Effects of Laser Irradiation on Caries Prevention

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Abstract:

Introduction: Although dental caries is a preventable disease, it is still common and remains a public health problem. One of the potentially effective preventive measures is the use of lasers. The purpose of this study was to review the studies about use of laser irradiation on the inhibition of carious lesions and the effectiveness of different commercial laser type (Nd:YAG, CO_2, and Argon).
Method: A literature search included journal databases, existing systematic reviews, and studies identified by content experts. Studies meeting inclusion criteria were assessed for quality.
Results: Some studies have demonstrated the potential preventive effect of laser irradiation on sound enamel; the effect of irradiation on white spot lesions is still unclear. The effects of irradiating demineralized enamel surfaces coupled with the use of topical fluoride application is also still unclear and further research needs to be conducted in this area. Laser irradiation alone can significantly enhance acid resistance of sound enamel surfaces and prevent caries progression.
Conclusion: Combined use of topical fluoride application and laser irradiation on sound enamel surfaces has provided the best protection against caries initiation and progression. Laser irradiation was of limited value in managing incipient carious lesions. Argon laser use may be easier clinically due to its large and visible beam diameter, which allows for irradiation of the whole surface of the tooth instead of the overlapping and time consuming pattern of the CO_2 laser.
Keywords: dental caries; laser; enamel

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Introduction

Dental caries continues to be a problem in many countries. According to reports from the World Health Organization (WHO), nearly 70 percent of the countries in the world have achieved the WHO oral health goal of 3 DMFT (Decayed, Missing, Filled, Teeth) or 12-year-olds (1-2). Although dental caries is a preventable disease, it is still common and remains a public health problem, especially in developing countries, and certain populations in economically developed countries (3-4). Therefore, there is still a need to prevent dental caries and search for alternative methods for disease prevention, or new ways of augmenting current preventive programs. One of the potentially effective preventive measures is the use of lasers. As early as 1966, Stern and Sognnaes, using an Nd:YAG (Neodymium-Doped Yttrium Aluminium Garnet) laser, showed that irradiated enamel specimens were resistant to acid demineralization(5). In 1980, also using an Nd:YAG laser, Yamamoto and Sato reported that irradiated enamel specimens, which were embedded into several human dentures, showed no detectable visible changes when compared to chalky white lesions on non-irradiated enamel specimens(6). Hicks, et al. in 1993, concluded that "exposure of sound enamelsurfaces to argon laser irradiation enhances the ability of lased enamel to resist a constantin vitro cariogenic challenge". They showed that irradiating the enamel surfaces with argon laser resulted in a significant reduction in lesion depth after acidic challenge(7). Featherstone and colleagues reported caries-inhibiting effects of CO_2 lasers invitro studies. Irradiating enamel surfaces with a low-energy CO_2 laser resulted in caries inhibition rates between 70-85 percent(8). The purpose of this study was to review the studies about use of laser irradiation on the inhibition of carious lesions and the effectiveness of different commercial laser models (Nd:YAG, CO_2, and Argon).

Laser Interaction with Dental Hard Tissues

Optical properties of enamel and dentin must be understood to ensure safe and effective laser treatment. Laser-tissue interaction is controlled by irradiation parameters: wavelength, repetition rate, pulse energy, pulse duration, continuous or pulsed emission, beam size, delivery method, and optical and thermal properties of the tissue. The optical properties are characterized by the refractive index, scattering and absorption coefficients, and scattering anisotropy or directional nature. The ultimate effects of laser irradiation depend on the energy distribution inside the tissue. The resulting temperature rise in the exposed area is the result of energy distribution and heat conductance away from the source of irradiation. This temperature rise determines the extent of change in the morphology and chemical structure of the irradiated tissue (9-11). For temperature rise at the surface of the tooth, the exposure time is equally important to the amount of energy delivered. To explain this, the concept of thermal relaxation time has to be defined. This is the time needed for temperature at a given depth to reach a temperature which is approximately 84 percent of the difference between the surface temperature and initial temperature. It can also be defined as the estimate of the time needed for thermal diffusion to reduce the temperature in a layer of certain thickness by approximately one half. Therefore, the pulse duration becomes an important parameter for determining laser tissue interaction. If the pulse duration of the laser used is the same or less than the thermal relaxation time for the tissue, the energy will remain in the volume where it was absorbed leading to large temperature increases near the surface using low energy input. If the pulse duration is much longer than the tissue's thermal relaxation time, the thermal energy will flow towards the center of the tooth and heat a large volume of the tissue. A large fraction of the absorbed laser energy will be conducted away from the enamel surface resulting in insufficient surface heating and possible pulpal damage. On the other hand, if the pulse duration is much shorter than the tissue's thermal relaxation time, the deposited energy density will be too high, causing ablation and removal of the tissue instead of desired heating and fusion (10, 12). Recent and previous observations provided irradiation parameters to choose to perform a certain task. For detecting caries, laser can be used because carious lesions will fluoresce differently from healthy tissue. To detect subsurface lesions, the laser must penetrate deeper into the tissues. If the task is to remove hard tissues as in caries removal and cavity preparations, the laser must be absorbed by these tissues. If the dentist needs to alter the tissue composition and solubility by heating, the laser must be well absorbed in the surface region and converted to heat without damage to the dental pulp(11). Enamel and dentin absorption are weak in visible and near infrared ranges. Dentin absorption is low in the visible range, but the tissue scatters more than enamel due to its higher content of water and protein than enamel. The enamel coefficient of absorption in the visible light range (400-700 nm) is less than 1 cm^{-1}, and about 10 cm^{-1} in the UV light range (240-300 nm). The scattering coefficient for enamel decreases between 240 and 700 nm and lower in the near infrared range. In the region of Nd:YAG laser (1064nm), the absorption coefficient of enamel is low, meaning that this laser light passes through enamel with minimal absorption and less scattering(10-11, 13-

14). For this reason, many researchers use dyes or inks with Nd:YAG lasers to improve enamel absorption of this laser(15-16). Available laser models which emit light at mid infrared ranges include the erbium and CO_2 types. The erbium lasers overlap with the water absorption band. Water then becomes the main absorber, and this property makes these laser models effective in removal of intact enamel and dentin and carious lesions (10-11, 14).

Pulpal Thermal Response

Another important issue to consider before using lasers is the temperature rise within the tooth. Early laser models caused significant thermal damages to the pulp. As different laser sources and parameters were refined, this problem has been addressed. Many in vivo and in vitro studies were conducted to examine the thermal effect of different laser models on the pulp. Zach and Cohen in 1965, in their pulp study, established that temperature rises of 5°C, or greater in the pulp for nearly one minute can cause necrosis the pulp(17). Since then, many pulpal studies have concluded that any type of treatment is safe as long as this level of 5°C rise in temperature is not achieved or increased. Goodis and colleagues tested the pulpal safety of a CO_2 laser in vivo(18). Erupted, caries and restoration free third molars of seven patients were irradiated by CO_2 laser. Before the irradiation, pulpal vitality tests were done, and radiographs were taken. Teeth were then extracted immediately or after one week and examined histologically for signs of inflammation. All teeth exhibited no signs of inflammation in the pulp tissues. The study concluded that this laser could be used for caries prevention treatments at the energy levels used. In a similar study, Wigdor and colleagues examined the effect of CO_2 laser. They irradiated the teeth, which were then removed for orthodontic or periodontal reasons. The pulp tissue of irradiated teeth had no apparent vascular or inflammation changes(19). Cobb et al. compared the temperature induced at the dentin-pulpal interface between argon laser and visible light curing light at a variety of exposure conditions(20). The argon resulted in a temperature rise which was less than what was recorded by the visible light source. They concluded that argon laser irradiation did not pose a serious thermal problem for the pulp tissue. Following research reports of Wigdor et al. and Visuri,et al. the United States Food and Drug Administration cleared the use of Er:YAG (Erbium Substituted: Yttrium Aluminium Garnet) laser for the treatment of carious lesion in humans. Their animal studies on dogs demonstrated no pulpal damages after irradiation with Er:YAG laser(21-22). Wigdor and Walsh also demonstrated that CO_2 laser does not cause damage to the dental pulp in dogs(19). The previous studies tested the safety of many lasers using relatively high energy densities and proved that irradiation of dental hard tissues at these levels were not damaging to the pulp. The use of dental lasers for caries prevention should not warrant concerns about pulpal tissue damage since many of these laser types are approved for use in the oral cavity for reasons other than caries prevention using higher energy levels than what would be needed for caries prevention.

Caries Preventive Effects

Hsu et al. reported a significant reduction in enamel solubility following CO_2 laser irradiation and reported that there was significant synergism between that laser and 0.2 ppm fluoride solution(23). The combined laser-fluoride treatment led to 98 percent reduction in mineral loss. In another study, Flaitz,et al. showed that combining acidulated phosphate fluoride with argon laser irradiation resulted in a 50 percent reduction in lesion depth compared with control lesions which did not receive any treatment(24). Although several studies have investigated the effect of different types of lasers used alone or together with topical fluoride application upon dental hard tissues, certain issues still need to be investigated. It remains unclear, for example, whether topical fluoride application is better done before or after irradiating dental enamel, or which laser type is more effective in preventing dental caries(7, 24-25). These lasers have different wavelengths and will interact differently with the tooth structure. These differences might affect the fluoride uptake in dental enamel. If laser irradiation changes the enamel surface in certain ways, this can enhance or reduce the fluoride uptake and retention. Depending on these results, topical fluoride treatment sequence becomes important for optimum fluoride uptake. One study compared an

Nd:YAG laser with a CO_2 laser with regards to their effect on enamel solubility and demineralization following acidic challenge(26). However, more research still needs to be done to compare these lasers alone, or combined with topical fluoride application to determine the best protocols for enamel surface protection against acidic challenge.

While some studies have demonstrated the potential preventive effect of laser irradiation on sound enamel, the effect of irradiation on white spot lesions is still unclear. The effects of irradiating demineralized enamel surfaces coupled with the use of topical fluoride application are also still unclear and further research needs to be conducted in this area.

Comparison of Laser Types

The literature is lacking in studies which compare the effect of different types of lasers on caries inhibition. The only one found was Tsai,et al. study, which compared the performance of CO_2 and Nd:YAG lasers on acid resistance of dental enamel(26). However, the pulse duration, number of pulses/second, the wattage used, and the pulse incident energy were all different. The study concluded that enamel surfaces treated with either CO_2 or Nd:YAG lasers were eroded to shallower depths than untreated enamel. The study failed to report whether the lactate buffer solution used was constantly changed to insure that the solution was not saturated at all times. In another study, Cernavin compared the ablation effects of Nd:YAG and Ho:YAG (Holmium) lasers irradiation on enamel and dentin(27). The author reported that the holmium laser was more suitable for cutting enamel and dentin when compared to the Nd:YAG laser, which caused more melting of tooth structure and was more difficult to control. There is a definite need for more laser comparative studies not only to determine the most effective laser types in preventing caries and providing more acid resistance to enamel surfaces, but also to compare their performance clinically to determine which system is easier to use in the shortest time with a minimal learning curve.

Clinical in Vivo Studies

Several studies tested the caries prevention effect in vivo. These studies included the use of intra-oral models, or actual irradiation of teeth in the oral cavity. As early as 1972, Stern and Sognnaes exposed intact enamel surfaces extra-orally to CO_2 laser irradiation(28). One of the investigators served as the carrier for the samples. Featherstone and colleagues used an intra-model to determine whether caries inhibition was observed in the human mouth(29). Artificial caries lesions were made in extracted human enamel and were exposed intra-orally in partial dentures in each participating subject either to a placebo, topical fluoride treatment, or CO_2 laser treatment. The irradiated specimens showed 84 percent inhibition of further demineralization when compared with control groups which did not receive any treatments. Kato et al. determined the effect of CO_2 laser irradiation in the prevention of pit and fissure caries in immature molars covered with opercula(30). The occlusal surface was then irradiated spot by spot along the pits and fissures of molars using pulsed mode of the CO_2 laser. Each of these teeth was clinically followed up for dental caries for 3 years. After three years, only two teeth developed dental caries. Several studies investigated the use of Nd:YAG laser in prevention of caries. In a study discussed earlier, Harazaki and colleagues concluded that this laser could be used as an effective means to reduce caries experience during orthodontic treatment(31). Birardi and colleagues demonstrated that traditional therapy of early childhood caries can be improved with the use of Nd:YAG laser. Fluoride gel was applied on the carious surfaces of teeth before irradiation with Nd:YAG laser. Nd:YAG laser tip was used in contact and caries was removed upon irradiation without using local analgesics(32). Treatment took few minutes without any complaints from the participating children and was not traumatic for them. The authors reported decreased hypersensitivity, and reduction of dentin permeability. Anderson and colleagues, in their in vivo study, examined the effects of argon laser irradiation on enamel decalcification (33). They used argon on premolars which were removed later for orthodontic purposes. They reported high percentage of lesion depth reduction compared with the unlased control teeth. Blankenau and colleagues, also reported in a similar study significant demineralization reduction in argon irradiated teeth(34). The studies show the great potential of using lasers for prevention of caries initiation and progression.

Conclusions

Laser irradiation alone can significantly enhance acid resistance of sound enamel surfaces and prevent caries progression. Combined use of topical fluoride application and laser irradiation (by CO_2, Nd:YAG, or argon lasers) on sound enamel surfaces provided the best protection against caries initiation and progression. Laser irradiation was of limited value in managing incipient carious lesions. Argon laser use may be easier clinically due to its large and visible beam diameter, which allows for irradiation of the whole surface of the tooth instead of the overlapping and time consuming pattern of the CO_2 laser.

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