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Review Article

Erbium Family Laser: Silent Revolution in Dentistry. Review

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Abstract

Erbium laser systems quickly began establishing themselves as compact and versatile additions to the dentist's repertoire, predominantly for performing hard tissue applications. Research has shown that their wavelengths are ideally suited for both soft and hard tissue procedures due to their high absorption in water and hydroxyapatite. Therefore, these lasers are considered one of the most versatile with regard to the number of possible treatment options, as their wavelength can be effectively used in the field of soft and hard tissue surgery, periodontics, endodontics, implantology, cavity preparation, and tooth whitening. The versatility of the instrument, combined with the latest achievements in laser technology, compact design and affordability, should appeal to dental professionals seeking to optimize the procedures they currently perform and expand the number of services they offer which is the main aim of the current review.

Keywords: *Lasers Basics; Laser Tissue Interaction; Chromophores; Erbium Laser Family; Erbium Laser Family Applications in Dentistry*

Introduction

Laser-assisted dentistry is a recent emerging trend. Dental lasers are frequently used in oral surgical procedures as well as restorative dentistry and prosthodontics [1]. The first dental laser – the Nd:YAG 1,064 nm – was marketed as being suitable in tooth cavity preparation – a claim that was quickly deemed to be erroneous for clinical relevance. Early research into this claim supported the ablative effect of the 1,064 nm wavelength on accessible pigmented carious lesions [2,3], but whenever healthy enamel and dentine was exposed to the laser energy, the comparatively long pulse width and associated heat transfer, combined with the lack of water spray resulted in thermal cracking and melting of hydroxyapatite together with high intra-pulpal temperature rise [4-6]. Although there is a high absorption peak of CO_2 laser by carbonated hydroxyapatite, its continuous wave emission of laser energy and lack of axial water coolant results in rapid carbonization, cracking and melting of tooth tissue. Therefore, the carbon dioxide wavelength is impractical for restorative dental procedures [7]. With the Erbium group of lasers, the free-running micro pulse emission mode results in rapid and expansive vaporization of interstitial water and dissociation of the hydroxyl radical in the hydroxyapatite crystal causing an explosive dislocation of the gross Structure [8,9].

Compared to near infra-red wavelengths, the explosive outward effect of Erbium laser energy results in minimal thermal diffusion through the tooth structure. Co-axial with this laser is a water spray, to aid in dispersing ablation products and to provide cooling of the target site. The development of ultra-short pulse laser emissions of the Erbium group of wavelengths appears promising in reducing the conductive heat potential, whilst increasing the rates of tissue ablation. Nonetheless, both laser wavelengths allow cavity preparation within acceptable clinical parameters [10]. The Er:YAG laser was introduced in 1974 by Zharikov., *et al*. as a solid-state laser that generates a pulsed laser with a wavelength of 2,940 nm. Since the Er:YAG laser is well absorbed by all biological tissues that contain water molecules, this laser is indicated not only for the treatment of soft tissues but also for ablation of hard tissues.

A more recent laser based on an Er,Cr:YSGG medium emits laser light similar to the Er:YAG laser at a wavelength of 2.78 μm, and has been reported to have similar effects upon soft and hard dental tissues [11].

Recently laser technology got a more and more important role in modern dentistry. In 1989, experimental work by Keller and Hibst using a pulsed Erbium YAG (2,940 nm) laser (Figure 1A), demonstrated its effectiveness in cutting enamel, dentine and bone. This laser became commercially available in 1995 and, shortly followed by a similar Er,Cr:YSGG (erbium chromium: yttrium scandium gallium garnet – 2,780 nm) laser in 1997, amounted to a laser armamentarium that would address the surgical needs of everyday dental hard tissue treatment (Figure 1B) [12].

Figure 1: *(A) representative of Er:YAG, and (B) Representatative of Er,Cr:YSGG lasers.*

A list of some manufacturers of Erbium family dental lasers are:

1. AMD LASERS, Picasso, Picasso+, Picasso Lite, Picasso Lite+ are registered trademarks of AMD GROUP LLC: Er:YAG. LiteTouch™ is the world's smallest Erbium YAG dental laser for both soft and hard tissue dental treatments. Its unique Laser-in-Handpiece™ technology houses the entire laser mechanism within an impressively small chamber (just 12 cm long, with a 2.5 cm diameter) (Figure 1A).
2. iPlus, Biolase (USA) (Figure 1B): Er,Cr:YSGG laser unit equipped with optic fiber. A Waterlase MD Er,Cr:YSGG laser (Biolase, Irvine, California, USA)

3. LightWalker AT, Fotona, Slovenia: Er:YAG and Nd:YAG combined laser unit equipped with a comfortable and well-balanced articulated arm (Optoflex, Fotona) and flexible optic fiber.
4. Gomecy, Changhshah Gomecy Electronics Co., Ltd. Er:YAG laser.
5. IPL, Beijing Starlight Science and Technology Development Co., Ltd: Er:YAG laser.

Laser terminology [13]

Absorption: The transformation of radiant energy to another form of energy (usually heat) by interacting with matter.

Chromophore: A targeted component of tissue that absorbs light at a specific frequency.

Coherence: All waves are in phase with one another in both time and space.

Collimation: All waves are parallel to one another with little divergence or convergence.

Energy: The product of power (watts) and pulse duration (seconds) which is expressed in joules.

Extinction Length: The thickness of a material necessary to absorb 98 % of the incident energy.

Focus: The exact point at which the laser energy is at peak power.

Irradiance (power density): The quotient of incident laser power on a unit surface area, expressed as watts/cm^2.

Joule: A unit of energy which equals one watt-second.

Laser Medium: A material or substance of solid, liquid or gaseous nature that is capable of producing laser light due to stimulated electron transition from an unstable high energy orbit to a lower one with release of collimated, coherent, monochromatic light.

Meter: A unit length based on the spectrum of krypton-86; frequently subdivided into millimeters (10^3 m), micrometers (10^6 ms), and nanometers (10^9 m).

Optically pumped laser: A laser where electrons are excited by the absorption of light energy from an external source.

Pockels cell: A device consisting of an electro-optical crystal that can be turned on or off very quickly by attached electrodes to allow the build-up of high amounts of energy within the optical cavity of a laser and then released as a single, powerful, extremely short pulse.

Population Inversion: The state present within the laser optical cavity (resonator) where more atoms exist in unstable high energy levels than their normal resting energy levels.

Power: The rate at which energy is emitted from a laser.

Power density (irradiance): The quotient of incident laser power on a unit surface area, expressed as watts/cm^2.

Pump: The electrical, optical, radiofrequency or chemical excitation that provides energy to the laser medium.

Q-switch: An optical device (pockels cell) that controls the storage or release of laser energy from a laser optical cavity.

Reflectance: The ratio of incident power to absorbed power by a given medium.

Scattering: Imprecise absorption of laser energy by a biologic system resulting in a diffuse effect on tissue.

Selective photothermolysis: A concept used to localize thermal injury to a specific target based on its absorption characteristics, the wavelength of light used, the duration of the pulse and the amount of energy delivered.

Thermal relaxation time: The time needed for 50 % of heat absorbed during a laser pulse to be dissipated without conduction to the surrounding tissue.

Component parts of laser machine and how laser light is produced (Figure 2):

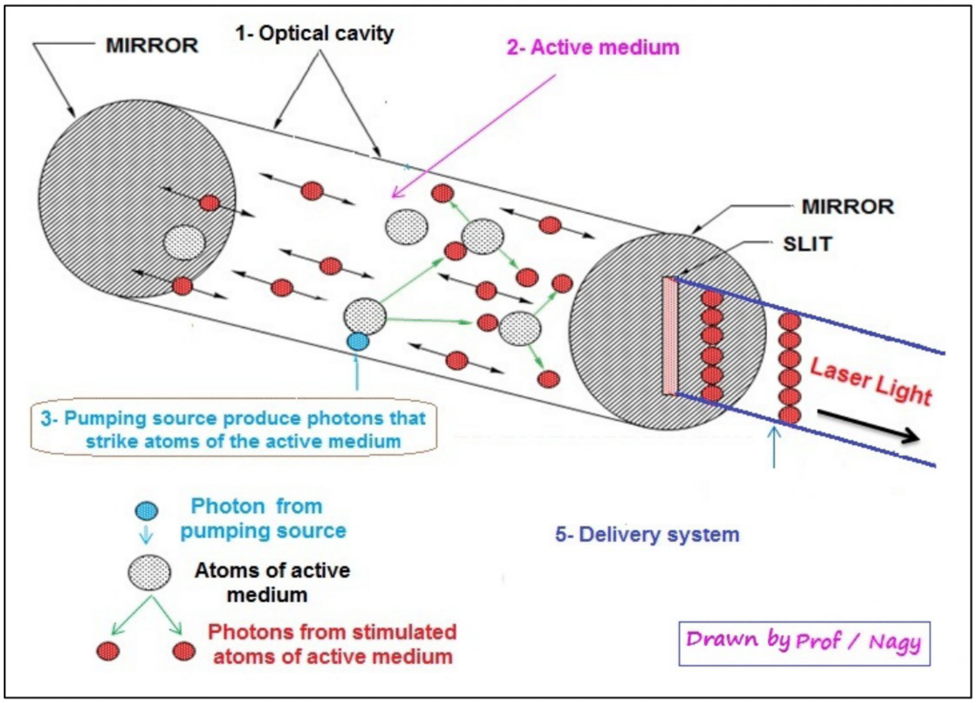

Figure 2: *Production of laser.*

Several components are necessary to constitute a dental laser unit [14].

The Optical Cavity (or resonator) that includes the active medium.

The active medium: It is the heart of the laser and is a solid in case of erbium family laser. The active medium determines the specific wavelength of different lasers and its name identifies different lasers. The active medium supplies the electrons for the production of the laser photons. Table 1 reports the active medium of the two erbium lasers used in dentistry.

Table 1: *Active media, hosting media, and doping atoms of the erbium family lasers in dentistry.*

Laser	Abbreviation	Active Medium	Medium	Atom	Wavelength (nm)
Erbium, Chromium doped yttrium-scandium-gallium-garnet	Er,Cr:YSGG	Solid	YSGG crystal	Er and Cr	2780 nm
Erbium doped yttrium-aluminium-garnet	Er:YAG	Solid	YAG crystal	Er	2980 nm

Erbium chromium:YSGG (2780 nm) has an active medium of a solid crystal of yttrium scandium gallium garnet that is doped with erbium and chromium and Erbium:YAG (2940 nm) has an active medium of a solid crystal of yttrium aluminum garnet that is doped with erbium. Caries removal and tooth preparation are easily accomplished by both the lasers [15,16].

The pumping source (or energy source) to supply the energy necessary for the Stimulation.

A controller that is a software that controls the modality and parameter of laser emission and a cooler, necessary for cooling the laser system.

The delivery system that transports the laser energy to a terminal handpiece and tips and finally to the tissue. Erbium lasers (2780 – 2940 nm) use more complex optic fibers as delivery system, of larger diameter, made of sapphire or fluorides, with a terminal handpiece holding the tips. This delivery system is the easiest to use in the oral cavity.

Handpieces and Tips Lasers such as Er,Cr:YSGG, Er:YAG, and CO2 have a more complex kind of handpiece, with internal angled mirrors and terminal tips for the transfer of energy to the target tissue. Furthermore, the laser handpieces of erbium have an integrated air-water spray that is better if coaxial to the laser beam. The disadvantages of this system are the fragility and wear of the tips and the loss of energy during transmission to the tissue.

Mechanism of laser production

The amplification of light within the laser cavity sets laser light apart from other sources. For most visible light applications, laser represents a conversion from lamplight to an amplified monochromatic form. The high power possible with lasers (especially peakpower) is achieved through resonance in the laser cavity. The scientific principle on which lasers are based is stimulated emission. With spontaneous emission, electrons transition to the lower level in a random process. With stimulated emission, the emission occurs only in the presence of photons of a certain charge. The critical point is maintaining a condition where the population of photons in a higher state is larger than that in the lower state. To create this population inversion, a pumping energy must be directed either with electricity, light, or chemical energy [17].

Characteristic properties of erbium family laser light as well as any laser:

There are four properties that are common to all laser types (Figure 3 A and B):

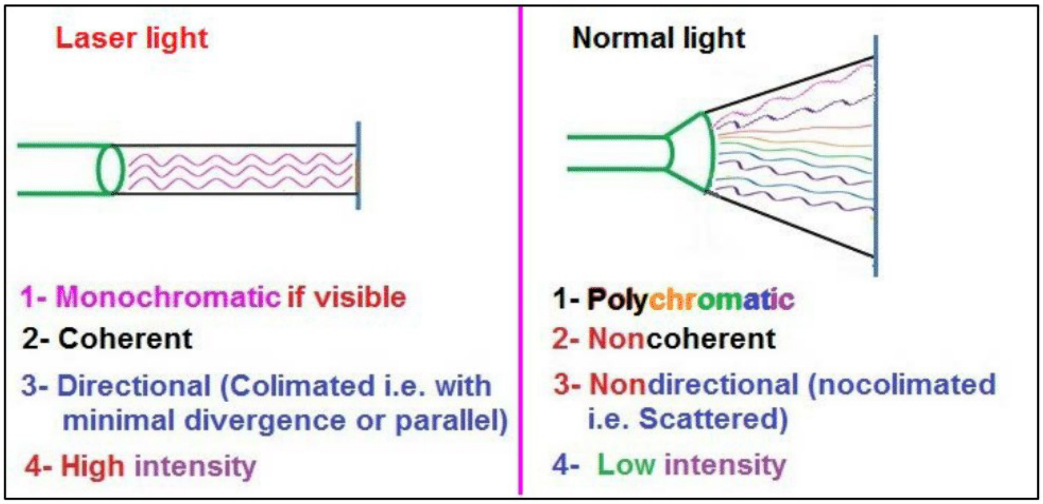

Figure 3A: *Characteristic properties of laser light.*

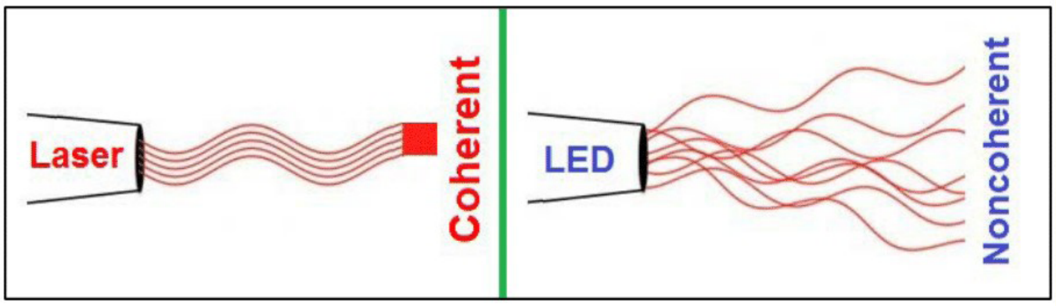

Figure 3B: *Difference between coherent (laser) and non-coherent light.*

1. **Beam directionality (collimation):** All waves are parallel to one another with little divergence or convergence. A collimated beam is created in the laser chamber when light is reflected between two mirrors and only the exit of parallel waves is allowed [18,19]. Collimation allows laser light to travel long distance without loss of intensity [18]. In practice, a lens on a laser focuses the parallel light beam down to the smallest possible spot size, or the diffraction limited spot, to allow the light to focus on the clinical target [20].

2. **Monochromaticity:** As opposed to light from the sun, laser light is monochromatic and emits a well-defined wavelength of light [21]. In terms of clinical significance, this monochromatic property of laser light allows it to target specific chromophores, such as water, hemoglobin, and melanin, and allows for specific clinical applications [22]. The liquid, solid, or gas contained in the laser medium dictates the wavelength of light that is emitted [18].

3. **Coherent:** All waves are in phase with one another in both time and space. Laser beams are both temporally and spatially coherent, and akin to a column of soldiers marching in step [22]. This phenomenon results from stimulated emission, and allows laser beams to have a high power density [18].

4. The intensity, directionality, and monochromaticity of laser light allow the beam to be expanded, or focused quite easily [23].

Erbium laser– tissue interaction

In clinical dentistry, all laser lights are used to effect controlled and precise changes in target tissue, through the transfer of electromagnetic energy [24].

Light energy interacts with a target medium (e.g. oral tissue) in one of four ways (Figure 4) [25]:

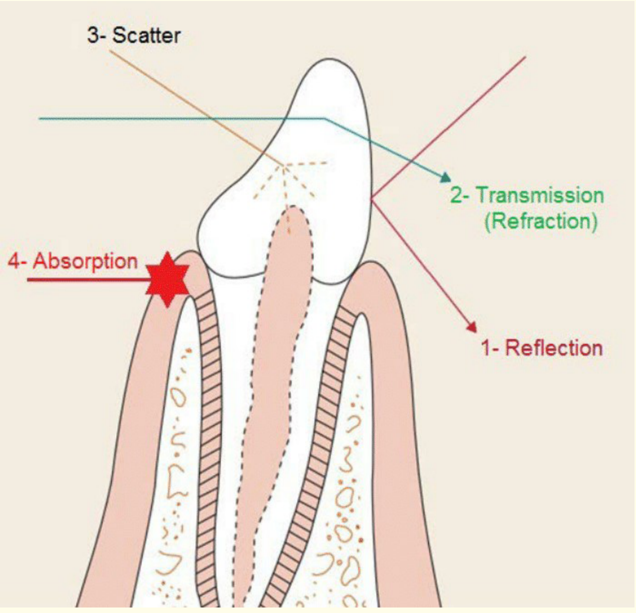

Figure 4: *Possible laser light - tissue interactions.*

1. **Reflection:** The beam redirects itself off the tissue surface without any effect on the target tissue.
2. **Transmission:** Laser beam enters the medium and emerges distally without interacting with the medium i.e. no effect on the target tissue.
3. **Scatter:** Result of light scattering is a weakening of laser energy producing no effect on target tissue.
4. **Absorption**: The incident energy of the beam is absorbed by the medium and transferred into another form of energy. Absorption is the most important interaction. Each wavelength has specific chromophores that absorb their energy. This absorbed energy is converted into thermal and and/or mechanical energy that is used to perform the work desired. Near infrared lasers like diodes and Nd:YAGs are mostly absorbed by pigments such as hemoglobin and melanin. Erbium and CO_2 lasers are predominantly absorbed by water, with erbium wavelengths also exhibiting some hydroxyapatite absorption [26,27]. Absorption requires an absorber of light, termed chromophores, which have a certain affinity for specific wavelengths of light. The primary chromophores in the intraoral soft tissue are [28]:
    a) Melanin, b) Hemoglobin, c) Water, 4) and in dental hard tissues (Water and Hydroxyapatite), and d) Photosensitive materials in visible light cured polymeric materials (Camphorquinone and α Diketone).

Temperature rise during tissue lasing [29]:

The most important and significant tissue alterations are dependent on the temperature of the tissue after absorption of the laser radiation, as follows:

- **At 37°C;** no measurable effects are observed for the next 5°C above this.
- The first mechanism by which tissue is thermally affected can be attributed to conformational changes of molecules. These effects, accompanied by bond destruction and membrane alterations due to hyperthermia at 42 - 50°C. If such a hyperthermia lasts for several minutes, a significant percentage of the tissue will already undergo necrosis.
- **At 60°C,** denaturation of proteins and collagen occurs which leads to coagulation of tissue and necrosis of cells. The corresponding macroscopic response is the visible paling of the tissue.
- **> 80°C,** the cell membrane permeability is drastically increased, thereby destroying the otherwise maintained equilibrium of chemical concentrations.
- **At 100°C**, water molecules contained in most tissues start to vaporize. Due to the large increase in volume during this phase transition, gas bubbles are formed inducing mechanical ruptures and thermal decomposition of tissues.
- **> 150°C**, carbonization takes place which is observable by the blackening of an adjacent tissue and the escape of smoke (plume).
- Finally, melting may occur. The temperature must have reached a few hundred degrees Celsius to melt the tooth substance which mainly consists of hydroxyapatite crystals.

The erbium laser family chromophores

Due to the specific affinity of water with medium- infrared wavelengths [30], specifically the erbium, chromium:yttrium–scandium–gallium–garnet laser (Er, Cr:YSGG at 2,780 nm) and the erbium:yttrium–aluminum–garnet laser (Er:YAG at 2,940 nm), now called erbium family laser, these are currently the only two wavelengths capable of being greatly absorbed within the dental tissues when used with safe and accepted clinical parameters [31-34] (Figure 5).

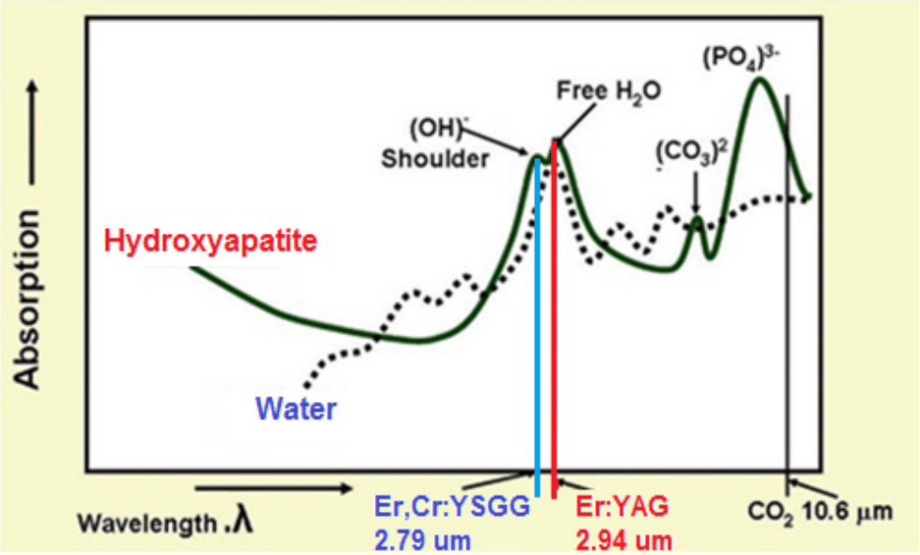

Figure 5: *Relative absorption of erbium wavelengths in hard tissue chromophores. The absorption peaks represent component radicals of the molecule (hydroxyl, free-water, carbonate, phosphate). The dotted line represents the absorption of laser energy in whole water.*

The Er:YAG laser wavelength operates into the peak of absorption of water, at 2,940 nm, while the Er, Cr:YSGG laser wavelength is absorbed slightly less by water (300 % less) at 2,780 nm [33,35] (Figure 6).

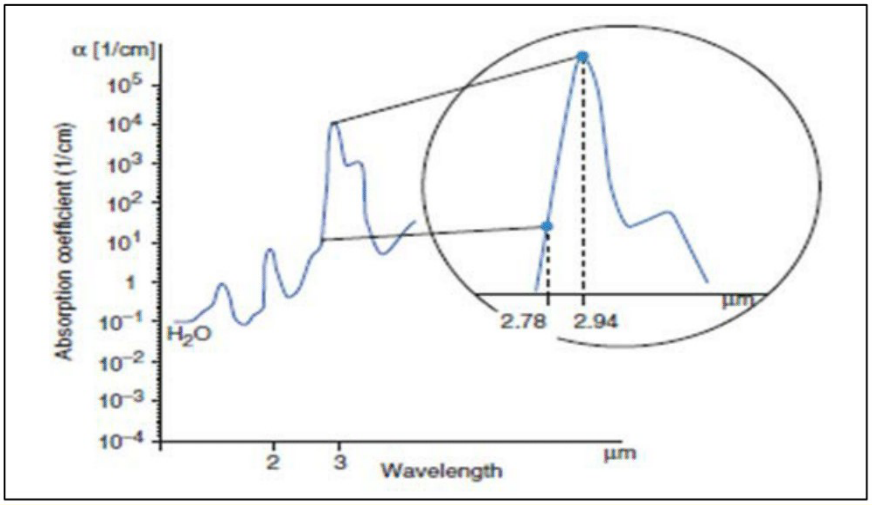

Figure 6: *Different absorption of water of different erbium lasers.*

The difference in the absorption coefficients leads to a difference in the penetration depths of the two erbium laser wavelengths in dental tissues. The Er:YAG laser wavelength penetrates approximately 7 μm in the enamel and 5 μm in the dentin; the Er, Cr:YSGG laser wavelength penetrates three times deeper, 21 μm in the enamel and 15 μm in the dentin (Figure 7) [36].

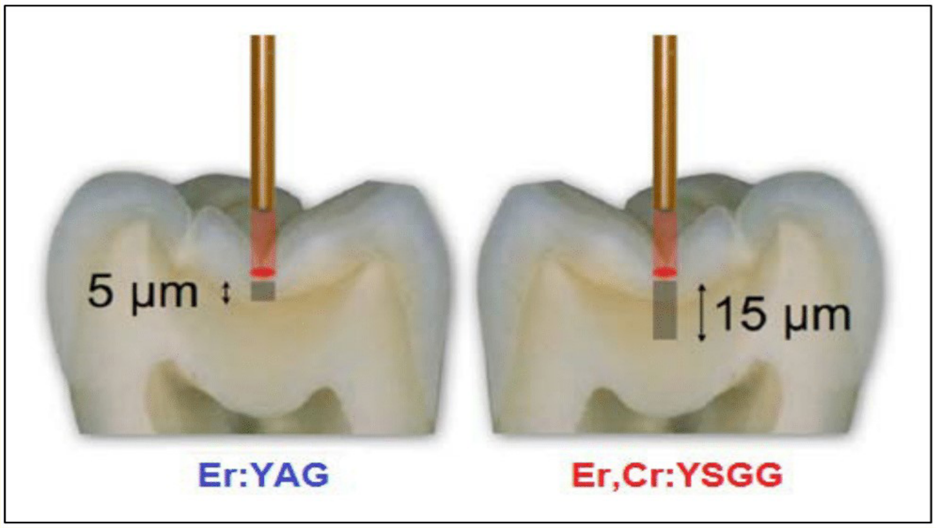

Figure 7: *Different penetration depth of Er:YAG and Er,Cr:YSGG laser in dentine.*

As a result of the very superficial absorption and due to the specific optical properties of these wavelengths, the diffusion phenomenon is negligible. Furthermore, the wavelength 2,780 nm falls into the second peak of the absorption curve of the hydroxyl group of hydroxyapatite in dental hard tissues [37-41], but its role in the ablation of hard tissues is secondary (see Figure 5); it is the stronger water absorption of 2,940 nm (Er:YAG) and 2,780 nm (Er, Cr:YSGG) that plays the dominant role in dental laser ablation [41].

Mechanism of Interaction of the Erbium Family Lasers on Hard Tissues

The interaction of the erbium laser with the hard tissue is the result of a complex mechanism, which involves primarily the photothermal effect and, secondarily, the photomechanical and photoacoustic effects that occur rapidly.

Thermal Effect

The first effect that determines the ablative action of the erbium family laser is a direct thermal effect on the water molecules within the dentin and enamel. The rapid temperature increase up to the boiling point of water (100°C), trapped within the dental interstitial structure, causes an increase of pressure when it exceeds the structural tension of the surrounding tissue, leading to a microexplosion within the tissue [39,40,42-44]. The richer the tissue is in water, the more quickly it reacts with laser energy [33].

Photomechanical and Photoacoustic Effects

The phenomenon that follows the primary thermal effect and the explosion of the water molecules inside the dental tissues is a secondary photomechanical effect, with a rapid shock wave that causes an expansion of the volume of the disrupted tissue, which results in the destruction of the surrounding mineral matrix that explodes and is removed from the irradiated surface, thus removing the tooth structure [33,35,43,45].

The microexplosion of the water molecules of the spray coaxial to the laser beam generates a pressure so high that it mechanically removes the hard tissues already irradiated and exploded by the effect of thermomechanical laser, thus participating in the ablative mechanism, with a cooling and cleansing effect [33,46].

Role of the Water in Hard Tissue Ablation

The water participates in the ablative process of the erbium family laser not only as a target chromophore but also by its cleansing and cooling action, for rehydration, which affects the quality of the ablation of the hard tissue [47]. The water spray appears to be important for its action on the tissue, because it removes the products of micro-explosion (cleaning effect) [48], modulates the laser energy directly absorbing it before interacting with the tissue (reducing the photothermal effect) [47], and cools the tissue (cooling effect) [47,48]; this enables undesirable structural thermal changes of the enamel to be avoided. An ablative "hydrokinetic" model has also been proposed; however, it is not widely accepted [49-53].

Water Within the Dental Tissue as Absorbent Chromophore

The primary role of water in the ablation of hard and soft tissues is as target chromophore. The greater the water content, the greater the absorption of the wavelengths 2,780 and 2,940 nm. It is reported that only the water content of dentin significantly influences the volume of ablation ($p < 0.0001$) of the Er:YAG laser. On the other hand, the ablative efficiency of the Er:YAG laser on the enamel is not affected by the few (minimal) water content of the enamel. The ablation volume of the Er, Cr:YSGG laser also would not be influenced by the water content of the dentin enamel This result can be explained by the low water content of the enamel and the ablative mechanism of the Er, Cr:YSGG laser (2,780 nm) that could also involve the interaction with the hydroxyapatite rather than with the water (Figure 5) [54].

Water Spray's Effects on Pulp Temperature

The interaction of erbium lasers with the water content of dental tissues and the instantaneous rise in temperature (up to 100°C) within the tooth itself during the laser ablation process should be taken into consideration. It is universally accepted that water cooling is mandatory for the safety of the pulp during the ablation of dental tissues. One of the first studies to evaluate the safety of Er:YAG laser ablation of dental tissues was carried out by Dostálová., *et al*. (1997), which evaluated, *in vivo*, on human premolars scheduled for extraction during orthodontic therapy and the pulpal response to Er:YAG laser cavity preparation. After extraction, the teeth were processed for light microscope observation that revealed no inflammatory reaction in the pulp and showed normal vascularity with the odontoblasts presenting the usual star like cell shape [55]. Eversole., *et al*. (1997) found no pulpal inflammatory responses either immediately or 30 days after Er, Cr:YSGG cavity preparation [56], and also Rizoiu., *et al*. (1998) showed that pulp temperature did not increase and even decreased by 2°C during tooth preparation with an erbium, chromium:yttrium–scandium–gallium–garnet (Er, Cr:YSGG) laser system. As a comparison, conventional burr preparation resulted in a 3 - 4°C rise [57].

Glockner., *et al*. (1998) confirmed the temperature drop after a few seconds of erbium:YAG laser preparation, from 37 to 25°C to 30°C, due to the water spray's cooling effect. In comparison, conventional preparation showed a higher rise in pulp temperature [8]. However, Armengol., *et al*. (2000), Louw., *et al*. (2002), and Cavalcanti., *et al*. (2003) found no significant difference in the Er:YAG laser and high speed handpiece groups when water spray was used to prepare class 5 cavities [58-60].

Other studies investigated the *in vitro* intra pulpal temperature variation during Er:YAG laser ablation. Oelgiesser., *et al.* (2003) reported a rise in temperature that was lower than 5.5°C (degrees Celsius) which is considered as the critical value for pulp vitality [61], while Attrill., *et al.* (2004) reported a rise in temperature that was lower than 4.0°C [62].

Other studies compared the intra pulpal temperature increases produced by a high-speed turbine and Er:YAG laser and concluded that Er:YAG laser generated a lower temperature rise but without statistical differences with both low- and high-torque handpieces groups [63,64]. Krmek., *et al*. (2009) examined the temperature variations in the pulp chamber during cavity preparation with an Er:YAG laser

(2,940 nm) using a very short pulse duration (100 µs), at different depths (enamel and dentin) and different settings with a 1-mm-diameter tip. The highest rise in temperature in the pulp was achieved after enamel irradiation with 400 mJ and 15 Hz (2°C) and the lowest was after irradiation with 320 mJ and 10 Hz (0.7°C).

In dentin, the highest temperature increase was achieved with 340 mJ and 10 Hz (1.37°C) and the lowest was with 200 mJ and 5 Hz (0.43°C). It appears evident that both energy level and pulse frequency affected the temperature rise; however, the two-way analysis of both enamel and dentin showed that the influence of energy on temperature increase was stronger than that of frequency [65].

A study by Olivi., *et al.* (2010) described the role of water spray as modulator of the laser energy to avoid the undesirable structural thermal changes to dental tissues; a safer and more effective irradiation of the enamel was found at high percentages of air and water (Er, Cr:YSGG 92 and 80 %: 56 mL/min). The authors reported the important role of the water flow rate to obtain a qualitatively better ablation, both reducing the thermal effect of the laser interaction and increasing the tissue, cooling, and cleaning action [47].

Lately, Kuščer and Diaci (2013) studied the efficiency of the erbium laser ablation of hard tissues under different water cooling conditions. They found that the use of a continuous water spray during laser irradiation of hard dental tissues reduced the laser ablation efficiency in comparison with laser irradiation in dry mode. The phenomenon of ablation stalling can primarily be attributed to the blocking of laser light by the loosely bound and recondensed desiccated minerals that collect on the tooth surface during laser ablation. Also no evidence of the influence of the water absorption shift on the hypothesized increase in the ablation efficiency of the Er,Cr:YSGG wavelength was observed. Another positive function of the water spray during erbium laser irradiation is that it rehydrates the minerals within the tooth, thus sustaining the subsurface expansion ablation process [66].

Mechanism of Interaction of Different Lasers on Soft Tissues

The different composition of the gum tissue in melanin, hemoglobin, water, and protein matrix (non-operator-dependent factors) determines the different interaction with the selected wavelength. Therefore, the choice of wavelength is the most important operational factor (operator dependent factor): visible, near-, medium-, or far- infrared lasers all interact with the soft tissues, but with different modalities (scattering or absorption), different target chromophores (hemoglobin and melanin or water), and different penetration depths (deeper or superficial) (Figure 8).

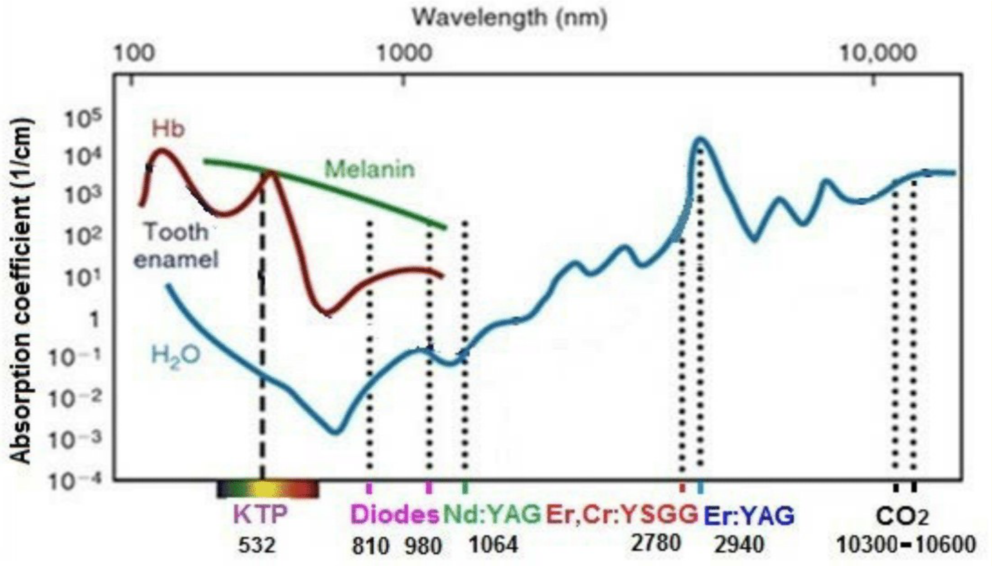

Figure 8: *Different laser wavelengths in the electromagnetic spectrum and the relative absorption in soft tissue chromophores.*

The lasers in the visible and the near-infrared spectrum are absorbed predominantly by melanin and hemoglobin. The lasers in the visible spectrum (532-nm KTP) have an optical behavior of absorption–diffusion to 50%, with less deep penetration in the soft tissue. The lasers in the near infrared spectrum are spread more in depth with the increase of their wavelength. The medium-infrared (Er, Cr:YSGG and Er:YAG) and far-infrared lasers (CO2) are absorbed by the water within tissues; the CO2 laser has a moderate surface absorption in tissue. The erbium:YAG laser is much more shallow, having a maximum absorption in the aqueous component of the gingiva, mucosa, and dental pulp. The absorption wavelength of 2.78 µm is lower, with greater penetration into the soft tissue; this translates, for the same energy emitted, in a higher ablative efficiency for the soft tissues.

Laser Parameters

The laser–tissue interaction depends on the wavelength and the target tissue. The consequent effects on tissue are closely influenced by the parameters used [33,43]. Erbium lasers are called "free-running pulsed" lasers because they emit pulses that have a specific beginning, peak, and end; pulsed emission concentrates the amount of energy and time in a defined space (temporal and spatial profile), at defined intervals.

The parameters of laser used that influence the effects on the tissue are:

Energy and Threshold of Ablation

Energy is the ability of the system to perform a task. The term therefore expresses the ability of a laser to emit particles of energy (quantum) that can perform a given work (job), in our case the ablation of dental tissues. The energy density (fluence) is the amount of energy emitted per unit of irradiated surface in a unit of time (expressed in J/cm^2). It is a value affected by the amount of irradiated surface covered in the unit of time, which also is closely related to the speed of hand movement when using the laser. It is more useful, clinically, to consider the energy density in relation to the diameter of the fiber tip to use. At the same amount of energy emitted, the smallest fibers emit energy at a higher density; to have the same energy density, a larger-diameter tip requires a greater amount of energy, while less energy is needed for a smaller tip. Other parameters that affect the fluence are focusing or defocusing the laser beam, which, respectively, increases or decreases the density of the energy. As the distance between the laser tip and the target tissue increases, the fluence decreases precipitously. At 2-mm tip-to-tissue distance, fluence is calculated to decrease by 68 % from its level at the tip surface. At 3 mm, it decreases by 78% [33, 67] (Figure 9).

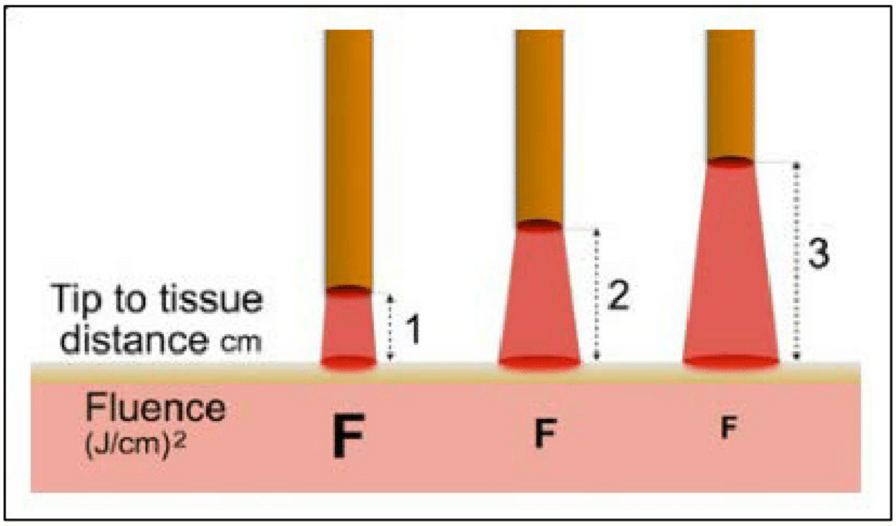

Figure 9: *Fluence and working distance; using the same fiber diameter and the same energy, the fluence decreases with the working distance.*

The minimum energy required to generate a clinical effect, ablation or vaporization, is called the "threshold of ablation." The energy that does not reach the ablation threshold is called sub-ablative. When considering an erbium laser and water, its target chromophore contained in the dental tissues, the ablation threshold of the enamel was approximately calculated by Apel., *et al.* (2002) in values of 9 - 11 J/cm^2 for the Er:YAG laser and slightly higher at 10 - 14 J/cm^2 for the Er, Cr:YSGG laser [68]. Lin., *et al.* (2010) have calculated that the threshold values for the ablation of dentin are approximately 2.97 - 3.56 J/cm^2 for the Er:YAG and 2.69 - 3.66 J/cm^2 for the Er, Cr:YSGG laser [69]. The shorter pulse durations, the energy has little time to escape from the ablated volume and so less heat is diffused into the surrounding tissue.

Pulse Repetition Rate

Also called pulse frequency or improperly frequency, expressed in Hz and/or more correctly in pulses per second (pps), it is an expression of the number of pulses emitted per unit of time. Numerous pulses per second increase the speed and power of the interaction; the more numerous the pulses in the time unit, the smaller the interval between one pulse and the other, with less time for tissue cooling.

Power

Power expresses the speed with which a certain amount of work is produced. The average power of the laser is determined by the energy emitted in the unit time (second). It is determined by the value of the energy of each single laser pulse (expressed in J) multiplied by the number of pulses in a second (pulse repetition rate or pulse frequency, expressed in Hz or pps). The greater the power applied, the faster the effect on the tissue. Power density is determined by the power emitted per unit of surface area of the fiber tip or tip (expressed in Watts/cm^2).

Pulse Duration and Peak Power

The peak power of each pulse is calculated by the energy emitted by a single pulse divided by its duration (pulse duration); it determines the effectiveness of the pulse output. The shorter the pulse duration, the more energy is concentrated in the unit time and the more effective is the ablative action with minimum thermal effect [35,70]. Long pulses have a higher emission of thermal energy on the tissue and are more effective for the vaporization of soft tissues. Short pulses have better efficiency for hard tissue ablation. Consequently, for an erbium laser, the possibility to vary and control the pulse duration is critical for the success of laser dental treatments. Table 2 summarizes the main operating parameters of the erbium laser.

Table 2: *The main operating parameters of erbium family laser.*

Energy (E): J
Fluence or energy density (Fl): J/cm^2
Pulse repetition or frequency (F): Hz or pps
Average power (P): Watt= E (J) x F (Hz or pps)
Power density (Pd): W/cm^2
Peak power (PP): W=E(J) ÷ pulse duration (s)

By learning how to set these parameters and operating modes, you can manage and influence the quantity and quality of irradiation on the tissue, being able to predict the resulting biological effects [70].

Versatile use of erbium laser in dentistry

The Er:YAG laser offers significant advantages over other conventional osteotomy techniques like a noncontact intervention, no mechanical vibration, free and elaborate cut geometries and aseptic effects. The Er:YAG laser is a state of the art and innovative bone cutting technique with a high potential for future applications and trends in oral surgery and implant dentistry [71]. Studies employing erbium laser wavelengths of 2.94 μm (Er:YAG laser) and 2.78 μm (Er,Cr:YSGG laser) found both systems to be efficient for dental hard tissue ablation [72,73]. The main components of bone have a high absorption of the laser light at the wavelength (2.94 μm) of the Er:YAG laser [48]. The wavelength-dependent absorption coefficient for water is at its maximum peak at 2.94 μm. The Er:YAG laser theoretically has an absorption coefficient of water that is 10 and 15,000 - 20,000 times higher than the CO_2 and the Nd:YAG lasers, respectively [74]. Thus, it was not surprising that the erbium laser was finally the first dental laser cleared by the US Food and Drug Administration for use in cutting human teeth *in vivo* [75], there have been several improvements in the treatment of periodontal disease, such as the usage of hard and soft lasers as an adjunctive to conventional periodontal therapy for the effective reduction and elimination of pathogenic microorganisms in the periodontal pocket, thus, leading to a more effective and pain free treatment [1,76-79].

As a member of the erbium laser family, Er,Cr:YSGG lasers demonstrate a very shallow penetration in tissue with a wavelength of 2.78 μm posing minimal thermal risk to the deeper tissues when compared with other lasers and provide a better surface for the attachment of blood derived components on roots [80,81]. It is also reported that ER,Cr,YSGG laser enhances cell attachment and migration on the root surfaces [82].

Although there is an ongoing debate about the benefits of the usage of adjunctive laser therapy with conventional periodontal treatment, the present study confirms that Er,Cr:YSGG assisted periodontal therapy improves periodontal parameters of probing depth (PD) and Bleeding on probing (BOP) in chronic periodontitis and reduces periodontal disease related oral malodor more effectively than conventional non-surgical periodontal therapy. The current study to the best of our knowledge is the first to evaluate the efficacy of Er,Cr:YSGG laser on halitosis. The study population should be expanded in further studies in order to achieve more definite results [83].

Erbium laser use in cavity preparation

Cavity preparation with an Er:YAG laser could be considered as an alternative to the conventional method of drilling [84]. Some authors showed that there is no statistically significant difference could be observed in the fracture strength of dentin beams when treating them either with Er:YAG and Er,Cr:YSGG laser irradiation or mechanically by a fine diamond bur in a high speed hand piece. Additionally, no statistically significant difference could be observed between treated and untreated specimens [85]. Er:YAG laser is more comfortable and pleasant for the patient, compared to conventional drill. Also, it reduces tooth hypersensitivity and microbial load within the cav¬ity [86]. Ablated dentin with different parameters of Er:YAG laser energy with powers below 3 W make no cracks. These facts are adjunct to suitable dentin surface treatment by Er:YAG laser, making Er:YAG laser a desir¬able alternative method for cavity preparation [87]. Ablation of dental hard tissues was achieved using the Er:YAG laser operating at high pulse repetition rates with minimal peripheral thermal damage [88]. In addition, since water is the primary absorber of Er:YAG radiation and demineralized areas are more porous and have a higher water content, the ablation rate is significantly higher for demineralized enamel [89], and dentin vs. sound tissues. The Er:YAG laser may be used in conservative dentistry as an alternative to conventional instruments and in association with orthophosphoric acid, with several advantages, such better strength bond [90], reduced microleakage [91], and also lower discomfort and higher patient satisfaction [92].

In an *in vitro* study, even if considered as preliminary due to the limited number of samples, it is confirmed that Er:YAG can be employed also in dental traumatology, to restore frontal teeth after coronal fracture, with the advantage of improved adhesion of the dental fragment to the tooth, in particular by decreasing microleakage [93].

In September 2016, the Cochrane collaboration published a systematic review of the current evidence comparing the use of lasers for caries removal, in both deciduous and adult teeth, with the standard dental drill. Nine trials were reviewed, published between 1998 and 2014, with 662 participants in total. These included three different types of laser: Er:YAG; Er,Cr:YSGG; and Nd:YAG. Overall the quality of evidence available was found to be low, and the authors were unable to recommend one method of caries removal over the other. There was no evidence of a difference between the marginal integrity or durability of the restorations placed. However, there was some evidence that the laser produced less pain and required less anaesthesia than the drill. The authors concluded that more research is required [94].

Applications of erbium lasers in Pediatric Dentistry

Caries Prevention

Resistance of the tooth surface to penetration of cariogenic agents plays an important role in prevention of caries. Er:YAG laser can be successfully used to increase resistance of a newly erupted permanent tooth in children and adolescents to acid erosion [95,96]. Er:YAG laser cavity preparation allows minimally invasive treatment of dental caries and also shows excellent acceptance among both young children and their parents. The choice of optimal energy parameters is a requirement for successful laser caries treatment in pediatric dentistry [97]. Resistance of the tooth surface to penetration of cariogenic agents plays an important role in prevention of caries. Erbium and CO_2 lasers can be successfully used to increase resistance of a newly erupted permanent tooth in children and adolescents to acid erosion. Studies have demonstrated that CO_2 laser at 9600, 9300 and 10,600 nm wavelengths, erbium laser at 2780 and 2940 nm wavelengths and argon laser can confer resistance to enamel surfaces against caries [96,98].

Restoration, Pit and Fissure Sealants

Laser can also be used for tooth surface preparation prior to the application of pit and fissure sealants. Laser can be applied for conditioning, cleaning and disinfection of pits and fissures as well [99]. Er:YAG laser at lower wavelengths causes only macro-roughening of pits and fissures [100].

Er:YAG in Endodontics

Application of Er:YAG laser for pulp coagulation has also shown more favorable results after 2 years in comparison with calcium hydroxide. Efficient use of laser technology in cleaning and shaping of the root canal system has also been demonstrated. For instance, Er,Cr:YSGG laser has cleaning and shaping efficacy similar to that of rotary instruments and superior to that of hand instruments. Moreover, this laser acts faster than the afore-mentioned 2 techniques [101-103]. Application of Er:YAG, Er,Cr:YSGG and CO_2 lasers for pulp coagulation has also shown more favorable results after 2 years in comparison with calcium hydroxide [103,104].

Exposure of Unerupted Teeth for Orthodontic Purposes

For soft tissue removal and exposure of unerupted teeth for orthodontic purposes, Er,Cr:YSGG, Er,YAG, diode and Nd:YAG lasers are used [105]. Erbium laser is efficient for both soft and hard tissue ablation. But, there is always a risk of enamel damage at the surgical site. However, this risk is nonexistent if diode or Nd:YAG lasers are used due to their specific wavelengths [106].

Etching of amalgam surface for orthodontic bracket bonding

The application of sandblasting technique accompanied by Er:YAG laser irradiation to an amalgam filling in a tooth can provide suitable surface for bonding of orthodontic brackets to that amalgam [107].

Etching of porcelains

To achieve proper bond strength for porcelains, adequate surface roughness is essential, which is traditionally gained by sandblasting or acid etching with hydrofluoric (HF) acid. Nowadays with the development of laser systems, serious efforts were made to apply this new instrument for surface etching of porcelains due to easy usage, safety, and more efficiency [108]. Er:YAG lasers are capable of bringing more significant changes on zirconi porcelains. Acceptable zirconia surface roughness by this laser at 400 and 600 mJ pulse energy. Akyil., et al. showed that Er:YAG can be beneficial at 2 W power and 200 mJ pulse energy as well; the irradiation time for this setting was 10 seconds [109]. Er,Cr:YSGG at 3 W power for 50 seconds and could make an acceptable surface roughness in zirconia porcelain [110]. Another study also supported usage of this laser at 1.5 - 2 W power due to the significant difference with the control group in feldspathic porcelains [111].

Advantages of erbium lasers over conventional dental techniques

In case of soft tissue treatment

Er,Cr:YSGG lasers have been used since the last decade in dentistry and reported to have provided better periodontal tissue regeneration than that of conventional non-surgical periodontal therapy [1,78]. It is reported that a combination of Er,Cr:YSGG laser and conventional scaling and root plaining had better results compared to scaling root-plaining alone in terms of attachment level restoration [78]. Other types of high intensity lasers such as Er:YAG and Nd:YAG lasers have been recently used in a way similar to Er,Cr:YSGG in the periodontal therapy [112,113]. Er:YAG lasers are securely used as an alternative to non-surgical periodontal therapy or as an adjunct for pocket treatment [114,115]. It is reported that the damage of the thermal side effects is prominently reduced in Er,Cr:YSGG laser and it can be safely and effectively used in non-surgical periodontal therapy [77].

In case of hard tissue treatment

The effect of erbium family lasers on tooth structure during cavity preparation has been investigated in several studies. Various pulse durations and repetition rates and different energy and power parameters were investigated in these studies regarding the micro morphological aspect of enamel and dentin, ablation speed, depth, and/or volume [116-118]. On the other hand, bur tooth preparation is associated with metallic noise and vibration that might cause discomfort and anxiety of the patient, as well as cracks and tooth weakening [119-121]. Less pain, noise, and vibration have been reported with laser cavity preparation [122,123].

Bactericidal and anti-infective effects are the other aspects that could be expected [124]. Staninec., *et al*. described a difference regarding fracture under bending between a free-running Er:YAGlaser of 135 µs and a q-switched Er,Cr:YSGG laser of 0.5 µs pulse duration. While the Er:YAG treated surfaces did not show visible cracks, the Er,Cr:YSGG treated surfaces showed significant surface cracks. They reported that this resulted in significant weakening for the Er,Cr:YSGG treated specimens. This was explained by the q-switch laser generating mechanical and thermal shock waves, thermal expansion, and recoiling ablation debris [125]. It is to be noted that in addition to the drastically reduced pulse duration (135 versus 0.5 µs) the irradiation with the Er,Cr:YSGG laser was also performed without a water spray which represents an experimental setup which does not simulate a clinical situation.

There is no statistically significant difference could be observed in the fracture strength of dentin beams when treating them either with Er:YAG and Er,Cr:YSGG laser irradiation or mechanically by a fine diamond bur in a high speed hand piece. Additionally, no statistically significant difference could be observed between treated and untreated specimens [85].

Discussion

The aim of this review article was to present the fundamental principles of laser with reference to erbium family, their interaction with soft and hard tissues, the method of their production, and the characteristic properties of laser light in a simplified manner.

The versatility of the instrument, combined with the latest achievements in laser technology, compact design and affordability, should appeal to dental professionals seeking to optimize the procedures they currently perform, expand the number of services they offer and enable the practitioner to make use of the new era of erbium family laser in dentistry. This technology needs to find its niche in dental practice by clinical and controlled research.

Conclusion

The basics of laser science, tissue effects of dental lasers, erbium family laser wave lengths and their chromophores, and some important applications of erbium family laser in dentistry have been discussed. It is important for the clinician to understand these principles to take full advantage of the features of erbium laser and provide safe and effective treatment.

Conflict of Interest

The author reports no conflicts of interest in this work.

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Volume 13 Issue 4 August 2017