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The influence of Er. YAG laser application in fenestration to the inner ear

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Abstract

Objective: Erbium (Er.) YAG laser may be usable for middle ear surgery because of its ability to ablate bony tissue. We investigated the inner ear damage caused by the fenestration to the inner ear with Er. YAG laser.
Design: We investigated the influence of Er. YAG laser on the inner ear using electrophysiological technique.
Results: Several cases had a decrease in endocochlear potential (EP) and cochlear microphonics (CM) after the fenestration to the inner ear.
Conclusions: Er. YAG laser is safe if it is used for the small and superficial fenestration to the stapes footplate. However, a few extra pulses after fenestration are dangerous.

Keywords: Er. YAG laser; Fenestration to the inner ear; Inner ear damage

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1. Introduction

Recently several types of lasers with various wavelengths and intensities have been used and established in middle ear surgery. The argon, CO_2, and KTP lasers are more common than the other types of lasers [1,2]. Each type of laser has various advantages and disadvantages. The argon and KTP laser have a high penetration depth in water and a limited energy absorption on white bone and perilymph. For this reason, these lasers have a potential to damage inner ear structures and do not seem to be ideal for middle ear surgery. However, they do have the advantage that they can be easily applied through optical quartz fibers. The CO_2 laser can effectively ablate tissue, but it produces char, requiring manual removal.

In recent years, erbium (Er.) YAG laser has come more and more into focus for middle ear surgery [3]. The major advantages of this laser are its restricted optical penetration depth in water and its ability to ablate a bony tissue. This means a very precise ablation of tissue and bone with minimal damage of underlying and adjacent structures. Therefore, when it is used for fenestration of the stapes footplate in case of otosclerosis, it may provide an attractive advantage over the mechanical drill or the other lasers. But we must consider the inner ear damage caused by fenestration of the inner ear with the lasers. Concerning Er. YAG laser, a number of experiments were performed. Most of them are reports about histological change or a rise in temperature in the inner ear liquid. We examined the influence of Er. YAG laser to the inner ear using electrophysiological technique when it was used for the fenestration to the inner ear.

2. Materials and methods

Albino guinea pigs with body weights of 280–600 g were used. Prior to the start of this experiment, each animal's Preyer's reflex was checked. They were anesthetized with

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Table 1
Group and laser parameter for experimental cochleostomy

Group	Number of pulses (power)	Number of animals
1	2 (17 J/cm^2)	4
2	5 (17 J/cm^2)	7
3	7 ~ 10 (17 J/cm^2)	4
control	30 (85 J/cm^2)	3

Repetition rate, 1 Hz in all groups.

an intraperitoneal injection of pentobarbital sodium (35 mg/kg), kept under artificial respiration (animal ventilator NEMI scientific 131, England) after tracheostomy, and immobilized by muscle relaxants (suxamethonium chloride 15 mg/kg). Their heads were fixed with ear bars in which there is a hall to let the stimulus sound pass through. To avoid hypothermia during anesthesia, the body temperature was maintained at 37 °C with animal blanket (KN-474, Natsume, Japan). Electrocardiogram was monitored through experiments. Experiments were performed in an acoustically and electrically shielded room. The cochlea was exposed by ventral approach. We tried to shoot the laser beam to foot plate for investigation of the effect of stapedotomy, but it was anatomically impossible. Therefore, the basal turn convolution of the cochlea was chosen as the application site for the laser beam to fenestrate into the inner ear, because its thickness is similar to that of the human stapes footplate, and is easily accessible surgically [4]. Consequently, the fenestration to the cochlea was performed into the scala tympani. An Er. YAG laser system (HOYA, Osaka, Japan) and a crystal monofilament fiber with a 0.6 mm diameter were used. A micromanipulator was used to fix the tip of the fiber to the basal turn convolution of the cochlea. The pulse duration was 200 ms, and the repetition rate was 1 Hz. The energy density was 17 J/cm^2.

Details of the experiments were summarized in Table 1. The only bony wall of the cochlea was carved slightly in group 1 (total 2 pulses). The small fenestration of the cochlea was made in group 2 (total 5 pulses). In group 3 (total 7–10 pulses), the fenestration, which was as large as the diameter of the laser beam, was made enough to carry out stapedotomy. Thirty pulses of 85 J/cm^2 were irradiated to the soft tissue near the cochlea in control group. This control experiment was performed to exclude the influence of acoustic trauma caused by noise which occurred with the Er. YAG laser. The repetition rate was 1 pulse/s in any group (Table 2).

Table 2
Case number of EP and CM deterioration by laser irradiation

	EP deterioration	CM deterioration
group 1 (n=4)	0	0
2 (n=7)	0	2
3 (n=4)	2	3
control (n=3)	0	0

EP: endocochlear potential; CM: cochlear microphonics.

The function of the cochlea was evaluated by endocochlear potential (EP) and cochlear microphonics (CM). A glass microelectrode (tip 2–3 μm) filled with 3 mmol/L of potassium chloride was inserted into the scala media of the first cochlear turn through the round window membrane. The electrode was used for measuring EP and CM. A ground electrode was placed on the cervical muscle. The microelectrode was connected to the high impedance dc amplifier (FD-223, WPI, USA) for measuring the EP. The acoustic stimuli used for the measurement of CM was a continuous 1 kHz pure tone, 70 dB sound pressure level (SPL), produced by sound stimulator (SSS-3200, Nihon Kohden, Japan), and attenuated by audio-amplifier (TA-F500, SONY, Japan). The stimulating sound was delivered from an earphone (NC-3, Cortiton, Japan) through the ear bar. The sound pressure level of the pure tone was calibrated by probe microphone (Acoustic calibrator type 4231, Bruel and Kaer, Denmark). Acquired signals were processed in two phases lock-in amplifier (5610B, NF electronic instruments, Japan). EP and CM were recorded into a personal computer with Power Lab (AD Instruments, Japan). We measured the EP and CM before irradiation, and at about 30 min intervals.

3. Results

EP and CM did not change by irradiation in all cases of the control group ($n = 3$) and group 1 ($n = 4$) (Fig. 1). The irradiation of the Er. YAG laser caused the CM amplitude to decrease in two cases of group 2 ($n = 7$), but the EP did not change (Fig. 2). In the two cases, the amplitude of CM was reduced by about 45 and 50%, respectively. In group 3 ($n = 4$), both EP and CM had decreased in two cases (Fig. 3), and the CM had decreased in only one case. The degree of EP reduction was 13% (from 93 to 81 mV) and 21% (from 62 to 49 mV), respectively. The CM was reduced by about 55, 20, and 40%, respectively. We observed the EP and CM about 30 min after irradiation, but their reduction did not recover in any case.

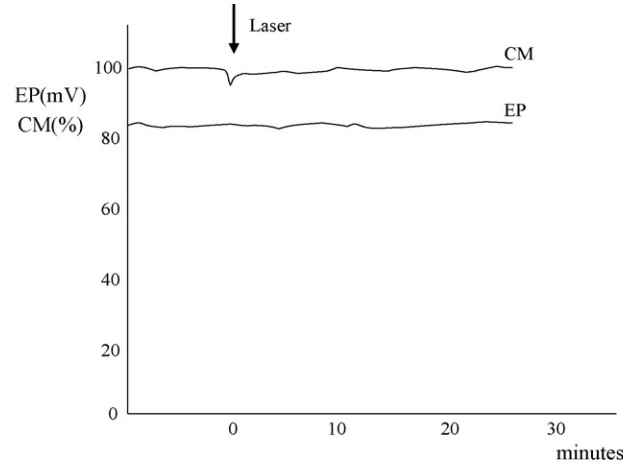

Fig. 1. Typical case (group 1). EP and CM did not change after irradiation.

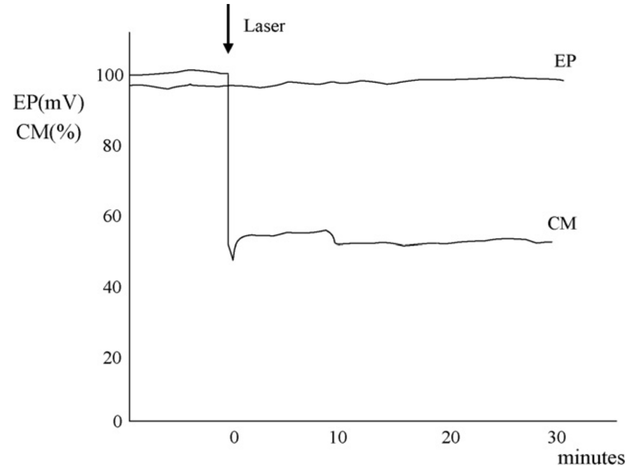

Fig. 2. Typical case (group 2). EP did not change after irradiation. The CM was reduced by about 50%.

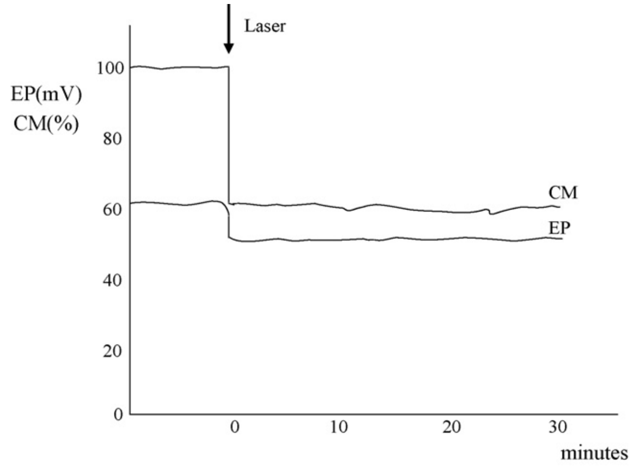

Fig. 3. Typical case (group 3). The CM was reduced by about 40%. The EP decreased from 62 to 49 mV. They did not recover within 30 min at least.

4. Discussion

The purpose of this study was to investigate the safety of the Er. YAG laser for the stapedotomy. In other words, whether the Er. YAG laser damages the inner ear or not. Laser-assisted stapedotomy has the following potential risks using pulsed laser radiation: (1) temperature rise in the cochlea or vestibule due to heat diffusion, (2) damage of organs lying behind the foot plate in the direction of the laser beam by direct irradiation, and (3) the destruction of the sensory hair cells by high intensity acoustic waves irradiated directly into the cochlea and vestibule due to the explosive ablation process [5]. It was confirmed that there was virtually no increase of temperature in the inner ear liquid [6]. Li et al. found a temperature rise of 4 °C in saline 1.5 mm away from the ablation site on a suspended rat femur model [7]. Jovanovic et al. reported a median peak temperature increase of 3.6 °C at 2 mm from the stapes footplate in the acrylic cuvette model. In contrast, the CO_2 laser raised the temperature by 8.8 °C in equivalent conditions [8]. Elevations up to 3.5 °C are regarded as‘‘modest’’ by some investigators [9]. Histological examinations on a perforated stapes footplate with Er. YAG laser pulses of 12 J/cm^2 show a border damage zone restricted to 5–10 μm [10] compared to 100 μm with the argon laser, and to even greater mechanical lesions with the skeeter microdrill [11]. Therefore, we can speculate that the Er. YAG laser does not cause damage by temperature rise or direct irradiation as the other lasers do. But it is known that the Er. YAG laser pulses produce pressure waves as a result of the explosive ablation of tissue. Hausler et al. reported that a particularly dangerous pressure wave was measured on the inner ear model when the stapes footplate was already perforated while the laser evaporated the perilymph liquid, resulting in the creation of a vapour channel. They reported that the pressure amplitude increased linearly with increasing laser fluence, and concluded that the maximum Er. laser power allowed for the use in stapes surgery was 10–17 J/cm^2 [10]. In this study EP and CM decreased in some cases of group 3. In one case the round window membrane was ruptured, so we also speculated that the elevation of pressure in the perilymph liquid may cause inner ear damage.

As a consequence, our consideration was as follows. The use of the Er. YAG laser is safe until the small fenestration of the stapes footplate is performed, but a few more pulses are necessary for the stapedotomy to extend the fenestration. Hence, the inner ear damage may be caused by the increase of the pressure of the perilymph liquid. It is difficult that we relate the danger of the Er. YAG laser to human surgical procedure by only this study. But we must consider the possibility of the inner ear damage when stapedotomy is carried out by the Er. YAG laser. In other words, the Er. YAG laser can be used safely if we do not perform the fenestration to inner ear, and very useful in many middle ear surgeries; for example; Ablation of superstructure of stapes, etc., because the Er. YAG laser can ablate bony structure precisely [12].

5. Conclusion

The Er. YAG laser may cause inner ear damage if it is used for performing stapedotomy. We thought that the cause might be the increase of the pressure of the perilymph liquid by irradiation after the fenestration to the inner ear, but the Er. YAG laser can be used safely except the fenestration to the inner ear.

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