Laser - Assisted Dental Caries Treatment

Violeta Dogandziyska, PhD

Department of Conservative Dentistry, Faculty of Dental Medicine, 1 blvd "St. George Sofijski", 1431 Sofia, Bulgaria
Email: *Dogandzhiyska[at]gmail.com*

Abstract: ***Dental caries is one of the most common chronic diseases in the world, affecting 60-90% of school-age children and almost 100% of the adult population. Disease prevention at early ages is a fundamental public health principle and particularly relevant for dental caries. One modern alternative method, gaining popularity in recent years is the application of lasers in clinical practice. Different type of laser systems are used in conservative dentistry in several fields as carious lesions diagnosis, desensitization of hypersensitive teeth, remineralisation of initial carious lesions and dental caries treatment.***

Keywords: laser, dental caries, photodynamic therapy, photoactivated disinfection

1. Introduction

Dental caries is one of the most common chronic diseases in the world, affecting 60-90% of school-age children and almost 100% of the adult population. The disease is caused by sugar being broken down in the mouth by the cariogenic bacteria (most notably Mutans streptococci) to produce lactic acid. Over time, lactic acid production leads to a breakdown of the enamel surface and development of dental caries.

Disease prevention at early ages is a fundamental public health principle and particularly relevant for dental caries, the most common noncommunicable disease of humankind. Current oral health promotion is based on the assumption that lower caries levels in childhood continue into later life, and thus the prevention must start at an early age. A lot of scientific researches present results and considerable evidence that supports a minimally invasive treatment approach. Because there is a wide variability in treatment decisions on when and how to prevent new lesions, on how to arrest the progression of existing lesions, and on when and how to place initial and replacement restorations, the findings from some studies differ significantly from the results of other studies. While fluoride treatments are known to prevent a percentage of new lesions, they do not have the ability to prevent all caries lesions. Modern management of caries entails treating patients according to risk and monitoring early lesions in tooth surfaces that are not cavitated [18]. Although we know that the DMFs score for children is a powerful predictor of caries increment in permanent teeth of these children a few years later, this score is rarely used in private practice as a measure of risk or as a measure of treatment success. Although these modern methods for caries management offer great promise for controlling the disease, they may take decades to apply in a standardized way so that the variability in treatment is reduced. However, during the next decades, an alternative approach to caries prevention such as replacement therapy and a caries vaccine may become available as a more consistent method of controlling this disease.

One modern alternative method, gaining popularity in recent years is the application of lasers in clinical practice. Different type of laser systems are used in conservative dentistry in several fields as carious lesions diagnosis, desensitization of hypersensitive teeth, remineralisation of initial carious lesions and dental caries treatment.

a) Laser- assited caries prevention and remineralization

Fluoride is stated to be the most important agent to prevent decalcification and inhibit lesion progression. Recently, more advanced fluoride varnishes with added calcium and phosphate ions have been developed to supplement the amounts of these ions in saliva and enhance remineralization by fluoride. The continued availability of fluoride in the oral cavity will be dependent on patients to follow oral hygiene measures regularly. Furthermore, fluoride products are less effective against pit and fissure caries. Besides that, in a recent study, it has been shown that administration of high dose of sodium fluoride might affect human embryogenesis

Laser is among the new techniques to inhibit enamel demineralization and reduce enamel permeability [20]. Recent research has shown that laser irradiation can produce positive effects on the increase of enamel acid resistance. The vast majority of the studies stated that heating of enamel surface leads to a caries inhibition effect. Heating of enamel surface leads to changes in its organic and/or inorganic constituent. Temperature below 100 °C is insufficient to cause crystal changes in hydroxyapatite. However, between 60 and 200 °C, enamel dehydration and protein denaturation will occur which leads to reduced permeability, and between 350 and 400 °C, protein decomposition occurs which consequently increases enamel permeability. Carbonate decomposition starts at 420 °C, which leads to decreased solubility. If enamel surface is heated to 1200 °C, melting, crystal size growth and recrystallization will take place. It has been mentioned that lased enamel favors fluoride uptake thereby increasing its caries-preventive effect. To this day, there is no agreement on evidence-based clinical protocols for caries prevention using lasers. This is due to controversy about which parameters are to be used for this purpose.A number of variables can be adjusted: wavelength, irradiation mode, power, pulse duration, irradiation time, and applied dose. On the other hand, it depends on the optical properties of dental enamel: scattering, absorption coefficient, refractive index, thermal conductivity, and thermal relaxation time. These properties are variable because enamel like other biological tissues is inhomogeneous in composition. All mentioned variables are responsible for a variation in treatment results. There are many studies reported in the field of using lasers as an assistance tool for caries prevention in enamel. The laser irradiation can be applied either alone or as assistance to achieve caries-preventive effect [28]. Different dental lasers in the mid-infrared, near-infrared, and visible and ultraviolet regions of the electromagnetic spectrum had been investigated for their caries inhibition effectiveness. CO_2 laser at 10.6 µm and 9.6 µm is the most used laser with a proven caries-preventive effect, followed by Nd:YAG laser.

Studies have demonstrated that a combined fluoride-laser treatment makes enamel more resistant to acid than does either laser treatment or fluoride treatment alone [2].

b) Cavity preparation with high energy laser systems

The improvement of dental technologies and the search for an alternative to conventional high- and low-speed handpieces for carious removal and cavity preparation, led to the development of new methods and systems, such as air abrasion, sound removal of dental hard tissue, lasers, etc. Recently, lasers are increasingly used in dental practice [24]. A lot of investigations on various types of dental laser systems show encouraging results regarding their effectiveness. The goal of their utilization is a faster, more efficient, conservative and painless preparation of hard dental tissue, with minimal damaging effect on the dental pulp. Favorable clinical results require not only an excellent knowledge of the physical characteristics of laser radiation and its effect on dental hard tissue and dental pulp, but detailed analysis of the characteristics of the carious lesion and the prepared cavity, as well as an accurate and precise selection of appropriate parameters and techniques.

Today, only Er-lasers (Er:YAG and Er:Cr:YSGG) are possible to be used in the dental practice for carious removal and preparation of dental hard tissues. Both laser systems emit light in the middle infrared, invisible, non-ionized part of the spectrum (Er:YAG λ= 2940 nm; Er:Cr:YSGG λ= 2780 nm) [1].

The mechanism of removal of hard dental tissues with Er lasers is not fully understood. Numerous unconfirmed scientific hypotheses have been developed regarding tissue dehydration, hydrokinetic mechanism of action, etc. Nowadays it is known that all Er lasers have the same photothermomechanical mechanism of action. It is expressed in the absorption of laser light by water molecules and rapid subsurface evaporation of the interstitially included water in mineral substrates, which leads to a massive volume expansion. This expansion causes multiple micro-explosions, which remove the surrounding organic and inorganic substances. Explosive tissue destruction (ablation) starts immediately after laser irradiation and ends when the power stops, without reaching the tissue melting temperature.

An optimal therapeutic effect is obtained when the tissue is exposed to radiation with a wavelength strongly absorbed by it. The most commonly used power values of laser radiation for oral tissue treatment are: enamel – 4-8W; dentin – 2-5W; caries – 1-3W; bone – 1.5-3W; soft tissues – 1-3 W [13,15]. The main principle of Er: YAG application is to use the lowest possible values for the treatment. The clinicians have to adjust the laser parameters for conservative, effective and comfortable for the patient removal of dental hard tissues [3]. Once the enamel is removed, the energy values should be reduced, because of the higher water content of the dentin and carious tissues. The water ensures better absorption of laser radiation, the ablative effect is faster and the affected tissues are removed more easily [9].

The scanning technique used for caries removal requires a movement of the handle until a typical cavity shape is obtained. The laser beam is directed perpendicular to the treated tooth surface, at an optimal distance of 0.5-2 mm from the tooth surface.

Many studies demonstrate a lot of advantages of laser cavity preparation. The laser systems reduce noise, heat, vibration, stress and general patient's discomfort. A lot of researches conclude that 80% of patients find the preparation with a laser more comfortable than the conventional drill [26]. The laser irradiation can reduce the pain in the way of "laser anesthesia". The laser beam provide more precise removal of carious tissue as a "caries-selective system" and have a bactericidal effect.

The surface treated with an Er:YAG laser is specific – clean, sterile, chalky and microscopically scratched to a depth of 70 µm [4,16,17]. The scientific studies found a minimal amount of debris and smear layer, in comparison with the conventional drill preparation, where 1-5 µm thick smear layer was formed. The smear layer decreases the bonding strength with the restorative material. Cavities prepared with a laser are ideal for fillings of composite, glass-ionomer cement, compomer and ormocer. The studies on bond strength and marginal sealing of Er-laser-prepared cavities present conflicting results. Some authors recommended a technique of "Laser etching". The conditioning of the enamel is achieved by using the lowest possible energy value, shortly before the ablation threshold is reached. Most studies, concluded that once Er: YAG laser radiation removes all organic ingredients, the formation of a hybrid layer is impossible. Only free adhesive protrusions (tags) inside the dentinal tubules were established. The strength of the mechanical connection is deteriorated, the mechanical bond between the dental hard tissue and the composite material is decreased. This requires additional acid etching of the laser treated surface. It has been proven that laser treatment achieves 75% of the effect of the total acid etching. Due to the advantages of laser radiation on intertubular dentin and the higher acid resistance of irradiated dentin compared to the acid-treated, the self-etching adhesives are considered unsuitable. The limited effectiveness of the self-etching primer on the laser-irradiated dentin may be due to the limited ability of the acid monomers to demineralize the laser-modified surface layer and to transform the resulting morphological forms. Thus, a total etching technique is recommended [27]. It ensures the presence of a microregular surface and opened dentinal tubules are microscopically demonstrated, as well as a hybrid layer and adhesive tags in the dentinal tubules.

c) **Photoactivated disinfection in the treatment of dental caries**

The mechanical instrumentation of the cavity leads to the formation of a smear layer, which covers the entrances of the dentinal tubules. Microorganisms, endotoxins and other bacterial products might be sealed inside, which could compromise the healing process and cause damage to the dental pulp. The microbial factor is especially dangerous in case of deep, rapidly progressing, active carious lesions, where the defense mechanism of the tubular sclerosis and the formation of tertiary dentin is difficult, so the protection of the dental pulp is reduced.

Current requirements for minimally invasive preparation suggest maximum preservation of dental hard tissue – we preserve the affected demineralized dentin for remineralisation. Therefore, the problem with the removal or disposal of residual microorganisms from the carious defect and the underlying tissues is extremely important. Current investigations are searching for new, alternative methods, with an ultimate antibacterial and minimal cytotoxic effect on the dental pulp cells.

Photoactivated desinfection (photodynamic therapy) is a minimally invasive and highly selective method for treatment of pathogens (bacteria, fungi and viruses) and tumor cells [5,7,10,11,22]. It involves the use of a photoactive dye (photosensitizer), activated by light with a particular wavelength in the presence of oxygen. The method is based on the tendency of certain types of cells or organisms to absorb light-sensitive substances and, after light-curing with a precise wavelength, to be selectively destroyed without affecting the surrounding healthy tissues [8,21]. Prokaryotic cells are more susceptible to photoactivated disinfection than eukaryotic ones [19].

There are two types of reactions which provide the interaction of high-energy photosensitizers with the biomolecules [12]. The first involves the production of ions directly from the photosensitizer and the formation of free radicals. They react fulminantly with the available oxygen and turn it into highly reactive, highly toxic oxygen forms (superoxide, hydroxyl radicals, hydrogen peroxide). The second is the production of a highly reactive phase of oxygen, known as singlet oxygen ($^1O_2$). Antioxidant enzymes produced by some pathogens (superoxide dismutase and catalase), protect microbial cells from certain oxygen radicals, except for the singlet oxygen. Differentiation between the two types of reactions in the course of the photodynamic therapy is difficult and, depending on the concentration of the photosensitizer and the oxygen pressure, they usually occur simultaneously. Photodynamic therapy has a cytotoxic effect, which is expressed with the photodestruction of cells, organelles and molecules. Detoxification and inactivation of endotoxins by reducing their biological activity have also been established.

The optimal effect of the photodynamic therapy depends on the structural features of the bacterial membrane, the concentration of photosensitizers, its solubility and polarity, the light source and its wavelength. There are three main mechanisms of interaction between photosensitizers and the target cell:

1) Connection to the cell membrane.
2) Penetration into the cell and attack of mitochondria.
3) Non-contact method – formation of singlet oxygen in close proximity to the target cell, without direct contact with it.

In vitro studies on the effects of photoactivated disinfection on S. mutans demonstrate a strong antimicrobial effect when the bacteria are exposed to erythrosine, activated by light with a wavelength of 530 nm, as well as toluidine blue and light with a wavelength of 630 nm [6,14].

The clinical protocol of photodynamic therapy in case of carious lesions includes removal of the carious necrotic dentin, topical application of the selected photosensitiser, activation with light of appropriate wavelength, washing of the photosensitiser and placement of a definitive filling [23].

As a new alternative method for cavity disinfection the photodynamic therapy has a lot of advantages. The repetition of the photo irradiation does not lead to the formation of resistant microbial strains and acts locally, inducing highly selective necrosis and minimal damage to the surrounding tissues [25]. Photoactivated desinfection is equally effective against microorganisms doesn't matter if they a resistant and sensitive to antibiotics. The destruction of target cells compared to conventional antimicrobial agents is faster with shorter action and presence of photosensitizers in the body.

Photodynamic therapy will not completely replace conventional caries treatment, but it can improve and accelerate its effect, as well as reduce the treatment costs.

References

[1] Al-Batayneh Ola B., W. Kim Seow, Walsh Laurence: Assessment of Er:YAG Laser for Cavity Preparation in Primary and Permanent Teeth: A Scanning Electron Microscopy and Thermographic Study. *J. Pediatric Dentistry*; 2014; 36 (3) :260-260

[2] Anderson JR, Ellis RW, Blankenau RJ, Beiraghi SM, Westerman GH. Caries resistance in enamel by laser irradiation and topical fluoride treatment. *J Clin Laser Med Surg*, 2000; 18:33–36. https://doi.org/10.1089/clm.2000.18.33.

[3] Armengol V., , A. Jean, Marion: Temperature Rise During Er:YAG and Nd:YAG Laser Ablation of Dentin. *Journal of Endodontics*; 2000; 26 (3): 138-141

[4] Armengol V., A.Jean, R.Rohanizadeh, and H.Hamel: Scanning Electron Microscopic Analysis of Diseased and Healthy Dental Hard Tissues after Er:YAG Laser Irradiation:In Vitro Study. *Journal of Endodontics*; 1999; 25(8): 543-546

[5] Barbosa P., D. A. Duarte,M. F. Leite, G. R. de Sant' Anna. Photodynamic therapy in pediatric dentistry. *Case Rep Dent*. 2014;1-5

[6] da Costa ACBP, J. Chibebe Junior, C. A. Pereira, A. K. da Silva Machado, M. Beltrame Junior, J. C. Junqueira, A. O. C. Jorge. Susceptibility of planktonic cultures of Streptococcus mutans to photodynamic therapy with a light-emitting diode. *Braz Oral Res.* 2010;24(4):413-8.

[7] Gueorgieva Tz., Sl. Dimitrov, V. Dogandhiyska, V. Kalchinov , M. Belcheva , V. Mantareva, I. Angelov, V. Kussovski "Susceptibility of S.aureus to Methylene Blue Haematoporphyrin, Phtalocyanines Photodynamic Effects", *Journal of IMAB*-Annual Proceeding(Scientific papers), 2010. book 4, p. 51-53

[8] Dave D, U. Desai, N. Despande. Photodynamic therapy: a view through light. *Journal of Orofacial Research* 2012; 2(2):82-86.

[9] Dederich Douglas, Ronald D.Bushick: Lasers in dentistry; *JADA*;2004; 135; February: 2

[10] Dogandzhiyska, V., R. Gergova, Sl. Dimitrov, M. Doychinova. Antimicrobial activity of photodynamic therapy against microorganisms isolated from deep carious lesions. *Journal of IMAB*,2013;19(4):430-434.

[11] Fontana CR, A.D.Abernethy, S.Som,K. Ruggiero, S. Doucette, R.C.Marcantonio,C.I.Boussios, R.Kent, J.M.Goodson, A.Tanner, N.S.Soukos. The antibacterial effect of photodynamic therapy in dental plaque-derived biofilms. *J Periodont Res* 2009; 44: 751–759.

[12] Gursoy H , C. Ozcakir-Tomruk, J. Tanalp,S. Yılmaz. Photodynamic therapy in dentistry: a literature review. *Clin Oral Invest* 2013; 17:1113–1125.

[13] Hadley Jack, Douglas A. Young ,Lewis R.Eversole, Jeffrey A. Gornbein,D.Sc.:A laser-powered hydrokinetic system for caries removal and cavity preparation. *JADA*; 2000; 131;June: 777-785

[14] Hakimina N, F. Khoei, A. Baharod, R. Fekrazad. The susceptibility of Streptococcus mutans to antibacterial photodynamic therapy: a comparison of two different photosensitizers and light sources. *J Appl Oral Sci*. 2014; 22(2): 80–84.

[15] Hibst R, U. Keller: Experimental studies of the application of the Er:YAG laser on dental hard substances . I . Measurement of the ablation rate. *Lasers Surg Med*;1989;9: 338-44

[16] Hoke JA, Burkes EJ, Gomes ED, Hooper BA, Wolbarst ML:The effect of free electron laser light on tooth structure. *Lasers in Life Sciences*;1995;6: 251-7s

[17] Keller U., R.Hibst: Zur ablativen Wirkung des Er:YAG lasers auf Smelz und Dentin. *Dtsch Zahnartztl Z;*1989;44 (8): 600-602

[18] Kenneth J. Present and Future Approaches for the Control of Caries. *Journal of Dental Education*,2005, 69 (5,) 538-554.

[19] Konopka K, T. Goslinski. Photodynamic therapy in dentistry. *J Dent Res* 2007; 86(8):694-707.

[20] Kotlow Lawrense A.: Lasers in pediatric dentistry. *Dent Clin N Am*; 2004,48: 889-922

[21] Malik R, A. Manocha, D.K. Suresh. Photodynamic therapy ‒a strategic review. *Indian J Dent Res* 2010; 21(2): 285- 291.

[22] MantarevaV., I. Angelov, D. Wöhrle, V. Dogandzhiyska ,Sl. Dimitrov and V. Kussovski. "Water-soluble phthalocyanine complexes of Ga(III) and In(III) in the photodynamic inactivation of pathogenic fungus", *Proceedings SPIE- The International Society for Optical Engineering* 7747, art. no. 774712, 2011.

[23] Nagata JY, N. Hioka, E.Kimura, V.R. Batistela, R.S.S. Terada, A.X. Graciano, M.L.Baesso, M.F. Hayacibara. Antibacterial photodynamic therapy for dental caries:Evaluation of photosensitizers used and light source properties. *Photodiagnosis and Photodynamic therapy* 2011; 10.1016/j.pdpdt.2011.11.006: 1-10.

[24] Niemz Markolf H., Lothar Eisenmann und Thomas Pioch:Vergleich von drei lasersystemen zur Abtragung von Zahnschmelz. *Schweiz Monatsschr Zahnmed;* 1993;103 (10): 1252-1256.

[25] Rajesh S, E. Koshi, K. Philip, A. Mohan. Antimicrobial photodynamic therapy:an overview. *Journal of Indian Society of Periodontology* 2011; 15(4): 323-327.

[26] Sarmadi R., E. Hedman, P.Gabre. Laser in caries treatment - patients' experiences and opinions. *International Journal of Dental Hygiene*; 2014; 12(1): 67-73

[27] Unal M., I. Hubbezoglu,R. Zan,A. Kapdan,F. Hurmuzlu: Effect of acid etching and different Er:YAG laser procedures on microleakage of three different fissure sealants in primary teeth after aging. *Dental Materials Journal*; 2013;32 (4): 557-563

[28] Verma S, S. Maheshwari, R. K. Singh, P. K. Chaudhari. Laser in dentistry: An innovative tool in modern dental practice. *National Journal of Maxillofacial Surgery* 2012:3(2):124-132.

Author Profile

Dr. Dogandzhiyska is an assistant professor at the Department of Conservative Dentistry, Faculty of Dental Medicine, Sofia, Bulgaria. Her research interests are in the field of endodontics, aesthetic restorations and laser dentistry.