Applications of Lasers in Modern Orthodontic Practice: A Review of Literature

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Abstract

Lasers are being introduced as an upcoming tool in medical and dental specialties. While there is a long list of its dental use, its use in orthodontics, in particular, is limited. Advantages of lasers over conventional technology and basic knowledge on lasers, their types, harmful effects and possible uses in clinical orthodontics are discussed

Introduction

The use of lasers in the medical field is very old. In many clinical situations of medicine and surgery, lasers are being used as the sole source of treatment. In dentistry, only during the last two decades have commercially available lasers been used as adjunctive in delivering tissue management conducive to achieving complete hard or soft tissue procedures. The contemporary lasers, however, offer an opportunity to deliver hard and soft tissue treatment that, at least in outline, makes the patient experience somewhat easier than conventional methods. Although lasers can be used in many clinical situations in orthodontics, there are a limited number of literature references mentioning their use, efficiency and cost to benefit ratio versus conventional methods. Thus, this article is an attempt to update the knowledge on lasers, their harmful effects and various possible uses in clinical orthodontics.

Description of Laser

'Laser' is an acronym for 'Light Amplification by Stimulated Emission of Radiation'.[1] *Light* is a form of electromagnetic energy that behaves both as particle and wave and has basic unit of energy called a photon. The three measurements that define the wave nature of photons produced by a laser are velocity, amplitude and wavelength. *Amplification* is a part of the process that occurs inside the laser. Laser devices consists of a central optical cavity containing elements, molecules and compounds in active state surrounded by an excitation source, which provides energy into the active medium, and thus, increases the energy levels to a higher degree. *Stimulated Emission* has its origin from the quantum theory of physics, introduced in 1900 by the German physicist, Max Planck and Danish scientist, Niels Bohr.[2,3] They advocated the smallest unit of energy called a quantum, which is absorbed by the electrons of an atom or molecule, causing a brief excitation and subsequently released as a photon, a process called a spontaneous emission. In 1916, Albert Einstein theorized that an additional quantum of energy to an excited atom would result in the release of two quanta, a process he termed as stimulated emission.[4] These released photons cause excitation of surrounding atoms that leads to generation of a beam of high energy. *Radiation* is the light waves produced by the laser as a specific form of electromagnetic energy.

History of lasers

The theoretical basis that postulated the production of intense light of a specific configuration pre-dated the development of the first laser by over forty years. In 1960, Maiman, a scientist with the collaboration of Hughes Aircraft Corporation USA, developed the first working laser device that emitted a deep red-colored beam from a ruby crystal.[5] In 1960, the first uranium laser was invented by IBM Laboratories. In 1961, Bell Laboratories invented the first helium-neon laser and in 1962 Robert Hall at General Electric Laboratories introduced the first semiconductor laser. The first working neodymium-doped yttrium aluminium garnet (Nd:YAG) laser and CO_2 laser were developed by Bell Laboratories in 1964 followed by the invention of the argon laser in 1964, chemical laser in 1965 and metal vapour laser in 1966. In 1965, Goldman et al. while experimenting with tattoo removal using the ruby laser focused two pulses of that red light on a tooth of his dentist brother and noticed painless surface crazing of the enamel.[6] In mid to late 1970s, the medical community had begun to incorporate lasers for soft tissue procedures, and oral surgeons added the technology in the early 1980s. Subsequently, many authors noted the benefits of CO_2 laser treatment of oral soft tissue lesions and periodontal procedures.[7-9] In 1987, a portable tabletop model was made available and in May 1990, the Food and Drug Administration cleared pulsed Nd:YAG laser (dLase 300 laser), developed by Myers and Myers specifically for general dentistry.[10] In 1989, Hibst and Keller showed experimentally the effectiveness of pulsed erbium YAG laser for cutting of enamel, dentin and bone.[11] In the 1990s, a wide range of lasers was introduced for various purposes like for curing of composites, tooth whitening, sulcular debridement, and removal of coronal pulp and for selective ablation of enamel caries. Recently lasers are also being used in various clinical procedures in orthodontics like bonding, debonding, craniofacial imaging, gingival contouring and prevention of enamel demineralization etc.

Laser delivery systems

The coherent, collimated beam of laser light must be able to be delivered to the target tissue in a manner that is ergonomic and precise. There are two delivery systems that are commonly used. One is a flexible hollow waveguide or tube that has an inferior mirror finish. In this system, the laser energy is reflected along this tube and exits through a handpiece at the surgical end with the beam striking the tissue in a non-contact fashion.

The second delivery system is a glass fiber optic cable that is lighter in weight, more pliant and has a smaller diameter than the waveguide. This fiber system can be used in non-contact or contact mode. Most of the time it is used in contact fashion, directly touching the surgical site.

Classifications of lasers

A. According to their mode of emission
   a) Fractioned
   b) Continuous
   c) Pulsed

B. According to their power
   a) High power laser
   b) Medium power laser
   c) Low power laser

C. According to the emitting material
   a) Gas laser
   b) Solid state laser
   c) Dye laser
   d) Semiconductor diode laser
   e) Ring laser

D. According to the type of tissue being acted upon

a) *Hard tissue lasers*- The hard tissue lasers are used to cut precisely into bone and teeth, to prepare teeth surfaces for bonding, to remove small amounts of tooth structure, and to repair certain worn down dental restorations.

b) *Soft tissue lasers*- Soft tissue lasers penetrate soft tissue while sealing blood vessels and nerve endings. This is the primary reason why many people experience virtually no postoperative pain following the use of a laser. Also, soft tissue lasers allow tissues to heal faster.

E. According to their potential of causing biological hazard

a) Class I- These lasers are found in compact disc (CD) players and laser caries detectors. Viewing these lasers with naked eye does not implicit any risk. The maximum power output of these lasers is 40μW for blue light emission and 400 μW for red light emissions.[12]

b) Class II- These lasers are found in laser pointers. There are risks in viewing light emissions, both to the naked eyes and when using magnification.[13,14] The maximum output of these lasers is 1 mW.

c) Class III- These are three subtypes like Class IIIa, IIIb and IIIr.

Class IIIa lasers can emit any wavelength and when viewed momentarily, they are non hazardous to an unprotected eye.

Class IIIb lasers are lasers with a maximum power output of 0.5 mW. Examples include ‘soft’ medical lasers, laser light show equipment and laser measuring devices. Environmental controls, protective eyewear, appointment of assigned safety personnel and training in laser safety are required by personnel using these lasers.[15] These lasers can be hazardous to unprotected eyes if viewed directly or from reflective light for any duration.

Class IIIr are lasers with lower power outputs than IIIa, and include like low-level medical devices and targeting lasers. For emission in the visual range of wavelengths

(400-700 nm), the maximum power output is 5 mW and 2 mW with invisible radiations. The same safety measures are required as with class IIIb lasers.[16]

d) Class IV- This class includes all high-powered, surgical and other cutting lasers. There is no upper limit of power output. All surgical lasers used in dentistry and in oral and maxillofacial surgery are included in this group. The protective measures applicable to class III lasers are further endorsed with the additional risk of fire hazards, due to flash-point temperatures being reached in chemicals used adjunctively to surgical procedures. This group of lasers represents the greatest risk of damage, both to unprotected persons and target tissues, either through direct or reflected and scattered beams. [17]

Various types of lasers

Various lasers are named according to their active medium, wavelength, delivery system, emission modes, tissue absorption and clinical applications.

Argon laser

Argon lasers have an active medium of argon gas. It is delivered in continuous-wave and gated-pulse modes by means of fiber optics. It has two wavelengths, 488 nm (blue) and 514 nm (blue-green). Both wavelengths are poorly absorbed by dental hard tissues and water and thus advantageous during gingival surgeries as there is no interaction and no damage to the tooth surface during those procedures. Argon laser in its wavelengths illuminates the tooth and hence can be used as an aid for caries detection, with the carious enamel showing a dark orange-red colour.

Diode laser

Diode laser is a solid-state semiconductor laser that uses some combination of aluminium, gallium and arsenide to change electric energy into light energy. The available wavelength for dental use ranges from 800 to 980 nm, which falls in near-infrared portion of electromagnetic spectrum. The diode is an excellent soft tissue laser indicated for sulcular debridement and gingival surgical procedures. It is not well absorbed by dental hard tissues. The main advantage of the diode laser is that it can be used in a small size instrument.

Nd:YAG laser

It has a solid active medium, a crystal of yttrium-aluminum-garnet doped with neodymium. It was the first laser designed exclusively for dentistry. The emission wavelength is 1064 nm and it is highly absorbed by water and pigmented tissues. It is absorbed slightly by dental hard tissues, allowing soft tissue surgery adjacent to the tooth to be safe and precise. This laser is commonly used in various periodontal procedures like sulcular debridement and vaporization of pigmented carious surface lesions. In orthodontics it is used for debonding of brackets after orthodontic treatment.

Ho:YAG laser

Ho:YAG laser has crystal of yttrium-aluminum-garnet doped with holmium as an active medium. The wavelength is 2120 nm corresponding to near-infrared region of electromagnetic spectrum. Its absorption by water is more than Nd:YAG but it has little affinity for pigmented tissues. The laser’s absorbency by tooth structure is low, which allows tissue surgery in close proximity to enamel, dentin or cementum to proceed safely.

The Ho:YAG laser is commonly used in arthroscopic surgery of the temporomandibular joint.

Er,Cr : YSGG and Er:YAG laser

Er,Cr : YSGG (2790 nm) laser has an active medium of a solid crystal of yttrium-scandium-gallium-garnet doped with erbium and chromium. Er:YAG (2940 nm) has an active medium of yttrium-aluminium-garnet that is doped with erbium. Both the lasers are highly absorbed by water and hydroxyapatite. These lasers are ideal for caries removal and tooth preparation when used with the water spray. Both lasers can ablate soft tissue readily because of its water content, but their haemostatic ability is limited. The advantage of these lasers for restorative dentistry is that a carious lesion in close proximity to the gingiva can be treated, and also the soft tissue can be recontoured with the same instrument.

CO_2 laser

The CO_2 laser is a gas-active medium laser that is delivered through a hollow tube-like wave guide in continuous or pulse gated mode. The laser has a wavelength of 10,600 nm and is well absorbed by water. It is a rapid soft tissue remover and is especially useful in cutting dense fibrous tissue. It has the highest absorption in hydroxyapatite than any dental laser. It is useful in orthodontics for bracket debonding procedures.

Orthodontic applications of laser

Polymerization of light cure adhesive

Notwithstanding improvements in orthodontic bonding materials,[18] decreased curing time for bonding orthodontic attachments is an important aspect of clinical success. Camphorquinone, the photo initiator in most visible-light cured adhesives,[19,20] is highly sensitive to light in the blue region of the visible light spectrum and has a peak area of absorption at 470 nm.[21] The wavelength specificity of the argon laser, coupled with the ability to consistently emit visible light with substantial energy density without any wasted or unusable emissions,[22] has been shown to enhance the physical properties of composite resins by achieving a more thorough cure with up to 75% shorter exposure time compared with conventional light-curing units.[23-26] Powell, Morton and Whisenat found that the laser energy required for polymerization of light-cured materials had no apparent detrimental effects to the pulp or enamel.[27] Several researchers used argon laser with significantly shorter curing times and achieved bond strengths comparable to those attained by conventional light-curing units.[28-31] Cobb et al.[32], Shanthala and Munshi[33] and Talbot, Blankenau and Zobitz[34] also demonstrated equal or higher shear bond strengths after curing the composite for 10 seconds with argon laser as compared to curing the composite by conventional visible light for 40 seconds.

Prevention of enamel scars

In 1965 Sognnaes and Stern were the first to report that when the enamel was exposed to laser irradiation, the resistance of enamel to acid attack was improved.[35] To confirm the previous report of Sognnaes and Stern[35], Yamamoto and Sato[36] embedded small pieces of lased enamel into several parts of human dentures. After three months, the unlased area of the enamel showed chalky white lesions, whereas no detectable visible change was observed in the lased area.[36] Using quantitative microradiography, argon laser irradiation of enamel reduced the amount of demineralization by 30-50%.[37,38] Fox, Duncan and Otsuka[39] found that, in addition to decreasing enamel demineralization and loss of tooth structure, laser treatment reduced the threshold pH at which dissolution occurred by about a factor of five. A number of studies have also shown that combining laser irradiation with fluoride treatment could have a synergistic effect on acid resistance.[40-45] In-vitro studies by Powell[38] and by Hicks, Flaitz and Westerman[42-45] had shown marked resistance (30–60%) to demineralization in artificial caries systems and decreased enamel solubility following argon laser irradiation.

Increasing bracket enamel bond strength

The ability of laser irradiation to remove the smear layer has been reported in the literature[46,47] and it was found that after being exposed to laser, enamel underwent physical changes including melting and recrystallization,[48-50] similar to the type III etching pattern produced by orthophosphoric acid.[51] With regard to bond strengths of restorative materials, some studies indicated that acid-etched teeth had significantly more bond strength than laser-etched teeth,[52-54] where as others demonstrated that laser etching could result in bond strength comparable with[55,56] or even stronger than acid etching.[57] The Er:YAG laser with a wavelength of 2940 nm is highly absorbed by water and hydroxyapatite[58] and it was the first approved laser tool applied to dental hard tissues in the United States.[59] Kim et al.[60] compared the effects of erbium-doped yttrium aluminum garnet (Er:YAG) laser ablation and of phosphoric acid etching on the in-vitro acid resistance of bovine enamel and found that reduction rate and reduced depth of calcium content along the subsurface was lowest in Er:YAG laser–treated enamel than the acid etched enamel. Hence, they concluded that the Er:YAG laser–treated enamels were more resistant to acid attack than phosphoric acid–etched enamels.

Reducing pain during orthodontic treatment

Some patients often feel pain or discomfort by orthodontic forces.[61] This discomfort appears immediately after the force application and may last several days after the initiation of tooth movement.[62] One of the suggested methods to control pain is laser therapy.[63,64] Several studies have reported analgesic effects of the tissue-penetrating Nd:YAG,[65] He:Ne,[63] and semiconductor lasers [64,66] for reducing orthodontic pain. Another report shows that the CO_2 laser has better analgesic and higher patient-satisfaction rate than Nd:YAG laser.[67] Pinheiro et al.[68] and Simunovic[69] also reported on the efficacy of low-level CO_2 laser therapy in reducing pain in patients with temporomandibular joint dysfunction. Fujiyama et al.[70] investigated the effect of CO_2 laser in reducing orthodontic pain and concluded that local CO_2 laser irradiation would reduce pain associated with orthodontic force application without interfering with the tooth movement.

Debonding of ceramic brackets

Although ceramic brackets offer better esthetics, but enamel and bracket fractures and cracks are the common problems during debonding procedures.[71] Wood burning pens,[72] warm air dryers,[73] specifically designed electrothermal debonding devices (ETD) [74] and lasers[75,76] have been used to soften bonding adhesives by heat conduction through the ceramic bracket. Strobl et al.[77] (1992) found laser-aided debonding as a safe and easy method for debonding of ceramic brackets and concluded that the debonding mechanism was thermal softening of the resin adhesive by the laser induced heat which transmitted through the brackets to the resin.[77] Actually laser-initiated resin degradation can occur as the result of either thermal softening or thermal ablation or photoablation. Thermal softening occurs when heating could occur directly in the resin or either in the bracket or tooth, depending upon how these components absorbed the light energy with large rise in temperature. Thermal ablation process is faster and rapid buildup of gas pressure along the bonding interface explosively “blow” the bracket off the tooth, independent of any externally applied debonding force without any rise in temperature. Photoablation occurs when very high energy laser light interacts with a material and like thermal ablation, high gas pressure develop rapidly within the interface, and caused the bracket to explosively blow off the tooth. According to Tocchio et al., if brackets debond by blow off and debonding time was greater than 0.5 seconds, then more than a single pulse was required and the thermal softening caused debonding.[75] Conversely, if debonding occurred by blow off and less than 0.5 seconds was required; then ablation caused debonding.[75] Hayakawa studied the debonding of monocrystalline and polycrystalline ceramic orthodontic brackets with a high-peak power Nd:YAG laser and concluded that the application of a high-peak power Nd:YAG laser at 2.0 J or more was effective for debonding the ceramic brackets.[78]

Image scanning and reconstruction (Holography)

New trends in technology include 3-dimensional (3D) digital imaging of the craniofacial region by using laser holography techniques. The basic components of a laser holographic system are the laser, lenses and camera. The laser light must be expanded and collimated and when it passes through the test section, some of it hits objects and deflects, but some passes straight through to create an interference pattern. Various applications of laser holography in orthodontics are:

Facial soft tissue analysis

Baik, Jeon and Lee scanned sixty Korean adults having normal occlusion using 3D-Vivid 900 laser scanner which was relatively easier to use and less time-consuming than computerized tomography.[79] It had also self-calibration and auto-image distortion correction ability. They interpreted from the results that the data obtained could be the guidelines for the 3D evaluation of the facial image, because the 3D facial model constructed by the averaged coordinate values could be a template for orthodontic diagnosis and treatment planning.[79]

Digital models

Kuroda and Motohashi proposed a three-dimensional dental cast analyzing system with laser scanner.[80] This system had an advantage of facilitating the otherwise complicated and time-consuming mock surgery necessary for treatment planning in orthognathic surgery. The system is composed of a measuring device with a slit-ray laser projector and two sets of coupled charged devised video cameras, an image processing unit, a 16-bit personal computer as a controller and an engineering workstation as a post processor. The dental cast is projected and scanned with a slit-ray laser beam. Along with the conventional linear and angular measurements of the dental cast, it also demonstrated the size of the palatal surface area and the volume of the oral cavity.

Measurement of pulpal blood flow during orthodontic treatment

It was proposed earlier that orthodontic treatment might cause a decrease in blood flow to the pulp.[81] McDonald and Pitt Ford found that human pulpal blood flow was decreased when continuous light tipping forces were applied to a maxillary canine.[82] Understanding the effects of orthodontic force on the pulp is of particular importance, especially because altered pulpal respiration rate,[83] disruption of the odontoblastic layer,[84] pulpal obliteration by secondary dentin formation, root resorption[85], and pulpal necrosis[86] have all been associated with orthodontic treatment. Nowadays, laser-doppler flowmetry is a commonly used method to determine the pulpal blood flow. Barwick and Ramsay evaluated the effect of a 4-minute application of intrusive orthodontic force on human pulpal blood flow with laser-doppler flowmetry and concluded that pulpal blood flow was not altered during the application of a brief intrusive orthodontic force.[87]

Gingival shaping and recontouring

Recontouring gingival shape and contour can be readily accomplished in the orthodontist's office with a diode laser. The advantages of a diode laser over other lasers is that it does not cut hard tissues thus making it ideal for gingival contouring without risk of damage to the teeth. The laser is small in size and is least expensive of the lasers making it practical for use in orthodontic practice. Another advantage of a diode laser is that it coagulates, sterilizes, and seals as it incises, creating a "biological dressing".

Apart from the above uses, the diode laser has also been tried in experimental animals for controlling the excessive growth of the mandibular condyle.[88] It was found that a laser is effective in regulating facial growth and could be a substitute for current conventional methods such as a chin-cup[88].

Dental laser safety

Safety is an integral part of providing dental treatment with a laser instrument. There are three facets to laser safety, namely:

a) The manufacturing process of the instrument
b) Proper operation of the device
c) Personal protection of the surgical team and patient

The four major organizations that are concerned with regulations regarding the dental laser systems are:

a) American National Standards Institute (ANSI)
b) Food and Drug Administration (FDA)
c) Center for Devices and Radiological Health (CDRH)
d) Occupational Safety and Health Administration (OSHA)

The FDA, through CDRH, regulates the laser manufacturer, ensuring compliance with medical device legislation[89] while ANSI provides guidance for the safe use of lasers and laser systems by defining control measures for all type of lasers.[90]

Harmful effects of laser

Fire and explosion hazards

Fire explosion is commonly associated with class IV lasers[91] and thus proper precautions like avoiding alcohol or other inflammable materials in the operating area and proper protection of healthy tissue adjacent to the surgical site is required.

Connections and traffic

All lasers require a cooling system; some use an internal fan and others use a fan and a radiator with self-contained coolant. The laser and the associated hook-up components must be kept out of the mainstream of traffic. Fiber-optic delivery systems need special attention because they can be up to 3m long and therefore, can drape easily from the emission part of the floor.

Eye protection

The dentist, assistant, patient and others who are inside the nominal hazard zone are at risk from the direct and reflected radiation of class III and class IV lasers. The majority of laser induced ocular injuries are considered due to operator error. Wearing the correct protective eyewear while using dental lasers is essential because different available wavelengths can and will damage various parts of unprotected eyes quickly. Longer wavelengths interact with structures in front of the eye, causing ablation, scarring and distortion of vision.[92] The additional focusing effect of the cornea and lens concentrates the laser beam, which means that retinal damage can occur even from a very low-powered laser. In fact, the retina is approximately 1,000,000 times more vulnerable to injury than the skin within the retinal hazard range. Retinal injury may initially pass unnoticed, due to lack of pain receptors.[93]

Skin risks

Whilst UV lasers (< 400 nm) are not commercially used in dentistry, there is a combined risk of ablative damage to skin structure and possible ionizing effects that may be pre-cancerous. All other laser wavelengths could cause ‘skin burns’ due to ablative interaction with target chromophores. [94,95]

Laser plume

Whenever non-calcified tissue is ablated, such as in caries removal and all soft tissue surgery, a complex chemical mixture is emitted. This may include water vapour, carbon monoxide and dioxide, hydrocarbon gases and particulate organic material (including bacterial and viral bodies). These products of laser tissue ablation are collectively termed a ‘laser plume’. The effect of plume inhalation can be serious and can cause nausea, breathing difficulties and distant inoculation of bacteria.[96,97]

Pulpal damage

The process of polymerizing composite resins can increase intrapulpal temperature. For the pulp to be able to recover from thermal damage, the temperature increase should not exceed 5.5°C.[98] Resin polymerization by argon laser accomplished polymerization is faster than halogen lamps, and was safer in terms of protecting the pulp from extreme temperature increases.[99]

Conclusion

Since the introduction of lasers to the dental profession, it is accepted as a very effective treatment modality both for hard tissue and soft tissue procedures. In the modern times, with the availability of more advanced laser devices at a relatively lower cost, laser treatment might be adopted as a routine procedure in orthodontics.

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