Chapter 8: Updates on Laser Therapy in Dentistry and Integration in the Dental Office

4 CE Hours

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Learning objectives

- Describe the basics of laser physics and the mechanism of laser action.
- List five uses of laser therapy in orthodontics.
- List the latest laser technologies available in dentistry, and give one example of each application and the advantages compared to traditional modalities.
- Explain the main application of lasers in each stage of the implant process.
- Explain five main clinical applications of lasers in restorative dentistry.
- List three key applications of lasers in Prosthodontics, and describe parameters setting for each laser.
- List three lasers used in the diagnosis of caries as well as the limitations and treatments available for TMD.
- List the application of lasers in oral surgery.
- Describe the practical application of lasers in periodontics.
- List three main safety requirements of lasers.
- Describe practical laser use in pediatric dentistry.
- Discuss ways to integrate lasers into dental practice.

Introduction

In the last decade alone, the research and application of laser therapy technology in general dentistry has expanded remarkably, heralding lasers as one of the most exciting advances in dental technology. This course will review the latest developments in dental laser application and provide evidence for its multitude of benefits in general dentistry, and also discuss the practical application and integration of lasers in dental offices. The science behind lasers, and the types of lasers available in the market and their specific dental applications will be reviewed. At the end of this course, general dental practitioners will be armed with knowledge and understanding of how and when to apply laser therapy in management of oral diseases as adjunct to or instead of other traditional treatments. Clinicians will also learn to carefully approach laser application with adequate training and an understanding of the optimal parameters required to achieve specific treatments. It is envisioned that this technology will increase the ability to provide quality oral treatment, and in effect, increase the standard of patient care.

Basics of laser physics and mechanism of action

"A splendid light has dawned on me..."- Albert Einstein

The concept of lasers was first proposed by Einstein in his 1917 paper on the theory of quantum radiation which postulated that light consists of photons with different wave energies which can produce amplified or stimulated particles of powerful light beams [1]. In fact, Einstein won the Noble Prize for describing the concept of radiation photoelectric amplification, not the theory of relativity! It took another 43 years for the first laser to be built by Theodore Maiman in California. The word **LASER** is an acronym for "**L**ight **A**mplification by **S**timulated **E**mission of **R**adiation" and was coined by Gordon Gould in 1957, an independent researcher considered one of the original fathers of laser [2].

Since its inception, laser has found numerous applications in the medical field and there are now growing practical uses for oral and dental-related treatment modalities. The amazing array of amplification mechanisms and the wavelength range of lasers are the drivers for these rapidly expanding dental applications. A laser produces energy in a coherent radiation of one wavelength, in either the infrared, the visible or the ultraviolet part of the electromagnetic spectrum. In effect, this means that laser light is a single colour (monochromatic) and each light wave is identical in physical properties (coherence). The principle mechanism of action of laser involves four main elements which are represented diagrammatically in Figure 1 [2]:

1. **Amplifier**: An active medium composed of either gas, liquid or solid molecules in a gas, that amplifies a passing light wave.
2. **Pumping source**: An excitation system that allows the active medium to turn into an amplifier for electromagnetic radiation.
3. **Optical resonator**: An optical cavity with excitable atoms that allows the pumping source to turn it into an oscillation resonator.
4. **Output coupler**: I.e. a mirror, that allows partial transmission of the stored radiation inside the optical cavity.

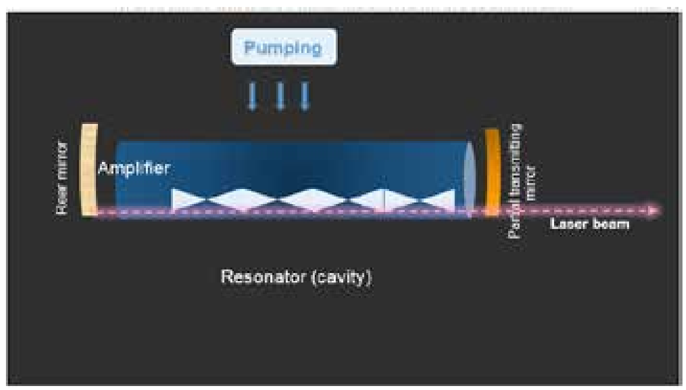

Figure 1. Schematic representation of laser mechanism

The light for dental laser systems is delivered through an optical fibre cable which is a hollow articulated arm [2]. The wavelength varies between 488nm-10,600nm. Lasers are classified according to the emission type (spontaneous or stimulated emission), output power, active medium (liquid, solid or gas state), target tissue (hard or soft tissue) and possible biological damage (Class I-IV) which will be discussed further below [3,4].

Update on laser technologies used in dentistry

The first laser designed for dental use was introduced in 1989 by an American dentist, Dr. Terry Myers, and was intended for commercial use on soft tissues only [4]. It was not until almost 18 years later when laser application in dentistry began to gain acceptance [5-7]. These applications expanded into the surgical areas of periodontal therapy, implantology, and endodontics [7]. More recent advances into the 3-D capability of lasers has allowed digital impressions using Computer-Assisted Design and Manufacturing (CAD/CAM) technology [8].

Currently there are more than 24 indications for clinical application of lasers in dentistry with mounting evidence of the benefits for treatment and patient well-being [9]. In this section, the different laser technologies, and their parameters and limitations will be discussed.

The lasers currently used in dentistry are argon, carbon dioxide, erbium (Nd: YAG and Er: YAG), diode, DIAGNOdent, DopplerFlowmetry, chromium (Er, Cr: YSGG), and Low-level Laser Therapy (LLLT). The names of the lasers reflect their active medium contents and states of suspension [7]. Optimal laser parameters depend on the target tissue, and involve power output, wavelength, exposure time, and energy quantity [6]. Some of the more common laser applications in dentistry include, but are not limited to, crown lengthening, caries detection, mid-line frenectomy, pain reduction and hypersensitivity treatment, gingevectomy, and removal of aphthous ulcers and soft tissue lesions (Table 1).

An argon laser produces light at the light wavelengths of 488nm blue, and 514nm blue-green in an active medium of argon gas with a high current of electrical charge. Due to its poor absorption by hard tissues, the risk of damage to enamel is negligible during soft tissue surgeries. The main uses of argon lasers are to control haemorrhage during gingival surgery, and to detect cracks or decay on tooth surfaces [7].

The carbon dioxide (CO2) laser is another laser which uses gas as active medium. They produce light at about 10,600 nm in the visible range and have very high water and hydroxyapatite absorbance properties compared to other dentistry laser systems [3]. The major advantage of carbon dioxide lasers is that they allow soft tissue surgery with ease and precision. The drawbacks are that the laser is not suitable for hard tissue use, and that it is technique-sensitive. During application the surrounding tooth structure requires protection [5].

Erbium lasers are the most frequently used lasers in dentistry. There are different types of erbium lasers including the Erbium-YAG (2,940 nm) and the Erbium-Chromium-YSGG (2,780 nm) which have active mediums of yttrium-aluminium-garnet and solid yttrium-scandium-garnet, respectively [10,11]. Due to their high hydroxyapatite and water absorbance properties, both of these lasers are excellent to use for caries and hard tissue removal [11]. The success rate of these lasers is also due to their minimal tissue penetration, and hence negligible thermal effects on pulp, as the soft tissue is removed [11]. Of note, there is no need for anaesthetics with an Er-YAG laser during caries removal. It has less vibration than a high speed drill, which is highly satisfying and comfortable for patients [9]. Recent studies have shown effective reduction of dentinal hypersensitivity using Er-YAG lasers with less thermal side effect than CO2 lasers [12,13]. The Er-YAG laser also has significant antimicrobial effects and is suitable for use in endodontic treatments. Similarly, the Er-Cr-YSGG laser has no thermal effect on pulp and results in excellent bonding properties [14].

Diode lasers' active medium source of emission is a semi-solid semiconductor with varying wavelengths in the 800nm-980nm range. This laser can be safely used for soft tissue surgery including crown lengthening and frenectomy due to its poor absorption by the tooth structure [3].

The LLLT laser is applied via a light emitting diode (LED) to support tissue repair and healing, induce analgesic effects, and decrease inflammation. Current studies indicate that LLLT is useful in the treatment of a plethora of oral conditions and has applications in nearly every dental-related field. This versatility is due to the mode of LLLT action, as light is absorbed by cell mitochondria with no thermal effect on tissues [15].

Nd-YAG lasers are the first laser system used in dentistry with an active medium of YAG crystal doped with neodymium. It produces a wavelength at 1,064 nm which is absorbed only by hard tissue, and has great use in surgery and soft tissue removal [8]. They can also be used to remove some enamel caries and provide good homeostasis during surgery. The main disadvantage with these lasers is the depth of penetration, which results in a risk of damage to the pulp and possibly the underlying bone [8,9].

Table 1. Summary of current dental lasers in the market and their main clinical applications

Laser type	Wavelength	Laser characteristics	Indication and tissue depth	Clinical use
Argon.	488nm, 514nm.	Low water absorption.	Soft tissue, 1mm.	Gingevectomy.
CO2.	960nm, 10600nm.	High water and hydroxyapatite absorption.	Soft tissue, 0.1mm.	Oral surgery.
Diode.	800-980nm.	Poor hard tissue absorption.	Soft tissue, 0.1-0.3mm.	Crown lengthening, frenectomy, diagnosis and disinfection.
Er-YAG.	1030nm.	High water and hydroxyapatite absorption.	Soft and hard tissue, 5um.	Remove dentinal, enamel/dentin cutting, hypersensitivity.
Potassium-titanyl-Phosphate.	532nm.	Low water absorption.	Soft tissue.	Surgery and periodontal bleaching.
Low level lasers (LLL).	600-1000nm.	Low water absorption.	Soft tissue.	Disinfection, treatment of recurrent aphthos ulcer and TMJ disorders.
Nd-YAG.	1030nm.	High water and hydroxyapatite absorption.	Soft tissue, >1mm.	Endodontics, disinfection, and selective caries removal.

Laser operation

Dental lasers either emit energy in a continuous wave or a free-running pulse. Both carbon dioxide and diode lasers emit energy in a continuous wave mode, which continues while the laser remains activated. The limitations of these lasers include associated thermal burn which is abated by using an electronic-controlled or gated-pulse laser. Laser systems that use Nd-YAG, Er-YAG, and Er,Cr-YSGG operate on the free-running pulse mode, where true pulses of ten thousandths of a second originate from a flash lamp [9].

Laser-tissue interaction

Laser-tissue interactions are dependent on the wavelength, laser mode of emission, and tissue characteristics [8,9]. The key factor for absorption of light in tissues is wavelength of the light. Generally, pigmented tissues tend to absorb more energy from shorter wavelengths in the 500-1000 nm range, such as the diode and Nd-YAG lasers. Tissues with higher water content and apatite crystals absorb energy better in the longer wavelength range (3000 nm-10,600 nm) which encompasses ER-YAG, Erbium and CO2 wavelengths [9]. Thus the depth of light absorption by target material is an indicator of the application of the laser: the CO2 laser depth of penetration is a maximum of 0.1mm which is capable of sealing blood vessels and achieving sufficient haemostasis [9]. However, while the Nd-YAG laser is capable of deeper (2-5mm) tissue penetration, the risk of damage to the surrounding tissue increases accordingly [9]. The energy absorbed from the light is converted to heat, which depending on tissue characteristics and the duration of light exposure, may alter the tissue structure and cause various effects such as carbonization, or in the case of hard tissues, recrystallization [7-9].

In summary, laser-tissue interactions depend on four properties of light energy and target tissues [16,17]:

- **Absorption**: Tissue characteristics such as pigmentation, and presence of chromophores (agents that absorb light) determine the

amount of energy absorbed. Other factors include the laser emission mode and wavelength, the laser wavelength used, and the laser emission mode.
- **Transmission**: This effect depends on tissue optical characteristics and the laser wavelength used.
- **Reflection**: There are either specular (mirror-image) reflections or diffuse (different directions) reflections of the light from the target surface without any effect on the target.
- **Scattering**: The laser light enters the target tissue across multiple directions, reducing the effect of the laser energy.

Advantages and disadvantages of laser systems

The advent of lasers in dentistry carries many benefits. One such benefit is the removal of a diseased or infected tooth structure while not affecting healthy tissues by using the selectivity of their higher water content. Recent studies have shown that lasers eliminate microfractures, and compared to high-speed handpieces, have a much lower thermal effect on the pulp [18]. Also there are reports of quicker healing of bone tissue after laser-surgical osseous tissue removal. Notably, it has been shown that lasers used to prepare enamel increase the bonding surface for composites [19].

One of the main advantages of utilizing a laser is the decreased microbial contamination risk in the operating field, especially during cavity preparation. Several studies show that laser post-operative healing is rapid and scar formation is diminished [18,20]. Additionally, the use of lasers in children and pregnant women has been deemed safe and is practiced regularly.

The obvious limitation of lasers is their high outlay and ongoing costs; these costs include training, maintenance, and the time taken to implement laser protocols in the practice. In addition to each manufacturer's in-house training, there are high end courses offered by the Academy of Laser Dentistry (ALD) that support dental teams in developing efficiency and skills. There are some limitations in the delivery system of lasers due to accessibility in the operating field. The removal speed of most lasers is slower than a high speed drill, but at the same time the damage to healthy tooth structures is minimal. Another drawback is that erbium lasers cannot interact with gold or porcelain materials [18]; although, they are advantageous when removing caries adjacent to these materials.

Table 2. Summary of key benefits and limitations of dental lasers in clinical applications

Key benefits for laser application in dentistry	Limitations of laser application in dentistry
Reduced risk of infection due to bactericidal action.	Cost prohibitive in terms of the outlay, maintenance and supplies for the laser.
No scar formation and excellent wound healing.	Lasers are wavelength specific with different properties.
Less requirements for anaesthetics and little to no pain or discomfort during and post operatively.	Insufficient clinical trials and standardization of protocols for use in RSTAPT.
Control of bleeding and achieving good hemostatic control.	Implementation of safety measures for all involved in the operating field and ensuring that staff are supportive and follow safety regulations.
Excellent diagnostic tool especially for pulp vitality assessment.	Continuing education and ongoing training required for the entire dental staff.

Laser applications in restorative dentistry

The traditional procedures for tooth preparation for restorations use high or slow speed rotary handpieces which are uncomfortable to patients and more time consuming because of the requirement to administer local anesthetics. In restorative dentistry, lasers have a long history of overcoming these limitations, and they have found application in diagnostic and common operative applications such as caries detection, curing composite restorations, bleaching, cavity preparation and caries removal [18]. More recent key applications of lasers in restorative dentistry areas include using lasers as an adjunct to bonding composite restorations, in the removal of defective restorations, and for the treatment of dentin hypersensitivity [18, 21].

Caries assessment, diagnosis, and prevention

Generally, the diagnosis of tooth decay or caries involves a visual clinical examination and the use of probes, complemented by bitewing radiographs. However, the conventional tools for decay detection are largely affected by the complexities of tooth morphology, accessibility and visibility hampered by presence of plaque, and limitations of radiographs to interproximal tooth decay. Furthermore, development of quantitative methods in dentistry for the detection and monitoring of caries have enhanced the reliability of detecting earlier caries lesions, and allowed quantitative assessment of the progress of the lesion [22].

The introduction of caries detection technologies including laser fluorescence tools such as DIAGNOdent (Kavo), and LED fluorescence tools such as Spectra Caries Detection Aid System (SCDAS) and Sopro-Life, have vastly improved the early detection of carious lesions [23-25]. Recently, Rechmann et al. [26] compared these technologies and concluded that the sensitivity and specificity of all three systems allows them to be utilized as an efficient addition to monitor and diagnose early carious lesions.

The sensitivity and specificity, respectively, of the systems were found to be: DIAGNOdent, 87% and 66%; Sopro-Life daylight mode, 95% and 55%, and fluorescence blue mode, 93% and 63%; and SCDA, 92% and 37% [26].

DIAGNOdent quantitatively measures presence of decay by photodiodes (655nm wavelength). It takes advantage of the differences in fluorescence emitted by healthy tissues and plaque metabolites. The digital values of fluorescence intensity ranges from zero to ninety-nine, and is represented as an audio signal reading as follows (Source: DIAGNOdent, KaVo, Biberac, Germany):

- 0-14: healthy occlusal surfaces.
- 15-20: enamel caries.
- >21: dentin caries.

There is no correlation between the depth of decay and the signal reading value [23,27]; however, the DIAGNOdent has been shown to be very effective as an adjunct to conventional clinical diagnostic methods, especially in early detection of occlusal caries [28].

The more recently introduced Sopro-Life (Sopro-Life, La Ciotat, France) laser has the extra benefit of magnification, and relies on visual assessment with the laser fluorescence device. The output of this system is largely influenced by the presence of calculus, plaque, prophylactic pastes, and therefore meticulous cleaning of the tooth surface before reading is essential. In addition, fluorosis or stained surfaces on teeth maybe give false positive score, so it is important that an adequate training session is undertaken before tooth examination to increase the sensitivity and specificity of the values [25]. The Spectra Caries Detection Aid System (SCDAS) utilizes fluorescence technology using light emitting diodes (LED) to project high energy light onto the tooth surface which results in plaque metabolites displaying as red and healthy enamel as green fluoresce [26].

Quantitative light-induced fluorescence (QLF, InspektorTM) lasers are the most widely reported diagnostic lasers shown to be more efficient at early caries detection. They have the added benefit of visual cues, and the ability to involve patients in treatment plan [29]. The principle mechanism involves enamel auto-fluorescence with the excitation of dentin using a blue light of 370 nm which allows detection of lesions as dark spots on a bright green background. An area with <5% fluorescence is considered a demineralized lesion. The QLF system demonstrates excellent reliability and reproducibility as well as sensitivity for early caries quantification [30]. Similarly, the Sopro-Life camera was developed as a potential diagnostic tool for early carious detection [24]. Furthermore, both of these latest technologies detect active lesions up to a depth of 500μm on the surface of demineralized tooth area [31,32].

One of the most useful diagnostic lasers in restorative dentistry is the Laser Doppler Flowmetry (LDF) which was developed to measure tooth vitality. Its mechanism of action is dependent on the vascular response of the pulp; red cells scatter light emitted from the LDF with a subsequent frequency shift processed as a signal [33].

The purpose of these caries detection tools is as an adjunct to visual assessment and to enhance the specificity and sensitivity of diagnoses in general. There are few clinical studies due to the lack of reference tests with most of the diagnostic tools. The exception is the QLF camera, the most widely reported tool, which has been shown to differentiate between caries and adjacent sound enamel accurately and consistently [34]. Therefore, laser fluorescence provides a quantitative and non-invasive method for the diagnosis of dental caries, and complements the conventional diagnostic methods.

Cavity preparation and caries prevention

The traditional preparation of a cavity first involves application of localized anaesthetic to eliminate patient discomfort during the procedure, followed by removal of carious tooth structures using rotary instruments. The drawback to this conventional method is the patient discomfort during the entire procedure, from the injection phase to the drilling noise and vibration stage, combined with the disadvantage of inevitably some healthy tooth structure removal during the process. The advent of lasers circumvents both of these issues. With lasers, local anaesthesia is not required, and most lasers selectively remove infected hard tissue while leaving healthy tooth structure intact. The three most commonly used lasers are from the erbium family and include the ER-YAG (2940 nm), the Er, Cr-SGG (780 nm) and Er-YSGG (2790 nm). Each of these provide unique applications in tooth ablation [35]. Er-YAG lasers have been demonstrated to be more efficient at removing infected hard tissue than conventional handpieces, and they stimulate dentin formation and exert an antibacterial effect [36]. However, some studies have indicated a risk of thermal damage to the pulp as a main drawback, despite use of water spray during the procedure [37]. Several more recent studies have demonstrated that adjustments to the pulse repetition rate and the power intensity have diminished this thermal alteration to safe levels for the pulp [37-40]. Although the literature is inundated with inconsistent reports on the thermal effects of erbium lasers during cavity preparation, the emerging evidence on erbium lasers, especially long term dataset, support the clinical use of erbium lasers for tooth ablation [38]. The factors that contribute to these inconsistencies are due to different operator factors including laser parameters (e.g. power intensity), pulse length, light profile, and other parameters that ultimately affect the outcome of laser-tissue interaction. Further clinical research on erbium lasers will be required to cement the position of these lasers in dentistry, and to encourage more clinicians to utilize the technology.

Another laser with potential in caries removal is the specific CO2-laser system (short-pulsed), also shown to reduce enamel demineralization. The remarkable efficacy of caries removal by hard tissue ablation and cavity design precision has been demonstrated with the more recent application of Ultra Short Pulsed Laser (USPL) systems which also showed minimal side effects [41-43]. The mechanism of ablation of the Nd-YVO4-USPL (1064 nm, 8 picosecond duration) in a recent study was described as that of a multi-photon process, which is in contrast to the ER-YAG thermal-mechanism; each exhibited different tissue-laser interaction [41]. Thus, the USPL technology offers huge potential for clinical dentistry in efficient and selective caries removal by allowing for different laser parameter settings to the control ablation rate, hence minimizing the thermal side effects.

Use of laser in enamel remineralization

One of the emerging benefits of lasers in restorative dentistry is their protection of the enamel surface from acid attack and demineralization [44-46]. This apparent acid resistance feature of lasers is of particular advantage in patients who have difficulty in maintaining an oral hygiene routine, high caries susceptibility, or rampant caries, and/or those under orthodontic treatment. Recent reports have shown an 87% reduction in the demineralization of enamel surface using specific Carbon dioxide (CO2) lasers with a wavelength of 9300-9600 nm and a short pulsed microsecond setting [47,48].

While the exact mechanism of enamel resistance to acid during laser exposure is not clear, there is accumulating evidence to suggest that the laser may introduce mechanical surface changes to the enamel crystals [49,50]. Other plausible mechanisms of action are discussed by Karandish et al. [46] in a recent review. Of note, several studies have established that a combination of fluoride application and laser exposure significantly reduces carious lesion depth and increases enamel acid resistance [45,51-53].

Laser application in management of dentin hypersensitivity

One of the key applications of lasers in restorative dentistry is in management of dentin hypersensitivity (DH). This condition is generally due to gingival recession, tooth wear and cracks as well as caries presence. Many lasers are capable of reducing DH and are essentially divided into two groups: (1) the low-power level lasers, such as Helium-Neon (He-Ne) and Gallium-ALuminumArsenide (GaAlAs or diode) lasers; and (2) the middle output power or high-level lasers such as CO2, Er-YAG and Er,Cr-YSGG and Nd-YAG lasers [21,54,55]. The low-power lasers such as the GaALA lasers (780, 830 or 900 nm) have been shown to lower pain levels and inflammation by suppressed nerve transmission [54], whereas irradiation with higher level lasers such as Nd-YAG and CO2 lasers results in thermal effects leading to complete obliteration of dentinal tubules [55].

A recent clinical study showed that a tooth brush with a built-in Low Level Laser was an effective alternative for treatment of DH [56]. This results were corroborated in another study which found that application of LLL therapy (685 nm) significantly reduced DH compared to a desensitizing agent containing 8% arginine-calcium carbonate [57]. The use of He-Ne Lasers has a varied efficacy of DH treatment ranging from 5-100%, and there is no consensus among studies to draw any conclusions regarding its application [21,54]. On the other hand, GaALAs lasers for the treatment of DH is well documented with at least a 50% rate of effectiveness [21].

The CO2 laser effectiveness in treatment of DH is reportedly in the 59.8%-100% range, but no analgesic effect has been noted [21, 55]. Similarly, the Nd-YAG laser mechanism of DH involves narrowing of dentinal tubules [58] as well as analgesic effect [59] despite mixed reports on its treatment effects in the 5-100% range [55]. In addition, the combination of Nd-YAG with topical fluoride has been shown to be quite effective at reducing dentin hypersensitivity [60].

The Er-YAG lasers have a range of treatment effectiveness in the range of 38%-47% , and are shown to enhance the bond strength of common desensitizing agents [61]. Furthermore, a recent systematic review of clinical research concluded that the ER-YAG efficacy in reducing DH was markedly higher than GaALA lasers [62].

In summary, the treatment of DH is essentially directed at inhibiting pulpal nerve response or limiting displacement of fluid within the dentin tubules. LLLT lasers such as He-Ne (630 nm) or GaAlA lasers (diode) limit pain stimulus transmission by increasing nerve cell function [55]. Both CO2 and Nd-YAG lasers (1064nm) are capable of stimulating secondary dentin production and sealing open tubules. There is also strong evidence indicating that combination of laser therapy and desensitizing agents is very effective in management of DH [63,64].

Use of lasers in direct pulp capping

One of the most successful application of lasers in restorative dentistry is in direct pulp capping. For decades, conventional methods used calcium hydroxide-based materials to treat exposed vital pulp once hemostasis and bacterial decontamination had been achieved [65].

Lasers offer the unique opportunity of non-invasive, minimal treatment of vital exposed pulps with both great success and a proven track record [65]. CO2 laser exposure in direct pulp capping, compared to calcium hydroxide treatment, has been shown to have a clinical success rate of 89% after a 12 month follow-up [66]. Remarkably, Nd-YAG laser treatment of vital pulps in permanent teeth showed a greater than

90% survival rate after 54 months compared to teeth treated with the conventional calcium hydroxide direct pulp capping method [67]. More recent clinical studies using Er-YAG lasers in human molar teeth achieved a clinical success rate of 93% after two years of pulpotomy treatment [68]. Similarly, clinical evaluation, eight months after Er,Cr-YSGG laser treatment of vital pulps, indicated positive vitality results with no sign of inflammation in 89% of the cases studied [69]. More recently, the diode lasers have also proven to be significantly effective in successful direct pulp capping with a long-term prognosis [70].

In a recent literature review on the "use of lasers for direct pulp capping", Komabayashi et al. [65], summarizes and illustrates the step-by-step clinical procedures for direct pulp capping with lasers. Clinicians are encouraged to examine this extensive review before embarking on laser-assisted direct pulp capping for the first time. Currently, laser application for direct pulp capping has an incredible 90% success rate compared to the 60% rate for conventional methods. This is a promising future alternative to the current methods and should result in greater long-term success rates and increase the quality of patient care [66-71].

Other applications of lasers in restorative dentistry

The use of lasers in etching the enamel has been shown to be comparable to the conventional acid-etching method [71,72]. More recently, laser etching as an adjunct to the conventional acid-etch method has been shown to increase tooth-resin adhesion with a significantly higher bond strength compared to using acid-etch alone [74,75].

Another useful application of lasers is in removal or repair of defective restorations. Conventional methods using high speed handpieces have the disadvantage of removing healthy tooth structure which increases the risk of pulp exposure and undermines the mechanical strength of the treated tooth. The advent of USPL technology has largely overcome these limitations of traditional restoration removal, and are reportedly effective at removing restorative materials with minimal thermal effects [43]. Further clinical research is required on the thermal effects of laser exposure on pulp to confirm their long term effectiveness in restoration removal.

One of the most effective applications of lasers is in the management of recurrent aphthous ulcers (RAUs), which commonly affect up to 60% of the general population [76]. These lesions are often painful oral ulcers that are a result of exposed nerve endings. They are debilitating to the patient without any definitive cure. The challenge in management of RAUs is to find a resolution in minimal time without side effects or patient discomfort [76]. Lasers such as Low-Level Laser Therapy (LLLT) have been suggested as alternative treatment for management of these ulcers. Several reports have demonstrated significant alleviation of RAU symptoms upon application of LLLT. LLLT not only reduced pain but also completely resolved the ulcer in less than half the time [77,78]. Since the pathogenesis of RAUs have been thought to involve the immune system, a plausible mechanism for the LLLT action is the reduction of inflammatory biomarkers such as cytokines and interleukin expression [79].

In summary, lasers are a more efficient and attractive alternative to conventional dentistry and appears to be effective in a number of restorative treatments. However, the cost, together with the need for specialised training and ongoing maintenance issues, has hampered their widespread use among dental professional. Nevertheless, the long term benefits for clinicians include predictable successful treatment outcomes when correct parameters of laser application together with sufficient training are applied. The benefits for patient include comfort, reduced pain, and optimal treatment results.

Laser uses in bleaching

As discussed earlier, the fundamental components of laser light that define its interaction with the target tissue include: the wavelength emitted by the laser; the density of power of the beam; and the operation of laser characteristics, such as a continuous versus pulsed delivery system. When the energy emission is low, laser-tissue interactions tend to be optical or a combination of optical effects, photochemical effects, or photo-biostimulation [80]. When the pulse energy is increased, photothermic interactions take over, leading to photoablation [81, 82], an undesirable effect in a bleaching gel [80]. Therefore, when bleaching, it is crucial to consider the level of light absorption (and hence laser wavelength) required to achieve the desirable bleaching efficacy with minimal thermal effects. Of note, the effect of additives in the bleaching gel and their effect on the absorption range of photons must be considered when using lasers.

Bleaching gel can be heated using lasers or special electric heating devices to enhance bleaching efficiency, as the chemical reaction occurs faster at higher temperature [82]. In addition, peroxide penetrates dental structures much more efficiently with thermal expansion [80]. The drawback is that heat can cause enamel dehydration and irreversible pulpal damage [80,81].

The process of the photo-oxidation (molecules in a triplet excited state becoming oxidized) effect leads to direct photo-bleaching, which is capable of penetrating tooth structure without absorption by water or hydroxyapatite. Lasers are more efficient at photo-bleaching due to their high density of light, and are effective at removing extrinsic stains [80,82]. Dental enamel can be stained with coffee, tea, wine and/or nicotine and these stains are traditionally removed using hydrogen peroxide bleaching. In some cases, these extrinsic stains can become embedded in the outer layer of the enamel which is then difficult to remove with bleaching treatments. Near UV Laser heat has been shown to remove such extrinsic stains with added benefit of ablating the affected underlying enamel [83]. Intrinsic stains are normally removed with photochemical or photo-thermal bleaching methods. Argon diode and CO2 lasers have both been used in tooth bleaching. Furthermore, excellent results in bleaching has been shown using potassium– titanyl–phosphate (KTP) lasers (specific Nd-YAG lasers) that have a wavelength of 532nm which is visible in the green spectrum. Further studies confirmed the safety and validity of KTP lasers for tooth bleaching, and showed significantly more whitening results compared to diode lasers [84]. Noteworthy, photodynamic office bleaching using KTP laser produced improvement in tetracycline discoloration [85].

Laser uses in pediatric dentistry

The application of lasers in pediatric dentistry has been by far the most active and widest clinical use to date. Lasers offer an attractive alternative to conventional methods as a minimally invasion technology for dental treatment in children. Not only are lasers well-accepted by children and parents alike, but studies have also indicated enhanced cooperation of children during more arduous treatments such as pulp and surgical treatments [86,87]. The most common application of lasers in pediatric dentistry are for caries detection and prevention, tooth structure preparation for sealants or restorations, and pulpotomies as well as numerous soft tissue indications [87].

The American Academy of Pediatric Dentistry (AAPD) has set protocols for the dental specialist on the judicious use of lasers in pediatric dentistry [88]:

- "Recognizes the use of lasers as an alternative and complementary method of providing soft and hard tissue dental procedures for infants, children, adolescents, and persons with special health care needs.
- Advocates the dental professional receive additional didactic and experiential education and training on the use of lasers before applying this technology on pediatric dental patients.
- Encourages dental professionals to research, implement, and utilize the appropriate laser specific and optimal for the indicated procedure.
- Endorses use of protective eyewear specific for laser wavelengths during treatment for the dental team, patient, and observers."

For diagnosis of caries, the most commonly used laser in pediatric dentistry is the DIAGNOdent laser (655 nm). This laser is effective for detection of occlusal caries in both deciduous and permanent teeth [87,89,90]. As described before, the degree of demineralization correlates with the emitted fluorescence and is quantified as the amount of decay present. The drawback is the lack of efficacy in detection of early enamel lesions; DIAGNOdent is more efficient at diagnosis of dentin occlusal caries. Argon lasers (488nm) address this shortcoming and have been successfully used as diagnostic tool in occlusal and interproximal caries detection; however, they are more efficient in detecting demineralization in primary rather than permanent teeth [91]. In addition, Argon lasers are a fantastic adjunct diagnostic tool during routine examinations to diagnose caries underneath fissure sealants [92].

There is some evidence for the application of argon lasers in enamel protection against caries. Especially when combined with topical application of fluoride, it has been shown to remarkably decrease the depth of carious lesions [44,93]. Another possible use of a laser system is for enameloplasty just before fissure sealant is applied; enamel becomes more acid resistant and bonding is enhanced as the laser complements the use of the acid-etch technique [89].

In pediatric dentistry, accumulating evidence on erbium lasers (Er-YAG and Er,Cr-YSGG) has demonstrated the efficacy of hard tissue ablation with minimal thermal effects [17,89,94]. This is in contrast to some of the research on erbium laser applications for adult teeth. This disparity could be either due to larger clinical samples on primary teeth, or possibly due to laser parameters more carefully set to reduce pulp effects in children. In either case, there is a great need for more clinical studies to standardize use of erbium lasers for hard tissue ablation without thermal side effects. The reduced vibration and noise and the negligible need for local anaesthesia during cavity preparation has been reported with successful applications of Er-YAG lasers [95,96]. In particular, research has demonstrated effective anaesthesia with success rates of 50-75% using pulsed Nd-YAG (660nm) lasers during cavity preparation of primary molar teeth [97]. LLLT is also effective at reducing pain and swelling during eruption of primary or permanent teeth as well as in instances of soft tissue trauma [98].

Pulpotomies are very common treatment procedures in pediatric dentistry. The results of CO2 laser application for vital pulp therapy have shown a 98.1% clinical success rate of treatment after a two year follow-up [99]. Similarly, a recent study using diode lasers for pulpotomy treatment showed a 100% clinical success rate after a 12 month follow up [100].

Soft tissue application of lasers in pediatric dentistry include gingevectomies, removal of fibromas, gingival hyperplasias, mucoceles and aphthous ulcer treatments [87]. The main lasers for soft tissue surgery have been the argon, CO2, and diode lasers, and Nd-YAG laser systems, especially for coagulations, and decontamination of the soft tissues [90]. Specific Er-YAG lasers with shorter pulse lengths modified for soft tissue surgery have also been utilized. Furthermore, lasers can be used to treat traumatic injuries to dental tissues with ease, with minimal local anaesthetics and discomfort. Laser Doppler Flowmetry (LDF) is a reliable and accurate tool used in the assessment of pulp vitality and monitoring mobility of traumatized teeth for the long term [33]. Also, ER-YAG and Er,Cr-YSGG lasers can be used to seal dentinal tubules in traumatized teeth, leading to reduced dentin hypersensitivity [98]. Other applications of lasers for traumatized tissues include localized application of lasers for facial swelling, soft tissue trauma, and wounds to reduce associated discomfort and pain [9].

Laser use in pediatric dentistry is on the cusp of becoming the Gold Standard with ever increasing new applications, and refinement of the existing ones to address conventional disease with modern non-invasive technology. Therefore, it is vital for the dental practitioners and their dental teams to continuously familiarize and educate themselves on the accumulating clinical evidence and research on safety issues, effectiveness, multiple applications, and more importantly, the laser parameters used for specific dental applications to deliver optimal patient care.

Table 3. Laser applications in pediatric dentistry

Benefits	Limitations
Hemostasis achieved during soft tissue surgery.	Costly in terms of outlay, and the time to plan and implement laser system in dental office.
Selective laser-interaction with infected tissue.	More than one laser may be needed for different soft and hard tissue applications requiring specific wavelengths.
Enhanced wound healing with reduced need for analgesics.	Strict adherence to infection control by all dental team involved is paramount to avoid contaminated aerosols.
Bacterial decontamination and disinfection of the localized area.	Safety protocols must be followed and individuals involved in the laser vicinity must wear laser specific eye protection.
Complementary tool to visual diagnosis for caries detection.	Limited diagnostic tool to unrestored surfaces due to fluorescence of the restorative material.
Less post-operative discomfort & scarring following soft tissue surgery.	

Laser use in periodontics

Lasers have been advocated and increasingly used as an adjunct to conventional scale and root planning to overcome limitations with periodontal therapies such as non-accessible pockets and delayed healing following non-surgical periodontal therapy (NSPT). The main concern with lasers is that there is no accepted standardized protocol for their use in dental practice, potentiating the risk for adverse events affecting the hard tissue and patient compared to other traditional modalities. In addition, the wavelength of each laser setting is different and exerts a different effect on the soft and hard tissues, leading to difficulties in comparing lasers and therefore achieving repeatable results among studies. Overall, there are very few randomized clinical trials and a statistically low number of sample sizes published. A recent systemic review and meta-analysis on NSPT concluded that sufficient evidence only exists for the use of PDT diode lasers as beneficial for adjunctive NSPT [101]. However, lasers continue to be beneficial and are successfully used in other areas of periodontal therapy. Here several types of lasers used in periodontal disease treatment with the supportive evidence will be discussed.

The main lasers with periodontal clinical applications include the CO2, diode, and Er-YAG and Er,Cr-YSGG as well as Nd-YAG lasers [102]. The applications include: biostimulation; microbial decontamination of roots and implants; soft tissue surgery; and bone (osseous) surgery [102]. The mechanism of lasers, as mentioned before, are governed by penetration depth into the target tissue, absorption characteristics including wavelength, and target tissue characteristics. Both CO2 and erbium families have surface penetration, while the diode and Nd-YAG lasers penetrate the target tissue deeply, up to 2-3 millimetres, and suit procedures that require coagulation. In addition, the diode and Nd-YAG lasers are desirable for removal of gingival pigmentation due to their absorption by the tissue. Owing to their high absorption by water and hydroxyapatite, the erbium family lasers are more ideal for efficient bone removal than other lasers [102].

The benefits of lasers in periodontal treatment have been shown in their control of microbial infection, bacterial reduction [102], efficient removal of subgingival calculus [104], and improvement of periodontal regeneration in human with minimal damage to the surrounding tissues [104]. Accumulating evidence supports the effective use of laser therapy in conjunction with traditional treatment modalities to reduce active periodontal pathogens, rather than the use of SRP alone [104-106]. This combination therapy efficacy is mainly due to the complete removal of the infected sulcular epithelium resulting in improved connective tissue attachment [107]. A recent study further corroborated the adjunctive use of lasers by demonstrating significant improvement in periodontal disease and treating pocket depths of 4-6 mm [108].

Laser therapy has been also shown to accelerate the periodontal healing process and attachment [109]. The bio-stimulation effect of laser therapy has been clearly demonstrated in recent studies. Laser therapy stimulates acceleration in cellular duplication process without any structural or functional changes of the target tissues.

Periodontal healing
Several lines of evidence have demonstrated effective application of lasers in regeneration and healing of periodontal tissues [110,111]. The emerging evidence on laser applications in non-surgical periodontal therapy suggests the use of lasers as adjuncts to conventional mechanical treatments. Recent clinical studies using different wavelengths confirm that combination laser-mediated therapy is the most effective approach for optimal treatment outcomes [112-114]. The combined use of SRP and diode laser therapy has been shown to produce the best results in reducing clinical probing depths and attachment loss than laser application alone [112,115]. Similarly, SRP, in combination with an Er-YAG laser, treated sites showed significant improvement in reduction of probing depth and attachment level [114]. More recent studies have demonstrated comparable results of SRP in combination with KTP laser (modified Nd-YAG) therapy supported improvements in all periodontal clinical parameters [116-118]. The KTP laser has been previously shown to be safe to use on root surfaces with minimal thermal effect on vital pulp or periodontal ligament [119].

Soft tissue periodontal laser application
One of the many benefits of lasers in periodontal therapy is their application in soft tissue surgery. The very first laser reported to have surgical application was the Nd-YAG laser. It was found to efficiently control gingival bleeding and bacteraemia as well as reduce periodontal pockets [120]. In addition, the Nd-YAG was shown to be efficient at removal of epithelium pocket linings [121], which is effective in reduction of probing depths and gingival recession [122]. Both diode and Er-YAG lasers have also demonstrated positive effects in subgingival curettage with significantly improved periodontal parameters compared to manual instrumentation [123].

Laser application in bacterial reduction & root surface conditioning
Laser applications in periodontal pocket and root surface decontamination are the most promising adjunct for periodontal conventional therapy due to their efficient bactericidal effect [9]. Originally, the Nd-YAG laser was found to reduce periodontal pathogens, and later diode laser (980 nm) applications, adjunct to ultrasonic scaling, showed a remarkably low prevalence of bacteraemia [124], suggesting a promising application in immunocompromised patients [102]. Furthermore, Er-YAG lasers (2940 nm) together with diode laser irradiation are proven effective in the removal of subgingival calculus without the risk of thermal damage to the vital tooth [125,126]. Similar studies corroborated these findings by using diode lasers to reduce periodontal pathogens in pockets without the need for antibiotic therapy [112].

The application of CO2 lasers in decontamination of root surfaces has been demonstrated by several clinical reports [127,102], provided that the power setting and parameters stay within a safety range to prevent root damage [128]. A recently published report found that combined CO2 laser root conditioning with coronal flap advancement resulted in long-term tissue stability after 15 years [127].

Laser use in orthodontic treatment

Laser use in orthodontics, similar to other fields of dentistry, has seen rapid growth in diagnosis, imaging, bonding and surgical applications. The key diagnostic applications include caries detection, digital models, and laser scanning. Laser etching, bonding to porcelain and adhesive curing are other applications. The laser effect extends to bio-modulations such as tooth movement, growth modification, pain control, and retention or relapse [129].

Laser application in diagnosis
In orthodontics, three-dimensional laser scanning has multiple applications in diagnosis, growth changes assessment, and in clinical results after orthognathic surgery [129]. The advantages of this technology include auto-calibration and correction, ease of use, and lower costs. Applications include the ability to monitor facial soft tissue changes that occur with growth and following orthognathic surgery, and functional movements of facial muscles [129]. Diagnostic dental casts are prepared using 3-D computer-aided design (CAD) systems once the dental model is generated from 3-D graphic information using laser scanning. Digital models not only abolish the need for storage space, but also allow reliable, reproducible, and efficient assessment of arch form, tooth size and tooth-arch discrepancies [130]. Laser scanning is also beneficial for studies of craniofacial abnormalities, assessment of cleft lip and palate, and nasal reconstruction procedures. Data from a 3-D laser scanner can be transformed to produce orthodontic appliances, splints, electronic models, and surgical simulation models.

Laser Doppler Flowmetry (LDF), aside from its application in restorative dentistry, is a very useful non-invasive diagnostic tool in assessment of tooth vitality before and during orthodontic treatment. In addition, LDF can accurately monitor pulp responses to orthodontic forces generated by rapid maxillary expansion [131]. Other diagnostic technology includes DIAGNOdent and QFL lasers supporting conventional methods in early detection of incipient caries lesions around orthodontic brackets.

Lasers are great tools for etching to possibly improve resin bonding and also reduce caries incidence by producing enamel surface that is acid resistant. The mechanism of action is thought to be due to the heat effect of the laser resulting in an enamel roughness comparable to the acid-etching method [132]. There is no need for water and air application during laser etching, and more importantly, there is remineralization of the enamel surface reducing acid attack [129].

Laser application in bonding brackets
Argon lasers have been shown to not only reduce the frequency of bracket de-bonding, but also to induce orthodontic resin polymerization four times faster than conventional curing lights while maintaining a comparable bond strength. While a drawback with this laser as a curing light has been cost, this issue has been largely overcome with the advent of diode-pumped solid-state lasers [131]. Laser etching is also advantageous for bonding to porcelain as it eliminates the use of hydrofluoric acid as well as the need to repolish the porcelain at the bracket de-bonding stage.

Lasers have the great advantage of decreasing operation time during the de-bonding stage and abolishing all the issues concerned with conventional ceramic de-bonding methods. The plausible mechanism of lasers during de-bonding is thermal mediated: initial laser heat softens the bonding agent, which results in the bracket sliding off the enamel [131].

Laser application in soft tissue surgery
The other useful applications of lasers in orthodontics are in soft tissue surgery, such as gingival recontouring, frenectomy, fibrotomy, exposure of unerupted teeth, ablation of inflamed tissue and gingival hyperplasia [129,133-135]. The main lasers used for soft tissue application are the Nd-YAG lasers [131]. The thermal ablation of tissue via the absorption, melting, and vaporization process is thought to be the mechanism by which lasers exert effects. Indeed, laser soft tissue ablation is more advantageous than use of a scalpel in terms of accuracy and minimal tissue damage, control of bleeding, ability to sterilize the wound area. Lasers reduce the operative time, and provide less post-operative discomfort as well as minimal swelling [135-137].

Other applications of laser in orthodontic practice
The most frequently used laser therapy in orthodontics is Low-Level Laser Therapy (LLLT), especially for pain relief. The plausible mechanism of the LLLT analgesic effect is its inhibitory action on pain fibres, which decreases action potentials and suppresses neurogenic inflammation [15]. Several reports have indicated that GaAlAs diode [138], Nd-YAG and CO2 laser therapy also exert analgesic effects, decreasing pain associated with orthodontic movement [139,140]. Therefore, analgesia-inducing lasers are beneficial in orthodontic treatment as they are non-invasive without causing any tissue-related side effects.

LLLT has also been shown to stimulate bone regeneration as well as mandible growth, possibly via stimulation of cellular proliferation and differentiation [15,141]. Similarly, GaAlAs diode lasers have been shown to accelerate bone regeneration during application of a rapid palatal expansion appliance [142]. Similarly, the combination of retainer and LLL therapy has been shown to reduce the retention period due to accelerating periodontal tissue remodelling.

LLLT has also been found to influence rate of tooth movement during orthodontic treatment phase in animal studies [15]. This could possibly be due to the increase of osteoclast formation, resulting in tooth movement, elevation of receptor activator of a nuclear factor kappa-B ligand in periodontal ligament, and possibly, stimulation of osteogenesis and bone formation on the traction side [129]. The implications of these research findings are significant for orthodontic treatment, and it is essential to be aware of optimizing the laser parameters to achieve positive treatment outcome. However, studies on the use of laser in tooth movement are controversial, and more research is required to determine the optimal laser parameters required to achieve tooth movement [15].

Laser applications in prosthodontics

The advent of lasers in prosthodontic field has been very encouraging, leading to increasing laser-integration in specialist clinics. These technical applications are replacing most of the traditional treatment procedures [143]. Lasers have numerous applications, especially as adjunctive therapy to conventional methods, in prosthodontics with the more common uses including crown lengthening, soft tissue ablation, troughing and veneer removal [144]. While initially, soft tissue lasers were used, with the development of a wider range of wavelengths, hard tissue lasers took centre stage and are used in tooth preparation and bone ablation, among other applications.

The greatest impact of laser application in prosthodontics has been on aesthetic considerations and functional stability [143]. In fixed prosthodontics, soft laser applications such as cosmetic crown lengthening, management of gingival overgrowth and retraction during crown placement and impression taking, are very frequent. In patients with "gummy smile", erbium lasers have allowed apical lifting of both soft and hard tissue to achieve an improved and favourable aesthetic result without the risk of damage to adjacent tissues or thermal effects [143]. Lasers used in crown lengthening are the CO2 and erbium lasers capable of removing bone without damaging the adjacent cementum [143]. Argon lasers are excellent for retraction and hemostasis of gingival tissue, allowing for accurate impression taking.

Lasers are also very effective at the removal of gingival overgrowth prior to re-cementation of a fixed prosthesis. In the aesthetic zone, lasers have the advantage of shaping soft tissue to fabricate ovate pontic for aesthetic improvement. Lasers result in efficient, predictable results with minimal discomfort and bleeding, which reduces operative time.

Gingival laser troughing is more efficient, and allows for better visibility of the margins than using retraction cords prior to impression taking. Diode lasers have been shown to be effective in tissue retraction instead of the cord, and show great results in accurate accessible margins for impression taking [143]. These lasers are also fantastic at recontouring gingiva and removing minor inflamed tissues without any thermal damage to the underlying tissues. There are times when porcelain veneers are required to be replaced and erbium lasers are able to predictably assist in efficient and safe removal of veneers with minimal harm to the underlying tooth structures [144]. Application of lasers in clearing tooth preparation margins by retraction of gingival tissue is highly desirable to produce distinct margins for impression, management of gingival overgrowth during temporization, and final prosthetic restoration placement.

Hard tissue lasers have wide applications in prosthodontics such as tooth preparation for crowns and veneers, caries and defective restoration removal, as well as the removal of failed or defective veneers, crowns or bridges [143]. Lasers such as Er-YAG and Er,Cr-YSGG have the advantage of removing veneers without any damage to the underlying tooth structure. The mechanism of laser involves the beam passing through the porcelain and de-bonding it at the silane-resin interface [144].

The applications of hard and soft tissue lasers include ovate pontic site preparation, and crown fractures at the gingival margin level. The design of pontic is important as part of the final fixed prosthodontic restoration and is particularly critical in the anterior region. To create a natural look, ovate pontic design is sculpted as a depression in the soft tissue using lasers [143]. In the event that the biological width is violated, lasers with a hard tissue setting can remove minimal bone to allow for the 2mm gingiva between the bone and pontic [143]. The application of Er-YAG lasers in crown fractures have been shown to safely ablate bone and expose the fractured edge when crown fracture extends below the bone margin [145].

In addition to the above applications, lasers are capable of increasing surface roughness to improve bond strength of the fixed restoration and luting cement. Recently, a study showed the use of CO2 and Er-YAG lasers enhanced bond strength between the zirconia crown and cement [146]. Of note, laser scanning of casts is becoming increasingly popular among specialists for the creation and design of indirect restorations as it is efficient, cost effective in the long term, and more comfortable for the patient.

The multiple advantages of hard and soft tissue combination treatment with lasers have facilitated extensive applications, and increased the interest of dental practitioners in integrating the technology into dental offices. Not only do patients benefit from less chair time and comfortable treatment without the need for anaesthetics or sutures, but the dentist can deliver a predictable and successful outcome by using optimal laser parameters for the specific treatment application.

Laser application in dental implantology

Soft tissue lasers such as CO2 and Argons have been shown to be beneficial in soft-tissue peri-implant recontouring, enhancing hemostasis, and decreasing post-operative discomfort and swelling as well as increasing wound healing [147]. Likewise, dental implantology benefits from hard tissue laser technologies such as Er-YAG and Er,Cr-YSGG lasers in the early osseointegration phase and in treatment of peri-implantitis [102]. Therefore, there are positive indications for both soft and hard tissue laser application in almost all phases of implant placement, including the post-implant healing stage which will be described below [102.147-149].

Implant dentistry and lasers

Laser applications in implant dentistry includes: prior to and during all stages of implant placement; treatment of peri-implantitis; removal of peri-implant soft tissue; and disinfection of failed implants [147-150]. Both CO2 and Er,Cr-YSGG lasers have demonstrated effective decontamination of the implant surface and re-osseointegration in pre-clinical studies [151]. Of particular interest is the CO2 laser application on the implant surface which was shown recently to reduce the risk of overheating, a concern with implant surface melting when using lasers [152].

During the implant placement process, lasers have been shown to be beneficial in decontamination of the site and flap incision, removal of any granulation tissues, and levelling the bone for restoration placement [147-150]. Erbium lasers are capable of bacterial reduction in the implant site [153], removal of granulation tissue as well as disinfection of the extraction site without damaging the surrounding bone [147]. Lasers, in general, are excellent at hemostasis compared to scalpel blades and are able to reduce discomfort and swelling post-surgery. Traditionally, electrosurgical units are used for implant processes, however these units usually induce heat and have thermal damage compared [154] to lasers such as erbium which has water-cooling mechanisms and thereby reduces thermal damaging effect to surrounding bone [155]. In addition, erbium lasers ablate bone and have been shown to produce osteotomies with post-operative stability of implants at the two-month mark [156]. Diode laser applications have been shown to encourage in hard tissue ablation, assist in coagulation as well as their soft tissue applications [157].

During implant placement, lasers have been indicated mainly in precise flap incision, creation of osteotomy, and guided tissue regeneration. The procedure for predictable bone generation for a deficient area follows four principles: wound closure to promote uneventful healing; vascularization of the healing area; space creation for bone; and wound stability for blood clot formation [158]. Research has shown that lasers such as Er-YAG irradiation appear to stimulate secretion of platelet-derived growth factors which promote bone repair and thus enhances healing of the osteotomy sites [159]. There are inconsistent studies on benefits of CO2 (9600nm) lasers in bone ablation. While they has been found to be safe when used for decontamination of implant sites [160], previous studies report a risk of thermal damage associated with use of CO2 lasers during irradiation, causing carbonization of the adjacent bone [161]. Therefore, erbium lasers with their water-cooling spray offer a safe and precise bone ablation tool without thermal damage during the initial implant placement [162]. Nevertheless, during the osteotomy process, just like using handpieces, clinicians must exercise caution to avoid thermal damage to the adjacent vascular structures when using lasers [147].

Once the fixture is in place, bone recontouring may be required to level the bone around the implant and allow for accurate impression as well as proper seating of the healing abutment, especially when the immediate implant placement technique is used. Here, the application of erbium lasers is ideal, as studies have found erbium lasers to be safe and posing no risk to the implant surface or causing thermal damage to the adjacent bone area [163]. Studies have shown erbium lasers to be precise in bone ablation for accurate placement of healing abutment. This prevents later discomfort and swelling associated with placement of final implant restoration [147,148, 163]. In addition, erbium lasers can be applied to minor soft tissue recontourings adjacent to the healing abutments. The clinical application of erbium lasers for both soft and hard tissue ablations are described and demonstrated in detail by van As (2015) [148,149].

The renewed interest in diode lasers in more recent years has resulted in electrosurgical units being replaced in dental practices owing to diode laser reliability, convenience, affordability and ease of application with dental implants [147,148]. Diode lasers are very safe to use around metals and implants without causing damage to the structure of the metal. Laser application in other areas of implant dentistry include implant site preparation, ablation of excessive tissue during implant placement, and removal of overlay hard or soft tissue during the uncovering implant stage [147-149].

Another useful laser with an emergent application profile in most areas of dental implantology is the Low Level Laser with wavelengths in the 655-810 nm range [164,165]. These lasers are used for pain reduction and wound healing and exert their therapeutic effects at very low powers without any damage to the tissues [166,167]. Several studies have demonstrated that LLL therapy irradiation resulted in stimulation of osseointegration, increased bone mineralization, and healing in the early stages of implant placement as well as improvement in nerve regeneration [168-170].

Lasers also have applications in the implant uncovering stage. While studies have shown that diode lasers at low settings allow safe uncovering of implant fixtures [171], it has been suggested to use water spray intermittently to manage potential thermal effect on the surgical site [157]. Furthermore, diode lasers reduce the number of appointments due to them decreasing both the need for sutures and the post-operative healing period.

Soft tissue management during the healing phase of implant therapy is possible using diode, CO2 and erbium lasers. Studies have suggested Er,Cr-YSGG to be very effective in soft tissue surgery as it showed minimal thermal damage compared to diode or CO2 lasers [172,173]. Indeed, soft tissue recontouring can save time and effort in the difficult management of the final restoration process.

Peri-implantitis and lasers

Despite the great long-term success of implant therapy in replacement of missing teeth in dentistry [174-176], there are increasing reports of implant failure either due to inflammation of the soft tissue (mucositis) or the bone (peri-implantitis). These conditions lead to chronic pain, infection, bone loss and eventual implant failure if untreated [174, 177,178]. A recent systematic review on peri-implant diseases found a significant incidence of both mucositis and peri-implantitis [178], potentially due to systemic disease (diabetes), smoking, improper implant placement, and/or poor oral hygiene [179].

It has been suggested to approach early peri-implantitis cases (probing depths of <5mm and bone loss of <2mm) using non-surgical treatment modalities [180]. The most challenging parts of peri-implantitis treatment are the decontamination of the implant surface, soft tissue ablation, and long-term maintenance of healthy tissues [181]. While mechanical decontamination methods combined with antibiotic therapy have been used, the side effects of surface damage to the implant and antibiotic resistance have been reported [182,183]. Lasers are reportedly very effective as an adjunct in the decontamination of implants. The most frequently applied lasers are the CO2, diode and erbium lasers simply because all have antibacterial effects, but also assist in removal of calculus as well as improving hemostasis [147]. Studies have shown the combination of traditional modalities with LLL therapy produces predictable results in dental implant decontamination. Recent studies have indicated that the effect of diode lasers (810 nm) at low power (LLLT) combined with conventional therapies is effective at decontaminating implant surfaces as well as in possible stimulation of collagen production [184,185]. Similarly, the CO2 and erbium lasers have been shown to be effective at elimination of bacteria from implant surfaces provided appropriate laser parameters are used [186].

There are cases where the bone loss around an implant is moderate-severe and a non-surgical option is not feasible. In such instances, whether to replace or save the existing implant should be carefully considered. Forum et al. developed a regenerative surgical approach for treatment of peri-implantitis with encouraging results of no implant loss after seven years of follow-up [187]. More recently, studies have demonstrated that the application of erbium lasers to effectively remove the contaminated layer with an optimal laser setting has potential application in surgical approach to peri-implantitis [188,189]. More clinical studies, especially long-term with multiple sessions of laser therapy, are required to establish the application and effectiveness of these lasers over conventional therapy in peri-implantitis treatment [190].

Despite limited published randomized clinical studies on lasers in dental implantology, there are emerging studies that describe widespread use in bacterial decontamination of extracted sockets for immediate implant placement, osseous remodelling and osseointegration, surgical flap raise, and uncovering submerged implants to preserve crestal bone [147]. The successful laser application in any dental procedure is dependent on adequate training and education on laser use, especially the application of correct parameters specific for the particular procedure as well as safety considerations [102, 147].

Laser application in oral surgery

The clinical application of lasers in oral surgery includes treatment of oral mucosal lesions, oral cancers, and oral benign lesions. In oral surgery, the most commonly used lasers are the CO2, erbium family, diode and Nd-YAG. There have also been some applications of the LLLs in disinfection and wound healing reported [191]. Since most of the applications are very specialized and out of the scope of this course, only a brief outline of the broad oral surgery applications will be discussed here for the general dental practitioner.

The most common oral mucosal lesions are oral leucoplakia and lichen planus. Treatment of oral leucoplakia, a pre-malignant oral mucosa lesion, was demonstrated effectively and safely using CO2 laser therapy and photodynamic therapy in randomized clinical studies [192,193]. Oral lichen planus treatment with a diode laser was shown to be effective for relief of associated symptoms. In addition, the efficacy of ER-YAG lasers in reducing symptoms of oral lichen planus has been reported [194].

In oral cancer treatment, clinical studies have reported use of: Nd-YAG lasers for management of lip carcinoma lesions; a specific CO2 (trans-oral) laser for early glottis cancer treatment and soft palate tumours; and diode lasers for healing and reduction in post-operative pain. The advantages of laser therapy include less treatment time, less costs compared to radio- or chemo- radiotherapy, and significantly less toxicity [195].

Application of lasers in removal of oral benign lesions includes the removal of mucoceles which are benign lesions of the minor salivary glands that most commonly occur in children on the lower lip. Application of erbium and CO2 lasers is demonstrated to effectively remove mucoceles with rapid wound healing and no scaring [86,196]. Other benign lesions are ranuals, which are traumatic sublingual mucus lesions; they have been reported to be removed by CO2 laser treatment safely with minimal recurrence [197].

Laser application in TMD management

The most common cause of orofacial pain of non-dental origin is from the Temporomandibular Disorders (TMD) which occur at a prevalence of more than 85% of the population [198]. This dysfunction is a collection of clinical symptoms involving the temporomandibular joint and its associated structures [198]. It is a debilitating condition affecting sleep quality, mood and cognition function [199]. The treatment usually is multidisciplinary and includes a physiotherapist in addition to a general dental practitioner. Traditional modalities used to address treatment of TMD frequently involve medication, adjunctive occlusal splint, physiotherapy, electrotherapy, or manual therapy in combination or individually. The availability of Low Level Laser Therapy (LLLT) expanded the horizon of treatment options. LLLT has been shown to not only reduce pain, but also reduce any associated inflammation and swelling [198]. Its mechanism of action is possibly a result of light penetration in target tissue leading to stimulation and release of many signalling pathways involved in analgesia, nerve excitability and increased blood circulation [15, 198,199]. Currently, there is no consensus on the benefits of LLL as therapy for TMD and the literature is saturated with conflicting reports that are not consistent in terms of parameters of the laser application. Further research and standardization of treatment parameters is required to clarify the emerging benefits of LLLT for TMD treatment.

Laser safety considerations

The safety consideration of lasers is an important aspect of providing quality treatment in a safe and efficient manner. It is crucial to be aware of the correct operation of the laser equipment and provisions must made for the protection of the dental team, patient and operator. The standards set out by American National Standards Institute and Occupational Safety and Health Administration classifies lasers according to their associated risks into four categories [200]:

- Class I: Low-powered lasers. These are safe to view.
- Class IIa: Low-powered visible lasers. These do not cause damage unless direct eye contact is made with the beam for >1000 seconds.
- Class II: Low-powered visible lasers. These are harmful when viewed directly for <0.25 seconds.
- Class IIIa: Medium-powered lasers. These are harmful when viewed directly for >0.25 seconds.
- Class IIIb: Medium-powered lasers. These are dangerous when viewed directly regardless of the length of time.
- Class IV: High-powered lasers that can cause damage to eyes and skin. Even a reflected or radiated beam is harmful. Appropriate safety measures required.

In summary, when visible or infrared radiation at wavelengths 400-1400nm are used, directly looking at the laser risks damage to the eyes. Therefore, all persons involved in the treatment room must wear the safety goggles normally supplied by the manufacturer. At all times, safety protocols associated with the particular laser machine must be followed. Protection of the skin is also required during laser operation at wavelength <400nm to avoid risk of tissue burning.

Integration of lasers in the dental practice

The integration of lasers just like any other new technology and requires fundamental planning for training, financial outlay, and ongoing costs. This planning must also include marketing, including introduction of the concept to the existing clients of the practice. The investment of time in planning meticulously to address all aspects of laser addition to a dental office will assist in achieving a smooth transitional phase in the process of integration.

In choosing a laser, the clinical applications that are more commonly employed in the dental office should be considered, in addition to space. The indications for investing in a laser system include:

- New treatments offered: Addition of a laser may provide new opportunities for treatments to the patients which were not available previously. These include crown lengthening, gingevectomy or uncovering tooth for orthodontic bracket bonding.
- Simplified and efficient treatments: Subgingival retraction for implant or crown restorations with localised hemostasis resulting in an accurate impression in a timely and cost effective (i.e., less materials used) manner. Manageable soft tissue surgery with successful hemostasis and recontouring margins around decayed lesions. Disinfection of aphthous ulcers to reduce patient discomfort and save treatment time.
- External referrals reduced: Depending on the level of clinician experience and training, most procedures referred out can be completed in-house. This is to the benefit of the dental office and the patient in terms of costs, time and efficiency. Suspicious lesions can be biopsied and send for pathology. Tissue contouring during orthodontic procedure can occur, common fibromas can be removed, and operculums over wisdom teeth can be removed for immediate relief.
- Efficiency in treatment procedures: Most lasers allow for excellent bleeding control and reduced use of anaesthetics, saving time to perform multiple treatment procedures. Restoration of few teeth in different quadrants that have cervical caries and require gingival recontouring can be completed efficiently and ultimately provide quality patient care.

The success of the integration process is largely dependent on the support and active involvement of the dental office team, from inception to implementation. The clinician is responsible for ensuring training opportunities are made available to all team members and involving the staff in experiencing laser effects first hand. Notably, most patients are not only grateful for additional treatment opportunities that add to their quality of care, but will also increase internal referrals to other patients who seek modern, cutting edge, and literally pain-free treatment.

Conclusion

The dental field is rapidly evolving and the advent of lasers offers more treatment options (Figure 2). Using lasers as an adjunct to specific procedures has not only imparted clinical benefits, but also increased patient comfort and ease. More and more patients are technology-savvy, and use online tools to educate themselves, looking for dental options that are technically advanced and offer a pain-free and comfortable dental experience. Dental practices can effectively integrate lasers as part of their routine dental procedures and offer lasers as an alternative or adjunct treatment for their patients. The most important part of the successful integration and practical use is the understanding of the essentials of laser application and safety requirements by clinicians and their dental teams.

There is comprehensive planning involved in integrating lasers including ongoing training, educating the dental team, and marketing and financial planning. Ultimately the economics, quality of dentistry on offer, patient comfort and financial rewards outweigh the initial time and costs spent for the inclusion of lasers into a dental office. This course highlighted the mechanism of laser actions, different types and typical application of lasers in dentistry with a focus on optimal laser parameters for positive treatment benefits as well as safety requirements and integration into dental offices. It also provided a comprehensive update on evidence-based laser applications in dentistry. The benefits of therapeutic effects of lasers are astounding and safe laser implementation should be considered in every dental office.

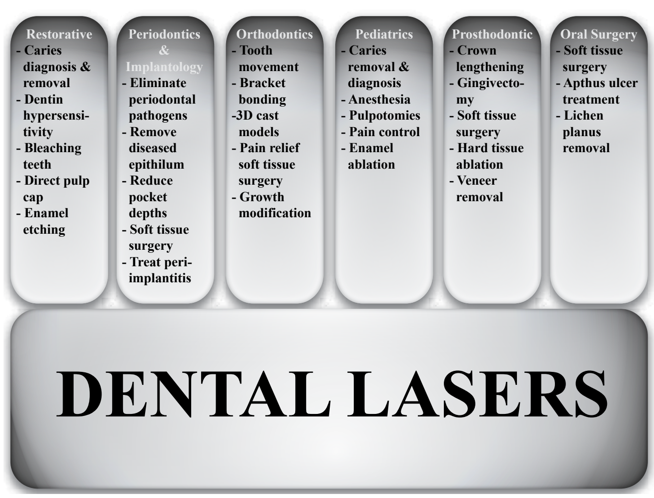

Figure 2. Summary of common laser applications in general dentistry practice

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Suggested reading list on dental lasers

Laser safety

American National Standard for Safe Use of Lasers in Health Care Facilities **https://www.lia.org/PDF/Z136_3_s.pdf**

Comprehensive overview of all lasers in dentistry

Koci E, Almas A. Laser application in dentistry: an evidence-based clinical decision-making update. Pak Oral Dent J. 2009;29(2):409-423.

Orthodontics

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Oral surgery

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Restorative dentistry

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UPDATES ON LASER THERAPY IN DENTISTRY AND INTEGRATION IN THE DENTAL OFFICE

Final Examination Questions

Select the best answer for each question and mark your answers on the Final Examination Answer Sheet found on page 112 or for faster service complete your test online at **Dental.EliteCME.com.**

1. Lasers produce a source of energy as a coherent radiation of one wavelength in the infrared, visible, or ultraviolet part of the electromagnetic spectrum.
   a. True.
   b. False.

2. The optimal parameters of lasers depend on the target tissue, and involve only the wavelength, exposure time, and energy quantity.
   a. True.
   b. False.

3. Laser-tissue interaction is dependent on the wavelength and mode of laser emission only.
   a. True.
   b. False.

4. ________ cannot interact with gold or porcelain material.
   a. Diode lasers.
   b. LLLT lasers.
   c. Erbium lasers.
   d. Nd-YAG lasers.

5. Strict adherence to ___________ by all dental team members in the vicinity of the laser is paramount to avoid contaminated aerosols.
   a. Rules.
   b. State guidelines.
   c. Ethical codes.
   d. Infection control.

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