Original Article

The Effects of Q-switched Nd:YAG Laser Irradiation on Demineralization in Early Enamel Caries Lesions

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Introduction

Dental caries is a dynamic process characterized by alternations of de- and remineralization. Caries prevention is, therefore, fundamentally achieved when the positive mineral balance exceeds the rate of demineralization over an extended period. In this phase, physicochemical properties of tooth surfaces and subsurface regions are important factors to define susceptibility and resistance to caries.

Recently, laser has been introduced as a new technology for dental treatments and some types of laser, e.g. CO₂ and Nd: YAG lasers, were suggested to reveal caries preventive effects for intact enamel by improving its acid resistance. Our previous studies also indicated that irradiation of second harmonic wave of Q-switched Nd : YAG laser significantly reduced Ca dissolution rate of human enamel in vitro.

The acid resistance of enamel surfaces has generally been assessed by a Ca dissolution rate. From viewpoint of cariology, however, one drawback of the Ca dissolution test is that an acid etching procedure usually employed does not simulate caries attack but erosion of enamel. In addition, it should be noted that caries prevention is essential rather for the most caries susceptible regions in enamel where surfaces are frequently demineralized by dental plaque. In this sense, recovery or arrest of incipient caries with subsurface lesions is primary clinically.

The aim of this study was to assess microradiographically whether irradiation of Q-switched Nd: YAG laser protects demineralized enamel from lesion formation under presence of dental plaque in situ and a caries simulation system using a viscous acidic gel which is known to produce caries-like lesions successfully by acting as dental plaque.

Materials and Methods

1. Sample preparation

Sound human premolars extracted from patients aged 11-14 years old (mean 11.7 years old) for orthodontic reasons were used. After removal of the roots, enamel blocks were cut from buccal or lingual side of the crowns using a water-cooled diamond-coated saw. The blocks were completely coated with an impression compound (Pericompound, Shofu, Japan) except for the original enamel surfaces. Subsequently, the enamel surfaces were slightly abraded to expose fresh enamel surfaces of about 15 mm² on a wet abrasive paper (grit 800). The samples were divided into 2 treatment groups; 24 samples for in vitro evaluation and 32 samples for assessment in situ. In the in situ group, an U-shaped groove (about 300 µm in width and about 500 µm in depth) was formed at the central part using a water-cooled blade (Isomet, Buehler, U.S.A.) to simulate a fissure structure and to enhance dental plaque accumulation. Subsequently, all the enamel samples were immersed in a 0.1M lactic acid gel (pH 4.5) containing 1wt% carboxymethylcellulose (CMC) at 37°C for 12h to produce artificial early caries lesions.

2. Laser irradiation

The second harmonic wave of a Q-switched Nd : YAG laser (Quanta-Ray DCR-3, Spectra-Physics, U.S.A.) with a wavelength of 532 nm was used in this study. Enamel surfaces of 18 samples in in vitro group and 16 samples in in situ group were painted with a black India ink and lased at a fluency of 1 J/pulse/cm² and a...
frequency of 10Hz for 10 s (100 shots) resulting in the total energy dose of 100 J/cm². This condition was employed because of ability to add acid resistance to enamel in vitro. The laser beam was guided by a quartz prism and projected vertically to the enamel target plane. The beam intensities were measured using a power meter (30A-P, Ophir Optics, Israel). The residual samples were used as unlased controls in each assessment.

3. **In vitro experiment**

Lased (n=12) and unlased controls (n=12) were again immersed in a 0.1M lactic acid gel containing 6 wt% CMC (pH=5) at 37°C for 3 w. The gel volume was always 100 ml per 6 samples.

4. **Intraoral experiment**

Sixteen adults aged 21-28 y (mean±SD=23.2±3.6, 8 males and 8 females) participated in the intraoral experiments. It was confirmed that they were free from xerostomia and chronic diseases under medication. The lased and unlased samples (n=16, each) were attached on the sound buccal surfaces of right and left maxillary first molars respectively using a non-fluoridated light-cured resin for 1 month. During the experimental period, the samples were kept from brushing to accumulate dental plaque in the grooves and the participants used non-fluoridated toothpaste to brush the other teeth. In addition, any fluoride agents were not applied, but diet was not controlled peculiarly to maintain natural caries susceptibility of each individual.

5. **Microradiography**

After the in vitro or intraoral experiments, a thin planoparallel sections of about 80 µm thickness were cut transversally from the central part of the sample. Each section was microradiographed together with a reference aluminium step wedge (30µm×10 steps) under a standardized condition. For theoretical background of the transversal microradiography (TMR), we refer to de Josselin de Jong, et al. As shown in Fig. 1, a mineral profile was computed from the videodensitometric data and the two mineral parameters of interest, namely the lesion depth \( l_d \) (µm) and the mineral loss value \( \Delta Z \) (vol%·µm) were measured.

**Results**

The histogram of the \( l_d \) and \( \Delta Z \) values were represented in Figs. 2a and 2b. The \( l_d \) values of the unlased control and lased samples were 104±38 and 82±34 µm (mean±SD), respectively from in vitro experiment, and 41±18 and 34±24 µm from in situ study. The \( \Delta Z \) values were 4,256±1,142 and 4,077±1,904 vol%·µm (in vitro) and 1,769±1,031 and 1,684±1,171 vol%·µm (in situ), accordingly. Although the lased group showed 21% lower \( l_d \) value compared with the unlased samples in vitro, no statistically significant difference was detected between unlased and lased samples for each mineral parameter (paired t-test) both in in vitro and in situ cases. In microradiographic images, no visual evidence of remineralization was observed for all the samples.
Discussion

In contrast to the results from Ca dissolution test, the same dose of Q-switched Nd: YAG laser irradiation failed to protect the underlying enamel lesions from further demineralization by caries challenge both in situ and in vitro. The disparity between our previous and present results indicates that the lased enamel surface is acid resistant but is not an effective barrier to inhibit penetration of hydrogen ions into a lesion body. To this point, Kinney et al. demonstrated a remarkable lesion progression in lased dentin when an acidic gel was applied as a caries attack. 

Integrating our studies on the Q-switched Nd: YAG laser, it is implied that the acid resistance of enamel surfaces determined by the Ca dissolution test does not always stand for clinical caries inhibition of underlying enamel. Thus, it should be attentive that acid resistance and caries resistance are not similar concepts fundamentally. Therefore, a reasonable illustration of lased enamel (or lesions) could be a mineralized tissue coated with a penetrable acid resistant layer.

The increased acid resistance of enamel surfaces by laser irradiation has been explained from presence of a fused (or melted) layer formed by the thermal effects of lasers. On the other hand, thermal effects of laser irradiation and subsequent cooling produce microcracks in enamel surfaces and this may be responsible for enhanced permeability of outer ions resulting in progressed subsurface demineralization. Moreover, it was revealed that laser irradiation at a dose of about 100 J/cm² alters only the outermost enamel surfaces up to 1-5 μm at most by electron microscopic investigations or within 100 nm in depth from crystallographical study. The fact that laser irradiation decreases water, carbonate and organic components from enamel sizably may attenuate its structure and rather contribute to enhance caries susceptibility.

Although these findings were assured mainly in lased sound enamel, such changes might be heightened in enamel lesions resulting in enhancement of ion permeability and progression of demineralization in underlying enamel. As observed in our previous SEM study, there is also a possibility that the second harmonic wave of the Q-switched Nd: YAG laser influences demineralized enamel destructively because of its greater amplitude of vibration. Recent TEM study on the Nd: YAG laser appended a new evidence that lased demineralized enamel showed a significantly inferior crystallinity in outermost layers up to 50-60 nm in depth compared with underlying areas.

The loss of organic components can be interpreted from another view point. Diffusion of Ca ions dissolved from subsurface enamel may...
be trapped in microscopic voids created by such morphological changes. But, it would be reasonable to consider that this alternation can conversely augment outer hydrogen ions to penetrate faster into subsurface enamel due to differences in elemental diffusion rates. The other is that such component damages may be capable of promoting remineralization by increased enamel permeability. However, our study suggested that irradiation of Nd: YAG laser had neither promotive nor inhibitory effects on subsequent remineralization of enamel lesions in vitro. Therefore, it is adequate to understand that subsurface demineralization of enamel can be rather stimulated by projection of Nd: YAG laser even if outermost enamel surfaces obtain acid resistance in part.

Relating to experimental methods, it should be noted that caries prevention is not achieved by a single factor related to a physical property of enamel. Actual caries formation or arrest is regulated by dynamic interaction between enamel and oral environment such as diet, dental plaque and saliva. Therefore, an intraoral experiment should be encouraged to examine whether a laser therapy can prevent dental caries effectively.

Conclusions

In conclusion, it was suggested that irradiation of the second harmonic wave of Q-switched Nd: YAG laser to the surface of incipient enamel lesion may not contribute to protection of its subsurface demineralization. Since caries inhibitory effects of laser irradiation are still needed to be examined from view point of cariology, further intraoral evaluation should be required to establish optimized laser treatments for practical caries prevention.

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References

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