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Restorative dentistry for children using a hard tissue laser – A Review

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Abstract:
The old concept "extension for prevention" is changed to "prevention of extension". It is important to be open to new technology, by being more creative in terms of developing new techniques or modifying and improving the existing ones. A review of the potential role of laser technology in pediatric restorative dentistry in terms of cavity preparation, dental pulp response, pain perception, and the treatment time is discussed in this present paper
Keywords: laser dentistry, restorative dentistry, pediatric dentistry.

Introduction:
In 1960, Theodore Harold Maiman, an American of Hughes Aircraft corporation, observed the stimulated emission in the visible portion of the spectrum by using an excited synthetic ruby rod, and generated the first "LASER" beam an acronym for "Light Amplification by Stimulated Emission of Radiation".[1]

The acceptance of lasers as viable alternatives to traditional methods in medicine was one of the events that created an explosion of interest in the last decade in the role of lasers in dentistry.[2]

For much of the history of dentistry, treatment was the main goal of our profession, but little by little it is being replaced by prevention as our priniciple objective. Fitting into concepts of

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microdentistry and prevention, laser technology caused the pendulum to swing from simple mechanics to the boundless era of photonics. Lasers are patient friendly; children and adolescents are the best candidates for laser use because they are especially bothered by pain, bleeding, incapacitation and a need for office visits for extensive postoperative care. Treating infants and young children is a rewarding experience, especially when we guide the parents and children down the path of prevention and interception of oral diseases.[3]

Lasers have evolved from the initial use for all class of cavity preparation to their ability for removing soft tissues, their usefulness in disinfection of bacteria with in endodontic canals, an alternative to the high speed handpiece.[4]

Through the continued development of laser technology, new applications and education, a new era of dentistry offers a rewarding and potentially profitable area which will be embraced by all.[4,5]

The purpose of this paper was to review potential role of laser technology in pediatric restorative dentistry in terms of cavity preparation, dental pulp response, pain perception, and the treatment time in comparison to the conventional hand piece. A summary of various studies is presented in Table 1.

Hard tissue laser biophysics:

To decide whether laser technology has advantages over conventional therapeutic methods, it is necessary to understand the various effects of laser radiation on organic tissues. The ultimate effects of laser irradiation on the tooth tissue depend on the distribution of the energy and how much is deposited in the tooth. The temperature rise at any point is a balance between energy deposited in a specific time and energy that is conducted away as heat. The temperature rise determines whether the morphology or chemical characteristic of the tissue at that point are changed.[6]

The independent factors which are under the control of the clinician, include the level of applied power (power density);the total energy delivered over a given surface area (fluence) ;the rate and duration of the exposure(pulse repetition rate and pulse duration);and the mode of delivery of the energy to the target tissue(pulsed Vs continuous; contact Vs noncontact).[7]

Laser effects of enamel:

Initially, when lasers were first considered in dentistry, it was thought for the drilling and cutting of enamel. Subsequently the effect of low laser energy densities has been applied to the problems of preventive dentistry to produce enamel surface alteration that may increase resistance to dental caries without pulp alterations. It produced tissue changes due to confined high energy pulses deposited at an incident surface altering enamel solubility and resistance to subsurface demineralization.[8]

Light scattered at the enamel has two components: The first component is that light scattered from surface macro roughness with the dimensions exceeding the wave length of the incident beam. The second component is the portion of light scattered from surface micro roughness with the dimensions that are less than wave length of the incident beam. Short light pulses can generate harmonic reflections from the enamel surface and at the enamel-dentin junction as hydroxyapatite crystals are not centrally symmetric. The nonlinearity of electron absorption could be substantial in the blue than near ultraviolet range.[2]

Enamel is made up of an extremely hard translucent substance composed of 97% inorganic material and 3% organic substance, with minimal water content. Enamel absorbs visible light in the 400 -700nm weakly (absorption coefficient$<1cm^{-1}$) and moderately (absorption coefficient about 10 cm^{-1}) in the UV (240-300nm). The scattering coefficients decrease rapidly between 240 and 700 nm and even lower in the near-infrared, values falling from 400 to15 cm.[1 9]

Effects of laser on dentine:

The specificity of this tissue is given by the dentinal tubules that communicate with pulpal surface, cementum, and enamel. Since the odontoblasts are arranged in a layer on the pulpal surface, their cytoplasm is located inside dentinal tubules. However, the process of dehydration of dentin will affect not only the hard tissue but also the first layer of odontoblasts. As a consequence of thermal stresses during laser, dentin develops multiple micro cracks and severe carbonization. Dentine consists of 70% inorganic mineral substance and 30% organic substance and water. Dentin absorption is low in the visible region (400-700nm), but the tissue scatters much more than enamel.[2]

Laser light that is highly energetic and short pulsed causes fast healing of dental tissues in a small area. A fast shock wave is created when energy dissipates explosively as volumetric expansion of the water in hard tissue called cavitation. All the hard tissues contains varied amount of water. The mechanical shock waves that occur are due to a rapid photovaporization of water, producing a volumetric change of state of the liquid water within the tooth. This change creates high pressures, removing and destroying selective areas of adjacent tissues.

The photoacoustic effect that develops is characteristic of a short interaction time and a high energy density. The incident laser energy is absorbed in a thin surface layer. Water-mediated explosive tissue removal has been shown to be most efficient way of removing tissue, while transferring minimal heat to the remaining tooth. Water molecules in the target tooth are superheated, explodes, and in turn, ablates tooth structure and caries.[6]

Laser application in restorative dentistry:

Wolbarst postulated that because enamel and dentin contain water, laser energy absorbed by water would cause volumetric expansion resulting in ablation.The ablation mechanism is determined by a localized plasma formation, it is called “plasma-mediated” or “plasma-induced” ablation.[10]

The ruby, argon, CO_2, Nd: YAG lasers have shown limited value as they compromise tooth structure and create pathological condition that is less favorable .The field of laser operative dentistry began with the FDA clearance of the Premier Laser system Er:YAG laser for cavity preparation. [11]

These lasers are indicated for all classifications of caries in enamel, dentin, and cementum for deciduous and permanent teeth. [11]

In contrast to G.V.Black preparation, improved precision results in minimal invasive dentistry, which compromises little noncarious healthy tooth structure. The strength of the tooth is maintained, and the bond strength of the restoration can be enhanced with the line angles and point angles placed for greater mechanical retention.[5] Cavity preparation in primary teeth often requires precise operator control as the pulpal outline follows the dentino-enamel junction more closely than in permanent teeth and dentin is not so thick. Hence, cavity preparation using a less traumatic system such as lasers is more favorable in primary dentition. [11]

There is decreased requirement of anesthesia and if patient is uncomfortable attempts are made to decrease the hertz, decrease energy, or move the cutting tip from the contact mode to a noncontact mode.

The operator also can detect different tooth structures by hearing the sound of ablation which is different for tissue types. For ablating enamel, once in dentin the contact cutting tip can be repositioned in a noncontact mode usually 1mm from the surface of the tooth which causes lower ablation effect. During inter proximal preparation, adjacent teeth can be isolated and protected with the rubber dam or a metal matrix. Fiberoptics or wave guides with disposable cutting tips of various diameters are coupled to the distal end of the delivery system. For wide cutting, the tip is moved constantly over the surface. For deep cutting, the tip is moved up and down as in pumping action. The laser is capable of ablating and preparing the cavity in an irregular fashion, which is ideal for glass ionomer or composite resin restoration.[5]

The CO_2 lasers irradiation to tooth enamel caused small amounts of hydroxyapatite to be converted to the more insoluble calcium orthophosphate apatite. The surface of the enamel became impermeable and reduced subsurface demineralization concluded that CO_2 laser could be used in the prevention of caries.[12]

In the United states the ability of the Er: YAG lasers to ablate hard tissues using low energies was tested for the first time showed that the pulpal cavity temperature increase was well within the margin of pulpal safety.[5]

When Er:YAG laser was used in conjunction with an adequate water spray for cooling during cavity preparation the normal architecture of the odontoblastic cellular layer was retained with no irreversible inflammatory cell infiltration. Reparative dentin formation immediately adjacent to the pulpal floor of the lased area occurred in 4 days maintaining the pulp integrity found to be comfortable alternative to hand piece.[13,14]

Very precise cavities with less thermal damage to the surrounding structures can be obtained in enamel and dentin with solid-state Nd:YLF picosecond laser pulses.[15]

The effects on Nd: YAG and Ho: YAG irradiation on the enamel and dentin surfaces were compared with varied spot size and energy densities concluded that Ho:YAG lasers with spot size 25µm and energy density 4160J/cm^2 produced a cleaner puncture in dentin with less melting of surrounding tissue than Nd:YAG lasers.[16]

Mark 3 free electron laser with 10m J/pulse energy and Er: YAG laser at 50m J/pulse applied to wet and dry extracted teeth and an average depth of penetration was measured which showed that the dry teeth had an average depth of 50µm and wet teeth had 250µm. Pulpal temperature was investigated with thermocouple probes and the results indicated that FEL application raised pulpal temperature 0.5^0C after 2000 pulses and 0.3^0 C after 4000 pulses application.[10]

Er: YAG laser emitting at a wave length of 2.94µm, irradiation at 8 Hz, and maximum outputs of 250mJ/pulse developed by Luxar was used for the clinical preparation of class 5 cavities without inducing pain. [17]

The patients perception and acceptance of Er:YAG, Er,Cr:YSGG lasers reported that need for anesthesia was 11% for mechanical preparation compared to 6% during laser application, and the 82% of the patients reported that they would prefer Er:YAG .The mean time for preparation by Er:YAG laser was 7.5±4.6 minutes, Er,Cr:YSGG laser, the time required for cavity preparation ranged from 5 seconds to 20 minutes as per the cavity size and 3.9±3.9minutes for the conventional preparation.[18]

The ablation depths and morphological changes in human enamel and dentin after Er:YAG laser irradiation with or with out water mist showed that addition of fine water mist for cooling and removal of tooth debris at the ablation site does not decrease greatly the ablation rate and does not cause any carbonization or melting in the surrounding tissues.[5]

During preparation with the laser, there was temperature change after a few seconds from 37^0C to 25^0C to 30^0C as a result of cooling with water and air. Even after trephination, there was an increase in temperature in the pulp only the temperature measuring probe was hit directly by the laser beam. With conventional bur preparation, even before trephination, there was a rise in temperature more than 60^0C.[19]

In a split mouth randomized clinical trail concluded that dentists preferred conventional handpieces for cavity preparation while patients aged greater than 10 years preferred laser treatment.[20]

The pulpal response to the either Er:YAG lasers or mechanically by a slow-speed conventional hand piece after an accidental exposure of the pulp showed that laser group showed no bleeding and no dentin chips at the exposure site immediately after pulp exposure. Subsequently, the Er:YAG laser group formed dentin bridges at the exposure site more frequently than control group and demonstrated good healing capacity with formation of dentin bridge and reparative dentin.[21]

Cavity was prepared by laser irradiation using, 0.4mm diameter tip, with Er:YAG lasers at 200mJ/pulse and 100mj/pulse.The burs used were stainless steel round burs by a laser it was0.4mm diameter tip with duration to cut enamel was 33seconds,rotary was 23.5seconds.Average time to cut dentin by Er:YAG lasers was 35.5 seconds, and with rotary 35 seconds. The time taken to remove carious enamel was longer than rotary devices, however, no difference between two methods observed in carious dentin removal.[22]

There is significant decrease in patient discomfort and the painless nature of laser is attributed to the transient anesthetic effect it has on the tooth by blocking nerve conduction at the Na/K pump and ablating the dentinal tubules. When decay is drilled out with a handpiece the friction creates heat, which is felt by the nerve and perceived by the tooth as pain. With lasers there was no heat build-up, no friction and no need of any local anesthesia.[2]

When class 1 to 5 preparations were done, the highest pulpal temperature rise was noticed with class I preparation with lowest values in cementum preparation but all the preparations were below the critical pulpal increase for maintenance of pulp vitality, which is 5.5^{0} C.[23]

Heat shock proteins (Hsp) 25, a low-molecular-weight Hsp,is found under normal and stressful conditions and reported during development and cell-differentiation. Odontoblasts have a specific expression of Hsp 25 immunorecativity in intact teeth and thus a useful marker for differentiation of odontoblasts during pulpal healing process.[24]

The depth and diameter of craters was measured when Er:YAG laser with fixed pulse energy of 450mj, variable duration pulses from 50µs(super short pulses) to 1000µs(very long pulses) as a function of pulse duration dynamics of ablation debris screening was measured by monitoring the transmission of He-Ne laser light formation of ablation debris cloud and showed that optimal Erbium dental laser pulses of 50µs duration, both heat diffusion and debris scanning effects are minimized, leading to efficient “drilling”. Variable square pulse laser technology provides Erbium laser ablation speeds are short, almost square shaped laser pulses. VSP pulses are shorter than 110µs results in effective and “cold” ablation of dental hard tissues and has superior debris screening on the ablation process.[25]

According to the psychological profile, the patients were classified as very calm, calm, anxious and very anxious when restorative and surgical cases were performed with conventional dental treatment under anesthesia and Waterlase Er,Cr:YSGG . At the end of restorative or surgical procedure, the patient was given the Wong-Baker facial image scale to indicate the degree of pain felt. The scale shows 6 different faces numbered from 0-5.The patient could choose just one face. The Er,Cr:YSGG laser offers a new and useful treatment possibilities in restorative and surgical procedures in pediatric patients.[26] Primary teeth with scleroticized carious defects in which the pulp has retreated react less sensitively to laser in terms of pain perception than permanent teeth. [3]

Er:YAG laser irradiation produced different morphological features after cavity preparation. Upon visual inspection the shade or color on the surfaces treated indicated as white, undulating surfaces. The cavity margins and wall showed a smooth, clear prepared surface on SEM.TEM observation of the lased dentin presented three zones: The uppermost characterized as the zone of complete ablation, revealed irregular micro particles of 0.5µmsurfaces, below which an ablation zone of mineral contents and an unaffected zone .Atomic analysis has revealed the quantities of Ca and P were significantly higher in the irradiated area compared to the non irradiated area. Er,Cr:YSGG laser produced regular holes having sharp edges and smooth walls, but no melting or carbonization. Atomic analysis showed that the ratio of calcium to phosphorus did not change.[27]

The SEM evaluation, when Er:YAG lasers were used to prepare cavities in the enamel of primary teeth concluded that there was reduction in the concavity angle of the cavities when the laser energy increased. The occlusal and cervical cavosurface angles were different when the energy was increased.[28]

The clinical, morphological and ultra structural aspects with the use of Er:YAG and Er,Cr:YSGG lasers wave lengths in restorative dentistry coincides with high absorption peaks of water and hydroxyapatite. The advantages include smear layer free cavity walls, selective and localized removal of tooth substance, a restricted need or absence of anesthesia.[29]

Conclusion:

Modern pediatric dentistry must take the advantage of all new advances, until an equilibrium is achieved between novelty effect, effectiveness, replacement of old treatments, modification of old techniques to improve the standard of care of children and adolescents. Due to their versatility, two types of lasers are more frequently used by pediatric dentists, Er: YAG and Er,Cr: YSGG, since they can be used in hard and soft tissues. Instead of routine cutting the tooth structure, tooth can be melted or fused so as to minimize the cutting procedures. As more and more clinicians and researchers discover the advantages lasers have to offer, the presence of lasers in dental office will become increasingly common with the future very promising.

Table 1: Summary of hard tissue laser studies in restorative dentistry

Author(s)	Study design	Conclusion
Anil[12]	Effects of CO_2laser irradiation in prevention of caries	Surface of the enamel became impermeable and reduced subsurface demineralization
Gimbel [5]	Ability of Er:YAG lasers with low energies to ablate hard tissues and its pulpal effects	The pulpal cavity temperature increase was well within the margin of pulpal safety
Keller et al [13]	A prospective study on application of Er:YAG lasers on dental hard tissues	It was a comfortable alternative to conventional mechanical preparation with little discomfort but pulpal integrity was maintained
Widgor et al [14]	Effects of lasers on dental hard tissues	Good definition of dentinal tubules with reparative dentin formation adjacent to pulpal floor in 4 days
Niemz [15]	Effects of Nd:YLF picoseconds laser on cavity preparation	Very precise cavities with less thermal damage can be obtained in both enamel and dentin

Cernavin [16]	Nd:YAG with 20 µm spot size 50,000J/cm^2 energy density and Ho:YAG laser of 25 µm spot size 4160J/cm^{2}irradiation effects on enamel and dentin were compared	Ho:YAG lasers with spot size 25µm and energy density 4160J/cm^2 produced a cleaner puncture in dentin with less melting of surrounding tissue than Nd:YAG lasers
Sonntag et al[10]	The pulpal response when cavity preparation to wet and dry extracted teeth and average depth of penetration with the Er:YAG and Mark 3 free electron lasers	FEL application raised pulpal temperature 0.5^{0}C after 2000 pulses and 0.3^{0}C after 4000 pulses application
Matsumoto et al[17]	Er:YAG laser emitting wave length 2.94 µm was used for clinical preparation of class 5 cavities for 40 patients	Class 5 cavities preparation were performed without inducing pain
Keller et al[18]	The patients perception, acceptance and mean time with Er:YAG ,Er,Cr:YSGG lasers and conventional preparation in caries therapy	The need for anesthesia was 11% for mechanical preparation compared to 6% during laser application, and the 82% of the patients reported that they would prefer Er:YAG .The mean time for preparation by Er:YAG laser was 7.5±4.6 minutes, Er,Cr:YSGG laser ranged from 5 seconds to 20 minutes as per the cavity size 3.9±3.9minutes for the conventional preparation
Glockner et al[19]	A comparison of Intrapulpal temperature during preparation with the Er:YAG laser and conventional bur	With the laser, there was temperature change after a few seconds from 37^{0}C to 25^{0}C to 30^{0}C but a conventional bur preparation showed rise in temperature more than 60^{0}C even before trephination
Evans et al[20]	A split mouth randomized clinical trial to determine acceptability of dentist and patient of cavity preparation in 3-68 year using Er:YAG laser and handpieces	Dentists preferred conventional handpieces for cavity preparation while patients aged greater than 10 years preferred laser treatment.
Jayawardena et al[21]	Pulpal response to either Er:YAG laser or mechanically by a slow speed conventional hand piece after accidental pulp exposure in 76 molars of rats.	Er:YAG laser group formed dentin bridges and reparative dentin at the exposure site more frequently than control group
Shiegtani et al[22]	Cavity prepared by Er:YAG laser using 0.4mmdiameter tip at 200mJ/pulse and 100 mJ/pulse were observed under scanning microscope and time necessary to remove caries was observed	The time taken to remove carious enamel(33seconds) was longer than rotary devices(23.5seconds) however, no difference between two methods observed in carious dentin removal.
Oelgiesser et al[23]	Class 1 to 5 cavities were prepared on 175 extracted teeth with Er:YAG laser and its pulpal response evaluated	The highest pulpal temperature rise was noticed with class I preparation with lowest values in cementum preparation but all the preparations were below the critical pulpal increase for maintenance of pulp vitality, which is 5.5^0 C.

Lukac et al[25]	Fast and precise cavity preparation with Er:YAG fixed pulse energy (450mJ),variable duration pulse from 50 µs(super short pulses) to1000 µs(very long pulses) and the depth and diameters of craters were measured	Variable square pulse laser technology provides Erbium laser ablation speeds are short, almost square shaped laser pulses. VSP pulses are shorter than 110µs results in effective and "cold" ablation of dental hard tissues and has superior debris screening
Boj et al[26]	According to Wong-Baker facial image scale ,the degree of pain felt at the end of restorative and surgical treatment using conventional and WaterlaseEr,Cr:YSGG was evaluated	The Er,Cr:YSGG laser offers a new and useful treatment possibilities in restorative and surgical procedures in pediatric patients
Hossain et al[27]	Ablation depths and morphological changes in human enamel and dentin after Er:YAG and Er:YSGG laser irradiation with or without water mist	With Er:YAG laser the cavity margins and wall showed a smooth, clear prepared surface on SEM. Atomic analysis has revealed the quantities of Ca and P were significantly higher in the irradiated area compared to the non irradiated area. Er,Cr:YSGG laser produced regular holes having sharp edges and smooth walls, but no melting or carbonization. Atomic analysis showed that the ratio of calcium to phosphorus did not change.
Jucaria et al[28]	SEM evaluation of cavosurface angle patterns of Er:YAG laser cavity preparation in primary teeth	There was reduction in the concavity angle of the cavities when the laser energy increased. The occlusal and cervical cavosurface angles were different when the energy was increased.

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