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Study of topical fluoride combined with semiconductor laser for the prevention of dental enamel caries

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Abstract: *The prevention of dental caries is one of the main goals of modern dentistry. Other major goals include remineralization of caries, rather than the traditional "drill and fill". Remineralization is a restorative process that restores minerals and occurs daily through the presence of calcium, phosphate and fluoride in the saliva. Enamel demineralization occurs when acids produced by bacteria attack the enamel. A dynamic balance between enamel demineralization and remineralization is maintained under normal conditions, and disruption of this balance leads to progression of the lesion and eventually to cavitation formation. Fluoride plays an important role in enhancing remineralization. Topical application of fluoride is one of the most effective ways to stop or prevent dental caries. Fluoride ions can replace the hydroxyl group in hydroxyapatite, which leads to the formation of fluorapatite. The solubility of fluorapatite in acid is lower than that of hydroxyapatite. The effect of laser irradiation on the prevention of dental caries has been reported by numerous scholars. Studies have shown that when fluoride, calcium or phosphorus ions are present, laser irradiation can effectively enhance the acid resistance of tooth enamel by altering its chemical or morphological structure and promoting the remineralization process. Laser combined with fluoride has good effect and easy operation compared with other methods for caries prevention, and this paper will review the research on laser combined with fluoride in caries prevention in recent years.*

Keywords: *Caries; Laser; Fluoride; Mineralization*

1. Progress in the application of fluoride for caries prevention

At present, the drugs that can enhance the caries resistance of dental hard tissues are mainly fluoride, which is also the more widely used anti-caries method in clinical practice today. Fluoride plays an important role in enhancing remineralization [1]. Topical application of fluoride is one of the most effective methods to stop or prevent dental caries. Fluoride ions can replace the hydroxyl group in hydroxyapatite, which leads to the formation of fluorapatite. Since fluorapatite is less soluble in acid than hydroxyapatite, it is more resistant to subsequent desalination under acid challenge [2]. Topical fluoride treatment is a convenient and effective method of caries prevention. It can affect the mineral phase as well as cariogenic bacteria [3]. Fluoride ions readily replace the hydroxyl groups in hydroxyapatite microcrystals, which makes them more resistant to acid dissolution. The dynamic process of demineralization and remineralization determines the progression of dental caries. It contributes to the reprecipitation of minerals in carious lesions. In addition, fluoride inhibits bacterial growth, affects its metabolism and weakens its ability to produce acid [4].

A large number of topical fluorides, such as sodium fluoride, acidified fluoride phosphate and silver diamine fluoride (SDF), are available for clinical use. Among the fluoride products available for clinical use, 38% SDF solution has the highest fluoride concentration of 44,800 ppm [5]. Therefore, more and more dentists are using 38% SDF solution because the caries prevention effect is positively correlated with the fluoride concentration. In addition, 38% SDF solution contains 25% silver ions (254,000 ppm). Silver ions have an antibacterial effect and inhibit the growth of cariogenic bacteria and biofilm formation. Topical fluoride is widely used in dentistry for caries prevention because it reduces demineralization and promotes remineralization of tooth surfaces. sdf is one of these topical fluorides [6]. It is considered to be a non-invasive, cost-effective and efficient medical device that can be applied to both primary and permanent dentition. Recent systematic evaluations have shown that SDF is effective in preventing and arresting root caries in the elderly and has been shown to be effective in preventing dentin caries in children [7]. The silver ions released by SDF inhibit the growth of caries-causing bacteria in the planktonic and biofilm growth stages. In laboratory models, SDF has been shown to have strong antibacterial properties against single, dual and multi-species cariogenic biofilms [8-9].

2. Progress of laser anti-caries application

The effect of laser irradiation on the prevention of dental caries has been reported since 1965. It has been shown that laser irradiation can effectively enhance the acid resistance of tooth enamel by altering its chemical or morphological structure and promoting the remineralization process when fluoride, calcium or phosphorus ions are present [10]. The most common lasers used to prevent enamel caries are argon ion lasers; er, Cr:YSGG lasers; er: YAG lasers; Nd:YAG lasers; carbon dioxide lasers; and semiconductor lasers. Carbon dioxide lasers have the highest absorption coefficient in hydroxyapatite of all dental lasers, with an absorption rate 1000 times higher than that of semiconductor lasers [11]. Therefore, absorption is limited to enamel surfaces of a few microns where temperatures may exceed 1000°C [12].

Heating the enamel can induce chemical changes in the enamel and enhance its resistance to caries. However, photothermal interactions are usually accompanied by unfavorable morphological changes to the enamel surface, such as cracks [13]. This may be a limitation of the CO_2 laser in clinical applications. Compared to CO_2 lasers, semiconductor lasers have a much lower absorption coefficient in hydroxyapatite. As a result, the surface temperature is much lower and the rest of the energy is scattered as heat [14]. The semiconductor laser irradiation has an anti-carious effect on the enamel and does not damage the integrity of the enamel surface. In addition, semiconductor lasers are small, portable, easy to apply and reasonably priced. All these advantages make it the first choice for caries prevention [15].

Traditionally, semiconductor lasers available for dental applications emit wavelengths in the range of 800 to 1064 nm. Recently, 445 nm semiconductor lasers emitting blue light in the visible spectrum have been commercially available in the dental market [16]. 445 nm semiconductor lasers are absorbed by pigmented tissues and collagen up to 10 times more than conventional infrared semiconductor lasers [17]. However, its absorption characteristics in dental hard tissues are not fundamentally different from those of conventional infrared semiconductor lasers [18]. Most research on semiconductor lasers has focused on soft tissue interactions and microbial reduction. However, there is a limited amount of literature examining the effects of semiconductor lasers on dental hard tissues.

Studies have shown that semiconductor laser irradiation increases fluoride uptake in human tooth enamel. Currently, several studies have investigated whether the use of semiconductor lasers alone or the simultaneous application of different fluoride products can increase the resistance of tooth enamel to acid attack or increase the remineralization effect of fluoride [19]. There is no general consensus on whether semiconductor lasers can facilitate the effect of topical fluoride applications on caries remineralization and caries prevention, as the results and quality of these studies vary.

3. Topical fluoride combined with semiconductor laser for prevention of enamel caries

Studies have shown that semiconductor laser irradiation can increase fluoride uptake in human tooth enamel [20]. Currently, several studies have investigated whether the use of a semiconductor laser alone or the simultaneous application of different fluoride products can increase the resistance of tooth enamel to acid attack or increase the remineralization effect of fluoride [21]. There is no general consensus on whether semiconductor lasers can promote the effect of topical fluoride applications on caries remineralization and caries prevention, as the results and quality of these studies vary. Therefore, we performed a systematic analysis of all published studies in the literature to provide preliminary but general evidence for clinicians and researchers [22].

Al-Maliky [23] et al performed the study by means of a semiconductor laser with a wavelength of 445 nm (parameters are Output power is 0.3W, Pulse duration is CW, Pulse energy is 18J, Frequency is CW, Average power is 0.3W, Spot Irradiation mode. Spot size is 3.2mm, Spot area is 0.2 cm2, Fluence is 90J/cm2) combined with Amine fluoride solution (10,000 ppm) to observe the caries resistance of tooth enamel. It was found that laser irradiation followed by topical fluoride could better prevent enamel demineralization. Moghadam [24] et al. showed that the caries resistance of tooth enamel by a semiconductor laser with a wavelength of 810 nm (parameters are Output power is 2W, Pulse duration is CW, Pulse energy is 80/160J, Frequency is CW, Average power is 2W, Motion Irradiation mode, Spot

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size is NA, Spot area is NA, Fluence is 444.5J/cm2) in combination with Sodium fluoride varnish (22,600 ppm) to observe the caries resistance of tooth enamel. It was found that laser irradiation followed by topical fluoride could better prevent enamel demineralization. yu [25] et al used a semiconductor laser with a wavelength of 830 nm (parameters are Output power is 2W, Pulse duration is CW, Pulse energy is 60J, Frequency is CW, Average power is 2W, Motion Irradiation mode, Spot size is NA, Spot area is NA, Fluence is NA) in combination with silver diamine fluoride solution (44,800 ppm) to observe the caries resistance of tooth enamel. It was found that laser irradiation followed by topical fluoride could better prevent enamel demineralization. Shetty [26] et al. used a semiconductor laser with a wavelength of 910 nm (parameters are Output power is NA, Pulse duration is 30ms, Pulse energy is NA, Frequency is 15 Hz, Average power is NA, NA Irradiation mode, Spot size is NA, Spot area is NA, Fluence is NA) combined with Sodium fluoride with tricalcium phosphate (22,600 ppm) to observe the caries resistance of tooth enamel. It was found that laser irradiation followed by topical fluoride could better prevent enamel demineralization.Kato [27] et al used a semiconductor laser with a wavelength of 960 nm (parameters are output power is 6.5W, Pulse duration is 5ms, Pulse energy is 0.01625J, Frequency is 10Hz, Average power is 1.6W, Average power is 1.6W, Average power is 1.6W, Average power is 0.01625J. Average power is 1.6W, NA Irradiation mode, Spot size is NA, Spot area is NA, Fluence is NA) in combination with Acidulated phosphate fluoride gel (12,300 ppm) to observe the caries resistance of tooth enamel. It was found that laser irradiation followed by topical application of fluoride could better prevent enamel demineralization.Moharam et al. is 2W, NA Irradiation mode, Spot size is NA, Spot area is NA, Fluence is NA) combined with Sodium fluoride mousse (1450 ppm) to observe the caries resistance of tooth enamel. It was found that laser irradiation followed by topical fluoride could better prevent enamel demineralization.Chand [28]et al used a 980 nm wavelength semiconductor laser (parameters are Output power is 5 W, Pulse duration is NA, Pulse energy is NA, Frequency is 16 Hz, Average power is NA, NA Irradiation mode, Spot size is NA, Spot area is NA, Fluence is 53 J/cm2) in combination with Acidulated phosphate fluoride gel (concentration not mentioned) to observe the caries resistance of tooth enamel. The results showed that laser irradiation followed by topical application of fluoride gel. It was found that laser irradiation followed by topical fluoride could better prevent enamel demineralization. Bahrololoomi [29] et al used a 980 nm wavelength semiconductor laser (pulse duration is 30 ms, pulse energy is 150 J, frequency is 15 Hz, output power is 5 W, average power is NA, NA Irradiation is NA, average power is NA, average power is NA, NA Irradiation is NA. Average power is NA, NA Irradiation mode, Spot size is NA, Spot area is NA, Fluence is NA) combined with Sodium fluoride (900 ppm) with casein phosphopeptide -Amorphous calcium phosphate paste was used to observe the caries resistance of tooth enamel. It was found that laser irradiation followed by topical fluoride could better prevent enamel demineralization. (CW, continuous wave; NA, not available.)

4. Discussion and Prospect

Laser treatment can inhibit demineralization, while the laser itself does not enhance remineralization [30]. However, laser used in adjunct to conventional fluoride treatment appears to have promising results in remineralization of tooth structure. No statistical difference was found between the combination of topical fluoride and semiconductor laser treatment and topical fluoride only in the prevention of artificial caries. Most of the studies reviewed in this systematic review were based on the near-infrared spectral band (810-980 nm), with only two studies using the 445 nm wavelength [31]. Note that this study only found an additional effect of the combined use of a semiconductor laser and fluoride on remineralized enamel caries at infrared wavelengths [32].

Many factors may contribute to this result. On the one hand, the parameters of the laser will greatly influence its effect, but most studies do not mention pilot studies on the process of selecting and determining the optimal parameters. In addition, differences in the sensitivity of various investigation methods may contribute to the results [33]. In addition, small sample sizes lead to less reliable results with lower precision and efficacy. In addition, the type and use of fluoride can affect the results. It was found that increasing the concentration of fluoride improved its effectiveness in preventing or remineralizing dental caries. In addition, some fluoride products contain non-fluoride remineralizing agents [34].

For example, CPP-ACP may have some interaction effects with semiconductor laser irradiation. A study reported that the combined use of Er, Cr: YSGG laser and CPP-ACP topical application was superior to Er, Cr: YSGG laser alone in preventing enamel demineralization. Beyond that, it remains unknown whether the order in which the F&L is used affects their combined effect, and further studies are needed [35]. The laser beam parameters were not fully described in most of the studies, which may be a major limitation of this study. Without spot size, it is not possible to estimate the power density, which has a direct effect on the tissue (not only the output power). Without this feature, it is not possible to

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compare certain laser parameters.

In addition, more than half of the studies did not provide sufficient and accurate information about the irradiation technique. The irradiation time in spot mode or the velocity in motion mode determines the total energy that the enamel surface will receive. It is important for researchers to document and provide correct and complete information on the parameters and techniques of the lasers used in the studies to inform future studies [36].

The in vitro evaluation of demineralization-remineralization can be performed by different methods. In the included studies, surface microhardness testing, polarized light microscopy, microscopic histological assessment and calcium release measurements were used to determine demineralization-remineralization. They are all indirect assessments of demineralization-remineralization. Methodological differences contribute significantly to the substantial heterogeneity between these studies. The Vickers microhardness test is a simple, non-destructive and rapid method for assessing the structure of tooth enamel. It is suitable for assessing fine microstructures. However, it does not provide the correct details of the hardness changes occurring beneath the enamel surface [37].

Polarized light microscopy is a descriptive analytical technique used to assess histological changes in dental caries. However, polarized light microscopy for histological assessment of samples shows a lower sensitivity for assessing LD compared to microscopic examination. Furthermore, for polarized light microscopy, the thickness of the enamel should be at least 260μm due to the cracks generated by the machine vacuum. Therefore, the magnification is limited to a maximum of 16 ×. The details of the magnification limitation can be observed. In addition, the thickness of the sample affects the light scattering.

The thicker the sample, the lighter the scattering. However, the thickness of the sample preparation required for histological evaluation by microscopy is only 90μm, which provides high magnification up to 400 ×. Thus, histological evaluation by microscopy can better avoid false-positive measurements of LD.34 In addition to understanding changes in the physical parameters of the mineral, demineralization measurements can also be evaluated from the perspective of chemical elemental changes by measuring calcium ions released from acid solutions.

The mineralization of constant enamel is greater than that of native enamel. The diffusion coefficient of constant enamel is also greater than that of primary enamel. The two articles included in the study featured primary enamel. In addition, as an alternative to enamel caries studies, bovine enamel has a chemical composition and physicochemical properties similar to those of human enamel. Therefore, their demineralization and remineralization characteristics are similar. However, a higher porosity was observed in bovine enamel. Thus, bovine enamel forms lesions more rapidly than human enamel. It can be hypothesized that the variance of enamel origin largely influences the heterogeneity of the results. Studies involving human teeth could serve as a basis for possible future therapeutic implications. In addition, the parameters of the laser and its irradiation technique varied among the included studies, which is one of the important reasons for the significant heterogeneity [38].

Laboratory studies have been used as alternative evidence for the selection of larger treatment strategies because of the correlation between the amount of laboratory demineralization and the clinical outcome of dental caries. However, laboratory studies have some limitations because the in vitro conditions are far from the real oral environment. In addition, nearly half of the included studies showed a high risk of bias. The results of this study should be interpreted with caution. Scientific evidence for combining F&L for remineralization and prevention of enamel caries is still lacking. Well-designed clinical trials are needed to help reach a consensus on whether the combination of F&L can enhance the preventive and remineralizing effects on enamel caries.

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