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Differnts Effectiveness of 10,600 nm Carbon Dioxide Laser on Enamel Surface

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Abstract

Besides having a modest penetration depth, a carbon dioxide laser operating at 10,600 nm has a strong absorption affinity for water. It's useful for coagulation of bleeding and soft-tissue surgery. Also, its absorption properties are consistent with hydroxyapatite, a mineral found in tooth enamel and dentin. This article examines the current research on the impacts of 10,600 nm Carbon Dioxide Laser on enamel surfaces. When compiling this review's data, we restricted our attention to articles that were made available online. For this study, we utilized the following search terms on "Google Scholar" and "PubMed" websites: CO_2 Laser (10,600 nm), Demineralized enamel, Microhardness, enamel erosion, remineralization, fluoride. Only publications written in English from 2005 through June 2023 were included in this review. Priority was given to original articles and clinical research.

Conclusion: The 10,600 nm CO_2 laser is widely accepted in caries prevention. CO_2 lasers have been the subject of much research but have yet to be used in therapeutic settings. Effective laser energy transmission to enamel allows for the transformation of carbonated hydroxyapatite into the purer hydroxyapatite of enamel. The laser enhances fluorides and other caries-preventive ingredients' effectiveness. As a result, resin bonds better to tooth enamel.

Introduction:

Since the 1960s, laser treatments have been studied in dentistry and medicine. There has long been discussion about replacing the drill with a laser to prepare dental hard tissues. In 1964, Stern and Sognnaes conducted the first experiment using a ruby laser (680 nm wavelength) to prepare dental hard tissue[1]. The surface had much carbonization despite the laser's ability to melt enamel and dentin. In addition to being most effectively absorbed by dark pigment, the continuous wave mode of the ruby laser also prevented thermal relaxation, making it unsuitable for use on tooth structures. This means we must know the precise wavelength at which the laser will interact with the tissue. The optical property of the tissue to the wavelength determines how the laser interacts with the tissue. The two chromophores of CO_2 lasers are carbonated hydroxyapatite and water, the two main components of enamel and dentin[2]. The most widely accessible CO_2 laser on the market operates at a wavelength of 10,600 nm. Regarding CO2 wavelengths, hydroxyapatite has a more significant absorption coefficient (8.25×10^2 cm^{-1}) than water (6.6×10^2 cm^{-1}). Enamel and dentin have a 12µm absorption depth compared to the water's 15 µm absorption depth. How laser radiation works on enamel and dentin at various depths determines the results. The laser's energy is determined by factors including its power, waveform (whether it's a continuous wave or a pulse), fluence (how concentrated its energy is), and dosage (how much energy it delivers)[3]. Researchers found that a carbon dioxide laser with a wavelength of 10,600 nm might cause both chemical and morphological alterations in hard tooth tissues[4, 5]. Not only that, but hydroxyapatite's phosphate, carbonate, and hydroxyl groups absorb light at this particular wavelength[6, 7]. The laser was also shown to ablate enamel and dentine with high efficiency. The 10,600 nm carbon dioxide laser is gaining popularity in dentistry due to its ability to prevent and treat caries lesions in the enamel[8].

To our knowledge, no previous comprehensive review study on the 10,600 nm carbon dioxide laser effect on enamel surface exists in the literature. This review examines the most, if not all, available studies.

The Search Methods

A PubMed database and Google Scholar were searched extensively for relevant articles. Manuscripts written in English between 2005 and June 2023 were included in the search, and the following terms were used to narrow the results: CO_2 Laser, Demineralized enamel, Microhardness, enamel erosion, remineralization, fluoride. studies unrelated to the topic, personal comments, editorials, and social media sources were removed. Only 47 articles remained after the screening procedure.

CO_2 laser (10.6 µm) as a protective effect with fluoride on enamel erosion.

Many researchers have reported that Carbon dioxide lasers can alter tooth structure and have complicated interactions with enamel. The laser's settings will dictate the degree of modification to the tooth's structure. To obtain the desired impact on dental hard tissue, it is essential to consider characteristics such as the laser's output power, energy density, pulse duration, and repetition rate, in addition to the wavelength. Wiegand et al.[9] concluded that the samples treated with CO_2 laser irradiation through Titanium Tetrafluoride (TiF4) showed considerably less cumulative enamel loss after 20 erosive cycles than untreated samples. Fluoride penetration into enamel may be increased by CO_2 laser irradiation, leading to more tightly bound fluoride rather than loosely bound CaF_2 precipitates. Furthermore, scanning electron microscopy (SEM) photos demonstrated that irradiation with a CO_2 laser caused melting of the granular surface precipitates, which might increase the absorption and retention of titanium, fluoride, or both, increasing enamel's acid resistance. In contrast, applying TiF_4 before irradiating with a CO_2 laser did not result in any observable modifications to the surface precipitates. Studies demonstrated that irradiation of carbon dioxide (10.6 nm) laser with fluoride agents showed that the enamel not only significantly decreased erosive mineral loss as a result of acid erosion but also rehardened previously softened enamel[10] [11] [12] [13] [14]. Also, another study has proven that the administration of fluoride forms a layer protecting the enamel surface, hence increasing its resistance to acid. Laser treatments altered the enamel surface, creating dense elemental lines mixed with mineral-depleted lines. To prevent the chemical changes in enamel produced by laser irradiation and soft beverages, fluoride is before laser irradiation (Figure 1) [15]. Rocha et al. [16] assessed in vitro the impact of CO_2 laser input power, with and without stannous fluoride (SnF2) gel, on intrinsic erosion control in primary teeth. Input power for a CO_2 laser can be either 0.5, 1.0, or 1.5 W. The permeability of enamel may be altered by changing the input power of a CO2 laser; more permeability was achieved at a power setting of 1.5 W. Contrary to these studies, Taisa Palazzo Lepri et al. [17] results indicated that in situ CO2 laser irradiation did not slow the development of citric acid-induced erosive lesions on enamel. Similarly, Ramos Oliveira et al. (18) investigated how well various fluoride treatments and CO2 lasers work together to prevent tooth enamel from wearing away. They found that the effects of either fluoride agent (AmF or NaF) were not considerably amplified by CO2 laser irradiation. In situ, study by Lepri, T. P. et al. (2015) Compares the efficiency of TiF4 and CO_2 laser in limiting enamel erosion. Laser irradiation did not suggest a reduction in permeability when TiF4 was applied to the enamel. However, the placebo gel, CO_2 laser, had the opposite effect. Reduced permeability of degraded enamel was achieved with TiF4 whether or not the CO_2 laser was employed(19). Also, another in situ study has shown that applying acidulated phosphate fluoride gel (APF) separately decreased enamel wear but, combined with CO_2 laser irradiation, did not enhance fluoride's ability to reduce enamel wear[20].

Currently, the CO_2 laser is not only used as a combination with fluoride; it has been proposed that laser irradiation, in conjunction with CPP-ACP (casein phosphopeptide-amorphous calcium phosphate), might boost the tooth's resistance against the loss of its hard components. Kasraei et al. (2021) concluded that the sequential application of CO_2 laser and CPP-ACP was more effective in rehardening the eroded enamel's surface to near-normal levels[21].

Reducing enamel demineralization around orthodontic brackets using fluoride-releasing with a CO_2 irradiation laser.

It is well-known that When orthodontic treatment has been completed, However, the occurrence of unattractive white spot lesions is a typical clinical issue that threatens this aim and may necessitate extra aesthetic therapy in some situations. [23] [24]. Previous research has found that approximately half of orthodontic patients have white spot lesions. These lesions can appear at least four weeks, significantly shorter than the typical interval between orthodontic check-ups[25, 26]. Based on that, several studies have concerned the effect of CO_2 laser and fluoride on the enamel around bonded orthodontic brackets. De Souza-e-Silva et al.[27] evaluated that Reducing enamel demineralization around cariogenic orthodontic brackets may be possible using a CO_2 laser with a fluoride-releasing bonding material. Bovine enamel slabs were used in this experiment, and each group was treated with either a non-inoculated brain-heart infusion broth, a non-fluoride-releasing composite resin, a resin-modified glass ionomer cement, a CO_2 laser with Transbond, or a CO_2 laser with Fuji. A microbiological caries model was conducted on slabs for five days. Biochemical and microbial analyses of the Streptococcus mutans biofilm produced on the slabs and measurements of the enamel Knoop hardness number (KHN) surrounding the brackets were performed. Researchers found that demineralization surrounding orthodontic brackets might be slowed with the help of a CO_2 laser, with or without using F-bonding compounds. In another study, Seino, P. Y et al.[28] combined the use of CO_2 (= 10.6 m) and Nd: YAG (= 1,064 nm) lasers with or without the use of topical fluoride for the prevention of caries lesions around brackets. They assess enamel demineralization by Quantitative light-induced fluorescence. In the Nd: YAG laser group, demineralization was greatest. At the same time, the irradiated groups using CO_2 had a lower mineral loss than those that were not illuminating and not treated with fluoride. All the other groups' demineralization rates were about the same as the control groups. Accordingly, they concluded that the CO_2 laser alone was equally effective as topical fluoride treatment in preventing enamel demineralization around brackets. Raghis, T et al.[29] used a CO_2 laser clinically. The two reversed quadrants of the dental arches in each patient were randomly allocated to CO_2 laser application around the orthodontic brackets. The remaining two sections were illuminated with non-therapeutic control light. The authors observed clinical and photographic assessments of the presence or absence of fresh demineralized lesions. DLs were also evaluated based on their severity and domain-specific performance. The laser group had considerably lower DL levels in digital imaging and DIAGNOdent evaluations. In a randomized, split-mouth controlled clinical trial, Belcheva et al.[30] showed that the effectiveness of a CO_2 laser and fluoride varnish in reducing the incidence, severity, and duration of white spot lesions in patients undergoing fixed-appliance orthodontic therapy resulting in lower rates of white spot lesions associated with it. It should be noted, in an in vitro study, Farzaneh Ahrari et al. reported that when compared to traditional plier debonding, laser debonding may make bracket removal safer for the tooth tissues. Therefore, laser debonding can lessen the potential for enamel damage when removing ceramic brackets [31]. Contrary to these studies, the study by regard Kaur, T et al.[32] showed that CO_2 laser does not highly impact the resist demineralization and microhardness value compared to Er, Cr: YSGG laser. Similarly, Mirhashemi et al.[33] investigated using a carbon dioxide (CO_2) laser and a titanium tetrafluoride solution on the enamel around the bracket. No significant difference was seen between groups treated with titanium alone or with titanium and laser, and laser therapy did not significantly affect demineralization. However, the study by Farhadian et al.[34] aimed to determine how irradiation with a CO_2 laser affects the demineralization of teeth close to orthodontic brackets and how it affects the shear bond strength of human premolar teeth. The study shows they apply CO_2 laser on an enamel surface considerably reduces enamel demineralization, and it didn’t show a negative impact on the shear bond strength of orthodontic brackets. In another study, Ghadirian et al.[35] evaluate the mechanical characteristics and shear bond strength of demineralized enamel to the orthodontic bracket after being treated with two remineralizing agents with and without CO_2 laser irradiation. There was no statistically significant difference in the atomic percentages of Ca and P between the laser-irradiated and control groups. The atomic Ca/P ratios for the laser groups demonstrated that adding laser irradiation to the remineralizing agents did not increase calcium and phosphate uptake. The laser did not significantly alter the enamel structure, as seen by comparing the laser groups and the sound enamel. Increased microhardness measurements were taken in the laser groups. This demonstrates that lasers are valuable tools for delivering remineralizing chemicals into the deeper layers of HA.

Effect of CO_2 laser on remineralization of white spot lesions and enamel surface resistance to demineralization with different remineralizing agents

1. Combining a CO_2 laser and fluoride

The main goal of treatment with CO_2 laser is remineralizing white spot lesions and enamel surfaces to become more resistant to demineralization[36]. Several studies in the literature have shown that CO_2 laser combined with fluoride agents has a positive effect by increasing enamel surface protection and demineralization resistance greater than either fluoride or CO_2 laser irradiation alone[8, 37] [38] [39] [40] [41]. Biofilm *streptococcus mutans* and *Lactobacillus* were included in one study by de Araújo Loyola et al.[42] . Enamel demineralization and biofilm development were examined utilizing in vitro and in vivo models to see how effective CO_2 laser therapy and acidulated phosphate fluoride (APF) were. However, none of the treatments examined successfully prevented bacterial colonization of the enamel, leading researchers to conclude that APF gel used in conjunction with the CO2 laser efficiently prevented demineralization. Caries on the occlusal surface of partially erupted first permanent molars in children at high risk for caries can be prevented using a CO_2 laser with or without topical application of acidulated fluorides, as shown in a controlled, randomized, double-blind clinical trial[43]. While Oliveira et al.[44] assess ultra-pulsed CO_2 laser and commercial fluoride products to enhance the microhardness of simulated enamel caries lesions. Fluoride varnish has considerably increased microhardness ($p < 0.05$). In another study, Chen et al.(45) treated incipient carious lesions with a CO_2 laser, an Nd: YAG laser, and acidulated phosphate fluoride (APF) and compared their results. Utilizing lasers and fluoride on decalcified enamel boosts acid resistance, producing more significant results than fluoride. While, Souza-Gabriel et al.[46], The impact of fluoride varnish paired with CO_2 laser was investigated in situ for its potential to prevent enamel demineralization brought on by cariogenic challenges. Subsurface demineralization of enamel might be slowed using a CO_2 laser, combining it with highly concentrated fluoride treatment could not have a synergistic effect. It must be pointed out; that Using a CO_2 laser on its own can be a useful tool in the fight against caries in baby teeth[47]. In return, this research aimed to investigate the effects of CO_2 (10.600nm) and infrared diode laser (980nm) on the surface composition of enamel and its capacity to resist demineralization. Laser treatment shows promise for tissue remineralization and strengthening enamel against bacterial acid assault. They concluded that When compared to CO_2 laser applications, diode laser applications have the potential to offer superior remineralization performance with low heat emission[48]. In addition, in the A. study, Lesion development in primary enamel was inhibited using a CO_2 laser (10.6 m) alone and in combination with acidulated phosphate fluoride (APF). Both laser irradiation and APF were proven to slow the spread of lesions in primary tooth enamel. However, there was no clear synergistic benefit from the two treatments together[49].it may be useful to emphasize that there were some studies on the CO_2 laser (10.6 µm) impact on mineral dissolution and change composition of enamel. The study was Acid resistance of human enamel treated with acidulated phosphate fluoride and irradiation with either an Er: YAG laser or a CO_2 laser in vitro was compared; the (CO_2 + APF) showed the highest percentage reduction in calcium dissolution of 59.7%[50]. In another study, A.L. Ahmad et al. (2010), Low-power CO_2 lasers irradiated 19 removed human molars. Exposure times of 5 seconds and 10 seconds, laser powers of 3 watts, 6 watts, 9 watts, 12 watts, and 18 watts, and a distance of 4 cm between the laser's aperture and the sample were employed. Teeth can be harmed by lasers with a power output exceeding 18W. The Fourier Transform Infrared Spectroscopy (FTIR) was utilized to analyse the tooth compositions. Due to the increased temperature speeding up chemical reactions, high laser power enhanced the beam's reflectivity. When the laser power was high, the beam reflected lighter because the temperature increased, making chemical reactions faster. Hence, this finding suggests that low-power CO_2 laser in the range of 3 W to 18 W is suitable for dentistry since it does not change the molar teeth composition. They concluded that This finding may help improve technology in dentistry since CO_2 lasers are useful in dentistry[51]. Vieira et al. [52]. investigated the impact of many applications of a CO_2 laser on the enamel's ability to resist demineralization. L1 = 1 CO_2 laser application; L2 = 2 CO_2 laser applications; L3 = 3 CO_2 laser applications; L4 = 4 CO_2 laser applications. Calcium and phosphorus levels in the irradiated samples were not significantly different from the control samples ($p > 0.05$), according to the EDXRF results. A statistically significant difference ($p < 0.05$) in cross-sectional micro-hardness was seen between the control and all irradiated groups. Still, no such difference was observed within the irradiation groups ($p > 0.05$) up to 30-µm depth. Demineralization tended to be lower for L3 and L4 groups at greater depths. SEM analysis revealed that repeated CO_2 laser treatments resulted in gradual surface melting and recrystallization of the enamel. Enamel demineralization can be prevented by irradiating teeth repeatedly. A tendency of lower demineralization occurred in deeper depths for L3 and L4 groups. The SEM results showed that with repeated applications of the CO_2 laser, a progressive melting and recrystallization of the enamel surface occurred. Repeated irradiations of dental enamel may enhance the inhibition of enamel demineralization.

2. CO_2 Laser combined with casein phosphopeptide amorphous calcium phosphate fluoride varnish (CPP-ACP).

Abufarwa et al.[53] In this study, the effects of a carbon dioxide (CO_2) laser and a casein phosphopeptide amorphous calcium phosphate (CPP-ACP) fluoride varnish on enamel demineralization were compared. Compare the effects of carbon dioxide (CO_2) laser and casein phosphopeptide amorphous calcium phosphate (CPP-ACP) fluoride varnish on enamel demineralization. The area of demineralization in the laser group was significantly greater than that of the fluoride group. In the same regard, Soltanimehr et al.[54] showed No synergistic effect between (CPP-ACP) fluoride materials and lasers for remineralizing primary teeth.

3. CO2 Laser combined with nano hydroxy apatite

Enamel's primary component, hydroxyapatite (HA), is responsible for the white color and lack of diffuse reflectance of light due to its closed pores[55]. biomimetic strategies have been employed to create nano-materials for early enamel lesion remineralization in recent years[56]. El Assal et al. [57]. The pure nanohydroxyapatite gave better results than the nano fluorapatite type in both tests. This was discovered by combining fractional CO_2 Laser and nano hydroxy apatite. The laser-treated teeth in both groups showed the highest mean hardness and the lowest color difference, whereΔE was less than 3.3 units. The authors concluded that when used with a laser, Nano-hydroxyapatite has been shown to significantly increase the remineralizing effects on early enamel lesions. Al_Bazaz et al.[58] examined The microhardness of tooth enamel was modified by exposure to nanoparticles and CO_2 laser radiation. Five seconds of continuous wave (CW) mode were used for the exposure. The hydroxyapatite nanoparticles solution used had a 10% concentration, whereas the iron oxide nanoparticles solution had a 12.5% concentration. Microhardness improved most in the groups treated with laser, followed by hydroxyl apatite nanoparticles (HANPs) or iron oxide nanoparticles (IONPs). Iron oxide nanoparticles (IONPs) caused the slightest change in enamel microhardness compared to the other agents, whereas laser, followed by IONPs, caused the most significant change in enamel microhardness.

4. CO_2 Laser combined with the Regenerate system

Study evaluated the structural changes of enamel treated by the Regenerate system and carbon dioxide (CO_2) laser against acid challenge. After an acid challenge, Raman microspectroscopy and micro indentation revealed modifications to the enamel's microstructure and mechanical characteristics, with phosphate peaks' intensities decreasing while carbonate had grown. Before and after pH-cycling, Regenerate-treated surfaces had more excellent mineral contents (phosphate and carbonate), but CO_2-treated surfaces had lower carbonate and increased microhardness. The enamel's resistance to the acid challenge can be improved, and its structure and morphology preserved with either treatment method [5].

Effect of CO_2 laser with and without fluoride on demineralization around composite restorations and bond strength of composite to enamel

Composite restorations have a natural tendency to shrink, which results in a space between the resin and the tooth[59]. Due to inadequate bonding of the composite to the cavity walls, the tooth structure surrounding the restoration is at a significant risk of decay[60].based on that, many studies have been a variety of methods used to reduce demineralization of enamel around composite restorations and increase composite bond strength to the enamel. The research looked at the effects of demineralization surrounding composite restorations when carbon dioxide and erbium-doped yttrium aluminum garnet (Er: YAG) lasers with and without fluoride varnish were used. The resistance of tooth structure to the cariogenic solution is not significantly altered by the CO_2 and Er: YAG lasers alone. But when used with NaF varnish, they can produce additive effects. Applying fluoride varnish to teeth before laser irradiation strengthens and hardens the teeth[61]. Nevertheless, the microshear bond strength (SBS) of composite to enamel was reduced when TiF4 was applied before and after CO_2 laser irradiation on enamel. On the other hand, the application of APF alone and after laser irradiation did not have any negative effect on the SBS of composite to enamel[62].

Researchers found that preventing enamel demineralization surrounding composite restorations might be accomplished by irradiating the cavosurface edge of cavities using a pulsed CO_2 laser[63].

Conclusions

The 10,600 nm CO_2 laser is widely accepted in caries prevention. A combination of a laser awith fluoride and other is considered the most promising treatment for caries prevention. This combination improved fluoride uptake, and minerals ion (calcium and phosphat).additionaaly .this decreased enamel solubility in acid,reduced the progression of caries like lesions. The laser energy is successfully transported to the enamel, converting the carbonated hydroxyapatite to the purer hydroxyapatite of the enamel and enhances the caries-prevention efficacy of fluoride and other compounds. It improves the adhesion of the resin to enamel.

Directions for future studies

The laser treatment was applied on smooth enamel surfaces, while in clinical reality, other surfaces are prone for caries lesions (i.e., proximal, adjacent to restoration) which cannot be treated using laser irradiation. Despite these limitations, the use of CO2 laser treatment alone or in combination with remenralization agents seems to be beneficial when applied clinically using the described laser settings, so additional research should be undertaken to utiliz other lasers and more suitable dental hard tissue.

Conflict of interest: None

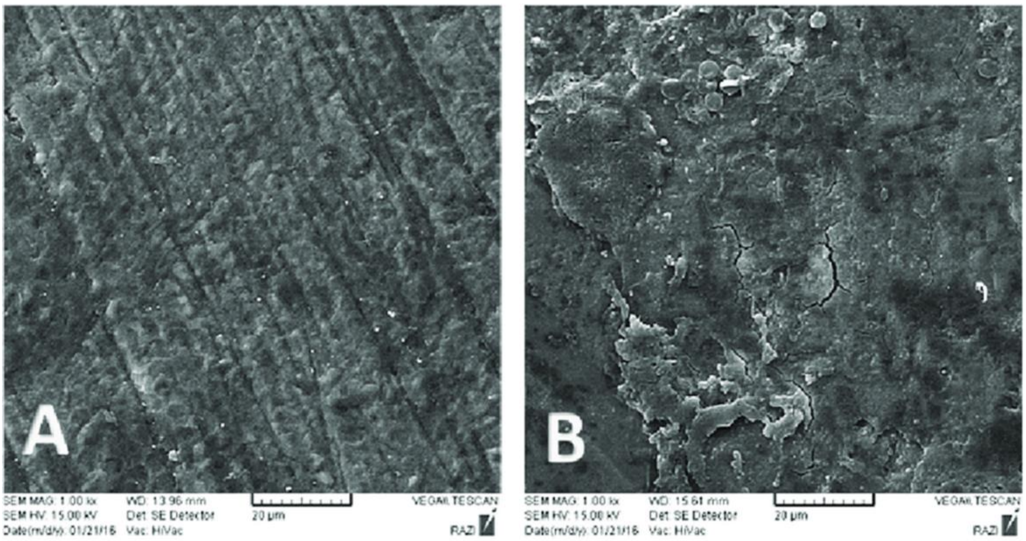

Figure: 1. SEM images of the samples in A: enamel surface treated with TiF4 followed by CO2 laser (a glaze-like layer on the surface was visible), B: enamel surface treated with CO2 laser followed by TiF4 (some micro-cracks on the surface were exposed, without the glaze-like layer)[22]

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