In vitro Investigation of the Harmful Effects of Smoke Plume Produced by Pulsed Nd:YAG Laser Treatment

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Ⅰ. Introduction

The clinical use of lasers is becoming more common in the practice of dentistry. Since the Food and Drug Administration(FDA)[1] approved laser therapy for use on human soft tissue, researches have been continued on the applicability of lasers on dental hard tissues. The advantages[2] of laser surgery are low complication rate, little blood loss, good operative fields, markedly reduced postoperative discomfort and recovery periods, and reduced bacteremia[3].

Lasers have been successfully used to destroy microorganisms for its bactericidal effect[4]. Although increasing use of the lasers in dentistry for soft and hard tissue therapy, there is potential transmission of viable viruses and bacteria via the smoke plume produced by lasing. There is evidence that dangerous materials may be disseminated via the laser smoke plume when the lasers are used on contaminated tissues. Baggish and his coworker[5,6] were the first to study the effects of carbon dioxide laser plume on the lungs of rats. They found congestive interstitial pneumonia, bronchiolitis and emphysema in rat lungs exposed to CO_2 laser smoke plume inhalation. Other researchers found melanoma cell[7]in the smoke plume from neodymium laser application, and infectious papillomavirus from CO_2 laser-generated plumes of bovine warts[8], and infectious human immunodeficiency virus (HIV)[9] in plume debris from concentrated HIV-infected tissue culture pellets, and viable bacteriophage in agar particles produced by CO_2 laser ablation of $\varphi \times 174$ suspend[10].

The purpose of this study was to perform an in vitro investigation of the harmful effects of smoke plume produced by pulsed Nd:YAG (neodymium yttrium-aluminum-garnet) laser applying to infectious substrates containing

viable bacteria.

Ⅱ. Materials and Methods

Ten *Escherichia coli* (*E. coli*, ATCC 2287 strain) cultured Brain Heart Infusion (BHI, BACTO®) agar plates and ten *E. coli* cultured suspension were prepared for this experiment. *E. coli* were used because they are facultative anaerobes[11], which can survive in aerobic or anaerobic conditions. Smoke plume was sucked at 5 cm distance from the tip of pulsed Nd : YAG laser (SUNRISE TECHNOLOGY CO., USA) by evacuator.

The experiment was performed in two subjects of in vitro soft tissue lesion and in vitro root apical lesion.

1. In vitro soft tissue lesion

1) *E. coli* culture

BHI 18.5g in distilled water 50ml and added 15% of agar for solidification was autoclaved for 15 minutes. After cooling it was poured in 10 petri dishes, and *E. coli* were streaked into BHI agar in condition of solidified state. After 12 hours incubation, they were used as experimental material. The colony of *E. coli* were observed in all agar plates.

2) Lasing of pulsed Nd:YAG laser

Nd:YAG laser was applied to *E. coli* cultured BHI under condition of 2.0 W, 20 Hz lased for a minute with contact mode under by using 200 μm fiber optics. During lasing, laser fiber optic was moved continually and circularly for all parts of agar plates.

3) Collection of smoke plume and its culture

Evacuator(HANSHIN MEDICAL Co., Suction Unit H-500®) was used under condition of pressure set for 10 cmHg during foot switch-on. Suction tip was joined with evacuator tip connected to Micro-syringe 25mm filter holder (Millipore, Millipore Corporation, Bedford, MA 01730) by using rubber tube. During lasing, smoke plume was filtrated through Millipore(Millipore®, Millipore corporation, 0.22 μm, GS type) inserted into filter holder(Fig. 1). Filter holder and Millipore were autoclaved against possible contamination. Smoke plume was sucked through 1 cc disposable syringe without a needle tip. Millipore was taken out immediately after lasing, it was poured onto new BHI agar plate, and it was cultured at 37 ℃ for 12 hours in incubator. The cultured colony of bacteria was identified as same strain of *E. coli* which had been used at the biginning of experiment.

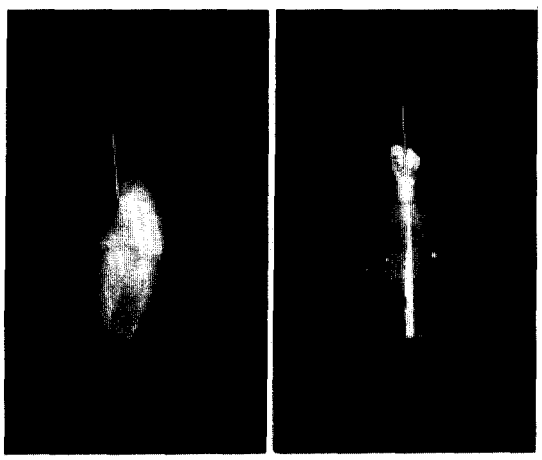
Fig. 1. Laser smoke plume collection devices

2. In vitro root apical lesion

1) Tooth preparation

Chamber opening was performed in ten single rooted teeth by using # 4 round bur, and then conventional root canal preparation was performed upto #45 by using H file. Thereafter the wax of 5mm diameter was attached around

root apex(Fig. 2a), and the tooth was invested 1mm below cemento-enamel junction with orthodontic resin(Fig 2b). It was cured in the air, also the tooth was soaked in 70% alcohol for sterilization for 24 hours and the invested orthodontic resin was put into boiling water for 20 minutes, and wax was removed.



(a) (b)

Fig. 2. Tooth preparation for lasing a) wax attached space for *E. coli* cultured suspension, b) resin build around the lased tooth

2) *E. coli* culture

BHI 18.5g was added to distilled water 50 ml, and it was autoclaved for 15 minutes. After cooling *E. coli* were inoculated and thereafter incubated for 12 hours. The cultured colony of *E. coli* were observed in all test tubes.

3) Lasing of pulsed Nd:YAG laser

Nd:YAG laser was applied to apices of ten teeth under 1 mm shorter than already measured working length by using radiological technique. Immediately after insertion of the 1 μl of *E. coli* suspension in the space which was occupied by the wax. Pulsed Nd : YAG laser was applied in 2.0 W, 20 Hz. The lasing was performed in sweep motion 5 times to inside wall of root canal devided into 5 parts. Lasing time was not exceeded 5 seconds per each wall.

4) Collection of smoke plume and its culture

Smoke plume was evacuated in the same method as the above at 5 cm distance from all teeth opening. Immediately after removal of Millipore from filter holder and it was cultured. And then filter was moved into BHI agar at 37 ℃ incubator for 12 hours in incubator. The cultured colony of bacteria was identified as same strain of *E. coli* which had been used at the biginning of experiment.

III. Results

All of the agar plates showed positive growth of bacteria(Fig. 3). The bacteria found on the plates were identified as *E. coli* which were inoculated into petri dish and root apex.

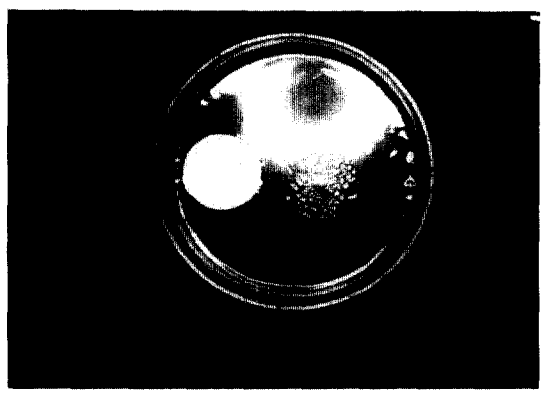


Fig. 3. Agar plates showed positive growth of *E. coli*.

Ⅳ. Discussion

"Laser" is an acronym for "light amplification by stimulated emission of radiation". Laser light is monochromatic, coherent and colliminated[12]. When laser energy strikes tissue, it may be absorbed, transmitted, scattered or reflected[13]. Absorbed laser energy vaporizes and carbonize tissue most effectively. Since development in 1962[14], lasers have been studied for use in dentistry. The Nd:YAG laser was introduced to dental surgery in 1983[15]. The Nd:YAG laser developed in 1963 by L. F. Johnson, an invisible, near-infrared light source and has a wavelength of 1064 nm and laser beam can be delivered through a fiber optic system, usually pulsed mode.

The Nd:YAG laser has received FDA approaval only for use on soft tissue. Since 1987, researchers have evaluated the Nd:YAG for use on mineralized tissue. Although not ADA or FDA approved, Nd:YAG lasers have also been used to vaporize carious tissue, to cut dentin, to sterilize tooth surfaces, to treat dentin hypersensitivity, to remove extrinsic stains, to seal pit and fissure with sealant, and to treat root canal.

Most experienced laser physicians use a smoke evacuator pump during laser treatment to clear the operative field and eliminate odors. The specifications for this type, substantial negative pressure, and efficient filtration system to absorb and collect particulate matter. Although some early laser physicians used operating room wall suction, this proved to be a costly error because without an adequate filter, the suction mechanism clogged up with particulate matter and was eventually rendered ineffective. High efficiency, particulate air filters are essential in smoke evacuation since they have a 99.97% efficiency[16] in capturing particles of 0.3 μm and larger. The filtered airstream is recirculated back to the operating room through a vent at the rear or bottom of the evacuator housing.

From this conception, the smoke plume produced by laser interaction with tissue has been recognized as potentially hazardous. The hazards of the plume fall into two categories : biological and chemical.

Baggish et al.[5] showed the first clinical study of pulmonary pathology increased proportionately with the duration of CO_2 laser plume. These authors concluded that the fine particulate matter contained in the laser vapor appeared to play a key role in the development of congestive interstitial pneumonia. In a follow-up study[17], routed plume through a smoke evacuator before connection to a rat chamber. One phase routed the plume through a single filter while a second phase utilized a cartridge filter plus an ultra low penetration air filter. Phase 1 showed pathology similar to, but less severe than unfiltered plume. No pulmonary pathology was observed in this latter group. Recommendations based on these data included the use of a two filtration system in addition to placement of an evacuation tube within inches of the laser site.

Lobraico et al.[18] attempting to identify the possible risks of laser plume with respect to human papilloma virus(HPV). In response to results of a questionnaire, these authors concluded that an association existed between the use of the CO_2 laser for treatment of verrucous lesions and the development of such lesions by physicians administering the treatment. Garden et al.[8] demonstrated that intact viral DNA can be recovered over a wide range of CO_2 laser parameters in both the in vitro and the in vivo settings.

But, Allan et al.[19] reported contrary result

on above. They showed that HPV DNA cannot be detected in the smoke plume from vaporization of laryngeal papillomas unless direct suction contact is made with the tissue during surgery. Recent studies documented the ability of lasers to disperse viable bacteriophage as well as to isolate viral DNA in laser smoke.

In dental literature, Black McKinley et al.[20] showed that laser smoke plume does present a hazard of bacterial dissemination and that precautions must be taken to protect against spreading infections in using lasers to the root canal.

The agar gel in which the target bacteria are suspended has high water concentration. Particles harboring viable bacteria which are produced during the explosive, initial phase of the laser exposure contain extremely high water concentration. In fact, it is depending on the relative humidity and temperature of the environment that the particles may decreased.

In this study, viable bacteria was detected in smoke plume produced by using pulsed Nd:YAG laser. It is apparent from this study that regardless of wide variations in power density, pulse duration and laser types, laser generated-smoke plume is harmful to a person who inhales the smoke plume. This study strongly supports the use of an efficient smoke evacuator to protect patients and operating room personnel from the harmful effects of any type of smoke plume that may be generated in an operating room setting. It would also seem to be true that the laser could produce contaminated environments with laser generated-smoke plume produced by the application of laser to any soft and hard tissue.

V. Conclusion

To evaluate, in vitro, the harmful effects of laser generated-smoke plume, the author applied Nd:YAG laser to the *E. coli* cultured agar substrate as a soft tissue lesion model and to *E. coli* cultured suspension in arbitrary designed root apical lesion.

The obtained results were as follows :

1. *E. coli* were identified in smoke plume produced by application of pulsed Nd : YAG laser to a *E. coli* cultured agar substrate and to arbitrary designed *E. coli* cultured suspension in root apical lesions.

2. The efficient evacuation of laser smoke plume is recommended to protect patients and operating room personnel from the harmful effects of smoke plume produced by application of pulsed Nd:YAG laser to infected lesions.

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국문초록

Pulsed Nd : YAG 레이저조사시 발생되는 연기의 유해효과에 관한 실험실적 연구

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레이저가 의학영역에서 사용된 후 구강내 연조직과 경조직 병소에 대한 임상적 적용에 관한 관심이 커져왔다. 레이저가 조사되는 부위에서는 대부분 연기가 발생한다. 이 경우 병원체가 존재하는 병소에 대한 레이저치료시 발생되는 연기속에 병원체가 포함되어 있다면 환자와 술자는 이의 흡입가능성이 크므로 균혈증 및 상기도나 호흡계의 의원성 감염이 유발될 수 있다.

저자는 레이저치료시 발생되는 연기속에 병원체가 포함되어 있는지의 여부를 규명하기위해 각각 10개의 실험군에 통기성 미생물인 *Escherichia coli*(*E. coli*)가 배양된 brain heart infusion(BHI) 배지와 *E. coli*가 존재하는 치근단 병소를 실험실적으로 만든 후 각각 pulsed Nd:YAG 레이저를 조사해 연기를 채취, 배양, 분석하여 다음과 같은 결과를 얻었다.

1. Pulsed Nd:YAG 레이저를 *E. coli*가 배양된 agar substrate와 실험실적으로 만들어진 치근단부위의 *E. coli* 현탁액에 조사시 발생된 연기에서 처음 접종된 것과 같은 *E. coli*가 검출되었다.
2. 감염병소에 pulsed Nd:YAG 레이저를 조사시 발생되는 연기의 유해효과로 부터 환자와 술자 및 보조자의 보호를 위해 효과적인 흡입기의 사용이 권장된다.