Sousa YT, Brugnera-Junior A, Sousa-Neto MD.Disinfection of root canals using Er:YAG laser at different frequencies. J photomed Laser Surg 2006;24:499-502.
49. Radatti DA, Baumgartner JC, Marshal JG. A comparison of the efficacy of Er,Cr:YSSGG laser and rotary instrumentation in root canal debridement. J Am Dent Assoc 2006;9:1261-6.
50. Jha D, Guerrero A, Ngo T, Helfer A, Hasselgren G. Inability of laser and rotary instrumentation to eliminate root canal infection. J Am Dent Assoc 2006;137:722-24.
51. Plotino G, Grande NM, Pameijer CH, Somma F. Ultrasonics in endodontics: a review of the literature. J Endod 2007;33:81-95.
52. Walsh LJ. The current status of low-level laser therapy in dentistry, part 1, hard tissue applications. Aust Dent J 1997;42:247-54.
53. Takeda FH, Harashima T, Kimura Y, Matsumoto K. A comparative study of the removal of smear layer by 3 endodontic irrigants and two types of laser. Int Endod J 1999;32:32-9.
54. Wang X, Sun Y, Kimura Y, Kinoshita J, Ishizaki NT, Matsumoto K. Effects of Diode laser irradiation on smear layer removal from root Canal walls and apical leakage after obturation. J Photomed Laser Surg 2005;23:575-81.
55. Ebihara A, Majaron B, Liaw L-H.L, Krasieva TB, Wilder-Smith P. Er:YAG laser modification of root canal dentin: influence of Pulse duration, repetitive irradiation and water spray. J Lasers Med Sci 2002;17:198-207.
56. Santos C, Sousa-Neto MD, Alfredo E, Guerisoli DM, Pecora JD, Comelli Lia RF. Morphologic evaluation of the radicular dentin irradiated with Nd:YAG laser under different parameters and angles of incidence. J photomed laser Surg 2005;6:590-5.
57. Altundasar E, Ozcelik B, Cehreli ZC, Matsumoto K. Ultramorphological and histochemical changes after ER,CR:YSGG laser irradiation and 2 different irrigation regimens. J Endod 2006;35:465-8.
58. Da Costa Ribeiro A, Ngueira GE, Antoniazzi JH, Moritz A, Zezell DM. Effects of diode laser 810 nm irradiation on root Canal walls: thermographic and morphological studies. J Endod 2007;33:252-5.
59. Ishizaki NT, Matsumoto K, Kimura Y, Wang X, Kinoshita J, Okano SM, Jayawardena JA. Thermographical and morphological studies of Er-,cr:YSGG laser irradiation on root canal walls. J Photomed Laser Surg 2004;4 :291-7.
60. Siqueira Jr JF. Aetiology of root canal treatment failure: why well-treated teeth can fail? Int Endod J 2001;34:1-10.
61. Peters OA, Schonenberger K, Laib A. Effects of four Ni-Ti preparation techniques on root canal geometry assessed by micro computed tomography. Int Endod J 2001;34:221-30.
62. Zehnder M. Root canal irrigants. J Endod 2006;32:389-98.
63. Siqueira Jr JF, Roc IN. Optimising single-visit disinfection with supplementary approaches: a quest for predictability. Aust Endod J 2011;37:92-8.
64. Lee MT, Birds PS, Walsh LJ. Photo-activated disinfection of the root canal:a new role for lasers in dentistry. Aust Dent J 2004;3:93-98.
65. Silva LA, Novaes Jr A, de Oliveira RR, Nelson-Filho P, Santamaria Jr M, Silva RA. Antimicrobial photodynamic therapy for the treatment of teeth with apical periodontitis: a histopathological evaluation. J Endod 2012;38:360-6.
66. Da Silva CC, Chaves Junior SP, Pereira GLD. Antimicrobial Photodynamic Therapy Associated with Conventional Endodontic Treatment: A Clinical and Molecular Microbiological Study. Photochemistry and Photobiology2018;94:351-6.
67. Asnaashari M, Ashraf H, Rahmati A, Amini N. A comparison between effect of photodynamic therapy by LED and calcium hydroxide therapy for root canal disinfection against Enterococcus faecalis: a randomized controlled trial. Photodiagnosis and Photodynamic Therapy 2017;17:226-32.
68. Rabello DGD, Corazza BJM, Ferreira LL, Santamaria MP, Gomes APM, Martinho FC. Does supplemental photodynamic therapy optimize the disinfection of bacteria and endotoxins in one-visit and two-visit root canal therapy? A randomized clinical trial. Photodiagnosis and Photodynamic Therapy2017;19:205-11.
69. Pourhajibagher M, Raoofian R, Ghorbanzadeh R, Bahador A. An experimental study for rapid detection and quantification of endodontic microbiota following photo-activated disinfection via new multiplex real-time PCR assay. Photodiagnosis and Photodynamic Therapy 2018;21:344-50.
70. Plotino G, Grande NM, Mercade M. Photodynamic therapy in endodontics. Int Endod J 2018;2:1-15.
71. Carvalho Edos S, Mello I, Albergaria SJ, Habitante SM, LageMarques JL, Raldi DP. Effect of chemical substances in removing methylene

blue after photodynamic therapy in root canal treatment. Photomedicine and Laser Surgery 2011;29: 559-63.
72. Ramalho KM, Cunha SR, Mayer-Santos E. In vitro evaluation of methylene blue removal from root canal after Photodynamic Therapy. Photodiagnosis and Photodynamic Therapy 2017;20:248-52.
73. Figueiredo RA, Anami LC, Mello I, Carvalho Edos S, Habitante SM, Raldi DP. Tooth discoloration induced by endodontic phenothiazine dyes in photodynamic therapy. Photomedicine and Laser Surgery 2014;32:458-62.
74. Zanin IC, Goncalves RB, Junior AB, Hope CK, Pratten J. Susceptibility of Streptococcus mutans biofilms to photodynamic therapy: an in vitro study. Journal of Antimicrobial Chemotherapy 2005;56:324-30.
75. Shahravan A, Haghdoost AA, Adl A, Rahimi H, Shadifar F. Effect of smear layer on sealing ability of canal obturation: a systematic review and meta-analysis. J Endod 2007;33:96-105.
76. Souza MA, Pazinatto B, Bischoff KF, Palhano HS, Cecchin D, De Figueiredo JA. Influence of ultrasonic activation over final irrigants in the removal of photosensitizer from root canal walls after photodynamic therapy. Photodiagnosis and Photodynamic Therapy 2017;17:216-20.
77. Upadya MH, Kishen A. Influence of bacterial growth modes on the susceptibility to light-activated disinfection. Int Endod J 2010;43:978-87.
78. Burns T, Wilson M, Pearson G. Sensitisation of cariogenic bacteria to killing by light from a helium-neon laser. J of Med Microbiol 1993;38:401-5.
79. Takasaki AA, Aoki A, Mizutani K. Application of antimicrobial photodynamic therapy in periodontal and peri-implant diseases. Periodontology 2000;51:109-40.
80. Nagata JY, Hioka N, Kimura E. Antibacterial photodynamic therapy for dental caries: evaluation of the photosensitizers used and light source properties. Photodiagnosis and Photodynamic Therapy 2012;9:122-31.
81. Soukos NS, Chen PS, Morris JT. Photodynamic therapy for endodontic disinfection. J Endod 2006;32:979-84.
82. Kesler G, Gal R. Histological and scanning electron microscope examination of root canal after preparation with Er:YAG laser micro probe:a preliminary in vitro study. JClin Laser Med Surg 2002;20:269-77.
83. Mazeki K, Kimura Y, Yokoyama K, Matsumoto K. Preparation of root canal orifices by Er:YAG laser irradiation: in vitro and clinical observations. J clin Laser Med Surg 2003;21:85-91.
84. Kimura Y, Yonaga K, Yokoyama K, Matsuoka E, Sakai K, Matsumoto K. Apical leakage of obturated canals prepared by Er:YAGLaser. J Endod 2001;27:567-70.
85. Lee BS, Jeng JH, Lin CP, Shoji S, Lan WH. Thermal effect and morphological changes induced by Er:YAG Laser with 2 kinds of fiber tips to enlarge the root canals. J Photomed Laser Surg 2004;3:191-7.
86. Kimura Y, Yonaga K, Murakoshi M, Yokoyama K, Watanabe H, Matsumoto K. Effects on periradicular periodontal tissues of root canal Irradiation with Er:YAG laser in rats. Photomed Laser Surg 2004;4:335-41.
87. Biedma BM, Varela Patino P, Park SA, Barciela Castro N, Magán Muñoz F, González Bahillo JD, Cantatore G. Comparative study of root canals instrumented manually and mechanically, with and without Er:YAG laser. J Photomed Laser Surg 2005;5:465-9.
88. Viducic D, Jukic S, Karlovic Z, Bozic Z, Miletic Y, Anic I. Removal of gutta percha from root canals using an Nd:YAGLaser. Int Endod J 2003;10:670-3.
89. Anjo T, Ebihara A, Takeda A, Takashina M, Sunakawa M, Suda H. Removal of two types of root canal filling material using pulsed Nd:YAG laser irradiation.J Photomed Laser Surg 2004;22:470-6.
90. Moshonov J, Peretz B , Brown T, Rotstein I. Cleaning of the root canal using Nd:YAG Laser and its effect on the mineral content of the dentin. J clin Laser Med Surg 2003;5:279-82.
91. Ali MN, Hossain M, Nakamura Y, Matsuoka E, Kinoshita J, Matsumoto K. Efficacy of root canal preparation by Er,Cr:YSGG Laser irradiation with crown down technique in vitro. J Photomed Laser Surg 2005;23:196-201.
92. Matsuoka E, Jayawardena JA, Matsumoto K. JA: Morphological study of the Er,Cr:YSGG laser for root Canal preparation in mandibular incisors with curved root canals. J Photomed Laser Surg 2005;23:480-4.
93. Jahan KM, Hossain M, Nakamura Y, Yoshishige Y, Kinoshita J, Matsumoto K. An assessment following root canal preparation by Er-,Cr:YSGG laser irradiation in straight and curved roots, in vitro. J Laser Med Sci 2006;21-229-34.
94. Kuzekanani M, Walsh LJ, Yousefi MA. Cleaning and shaping curved root canals: Mtwo vs Protaper instruments, a lab comparison. Indian J Dent Res 2009;20:268-70.
95. Kuzekanani M. Nickel-Titanium rotary instruments: Development of the single-file systems. J Int Society of Preventive and Community Dentistry 2018;5:386-90.
96. Park DS, Lee HJ, Oh TS. Effect of Nd:YAG laser irradiation on the apical leakage of Obturated root canals: an electrochemical study. Int EndodoJ 2001;34:318-21.
97. Kovacevsk I, Georgiev Z, Dimova C, Muratovska I. The use of Nd: YAG laser in root canal obturation: In vitro evaluation. In: 19th Congress of the Balkan Stomatological Society (BaSS), 24-27 Apr 2014, Belgrade. Serbia.
98. Maden M, Gorgul G, Tinaz AC. Evaluation of apical leakage of root canals obturated with Nd:YAG laser-softened gutta-percha, system-B and lateral condensation techniques. J Contemp Dent Pract 2002;15:16-20.
99. Anic I, Matsumoto K. Dentinal heat transmission induced by a laser-softened gutta percha obturation technique. J Endod 1995;21:470-4.
100. Sheets CG, Paquette JM, Wright RS.Tooth whitening modalities for pulpless and discoloured teeth. In:Cohen S, Burns RC.Path ways of the pulp.8th ed.London: Mosby;2002. P.751.
101. Van der Burgt TP, Mullaney TP, Plasschaert AJ. Tooth discoloration induced by endodontic sealers. Oral Surg Oral Med Oral Pathol 1986;61:84-9.
102. Kuzekanani M, Walsh LJ. Quantitative analysis of KTP laser photodynamic bleaching of tetracycline-discolored teeth. Photomed Laser Surg 2009;27:521-5.