Review Article

Laser Applications in Orthodontics

Somayeh Heidari[1], **Sepideh Torkan**[2]

[1]Department of Orthodontics, Faculty of Dentistry, Bushehr University of Medical Sciences, Bushehr, Iran
[2]Department of Orthodontics, Faculty of Dentistry, Lorestan University of Medical Sciences, Khorram Abad, Iran

Abstract:

A laser is a collimated single wavelength of light which delivers a concentrated source of energy. Soon after different types of lasers were invented, investigators began to examine the effects of different wavelengths of laser energy on oral tissues, routine dental procedures and experimental applications. Orthodontists, along with other specialist in different fields of dentistry, can now benefit from several different advantages that lasers provide during the treatment process, from the beginning of the treatment, when separators are placed, to the time of resin residues removal from the tooth surface at the end of orthodontic treatment. This article outlines some of the most common usages of laser beam in orthodontics and also provides a comparison between laser and other conventional method that were the standard of care prior to the advent of laser in this field.

Keyword: laser; orthodontics; applications

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***Corresponding Author:** Sepideh Torkan, DDS. MS; Department of Orthodontics, Faculty of Dentistry, Lorestan University of Medical Sciences, khorram abad, Iran. Tel: +98-7712522206; email:sepideh.torkan@yahoo.com

Introduction

The application of lasers in the field of medicine and surgery has gained wide popularity following the discovery of the "Rubby Laser" by Maiman[1]. Since then, research has been directed to introduce laser technology in the field of dentistry. Lasers can be applied to many fields in dental research and basic research offers new possibilities by advancing laser technology[2].

Now, lasers find numerous applications in orthodontics as an important field of dentistry. The purpose of this article is to review some of the major applications of laser in the field of orthodontics.

Low-energy laser irradiation accelerates the velocity of tooth movement

During the orthodontic treatment, slight dental movements within the alveolar bone are performed in a way that optimal dental arch form, functional occlusion and desired smile for each patient are achieved[3]. In order to attain physiologic tissue reactions during tooth movement, the period of time required for fixed appliance treatment in orthodontics is approximately 2-3 years which is a long time and may cause a great burden for the patient[4].In long-term treatment, there is an increased risk of root resorption, gingival inflammation and dental caries[3,4].Successful reduction in orthodontic treatment time requires an increase in the rate of tooth movement. To achieve this goal, having a thorough knowledge regarding the mechanism of tooth movement during orthodontic treatment is essential.

When orthodontic force is applied to the tooth, periodontal ligament (PDL) is compressed on one side of the root (the side which the root of tooth is moved toward). It causes alteration in blood flow, release of chemical messengers and osteoclastic activity which in turn leads to resorption of the alveolar bone at the side of pressure. Simultaneously, on the opposite side from which the root is moving away, PDL is stretched. On the latter side which is also called the "tension side", bone formation occurs due to osteoblastic activity. This couple of bone resorption/formation is called “remodeling”. Any factor that could affect bone remodeling, would affect the rate of orthodontic tooth movement as well[3-6].

In recent years different investigators have studied the results of low level laser therapy (LLLT) during orthodontic tooth movement. Lasers used for therapeutic measures with an output energy below 500 mW are called low level lasers (LLL) and are proven to have a biostimulatory effect on the tissues without increasing the temperature of treated region above the normal body temperature[2,4].So they have the potential to accelerate orthodontic tooth movement by means of influencing the remodeling of alveolar bone without unwanted impacts on the tooth and periodontium[3-6].

Histologic investigations revealed that LLLT during orthodontic tooth movement can profoundly affect cell-mediated alveolar bone remodeling. It was observed that following the commencement of tooth movement, resorption lacunae with TRAP-positive multinucleated osteoclasts was significantly greater on the alveolar surface on the pressure side[5,7,8].RANK/RANKL expression in osteoclasts precursor cells was detected at early stages of tooth movement[5]. The number of matrix metalloproteinase-9 (MMP-9), cathepsin k and alpha(v) beta(3) integrin [$\alpha(v)\beta(3)$]-positive cells was significantly greater in laser irradiated teeth from the second day[7]. At the tension side significantly greater development of trabecular bone formation and higher rate of cellular proliferation were seen[3,8]. Degree of fibronectin and collagen type I expression with an even distribution was significantly increased from the beginning of the experimental tooth movement on both the pressure and tension sides. Reorganization of collagen fibrils was high from the first day[4].

An increase in the number of osteoclasts, osteoblasts, inflammatory cells and chemical mediators, capillary vascularization, new bone formation, collagen fibrils and matrix deposition suggests that low level laser irradiation accelerates the bone remodeling and facilitates the reorganization of the connective tissue[4,9-11]. Since orthodontic tooth movement is based on alveolar bone remodeling and periodontal ligament reorganization, it is not unexpected that numerous investigators came to the conclusion that low level laser irradiation can accelerate tooth movement during orthodontic treatment[3,5,8,9]. In addition, short-term evaluation revealed that laser irradiation leads to a significantly higher bone density 6 months after the completion of orthodontic treatment when compared to a non-irradiated group[12].

Clinical effect of low-level laser therapy in reducing pain in orthodontics

Mechanical forces used during orthodontic treatment lead to acute inflammatory processes that cause some pain and discomfort in the teeth and their supporting tissues [13]. It is usual for patients to experience some pain at certain stages of treatment; after placement of tooth separators [14,15], or fixed orthodontic appliances [16] specially after placement of the first orthodontic archwire [17,18] and on every 21st day after re-activation of the coil springs until complete canine retraction [19] are some of the common examples. The fear of reproducing or exacerbating this pain is an important factor in discouraging patients from seeking or maintaining adequate dental hygiene during orthodontic treatment[13,14]. One way to relieve the symptoms of pain is to use analgesic drugs such as non steroidal anti-inflammatory drugs (NSAIDs). Although this method is effective in minimizing the pain, adverse systemic side effects of the drugs might reduce the rate of tooth movement[14,15,17]. In addition, the pain induced by orthodontic forces is mostly local and therefore local treatment may act more efficiently[15]. Recently low level laser irradiation(LLLT) was introduced as an effective method for localized pain control in medicine and dentistry[2]. Studies have suggested that LLLT can efficiently reduce the pain immediately after insertion of separators or after the first orthodontic archwire placement[14,15,17]. Both single dose and frequent laser irradiation regimens have been reported to be efficient methods in pain reduction. However some authors believe that laser irradiation does not affect the start of pain or alter the most painful day, but can reduce the duration and intensity of pain[17].

The exact mechanism of pain control by laser is not well understood. Inhibition of inflammatory mediators’ secretion is a path suggested for its analgesic effect. Experimental tooth movement revealed that chemical mediators such as prostaglandin E2 (PG-E2) and Interleukin 1-β (IL1-β) are significantly expressed in the periodontium following orthodontic treatment which can cause pain and hyperalgesia[6,13]. Shimizu and et al. reported that LLLT considerably inhibited the production of these inflammatory mediators in stretched human periodontal ligament.[13] Moreover, improvement in peripheral circulation that facilitates hypoxic cells oxygenation and removal of noxious products, stabilization of membrane potential and release of neurotransmitters in the inflammatory tissue are other mechanisms enumerated as laser advantages that can result in analgesic effect during orthodontic treatment[15,16].

Stimulatory effects of low-power laser irradiation on bone regeneration in midpalatal suture during expansion

Having a Constricted maxillary dental arch and narrow palatal vault might lead to problems such as wide buccal corridors which has a deleterious effect on smile esthetics. The resultants dental cross bite also leads to disharmony in occlusion and function of the individual.

Rapid maxillary expansion (RME) is the preferred treatment approach to correct a constricted maxillary arch[20].This technique is used in orthodontics to expand the maxillary arch by lateral repositioning of maxilla and an increase of bone mass on the center.

The principal methods suggested for expansion of midpalatal suture are the following:

1- Orthopedic approach during childhood and early adolescence
2- A combination of surgical and orthopedic approach (Surgically Assisted Rapid Palatal Expansion-SARPE) for adult patients in which mere orthopedic movement is no longer an option due to skeletal maturity or in patients with 5 millimeters or more of maxillomandibular disharmony[20-22].

The major disadvantage of these two methods is the high rate of relapse. Unstable oral myofunction, regeneration of suture related to other facial bones and tension across the palatal tissue are stated as the possible causes of relapse. However, the major cause of early relapse following expansion could be attributed to insufficient bone regeneration along the midpalatal suture. In order to reduce the relapse tendency, retaining the expansion device in place for a long period of time (few months) is advised to ensure suture ossification and maturation takes place sufficiently along the suture[20-24].

Low-level laser irradiation (LLLT) has been suggested as a reliable method to increase tissue regeneration. It has been stated that LLLT induces angiogenic and osteogenic responses which accelerates bone regeneration that leads to a higher stability in treatment results. This results in a reduced required retention period following expansion which is highly desirable[20,21-23].

Effect of LLLT on bone regeneration in midpalatal suture has been studied from histopathologic and cellular standpoints in several studies. Based on the studies conducted on animals with either bone fracture or those undergoing Rapid Maxillary Expansion (RME) who received LLLT, the proliferation of fibroblasts and the formation of osteoid tissue increased in the area of irradiation compared to a non-irradiated group which suggested a subsequent increase in the rate of ossification and the mineral density of the bone[20,23]. It has been suggested that LLLT also stimulates the formation and synthesis of collagen which is the main scaffolding for the osteoid matrix[21].

Form a cellular point of view, effect of LLLT on proliferation and differentiation of osteoblasts following RME has been studied. Proliferation and expression of osteoblastic phenotype cells of midpalatal suture increase in response to laser irradiation which in turn increased the alkaline phosphatase activity[21, 24].

It has also been shown that connective tissue of the suture irradiated with LLLT after midpalatal expansion is similar to its original configuration, owing to a more advanced osteogenesis and fibrogenesis which suggests the effect of laser in the repair process during and after the expansion procedure[25].

Saito and Schimizu concluded that laser irradiation was more effective during the initial stages of bone regeneration (i.e days 0-2), not the same results were observed by irradiation during the later periods (i.e days 4 to 6) or by one-time irradiation[23]. In addition, it is believed that the effects of LLLT depends on the total dose, the frequency and intensity of the irradiation[20].

Overall, a decreased tendency towards relapse and a decrease in retention period are the expected results when LLLT is used in maxillary midpalatal suture expansion, both of which are desirable in the treatment process[20, 21, 23-25].

Laser-welding of NiTi orthodontic archwires for selective force application

Orthodontic wires are responsible for producing the biomechanical forces that are introduced to the teeth via brackets. They are made of four major alloys; stainless steel (SS), cobalt-chromium- nickel (Co-Cr-Ni), nickel-titanium (Ni-Ti) and ß-Ti. Ni-Ti wires benefit atomic properties of both Ni and Ti and have a modulus of elasticity that is one fifth that of SS wires and therefore possess superelasticity and shape memory effect[26]. Ni-Ti wires exert forces that are low and consistent and thus are capable of correcting teeth position in the primary stages of orthodontic treatment[27]. In contrast, the modulus of elasticity of ß-Ti alloys is half of SS wires and the specific properties of ß-Ti wires include excellent formability and corrosion resistance[26].

Conventional superelastic wires, however, have the same mechanical properties through all the length of the wire, while the forces required to move canines or molars are higher[27].

To produce selective force application of orthodontic wires, archwire welding has been suggested. However, welding or soldering of the Ti-based alloys is more difficult due to the high melting point of Ti and its high reactivity potential with Oxygen[26, 28].To overcome this problem, laser welding under Argon shielding has been suggested[26]. An advantage of laser welding is that joining different alloys, regardless of their respective melting points is possible. Laser welding provides selective force and torque application through the archwire by welding different sizes and shapes of wire[26, 27].

It has been reported that laser welding does not affect the superelasticity of the Ni-Ti wires and the deflection-load rate of heterogeneously welded wires is similar to those homogeneously welded[26-28]. However, a high corrosion resistance has been observed in welded wires. The nickel ion release in welded wires was higher than conventional wires, but still lower than the amount contained in drinking water and thus within normal limits[27].

Laser wavelength, peak pulse power, output energy and pulse duration are among several factors that can affect the mechanical strength of the welded joints[29].

Laser as a device for resin adhesive curing

Light-cured adhesives are a popular method in bonding orthodontic brackets due to their ease of application, easy manipulation and the extended time they offer for concise bracket placement compared to previously used chemically-cured adhesives. However, some clinicians are still reluctant to use them since an additional 40 seconds is required for the light curing of each bracket which can easily add up to 13-14 minutes to chair-side time of each patient in case of bracket placement of both arches[30, 31].

The conventional light curing systems such as tungsten and halogen emit a range of wavelength (400-520 nm) in the blue-green spectrum which activates comphorquinon -a photoinitiator in most common dental adhesives- and causing the curing cascade to initiate[32, 33].

Recently, to accelerate the rate of curing in orthodontic brackets, other light curing systems have been introduced such as plasma arc and most recently, Argon laser was introduced as a means to accelerate the bonding process. Unlike the conventional curing systems, Argon laser is monochromatic and produces light in a limited wavelength (with a peak of 488 nm) which is well within the activation range of comphorquinon. Another advantage of Argon laser is that it produces a coherent beam, thus resulting in a collimated light that can easily be focused on a small spot. The superior characteristics of Argon laser can lead to a polymerization process of bracket adhesives up to 4 times faster compared to conventional curing systems[30, 32, 33].

In addition to providing a faster curing time, based on in-vitro studies, it has been concluded that the increase in pulp chamber temperature with Argon laser is significantly lower than that of conventional curing systems. Less frequent enamel fracture during debonding has also been reported with Argon lasers compared to conventional systems[30].

As for bond strength, the results remain controversial. While some authors believe that there is no statistically significant difference in the bond strength of brackets bonded with Argon laser compared to conventional units[30, 33], some others believe that the resultant bond strength with Argon laser is superior to conventional curing systems[32].

What can be deducted from the aforementioned studies is that the Argon laser beam is a collimated coherent beam which is capable of reducing the chair-side time in placement of orthodontic brackets and a more efficient curing process owing to its more consistent wavelength[32].

Laser debonding of ceramic bracketes

Recently, ceramic brackets have been increasingly used in orthodontic treatment of adult patients. Ceramic brackets provide superior esthetics compared to metal brackets which makes them very desirable for patients. However, the major drawback of these brackets is their brittleness which makes bracket removal process very difficult. While metal brackets are ductile and thus can be easily peeled from the tooth surface, ceramic brackets might cause serious problems such as enamel tear outs or pain at the time of removal[34-37].In addition, the lower fracture toughness of ceramic brackets might lead to shattering of the bracket which will subsequently require extra time to remove the remaining of the bracket from the tooth surface. Therefore, different debonding methods have been suggested such as using the ultrasonic or thermal debonding, use of special pliers or warm-air dryers[34-36]. Different laser devices have also been introduced as an adjunct in the removal of brackets. It has been stated that Carbon Dioxide (CO_2), Neodymium-Doped Yttrium Aluminium Garnet (Nd-YAG) or Erbium-Doped Yttrium Aluminum Garnet (Er-YAG) lasers can cause a degradation in the adhesive resin that holds the bracket in place, thereby facilitating the debonding process[34, 36].This can be accomplished through three different mechanisms:[34, 35, 37,38]

1- Thermal softening which is the softening of the bonding agent through heating. As a result, the bracket will fall off the tooth surface.
2- Thermal ablation happens when the temperature of the resin rises so fast that the vaporization happens before thermal softening occurs. This process takes less time than thermal softening and the resultant heat remains focused, keeping the tooth and bracket temperature within normal limits
3- Photoablation happens when very high energy laser is used and as a result the energy level of the bonds between the bonding-resin atoms rises beyond their dissociation energy causing the material decomposition. The bracket, therefore, will be blown off the tooth surface. In this method, little heat diffusion occurs which keeps the tooth temperature well within normal limits

Thermal softening is believed to happen at low power densities, while the other two phenomenons occur more with high power densities.

The main advantages of laser-aided bracket removal are that the produced heat is localized and this method can be used for different bracket designs. With a 2 -second-exposure time with a CO_2 laser, an efficient debonding process could be achieved and lower force would be required[36].

It was concluded that Diode lasers could decrease the debonding force required in monocrystalline ceramic brackets without significant increase in the pulp chamber [39].On the other hand, Er-YAG laser was shown to reduce the force required to remove polycrystalline ceramic brackets[35].

It has to be kept in mind that the laser type, the application technique and bracket characteristics have to be fully considered to prevent undesirable results[34,35].

Laser radiation for resin residues removal after bracket debonding

Once fixed orthodontic treatment is over, what patients are looking forward to is having clean teeth surfaces without any remnants on them. The problem is that after removing brackets, some resin residues remain on tooth surface. The aim is to remove all the residue that might exhibit an appearance of plaque or stain and return the enamel surface to its original condition[40, 41].

Damage to enamel surface might occur at any stage during orthodontic treatment; from cleaning with abrasives before etching the tooth surface to the use of excessive force while removing brackets to incorrect measures in removing composite remaining off the tooth surface with rotary instruments[41].

In order to remove the adhesive resins efficiently, different methods have been suggested such as the use of a scaler or band removing plier, different types of tungsten-carbide burs with either high or low-speed handpieces, Soflex discs and special composite finishing systems with Zirconia paste or slurry pumice as well as ultrasonic application[41-44].

Studies evaluating the efficiency of these different approaches have suggested that they can cause enamel tearouts or enamel loss. Another important concern is the potential hazardous increase in pulpal temperature if an appropriate cooling system is not used[45].

Recent approaches include the use of Carbon dioxide lasers as well as Nd:YAG lasers. Nd:YAG lasers have shown effective removal of composites. It has been shown that Nd:YAG. Lasers can remove the resin residue without causing damage on enamel surface[41,45].

It is well understood that a 6-degree-increase in pulp temperature can lead to irreversible pulpal damages. When the effect of laser on pulp temperature in composite removal procedures was assessed, it was concluded that the duration of application and laser power are the variables that can determine pulpal changes. Therefore, shorter duration of laser application and lower-power units are advocated[45].

The energy of the laser beam can also affect the depth of the craters created on the enamel surface following laser application[41].

When the efficacy of laser in resin removal was compared to conventional tungsten-carbide burs, it was found out that the latter provides a better result[40,46]. One of the major drawbacks of laser was its inability to selectively remove resin[40]. In another study, Almedia et al concluded that although Er:YAG laser does a better job in removing resin remnants, higher amount of enamel is lost with it as opposed to tungsten-carbide burs[47].

It can be concluded that further studies are required for specific details of an ideal resin residue removal method with laser devices.

In addition, there are several other areas where laser can be applied in orthodontics. Among these are low level laser irradiation for fluoride release of fluoride-containing orthodontic bonding material[48], laser aided circumferential supracrestal fibrotomy[49], inhibition of open gingival embrasure space after orthodontic treatment[50], neurosensory recovery after orthogenetic surgery[51], measuring tooth movement[52], prevention of white spot lesions during orthodontic treatment[53], and etching of enamel for orthodontic attachments bonding[54,55].

Conclusion

The number of young orthodontic researchers developing interest in laser application is increasing exponentially. Dental laser research has emerged to maturity and presages a substantial contribution to the future of clinical dental practice. Orthodontists, along with other specialist in different fields of medicine and dentistry, can now benefit from several different advantages that lasers provide during the treatment process, from separators placement to removal of resin residues from the tooth surface.

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