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Review Article

Lasers in orthodontics

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ABSTRACT

Many types of dental lasers are currently available that can be efficiently used for soft and hard tissue applications in the field of orthodontics. For achieving the desired effects in the target tissue, knowledge of laser characteristics such as power, wavelength and timing, is necessary. Laser therapy is advantageous because it often avoids bleeding, can be pain free, is non-invasive and is relatively quick. The high cost is its primary disadvantage. It is very important to take the necessary precautions to prevent possible tissue damage when using laser dental systems. Here, we reviewed the main types and characteristics of laser systems used in dental practice and discuss the applications of lasers in orthodontics, harmful effects and laser system safety.

Key words: Dentistry, laser, orthodontics

INTRODUCTION

Laser is the acronym for "Light Amplification by Stimulated Emission of Radiation" that dates back to approximately 50 years ago. In 1960, the first functioning laser was built by the American physicist Maiman at the Hughes Research Laboratories by using a synthetic ruby crystal made of aluminum oxide and chromium oxide.[1] In general, lasers are composed of the three principal parts: An energy source, an active medium and a set of two or more mirrors that form a resonator. Properties such as wavelength are determined primarily by the active medium, which can be a gas, crystal or solid-state conductor.

Laser light is produced as a result of the stimulation of the active medium with an external agent such as a flash lamp strobe device, an electrical current or an electrical coil. A laser beam has several physical characteristics that distinguish it from a typical white light source, including collimation, coherence (phase correlation) and monochromaticity (single wavelength).[1] For dental laser systems, the light is typically delivered to the target tissue through an optical fiber cable, a hollow waveguide or an articulated arm.[2]

Thousands of lasers capable of producing light in the visible, infrared and ultraviolet wavelengths are available. Lasers used in dental practice vary between wavelengths of 488 nm and 10,600 nm. Dental lasers can be further classified in terms of the following characteristics:[3]

- Emission type: Spontaneous emission or stimulated emission
- Output power: High-powered, mid-powered or low-powered
- Active medium: Liquid, gas or solid state
- Target tissue: Hard or soft-tissue
- Potential biological damage: Class I, Class II, Class III or Class IV.

The primary lasers used in dentistry today are the argon, carbon dioxide (CO_2), diode, neodymium-doped yttrium aluminum garnet (Nd: YAG) and the erbium lasers, erbium-doped yttrium aluminum garnet (Er: YAG) and erbium, chromium: yttrium-scandium-gallium-garnet (Er, Cr: YSGG), all of which are named for their active medium content and state of suspension.[3]

During a dental treatment, the effects of the laser on target tissues will depend on the wavelength, power output, exposure duration and the amount of energy delivered to the tissue.[4]

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Most common dental procedures, including the removal of maxiller or lingual midline frenectomies, crown lengthening, composite curing, control of hemorrhage disorders, caries detection and removal, reduction of pain and treatments of hypersensitivity, gingivectomy, gingivoplasty, soft-tissue lesions and aphthous ulcers can all be effectively performed using dental lasers.[5]

DENTAL LASERS

Argon laser

The argon laser, the active medium of which is argon gas, produces light at two wavelengths. The 488 nm blue light is commonly used to initiate the polymerization of restorative composite materials. The 514 nm blue-green light has maximum absorbance in tissues that are composed of pigmented molecules such as hemosiderin and melanin. Both wavelengths of the argon laser are poorly absorbed by non-pigmented and hard tissues.[2] This laser is often used for hemorrhage control in gingival surgery, as well as for detecting cracks and decay on the surface of teeth by using the transillumination technique.[6]

CO_2 laser

The active medium of this laser is CO_2 gas. It produces light at ~ 10,600 nm, which is invisible to the eye. This wavelength has a very high absorbance in water and the highest absorbance in hydroxyapatite as compared with other dental laser systems.[2] The CO_2 laser has some advantages, including rapid soft-tissue removal, perfect hemostasis and shallow depth of penetration, which is why it is commonly used for soft-tissue surgery. However, when using a CO_2 laser, the tooth structure surrounding the soft-tissue surgery site should be carefully protected. These lasers are not suitable for hard tissue applications.[4]

Erbium lasers

Today, erbium lasers are the most commonly used for dental applications. Types of erbium lasers used in dentistry include the Er:YAG and Er, Cr:YSGG.[2,7] The Er:YAG laser (2,940 nm) has YAG as its active medium, while the Er, Cr:YSGG (2,790 nm) has solid yttrium, scandium and garnet.[2] Both wavelengths exhibit high hydroxyapatite absorbance and the highest water absorbance of any dental laser. Because bone and tooth both contain great amounts of hydroxyapatite and water, erbium lasers can be successfully used in hard tissue removal. For such applications while the water in the tooth evaporates, the surrounding soft-tissues can be removed with a minimal thermal effect on the pulp.[7]

Nd:YAG laser

The first laser system designed for dentistry used a Nd:YAG, which has a crystal of YAG doped with neodymium as its active medium.[8] Its wavelength, 1,064 nm, has higher water and pigmented tissue absorption than the wavelength of CO_2 and Er: YAG lasers does. The Nd:YAG results in long-term hemostasis because of the thick coagulation layer. In addition to surgical applications, it has been used for soft-tissue removal[9] and researchers have also explored its use for non-surgical sulcular debridement. Because Nd: YAG light is only absorbed by dental hard tissue, it can safely be used to perform soft-tissue surgery adjacent to the teeth.

Diode lasers

Diode lasers use a semiconductor as the source for emission. Gallium aluminum arsenide (GaAlAs) and helium-neon (He-Ne) are two examples of semiconductor lasers. The active medium of the GaAlAs is solid, consisting of Ga, Ar and Al. Diode lasers used in dentistry vary between approximately 800 nm and 980 nm. Although light in this range is highly absorbed by pigmented tissues and has a great penetration depth in soft-tissues, it is poorly absorbed by dental hard tissues and water.[2] It is not as effective as the argon laser for hemostasis. Because light emitted from diode lasers is poorly absorbed by dental hard tissues, these lasers can be safely used for soft-tissue surgery applications, including gingival recontouring, crown lengthening, removal of hypertrophic tissue and frenectomies close to the enamel, dentine and cement.

LASER USE IN ORTHODONTIC PRACTICE

In orthodontic practice, lasers have many common applications, including acceleration of tooth movement, bone remodeling, enamel etching prior to bonding, debonding of ceramic brackets and pain reduction after orthodontic force and prevention of enamel demineralization. Soft-tissue applications such as frenectomies, gingival contouring and crown lengthening can also be achieved using the dental lasers.

REDUCING PAIN DURING ORTHODONTIC FORCE APPLICATION

It is well-known that following the application of orthodontic appliances, the patient feels pain or discomfort for 2-4 days. Low-level laser therapy (LLLT), in which the energy output is

sufficiently low to prevent a temperature rise above 36.5°C (normal body temperature) in the target tissue,[10] can be used as a convenient analgesic therapy for orthodontic patients.[11-18] This type of therapy also has non-thermal and biostimulatory effects. Although the precise mechanism underlying the analgesic effect of LLLT is not completely known, laser irradiation has neuropharmacological effects on the synthesis, release and metabolism of serotonin and acetylcholine in the central level, as well as histamine and prostaglandin in the peripheral level.[19]

Many researchers have reported that Nd: YAG,[11] He-Ne,[12] and GaAlAs diode[13-15] lasers have analgesic effects for reducing orthodontic pain. Moreover, local CO_2 laser therapy has been found effective in reducing the pain associated with orthodontic force applications.[20]

Tortamano *et al*.[16] concluded that LLLT effectively controls pain caused by the application of the first archwire, but it does not affect the start of pain after the first archwire is placed and does not alter the most painful day. According to findings, LLLT reduces the prevalence of pain after multibanding compared to a control group at 6 and 30 hours.[15] On the other hand, some studies in the literature have shown that LLLT offers no significant pain reduction after separation or placement of archwires.[11,13] In conclusion, induction of laser analgesia is a new treatment modality that has the advantages of being non-invasive, being easy to apply and having no known adverse tissue reactions.

EFFECTS ON TOOTH MOVEMENT

There have been several studies concerned with the biostimulatory effects of LLLT.[19,21] However, the findings on the effects of LLLT on tooth movement are controversial. Seifi *et al*.[22] investigated the quantitative effects of a pulsed laser (Optodan) and a continuous laser (KLO_3) on the orthodontic tooth movement of rabbits. In this study, teeth were irradiated for 9 days according to the periodontal therapeutic protocol; a control group was not irradiated. The authors concluded that LLLT reduced orthodontic tooth movement after treatment.

In another study, Kawasaki and Shimizu[23] applied 10 g orthodontic force to rat molars and experimentally observed tooth movement. A GaAlAs diode laser was used to irradiate the area around the tooth and after 12 days, the amount of tooth movement was measured. Immunohistochemical evaluation showed that the amount of tooth movement was significantly greater for the laser irradiation group (1.3 times) than for the non-irradiation group. The authors also stated that the amount of bone formation and rate of cellular proliferation on the tension side and the number of osteoclasts on the pressure side were both significantly increased in the irradiation group.

Altan *et al*.[24] evaluated the effects of 820 nm diode laser irradiation on osteoclastic and osteoblastic cell proliferation activity and receptor activator of the nuclear factor-kappa B ligand (RANKL)/ osteoprotegerin (OPG) release during orthodontic tooth movement. In this study, the maxillary incisors of 38 albino Wistar rats were moved orthodontically by a helical spring. The laser treatments were performed at five points on the distal side of the tooth root on the 1st, 2nd and 3rd days of the experiment. Based on immunohistochemical parameters, the authors concluded that LLLT accelerates the bone-remodeling process by stimulating osteoblastic and osteoclastic cell proliferation and function during orthodontic tooth movement.

Most of the studies investigating the effects of LLLT on tooth movement have been performed in animals.[21-25] In 2004, Cruz *et al*.[26] investigated for the first time the effects of LLLT on humans. For the 11 patients in the study, half of the upper arch served as a control group, receiving mechanical activation of the canine teeth every 30 days. The opposite half received the same mechanical activation, but was also irradiated with a diode laser. The results of the study showed significantly greater acceleration of canine retraction on the side treated with LLLT compared with the control.

Similarly, Youssef *et al*.[17] investigated the effects of LLLT on canine distalization rate. They irradiated with a GaAlAs diode laser (809 nm, 100 mW) on the 1st, 3rd, 7th and 14th days and reported that LLTH was effective at accelerating the tooth movement rate. Furthermore, Fujita *et al*.[27] concluded that LLLT stimulates tooth movement through induction of the receptor activator of the nuclear factor-kappa B (RANK) and RANKL. In their study, the number of cells that showed positive immunoreactions to the primary antibodies of RANKL and RANK was significantly increased in the irradiation group on days 2 and 3 compared with the non-irradiation group.

Contrary to these studies, the study by Limpanichkul *et al*.[28] showed that GaAlAs (25 J/cm^2) LLLT does

not have any effect on the rate of orthodontic tooth movement. Although there has been no consensus on a proper application dose for stimulating and accelerating tooth movement, researchers advocate that LLLT for this purpose used laser energies varying from 2 to 54 J.[17,21,23-26] Further studies are needed to determine the optimal dose, taking into account variable dose and wavelength.

EFFECTS ON BONE REGENERATION

A number of studies in the literature have shown that LLLT increases fibroblast proliferation and the quantity of osteoid tissue.[29-31] Laser irradiation may play two principal roles in inducing bone formation. The first is stimulation of cellular proliferation, especially nodule-forming cells of osteoblast lineage. The second is stimulation of cellular differentiation, especially to committed precursors, resulting in an increase in the number of differentiated osteoblastic cells and an increase in bone formation.[31]

Saito and Shimizu reported that a GaAlAs diode laser (100 mW) can accelerate bone regeneration in a midpalatal suture during rapid palatal expansion. They advocate that LLLT inhibits relapse and reduces the retention period by accelerating bone regeneration in the midpalatal suture.[29] Angeletti *et al*. evaluated the effects of a GaAlAs laser (830 nm, 100 mW) on bone regeneration in the midpalatal anterior suture after surgically assisted rapid maxillary expansion *in vivo*.[30] According to their study, bone regeneration can be accelerated during the early stages of laser therapy. These results are important for orthodontic practice. However, it is important to remember that the outcome of LLLT on bone regeneration after midpalatal suture expansion depends on total laser dose, the frequency of irradiation and the application timing.

In vivo studies have shown that LLLT has positive effects on wound healing through acceleration of bone regeneration and stimulation of trabecular osteoid tissue formation.

ENAMEL ETCHING DURING BONDING PROCEDURES

Physical changes such as melting and recrystallization occur in enamel after laser irradiation, causing the formation of numerous pores and bubble-like inclusions.[32-34] This process is similar to the type III pattern produced by orthophosphoric acid.[35] Because of this, laser irradiation is a feasible method to etch enamel surfaces as an alternative to traditional acid etching. Furthermore, laser etching of enamel and dentin have been reported to produce a fractured, uneven surface and open dentin tubules, which is ideal for adhesion.[36]

Laser etching produces an acid-resistant surface. Laser radiation of dental hard tissues modifies the calcium-to-phosphorus ratio, reduces the carbonate-to-phosphate ratio, reduces water and organic component content and leads to the formation of more stable, less acid-soluble compounds (thus reducing susceptibility to acid attack and caries).[37] Accordingly, caries resistance by laser etching is a promising topic in orthodontics.[37]

Lee *et al*.[37] compared the bond strength of orthodontic brackets after three different etching procedures: Acid etching, Er: YAG laser etching and a combination of these two methods. Based on their results, the authors demonstrated that Er: YAG lasers may be an effective alternative to conventional acid etching. Uşümez *et al*.[38] evaluated the effectiveness of an Er, Cr:YSGG hydrokinetic laser system in two different power settings in etching enamel for direct bonding of orthodontic appliances. The study showed that etching of the enamel with the Er, Cr: YSGG system yielded lower (though statistically similar) and less predictable bond strengths than acid etching with 37% orthophosphoric acid for 30 s did. On the other hand, they found laser etching to be more practical and faster than conventional acid etching.

To summarize the literature, some authors[39-42] have found laser etching of enamel lead to significantly lower bond strengths compared with acid etching, while others[33,43,44] have reported laser-etching is comparable with or stronger than acid-etching.[33] However, many of these studies evaluated the laser irradiation in different power settings. With regard to the mean shear bond strength, an Er, Cr: YSGG laser operated at 1 or 2 W for 15 s showed comparable results to acid etching.[45] The same laser and application timing produced significant effective etching for orthodontic bonding with the power at 1.5 W.[46] Although 1.5 and 2 W laser irradiation can be an alternative to conventional acid etching, 0.5, 0.75 and 1 W settings are not capable of etching the enamel suitable for orthodontic molar tube bonding.[47]

ENAMEL DECALCIFICATION REDUCTION

Today, phosphoric acid etching appears to be the best method for preparing the enamel for the bonding of

orthodontic attachments. After bonding, the enamel becomes more vulnerable to carries due to increased plaque accumulation around the attachments. This often leads to decalcification of the enamel or formation of white lesions and presents a major problem for orthodontic patients.[48] It has been reported that the laser-irradiated enamel becomes acid resistant.[49] A number of studies showed that an argon laser can be used to prevent enamel decalcification by altering its crystalline structure.[48,50-52] Blankenau *et al*.[50] investigated the effectiveness of argon laser irradiation to reduce demineralization and loss of tooth structure *in vivo*. The experimental teeth in this study were irradiated with a 250 mW argon laser at ~ 12 J/cm^2 prior to banding and exhibited a 29% decrease in demineralization compared with the bilateral control teeth.

Anderson *et al*.[48] also studied the *in vivo* effects of argon laser irradiation on enamel decalcification during orthodontic treatment. In their study, nine volunteers underwent four first premolar extractions; these volunteers were then grouped by the following treatments: Non-pumiced, non-etched enamel; pumiced enamel and pumiced-etched enamel. The experimental groups received irradiation with an energy density of 100 J/cm^2 for 60 s. The authors concluded that argon laser irradiation is effective in reducing enamel decalcification during orthodontic treatment and pumicing and etching prior to laser treatment does not reduce this effect. Another study showed that Er: YAG laser etching of the enamel also imparts greater resistance to acid attack compared with acid etching[53] and several studies have demonstrated that laser irradiation combined with florid treatment produces synergistic effects against acid attack.[54-57]

CERAMIC BRACKETS DEBONDING

Clinicians often encounter fractures and cracks in the enamel and brackets during the removal of ceramic brackets. With the application of laser irradiation, the adhesive resin can be softened, allowing light force to be applied during debonding. An Nd:YAG laser applying at 2 J or more is effective during the removal of monocrystalline and polycrystalline ceramic brackets, although it significantly decreases the bond strength to a greater extent for the polycrystalline ceramic brackets than for monocrystalline brackets.[58]

Feldon *et al*.[59] used a diode laser to irradiate monocrystalline and polycrystalline ceramic brackets for 3 s at 2 and 5 W/cm^2, after they assessed shear bond strength and thermal effects on the pulp chamber. The authors observed that the laser treatment did not decrease the debonding force required for the polycrystalline ceramic brackets, but did significantly decrease the debonding force for the monocrystalline brackets. The treatment did not increase the pulp chamber temperature.[59]

Tocchio *et al*.[60] reported that polycrystalline bracket debonding times were ~ 3 s, 5 s and 24 s for 248 nm, 308 nm and 1,060 nm radiation, respectively, at power densities of 3-33 W/cm^2. No enamel or bracket damage was present in any sample. Strobl *et al*.[61] successfully debonded single crystal alumina (sapphire) and polycrystalline alumina orthodontic brackets with both Nd: YAG (1,060 nm) and CO_2 (10.6 μm) lasers. They concluded that the debonding mechanism was thermal softening of the resin adhesive due to laser-induced heating of the labial surface of the bracket, wherein the heat was transmitted through the bracket to the resin.[61] Several other researchers have also demonstrated that laser irradiation can be effectively used during removal of ceramic brackets.[61-64]

SOFT-TISSUE APPLICATIONS RELATED TO ORTHODONTIC TREATMENT

Dental lasers provide convenience and accuracy during soft-tissue incision. They cause minimal tissue damage, provide hemorrhage control and can also reduce post-operative pain. Soft-tissue applications related to orthodontic treatment include gingival recontouring, exposure of unerupted and partially erupted teeth, removal of hypertrophic and inflamed tissues, frenectomies, miscellaneous tissue and treatment of aphthous lesions.[65] Soft-tissue lasers can also be used for aesthetic contouring of the gingiva within the smile framework, establishing tooth proportionally prior to bracket placement, crown lengthening, treatment crown height asymmetry or contouring of gingival and interdental margins.[66] Nd:YAG lasers are primarily used for soft-tissue applications such as frenectomies, papillectomies and gingival incision.

LASER SAFETY AND HARMFUL EFFECTS OF LASERS

According to the standards of American National Standards Institute and Occupational Safety and Health Administration, lasers are classified into four different classes based on potential danger, as follows:[67]

Class I: These are low-powered lasers that are safe to view

Class IIa: These are low-powered visible lasers. They do not cause damage unless one looks directly along the beam for longer than 1,000 s

Class II: These are low-powered visible lasers. They are dangerous when viewed along the beam for longer than 0.25 s

Class IIIa: These are medium-powered lasers that are not dangerous when viewed for less than 0.25 s

Class IIIb: These are medium-powered lasers that are dangerous when viewed directly along the beam for any length of time

Class IV: These are dangerous high-powered lasers that can cause damage to the skin and eyes. Even the reflected or radiated beams are dangerous. It is necessary to take appropriate safety measures. Most of the lasers used for medical and dental purposes are in this category.

In addition, the inhalation of laser deposits consisting of organic materials, water vapor, carbon monoxide, carbon dioxide and hydrocarbon gas can be dangerous. It is known that lasers operating at wavelengths below 400 nm (although not typically used in dentistry) have a detrimental effect to the skin. Lasers operating at non-visible wavelengths (ultraviolet and infrared) and reflection of laser light from various surfaces can also increase potential danger. Because the biggest risk is for the eyes, protective glasses must be worn by the patient and the practitioner during laser therapy.

CONCLUSION

Laser etching, biostimulant effects and softening of adhesives during debonding are promising areas of laser use in the clinical orthodontic practice. Currently, lasers are predominantly used for research studies in the field of orthodontics. In the near future, with the clarification of laser exposure protocols and a decrease in cost, lasers may play an increasingly important role in orthodontic therapy.

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