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.

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.

**CO₂ 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 odontoblastic 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 [CO₂ laser, neodymium- or erbium-doped yttrium aluminium 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).

**CO₂ 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 CO₂ 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. Branches 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 such as clearance 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 microorganisms 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). Debridging 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 maintenance. 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


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


