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ORIGINAL RESEARCH

Human Dental Enamel and Dentin Structural Effects after Er:YAG Laser Irradiation

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ABSTRACT

Ideally projected to be applied on soft tissues, infrared lasers were improved by restorative dentistry to be used in hard dental tissues cavity preparations — namely enamel and dentin. This paper evidentiates the relevant aspects of infrared Erbium laser's action mechanism and its effects, and characterizes the different effects deriving from the laser's beams emission.

The criteria for use and selection of optimal parameters for the correct application of laser systems and influence of supporting factors on the process, such as water amount and its presence in the ablation process, protection exerted by the plasma shielding and structural factors, which are indispensable in dental tissues cavity preparation related to restorative technique, are subordinated to optical modifications caused by the interaction of the energy dissipated by these laser light emission systems in the targeted tissue substrate.

Clinical relevance: Differences in the action of infrared Erbium laser system in regard to the nature of the ablation process and variations on the morphological aspects observed in the superficial structure of the target tissue irradiated, may be correlated to the structural optical modifications of the substrate produced by an interaction of the energy propagated by laser systems.

Keywords: Laser ablation, Dental enamel, Human dentin.

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INTRODUCTION

Laser systems have risen as an innovative treatment option because of scientific advances applied to high-technology aiming techniques and instrumentation improvements. Since the publication of favorable reports on research carried out with lasers in intraoral soft tissues,[1] high-intensity infrared lasers were adapted to provide a sharp and selective removal of carious process in hard dental tissues, while minimizing the loss of healthy dental tissue and patient's discomfort.[2-6] Countless applications involving restorative dentistry provide brief procedures without noises or vibration, partial pain reduction or elimination with minimum endangering of the dental morphology mechanical structure.[7] Some examples of these (procedures/applications) are ablation of hard dental tissues — photomechanical effect,[2,7] inhibition of the carious process by a local heating — photo thermal effect,[8] and superficial conditioning — bonding mechanism.[2]

Laser offers a number of advantages when compared to high-speed handpieces with burs in hard dental tissues removal. The reason is the high selectivity of the process, where the decayed tissue can be preferably removed by water's high concentration and volatility of the proteins that are present in decayed rather than in healthy tissues. Lasers can also be used to effectively modify the chemical composition of the enamel mineral phase remainder,[9,10] providing resistance against hydroxyapatite acidic dissolution carried out by organic acids derived from bacterial activity. One final important factor is the laser's 'cutting' effectiveness regarding reaching inaccessible sites, due it's selectivity and precision,[7] when compared with bur cutting system, due to its limited configuration and industrial design.

Furthermore, lasers have the potential to substantially reduce the amount of tissue to be removed during cavity preparations, therefore, eliminating the formation of smear layer,[11,12] permitting bonding and restorative materials to be applied directly onto the ablated area, without the need for previous acid-etching of the region.[2]

However, many studies published after this report suggests very low bonding values when compared to those from acid etching performed previously to the application of bonding agents in direct adhesive restorations in restorative dentistry.[13-18]

The advantages of laser system's application include significant reduction in the microbial activity,[8] besides vaporization and modification of the altered dental tissues.[7,9] The photothermal effect of laser acts as supporting therapy associated with dentin hypersensitivity treatment. Because of its pulsed application procedure, high-intensity laser may provide the obliteration of dentin tubules entrance, diminishing fluid movement inside them.[19]

Another relevant aspect on ablation procedure is related to temperature dissipation during the application of lasers onto dental hard tissues.[7] The heat produced may be accumulated at dangerous levels during the emission of laser pulses, and this effect is the main limiting factor during the application of laser systems,[3,20] but it may be minimized with the use of wavelengths in optimal absorption bands for enamel and dentin, dosimetry and energy densities compatible with the optical properties of the irradiated tissue modulated in safe parameters established in scientific literature,[7,8,20,21] besides the appropriate calculation for time and emission mode of the laser beams as well as the interaction of the electromagnetic waves with the targeted tissue.[7]

OPTIMUM LASER PARAMETERS FOR THE ABLATION PROCESS

Ablation rates and efficacy levels of the process in enamel and dentin have a number of variables in specific literature, which demands the need for specification of the conditions in which these parameters are measured. Thus, radiometric measurements of the ablation rates and speed should have clinical relevance and be used to compare different laser systems.

Several researchers identified the number of laser pulses needed to cross and perforate transversal sections of 1 mm in human dental enamel. Ertl and Muller (1992)[22] concluded that the first few initial pulses are more effective than subsequent pulses, justifying the fact that an escalating number of pulses would induce alterations in the substrate morphology and chemical components. Therefore, the reaction speed reaches efficiency at the ablation rate, minimizing the effects and local residual energy, resulting from the structural modification generated by the interaction laser/tissue.[23,24]

The amount of energy deposited or transmitted to the target tissue as well as the dissipation of the resulting temperature is correlated to the substrate refraction degree. The structural composition comprehension and the dental substrate dehydration degree influence directly in the interaction of the laser beam transmitted with the target tissue.[7]

ERBIUM LASER SYSTEM

Erbium lasers are systems that feature a solid active medium of emission. The electromagnetic waves from 2.69 to 2.94 μm are highly absorbed by water and apatite hydroxyl radicals, generating optical modifications in the target substrate, causing alterations in hydrogen bonds during the temperature's raise, providing different absorption coefficients.[7]

Many Erbium lasers have been studied to be used for enamel and dentin ablation; Er:YAG ($\lambda = 2.94$ μm), Er:YLF ($\lambda = 2.81$ m), Er:YSGG ($\lambda = 2.79$ μm), Er:YLP ($\lambda = 2.73$ μm) and CTE:YAG ($\lambda = 2.69$ μm) lasers. These wavelengths allow access to the water absorption band between 2.6 and 3.0 μm.[25] Recent researches have determined that the threshold of the ablation effect is proportional and gradually higher for Er:YSGG, Er:YLF, Er:YAP and Er:YAG lasers respectively.[25]

The ablation threshold for CTE:YAG laser is considerably higher than in other laser systems blended with erbium due to the low rate of electromagnetic waves absorption of this laser by water, since its wavelength is in the limit of optimum absorption band for this substrate.[4,26]

Erbium lasers produce photomechanical effect, resulting in hard tissues ablation, such as enamel and dentin, and it has the official seal of the FDA (Food and Drugs Administration, USA) since 1997.[27]

Water content in the mineral substrate in the dental enamel interprismal space and dentinal organic matrix absorbs electromagnetic energy of Erbium laser, turning it into thermal energy. This event is characterized by an alteration of the matter physical state, turning liquid water into steam quickly, followed by expansion and raise of the internal pressure, disrupting mineral structure by means of tension and collapse strengths, resulting in a micro-explosion process referred to as ablation. Studies confirm the total consume of the energy deposited onto the target tissue during ablation process.[21]

Erbium laser systems produce cold ablation characterized by the consumption of the total residual energy during ablation process. The morphological aspect of dental enamel after Erbium lasers irradiation is characterized by a surface featuring acid-etching appearance (Fig. 1).[4,18] Scanning electronic microscopy (SEM) studies carried out in human enamel irradiated with pulsed Er:YAG laser demonstrate enamel prisms ejected by ablation effect, without showing areas of carbonization or fusion of the enamel prisms.[18,28] The surface and the walls of the ablated cavity demonstrate lack of tissue fusion; they are usually rough surfaces, which can be observed under SEM within appropriate parameters of irradiation (Fig. 2). Due to the absorption high rate of the electromagnetic beams by the water in the interprismal space, a lateral exposition of the enamel prisms occurs after laser light irradiation; this observation probably justifies the low values of bonding strength (Fig. 3).

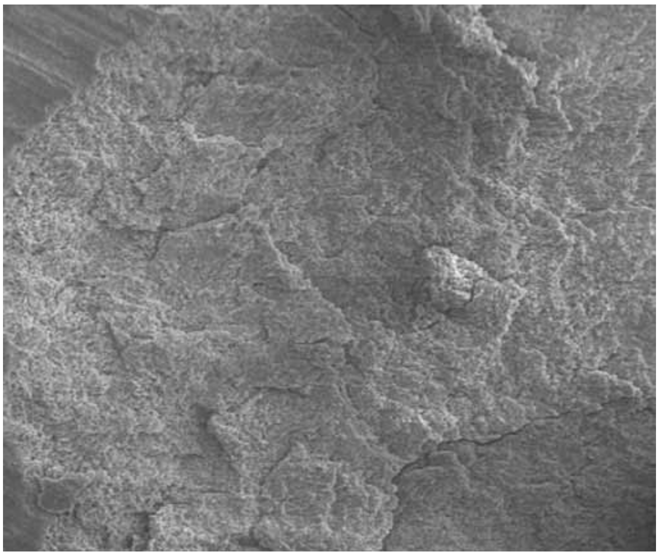

Fig. 1: Enamel surface irradiated with Er:YAG laser (pulse energy of 200 mJ for 2 seconds, focused, noncontact mode, cooling to 0.14 ml/seconds, twinlight, Fotona Medical Lasers, Ljubljana, Slovenia) (Magnification at 200×)

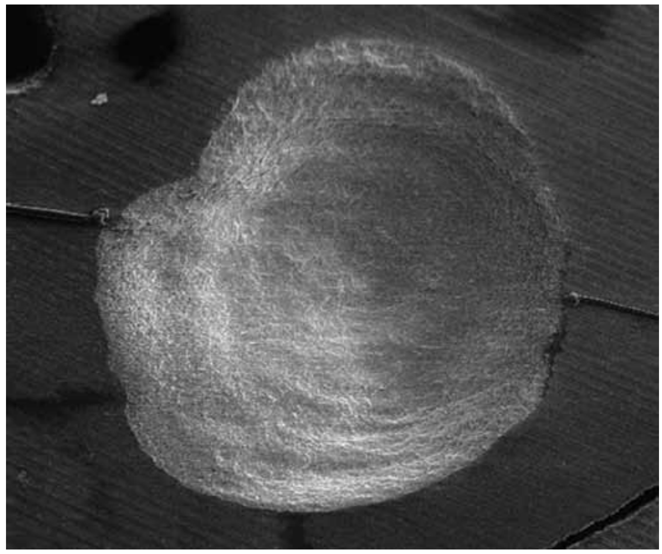

Fig. 2: Enamel surface irradiated with Er:YAG laser (pulse energy of 200 mJ for 2 seconds, focused, noncontact mode, cooling to 0.14 ml/seconds, twinlight, Fotona Medical Lasers, Ljubljana, Slovenia) (Magnification at 45×)

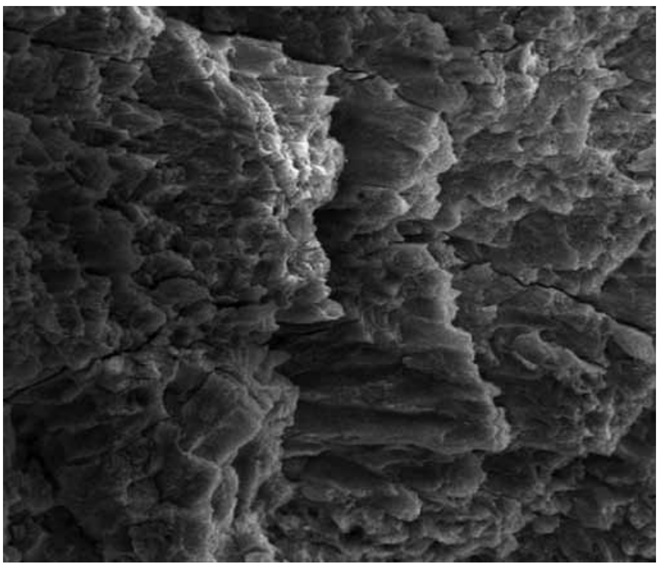

Fig. 3: Exposure side of the prisms of the enamel surface irradiated with Er:YAG laser (pulse energy of 200 mJ for 2 seconds, focused, noncontact mode, cooling to 0.14 ml/seconds, Twinlight, Fotona Medical Lasers, Ljubljana, Slovenia) (Magnification at 1000×)

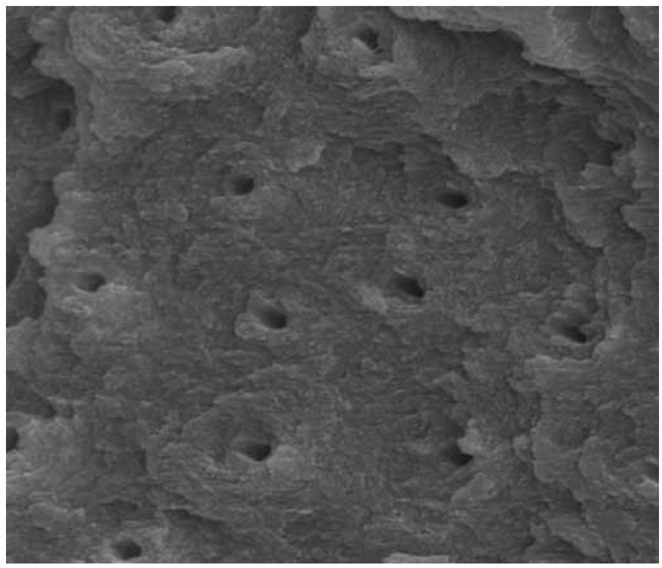

Fig. 4: Absence of smear layer on dentin irradiated with Er:YAG laser (pulse energy of 200 mJ for 2 seconds, focused, noncontact mode, cooling to 0.14 ml/seconds, Twinlight, Fotona Medical Lasers, Ljubljana, Slovenia) (Magnification at 3000×)

Studies on bonding strength by microtraction in enamel demonstrate lower values than those from superficial treatment by 37% phosphoric acid-etching in adhesive restorations in dentistry.[13-18] The analysis of these events justifies the priority of acid-etching stage of the laser system irradiated surface.

Irradiation with Er:YAG laser system is found to be more effective in dentinal tissue when compared to dental enamel, due to the presence of a larger amount of aqueous content in the dentin structure.[11,29] In dentin, Er:YAG laser irradiation produces a superficial ablation effect without forming craters and vitrification areas; this aspect results from photomechanical effect of this laser type.[4,13] Therefore, the lack of events, such as fusion and resolidification determine the lack of smear layer formation (Figs 4 and 5), which is evidently observed in conventional cavity preparations performed with high-speed diamond burs. Under SEM, the ablated dentinal surface shows an enlargement of the dentinal tubules internal space in their superior portion; this feature is inherent to ablation process by Erbium lasers photomechanical effect.

With the considerable temperature raise, the vaporization of dentin mineralized matrix aqueous portion is instantaneous and collagen fibers, formerly dispersed and supported in this framework, tend to collapse, decreasing the diffusibility of the bonding agent in the collagen fiber net.

Scientific studies demonstrate higher bonding strength values in peritubular dentin region when compared to intertubular dentin, due to the difference of their calcification degree.[11,13,17,21] Bonding strength values for irradiated dentin with erbium laser systems become relatively lower when compared to those of dentin treated with later acid etching, justified by the effective action of this laser system at intertubular dentin level, where, there is a larger amount of dispersed water content.

Prominent researches in the bonding field point out a spontaneous re-expansion of the collagen fibers net provided by the emergence of dentinal fluid through dentinal tubules space, preventing the need for rehumidification by external agents, such as bonding systems with aqueous components.[17]

PLASMA SHIELDING INFLUENCE

During the emission of the laser beams in ultrashort pulses, a layer of protection is formed with the ablation process, which is called plasma shielding, and it's characterized by a dense gas layer of ions and electrons, formed during the application of pulses with duration expressed in peak, nano and femto seconds.[3,30]

As soon as the plasma shielding is formed, the emitted laser beams could have its effect reduced. This is related to the degree of saturation in which the plasma shielding becomes cloudy, during the emission of one determined wave length.[4,7]

The electrons absorb the laser energy for the collision with ions that are warm in high temperatures, at the same time that the electron transfers the energy to the ion the substratum is warmed.[31]

The formation of the plasma shielding layer can be controlled planning the fluency of laser beams to be used in the process.

During the emission of long pulses, the ablation tax becomes saturated, same without the protection of the plasma shielding. This fact is explained due to the circulation's speed of the debris against the walls of the preparation.

CONCLUSION

High-intensity infrared lasers used in dentistry have different action mechanisms in the irradiated target tissue. Erbium laser beam emission results in dental hard tissues ablation and photoelectric interaction when using pulses in ultrashort parameters.

The restorative tactics for laser ablated cavity preparations are related to laser/substrate interactions in regarding photothermal and photomechanical effects, since smear layer features may directly influence on the choice of the restorative material.

Absorption rate in target tissues depends on the refraction substrate coefficient, composition and microstructure.

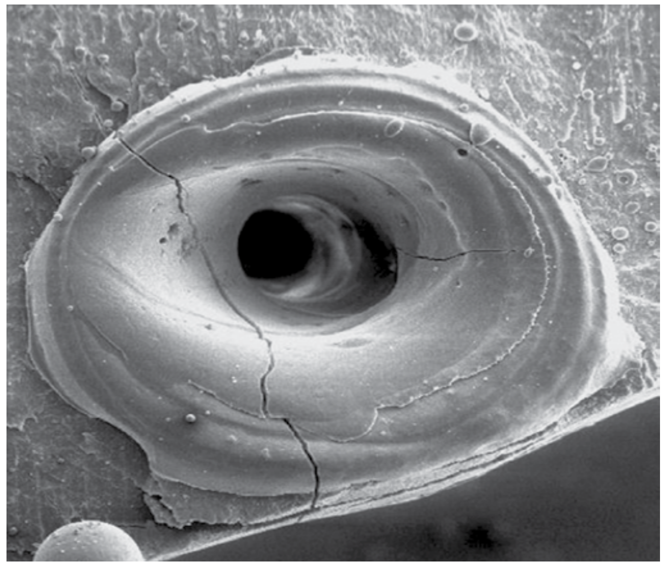

Fig. 5: Dental surface irradiated with CO_2 laser (pulse energy of 2 W for 2 seconds, focused, noncontact mode, no cooling, switched, 50 Hz, 10%, Twinlight, Fotona Medical Lasers, Ljubljana, Slovenia) (Magnification at 150×)

Other factors, such as emission fluency, appropriately planned, and pulse emission mode allow minimization of the residual effects and temperature rises in the target tissue. The amount of water in the substrate's structural composition influences directly upon the efficiency rate of the laser systems' action as well as its use in order to modulate the ablation effect on the tissues, providing ablation rate level increase.

The observation of parameters and optimum aspects for the conduction of ablation process in enamel and dentin as well as microscopic assessment of the structure and ablation resulting aspects contribute to the clinical use of these lasers as much conservative as possible, decreasing harmful effects on subjacent and healthy tissues. The correct understanding of the different interactions of infrared lasers/dental hard tissues contributes to the refinement of procedures in restorative dentistry.

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