Application of Laser Technology in Dental Clinical Treatment

Xinyue Lyu

Epsom Girls Grammar School, New Zealand

Abstract

In recent years, the application of laser technology in dental treatments has been increasing. Erbium laser is commonly used in the treatment of dental hard tissue diseases, such as dental caries, desensitization, root canal disinfection, apical surgery and so on, because its wavelength is close to the infrared absorption peak of water and hydroxyapatite. On the contrary, Nd:YAG laser, CO_2 laser, He-Ne laser and Diode laser are often used in the treatment of oral soft tissue diseases, such as labial frenulum repair, mucosal diseases and so on, because of their good absorption characteristics of wavelength, and their bactericidal and hemostatic effects. Treatment of both soft and hard oral tissue can be achieved by using different types of lasers. This article describes the active mechanisms of the most commonly used lasers and their applications in clinical treatment.

Keywords

Lasers; Active Mechanism; Dental Clinical Treatment; Applications.

1. Introduction

In July 1960, the first laser in the world was developed by Maiman, an American scientist. It began to be used in the clinic the following year. Since then, lasers have been applied in various fields of medicine. Lasers have some characteristics different from ordinary light, such as high brightness, good direction, high monochromaticity and high coherence. The laser has the functions of ablation, vaporization, hemostasis and biological stimulation.

Since then, laser technology has progressed quickly, with it being applied for a variety of dental procedures. This has been due to multiple advantages laser-based methods have over traditional drilling practices, such as inducing less pain and emitting less sound and vibrations. Laser technology has allowed for a drier and cleaner environment around the clinician’s viewing and working areas, which also may increase the likelihood of satisfactory outcomes for patients. Furthermore, the utilization of laser-based tools in place of other instruments may attract patients that otherwise would perhaps avoid seeking dental care due to phobias surrounding traditional, sharp-looking instruments.

When laser energy reaches the surface of the tissue, it can be reflected, scattered, absorbed or transmitted to surrounding tissue. The performance of laser depends on the degree of absorption, the presence of free water molecules, proteins, pigments, inorganic substances (such as apatite) and other macromolecules are the main factors affecting the absorption of laser in biological tissue. The degree of absorption (i.e. the penetration depth of laser in biological tissues) depends on the wavelength. Lower absorption coefficients indicate deep penetration into biological soft tissues, while higher absorption coefficients represent surface absorption, therefore, according to the different wavelength, lasers are generally divided into: (1) deep penetration type, such as Nd:YAG laser and Diode laser. Shallow penetrating lasers, such as CO_2 laser, Er: YAG laser and Er, Cr: YSGG laser, are absorbed in the shallow layer and cannot penetrate or scatter very deep. According to the energy level, they can be generally divided into: (1) low-energy output lasers, also known as "soft lasers", such as He-Ne laser and Diode laser; and (2) high-energy transmission. Laser output, also known as "hard laser", such as Nd: YAG laser, CO_2 laser, Er: YAG laser, Er, Cr: YSGG laser.

so this article aims to review different types of lasers and their applications in dental clinical treatment.

2. Er: YAG and Er, Cr: YSGG Laser

The Erbium Family contains two distinct wavelengths: (2) Erbium:YAG (2940 nm) which has a medium of yttrium aluminum garnet doped with erbium (Er:YAG) and (1) Erbium, chromium: YSGG (2780 nm) which has a solid crystal of yttrium scandium gallium garnet doped with erbium and chromium as medium (Er,Cr:YSGG).

2.1 Er:YAG: Mechanism of Action

The Er:YAG laser of the mid-infrared spectrum is the most effective one for enamel ablation. Its wavelength is close to the absorption peak of infrared radiation by water and hydroxyapatite. When the laser energy makes contact with the enamel matrix, water molecules and hydroxyapatite in the enamel will absorb the laser energy. The local thermal energy then causes a volume expansion in the enamel matrix and hence a series of micro-evaporative thermal explosions that result in a mechanical ablation in thin layers. Furthermore, minimal thermal diffusion and an increase in tissue temperature can be achieved by keeping the enamel hydrated with water. The ablation ability of the laser is the smallest for soft tissue and hard tissue, but the hemostasis effect is not as good as that of CO_2 laser, and the cost is high.

2.2 Er:YAG: Applications in Dentistry

The Er:YAG laser can be used in enamel cutting and was firstly reported for use in preparing hard tissue treatment of preparing enamel and dentin in 1988. The rate of ablation should be within 20-50 μm/pulse to maintain efficiency. In subsequent experimentation, it was shown to be as effective as handpiece and has minimal adverse side effects and risks. Caries removal and etching can also be achieved by the Er:YAG laser. In fact, due to its high water content, the Er:YAG's ablation efficiency in removing caries is greater when compared with other tissues and makes the procedure more convenient. Thus, the Er:YAG laser, which emits limited vibration and causes minimal damage to surrounding tissues, is effective for use in removing caries. The bond strength of dental hard tissues treated with Er:YAG laser are further improved when combined with the use of etchant.

The Er:YAG laser have been used periodontal treatment as well. In the treatment of periimplantitis, it can be used to clean the implant surface. Low power pulsed Er: YAG laser can enter periodontal pocket to remove subgingival calculi and superficial infection of cementum on root surface, prevent inflammation progress, and promote periodontal healing. Due to its outstanding ability to cut hard tissues and dental calculus with a low risk of damaging to adjacent tissue, Er:YAG lasers are the best choice in treating periodontal diseases. They are also able to result in a smooth root surface at any energy settings in clinical use. Er:YAG laser can be used for root canal disinfection and kill bacteria including Enterococcus faecalis, remove the smear layer in the root canal, significantly improve the clearance rate of bacteria in the root canal, isthmus and extraapical area.

Er:YAG laser-assisted bleaching can enhance the bleaching effect and shorten the diagnosis and treatment time. For patients, less pain, no dentin-sensitive symptoms. However, the long-term effect of Er:YAG laser in tooth bleaching still needs to be further explored. Er:YAG laser used in soft tissue incision, such as frenulum plasty, without anesthesia, painless, clean incision, accurate, effective hemostasis during operation, good disinfection effect, no need to suture, and faster healing after operation, low scar incidence Er:YAG laser can coagulate and seal small vessels. Regional hemorrhage to obtain a clearer vision can reduce postoperative swelling and promote healing.

2.3 Er,Cr:YSGG: Mechanism of Action

Er, Cr: YSGG laser, also known as water laser, belongs to a mid-infrared solid-state laser. Its wavelength is 2780 nm, which is close to the absorption peak of water and consistent with the absorption band of hydroxyapatite. Its mechanism of action is similar to that of Er: YAG laser. The use of Er,Cr:YSGG in cutting teeth was first reported by Friedberg et al., whom in 2002 discovered that, when the laser passes through a mixture filled with water molecules, extra energy can be required to initiate the ablation. This method is used to weaken the infrared beam and thereby absorb heat.

Compared with Er: YAG laser, Er, Cr: YSGG laser has better absorption of water and enamel apatite. R:YSGG laser irradiation can inhibit the conduction of local nerve impulses and relieve pain.

2.4 Er,Cr:YSGG: Application in Dentistry

Studies show that Er, Cr: YSGG laser can effectively remove caries tissue, and in the condition of 4W to remove decayed enamel and dentin surface without melting and carbonization and other changes in thermal damage. Pulp capping: It was found that Er, Cr: YSGG laser irradiation in 0.5W anhydrous condition can achieve significantly. The bactericidal effect, combined with pulp capping agent, has a better prognosis. Root canal disinfection: Er, Cr: YSGG laser cannot only remove biofilm but also play a bactericidal role in root canal. It has a better effect on the removal of Enterobacter faecalis and Candida albicans. However, some studies have found that Er, Cr: YSGG laser has a better effect on the removal of Enterococcus faecalis in infected root canals Better than NaOCl solution.

Er, Cr: YSGG laser subgingival debridement is a safe, comfortable and clinically effective method of periodontal debridement. In some in vitro studies, Er, Cr: YSGG laser has been proved to be effective in removing subgingival calculi, eliminating inflammation and edema, without causing damage to the root surface Er, Cr: YSGG laser in periodontal pocket debridement. Another advantage of the operation is that as long as sufficient water mist cooling is used, thermal damage (such as carbonization or fusion of the root surface) can be avoided. Desensitization: Er, Cr: YSGG laser (1.25W) can effectively treat dentin hypersensitivity.

As research has shown, the Er,Cr:YSGG laser can be used to perform other various kinds of ablation – such as maxillary frenectomy and pyogenic granuloma excision – due to its excellent ability to promote good wound healing in children with no discomfort or complications.

3. Nd:YAG lasers

3.1 Mechanism of Action

The Nd:YAG laser (1060nm) is used with a clear solid crystal medium emitting radiation in the infrared spectrum and, due to its wavelength, is invisible. Like the CO_2 laser, it can be divided into two irradiation modes: pulse type and continuous type. The pulse type can emit laser intermittently, which greatly reduces the heat accumulation, avoids excessive temperature and reduces the possibility of damage to adjacent tissues. Therefore, it is obtained more than continuous Nd:YAG laser. Its wavelength is barely absorbed in water, but well absorbed by dark pigments of blue or black (such as hemoglobin and melanin which can improve the laser absorption). The super-light-heat effect achieves homeostasis for blood vessels, and it can also coagulate and sterilize the incision and effectively reduce the incision infection. The depth of penetration ranges from 2 to 6 mm, which is a bit less than that of the CO_2 laser. The energy is emitted from a carbonized tip of a fiber, and the peak power of the Nd:YAG is great enough to penetrate the carbonized debris at the tip.

3.2 Applications in Dentistry

It has been found that Nd:YAG laser combined with dye irradiation on enamel surface can reduce the content of bicarbonate and water in enamel. And eventually form a structure which is more resistant to acid dissolution, so it can prevent dental caries Nd:YAG laser irradiation of enamel can show rough surface, large porous surface depth, obvious surface particles, less dents and similar to the enamel surface blown by traditional etchant. Therefore, Nd:YAG laser can be used as an alternative to acid etching technology in enamel etching. However, cracks might appear in some cases. Overall, successful ablation of dentin with smear layer and debris removal has been observed (Rossella Bedini et al).

Nd:YAG laser is applied to pulpotomy. No carburized area or coagulative necrosis of pulp tissue was found and the clinical success rate was higher root canal cleaning and disinfection: In vitro studies showed that Nd: YAG laser (15Hz, 35mJ) could effectively remove Enterococcus faecalis desensitization: Nd: YAG laser (20Hz, 100mJ) was a rapid and successful method to alleviate dentin hypersensitivity. Periodontal therapy: Nd:YAG laser can remove epithelial cells in periodontal pockets and inhibit or eliminate periodontal pathogens in periodontal pockets. It is reported that Nd:YAG laser combined with subgingival curettage and root surface leveling can significantly reduce the number of bacteria in chronic periodontitis patients with type II root bifurcation defects.

Nd:YAG can be successfully used for soft tissue applications with no anesthesia and minimal bleeding. Excision, coagulation like maxillofacial procedures, and soft tissue surgery are good examples of such uses. The Nd:YAG laser can assist a CO_2 laser with the resection in vascular tissues. Nd:YAG laser combined with tonsillectomy, tongue-based surgery and nasal surgery are effective methods for the treatment of OSAS with mild to moderate operation.

4. CO_2 laser

4.1 Mechanism of Action

The CO_2 laser (10,600 nm) is the discharge of water or cooled air that contains a gaseous mixture with CO_2 molecules, which assist with producing a beam of infrared light. The light energy is well absorbed by water and produces light through a hollow waveguide continuously. Its wavelength makes it easier to cut and coagulate soft tissue in a clear operating area. Ablation is one of the functions of the CO_2 laser and can be achieved by a fluence of 5 J/cm^2 delivered via a required per pulse rate of less than 1ms (so as to avoid excessive thermal damage). Once it absorbed the laser-generated heat (notice the temperature is around 66.8°C), collagen will denature and contract immediately due to the shrinkage of fibers; this is, together with the assistance of vaporization of intracellular water and ablation, the primary mechanism of tightening skin.

On the other hand, wound healing starts with matrix metalloproteinases, which is the breakdown of the collagenous matrix. This leads to the rapid healing of the epidermis from the epidermal cells besides. The dermal neocollagenesis can last at least half a year.

4.2 Applications in dentistry

The CO_2 laser has been widely used as a “light scalpel” and is effective for oral surgeries. In surgical applications, a CO_2 laser can make the soft tissue procedures bloodless, with the least amount of disturbance to neighbor tissues and no negative biological side effects. When applying a CO_2 laser on the base of a lesion, it causes tissues to contract and thus providing a clean and dry operating field.

This therapy can be used to treat mucosal lesions due to its penetration depth of 0.01mm. The study shows low-power level CO_2 laser beams can also limit pain after applications without interfering with tooth movement, due to a reduction in local neural anesthesia.

The use of CO_2 laser at a certain power can effectively treat dentin allergies and reduce symptoms of dentin hypersensitivity. The orifice of dentin tubules becomes smaller, the peritubular area melts, and the tubular occlusion rate is relatively high. There is no significant impact on the composition and structure of the mineral content caused by CO_2. Some research showed that 2% sodium fluoride was able to more effectively alleviate the pain caused by dentin hypersensitivity. The CO_2 laser can also be implemented in endodontics. The enamel absorbs all of the CO_2 radiation, which transfers heat since the thermal damage is brought out by transporting energy. Although a study by Fried (1997) shows that the wavelengths between 9.3 and 9.6 um with a high reflective rate might pose a safety hazard, a 10.6um-pulsed CO_2 laser works properly in cutting hard tissues in 1990’s TEA.

Periodontal procedures also benefit from CO_2 laser as it can provide a clear surgical field through rapid hameostasis with minimal damage to hard tissue. For treatment of peri-implant infection, CO_2 laser (5W) removes bacterial contaminants on the implant surface without any damage to the implant surface structure. Furthermore, studies have shown the efficiency of this therapy by applying in regeneration of tissues and gain attachment cases.

Studies have confirmed the effectiveness of CO_2 laser in reducing surface enamel demineralization. The depths of surface loss (erosion) and severity of demineralization in the irradiated area of CO_2 laser have been significantly reduced. If combined with fluoride treatment, this protective effect can be enhanced.

However, there are some disadvantages to using CO_2 laser. For example, it can rapidly carbonize the tissue involved and cause dentin cracking or melting on root surfaces. Additionally, reforming epithelial tissue and contracting of the wound can delay the healing process by several days.

5. Low-Level Laser Therapy

5.1 Mechanism of Action

Low-level laser therapy (LLLT) is a form of medicine, which involves the applications of low power laser, such as He-Ne laser and Diode laser, to the surface of the body. This therapy can relieve pain and is typically used to cut tissue. The wavelengths used in LLLT range from 630 to 980nm with pulsed emission and a power output of 50 to 500mW. Instruments using such wavelengths and output powers, while excellent as coagulators, make for poor scalpels. Temperatures keep steady when using low-level lasers and results are brought about by photobiostimulation effects in the targeted tissues. The therapy implemented with this type of lasers is described as LLLT, which are related with biostimulation and biomodulation. Moreover, the strength of the absorbed light energy depends on the biostimulatory effects of laser irradiation. The applied irradiation factors: such as wavelength, power, energy value, exposure time and wave shape are required within appropriate limits to make LLLT work effectively.

The biostimulatory effects of low-level lasers, and the use of LLLT as a treatment, was first reported by Dr. Endre Mester in 1967. These biostiumulatory effects are reactions that occur upon the absorption of photons by chromophores. This process increases DNA and RNA synthesis and is used in laser therapy to ensure that the procedure can be done safely. The absorption of particular wavelengths mostly determines the mechanisms of LLLT by photoreceptors in sub-cellular components. This absorption may cause alterations in molecular configuration, including primary reactions that may lead to structural changes and stimulate biochemical activities, as well as secondary reactions that increase signal transduction and energy availability upon light absorption. Some studies suggest that laser energy may be absorbed by intracellular chromophores and converted into metabolic energy, which increases the activity of adenosine triphosphate, thereby promoting the release of macrophages and fibroblast growth factor and the proliferation of these cells. Therefore, many studies have found that He-Ne laser has achieved good results in the treatment of refractory wounds and chronic ulcers. In bone tissue, it can promote the formation of new bone, enhance the activity of osteoblasts, increase vascularization, and promote collagen fiber tissue growth.

Diode laser, also known as semiconductor laser, belongs to near infrared (NIR) solid-state laser. Diode laser medium is mainly composed of aluminum, gallium, arsenic, indium compounds. The composition of the medium determines the wavelength. Diode laser is emitted in continuous and gated pulse mode. At present, the most widely used Diode laser is GAl. The mechanism of action of As (Gallium Aluminum-Arsenide) laser (810-830 nm) and InGaAs (Indium Gallium-Arsenide) laser (980 nm). The diode laser is based on the difference of energy levels between conducting electrons and valence band electrons in these semiconductors Due to the absorption characteristics of wavelength (805-980 nm), Diode laser irradiates pigmented tissues hemoglobin Protein and Oxyhemoglobin have affinity, and the thermal effect of laser also blocks capillaries. It is found that they can stimulate fibroblast proliferation and cell differentiation without changing cell cycle, which is conducive to wound healing. Good results have been achieved in the treatment of diseases such as peri-implant inflammation. In soft tissue cutting, it can reduce bleeding in the operative area, keep the operative field clear, have higher penetration depth to biological tissues, and save space and cost than other laser systems.

5.2 Applications in dentistry

The clinical applications of LLLT include wound healing and pain reduction. Bjordal et al. (2006) concluded that laser phototherapy can be titrated to reduce acute inflammatory pain. LLLT can relieve pain in burning mouth syndrome, lichen planus. LLLT can promote the proliferation of oral mucosal fibroblasts. Therefore, LLLT can effectively promote wound healing and shorten healing time in the treatment of recurrent aphthous ulcer.

Dentin hypersensitivity can be effectively decreased through LLLT. Usually anti-sensitivity matters are implemented, but the laser irradiation on the cervix and apex areas of the problem teeth can be required to assist for those complex cases such as reversible pulpitis. In 1994, Gerschman et al. published a study showing that 830 nm is the most effective wavelength for a low-level laser to reduce sensitivity in the dentinal area of sensitive teeth by repeating treatment in three-time intervals.

In implantology, low power laser irradiation of titanium implants has been found in animal studies, which increases bone-implant contact, better connect bone implants, increases the percentage of calcium and phosphorus, hydroxyapatite calcium, and has no effect on bone resorption laser irradiation is helpful. Promoting bone healing increasing the cellular activity of tissues. With the increase of ATP activity, the activity and activity of bone cells also increase. Some studies have shown that LLL photon energy is transferred to the nucleus, through the synthesis of DNA, RNA and protein, will lead to new bone formation and absorption, thereby increasing bone integration.

Low-energy laser application in direct pulp capping can promote cell differentiation of odontoblast-like cells, synthesis of extracellular matrix and formation of reparative dentin while effectively sterilizing. In addition, hemoglobin and melanin are beneficial to large absorption of the low-energy laser. The treatment area was dry in a short time and the hemostasis effect was good. LLLT results in improved wound healing and may also be used to address periapical lesions. A study reported reduced inflammation experienced by participants in its treatment group. Additionally, the frequent use of LLLT may lead to the stimulation of type I collagen fiber synthesis and the consequent reinforcement of scar tissue.

The repairing of damaged nerves and tissues, while generally slow processes by nature, can be sped up through LLLT due to the treatment’s stimulation of axon growth in damaged fibers. Additionally, nausea can also be effectively reduced by using at least 2J of energy aimed at the hand-wrist region and the pericardium 6 meridian acupressure point.

It should be noted, however, that LLLT is not without its risks and shortcomings its own. These include possible occurrence of vertigo in patients due to drops in blood pressure, high costs, accessibility issues, thermal damage to soft tissues, etc.

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