YAG Laser Treatment of Tinea Pedis

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A clinical experiment on the treatment of *tinea pedis* infections (common as an athlete's foot) was conducted using a pulsed Nd-YAG laser with an output energy of 0.5 joule/pulse and pulse duration of 1 millisecond. The experiment was supported by 13 volunteers for skin samples used in this experiment. The treatment was performed with the following irradiation condition; an energy density of 400 joule/cm^2 at a skin sample surface, a spot diameter of the laser beam on the surface of 0.4 mm and a repetition rate of laser pulse shots of 3 Hz. It was shown that the laser treatment was very effective even when a horney layer was thickly cornified by serious *tinea pedis;* about half of the volunteers were healed with a cure rate of about 70% and, among others, two were cured completely.

1. Introduction

In the previous studies on the laser treatment of *tinea pedis,* a N_2 laser was used by Maeda et al.[1] and a CO_2 laser by Ueda et al.[2]. Although both the lasers showed a lethal effect to ringworm, ones living in the deep layers of a foot skin were not burnt to death since the N_2 laser had too small output energy for this application and large part of the CO_2 laser energy was absorbed within a very thin layer from a skin surface. By contrast, a YAG laser light penetrates into a skin tissue so that ringworms in deep layers would be burnt to death. The extinction length of a YAG laser in a normal tissue, in which 90% of the light energy is absorbed, has been found to be about 0.8 mm[3].

The purpose of the present study is to examine the effectiveness of the YAG laser treatment for a skin thickly cornified by serious *tinea pedis* infections.

2. Experimental Method

A pulsed Nd-YAG laser with maximum energy of 10 joule/pulse, pulse duration of 1 msec and a beam diameter of 5 mm at the exit port of the laser was employed in this study. The beam was focused by a lens having a focal length of 70 mm. In order to explore an effective treatment condition two energy densities of 140 and 400 joule/cm^2 were used; a density of 140 joule/cm^2 was obtained by using the laser's maximam output of 10 joule/pulse and focusing the output laser beam into a beam diameter of 3 mm and a density of 400 joule/cm^2 by reducing the laser power to 0.5 joule/pulse and focusing it into a beam diameter of 0.4 mm. From a clinical point of view, i.e., heat accumulation during the irradiation, the repetition rates of the pulse shots were chosen 0.5 Hz for the laser beam of 140 joule/cm^2 and 3 Hz for 400 joule/cm^2. Laser pulses were shot to the irradia-

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tion area of a sample such that unirradiated area would not be left. Since the laser beam had a circular cross-section, some portions of the sample were inevitably double-irradiated to cover the whole area of a sample with the laser pulses. This double-irradiated area was estimated at about 20% of the irradiation area of the sample.

In order to determine an optimum treatment condition including the output energy of the laser pulse, the energy density and the repetition rates of the pulse shots, a semi-clinical experiment was conducted as well as a clinical experiment. There was slight differences in sample preparations between the two experiments. The details are given as follows.

In the clinical experiment two areas, 15 mm × 15 mm each, of an infected portion of a foot sole were directly irradiated by a laser beam at an energy density of 400 joule/cm^2. The surface of the two areas was colored by black to clearly mark an irradiated area, which also shortened an extinction length to a proper one. Irradiation time for each area was about 10 minutes. After a laser irradiation, eight small samples (2 mm × 1 mm) were resected from each area. The samples were further divided into two pieces (1 mm × 1 mm); one was used for microscopic observation and the other for the tissue culture. The culture test proceeded only when ringworms were found in the other part of the pair by the microscopic examination and was completed in two weeks after the laser irradiation.

The semi-clinical experiment used small skin samples resected from an infected portion of a foot sole. The size of the skin sample was 5 mm × 5 mm and the thickness ranged from 0.3 mm to 1 mm. The surface of the sample was also colored by black as in the clinical experiment. During the irradiation the sample was placed on starch gell so that heat transfer from the sample would be identical to it in a clinical condition. The irradiated sample was divided into 8 pieces (2 mm × 1 mm) and each piece was further divided into two part (1 mm × 1 mm); one was used for the microscopic observation and the other for the tissue culture.

3. Results

Table 1 shows the lethality of ringworms obtained by the single treatment for three typical conditions in the semi-clinical experiment; two of these are for a YAG laser and one is for a CO_2 laser. The lethality is defined by the ratio of the number of samples in which no ringworms grow to the total number of cultured samples. The YAG laser shows a greater lethal effect than the CO_2 laser particularly for a thick skin. It shows almost same effects for both thin and thick skins in contrast to the CO_2 laser case. This is due to the fact that the YAG laser has a far longer extinction length than the CO_2 laser[3]. Comparing the irradiation of 140 joule/cm^2 to that of 400 joule/cm^2, the former has shown a slightly higher lethality than the latter. This may be attributable to that an unirradiated portion was left in the latter because of its very small irradiation spot size. However, the latter is lower in a heat accumulation in an irradiated area since it uses a lower pulse energy. This low heat accumulation is preferable for a clinical treatment and the latter condition has been adopted for the clinical laser treatment of this study at a little sacrifice of lethality. The laser

Table 1 Lethality of ringworms [%] for three types of irradiation conditions.

LASER	YAG LASER		CO_2 LASER
PULSE ENERGY (J)	10	0.5	4
ENERGY DENSITY (J/cm^2)	140	400	50
REPETITION RATE (Hz)	0.5	3	10
LETHALITY FOR THIN SKIN (0.25-0.4 mm) (%)	78	70	51
LETHALITY FOR THICK SKIN (0.5-1.3 mm) (%)	72	66	27

pulse energy of the latter case also leads to a compact power supply of a YAG laser, which is necessary for a clinical use.

Table 2 shows the results of microscopic examinations and culture tests for a single subject in the clinical experiment. The microscopic observation was made immediately after the laser irradiation, giving an initial existence rate of ringworms. In this table a cure is considered as a change from "+" to "−". The initial existence rate is then calculated as 88%(=14/16) and the cure rate as 79%(=11/14) in this particular case. Table 3 summarizes the cure rates for each subject. Two subjects are cured completely and about half are healed at a cure rate of about 70%.

Figure 1 shows the efficacy of the laser treatment, in which cure rate for all subjects are grouped into three classes; highly effective (cure rates of above 70%), medially effective (cure rates of 20-69%), and ineffective (cure rates of 0-19%) cases. The efficacy for the CO_2 laser[2)] is also shown in Fig. 2 for a comparison.

4. Discussion

As the treatment of *tinea pedis* is result of

Table 2 An example of the YAG laser treatment. In this table "+" shows the case that ringworms were observed microscopically in the samples numbered 1 through 16 or grew in the culture test and "−" shows the case that no ringworms were observed microscopically or no ringworms grew in the culture test. The results of microscopic observation were obtained immediately after the laser irradiation and those of the culture test were obtained in about two weeks after the irradiation.

SUBJECT J	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
MICRO.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	−	−
CULTURE	+	+	+	−	−	−	−	−	−	−	−	−	−	−	/	/

Table 3 Cure rate for each subject.

SUBJECT	A	B	C	D	E	F	G	H	I	J	K	L	M
CURE RATE (%)	43	40	88	100	78	67	56	100	54	79	33	90	62

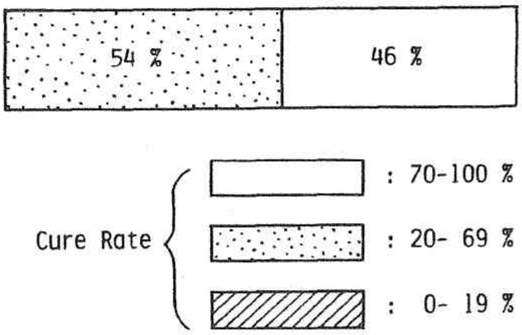

Fig. 1 Efficacy of the YAG laser treatment. This shows the distribution ratio of the subjects having a cure rate of above 70% and between 20 and 69% to the total subject numbers.

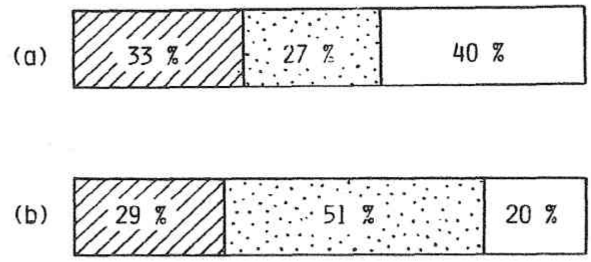

Fig. 2 Efficacy of the CO_2 laser treatment (from Ref. (2)). This shows the distribution ratios of the sample numbers having a cure rate of above 70%, between 20 and 69%, and below 19% to total sample numbers, respectively, and for thin and thick skins. (a) thin skin, (b) thick skin.

thermal action of a light energy, it is necessary to raise temperature above 80°C for this treatment in a corneous tissue, which corresponds to the temperature for a tissue coagulation. For the estimation of temperature rise in the tissue, ΔT, we assume that 1) all the light energy of the YAG laser, E, is converted to heat within a small volume given by Sd(S; area, d; depth), 2) a part of the light energy, E', is consumed for the evaporation of the water in the skin tissue and 3) the heat conduction in a pulse duration is negligible. The temperature rise, ΔT, is then calculated approximately by

$$\Delta T = \frac{E(1-R)-E'}{Sd\rho C}$$

where R is the reflectivity of the laser light on the irradiated surface, ρ the density of the tissue and C the specific heat of the tissue. Substituting typical value applied in this study, $E=0.5/4.18$ [cal], $R=0.2$, $E'=0.2E$ [cal], $S=0.0013$ [cm^2], $d=0.15$ [cm], $\rho=1$ [g/cm^3] and $C=0.9$ [cal/g°C], we obtain $\Delta T=409$ [°C]. The actual temperature rise, however, may be considerably lowered by light dispersion in the tissue. Even if the light was dispersed 3 times in the volume, the temperature rise would be 136°C,which is quite sufficient for the treatment.

In a clinical use of the YAG laser, a possible serious problem is an injury, i.e., inflammation, in a corium or subcutaneous tissue due to a long extinction length of the laser light into the tissue. A preliminary experiment using a skin sample resected from a foot sole has shown that the YAG laser has an extinction length of about 2.5mm for a crude skin and about 1.5 mm for a skin colored by black. These values are two or three times as long as the one for a normal tissue[3)]. It is, therefore, preferable to use the YAG laser for a corneous tissue which is thicker than 0.5 mm and the CO_2 laser for a tissue thinner than 0.2 mm. A slight burn was experienced after the YAG laser irradiation, but healed within a day like a burn by a CO_2 laser irradiation.

Time required by the YAG laser treatment is far longer (about 5 times) than required by the CO_2 laser treatment. The YAG laser system, however, can be made more compact than CO_2 laser system since an output laser energy per one pulse is much lower (about 0.5 joule) than the CO_2 laser (about 4 joule).

It is obvious in table 1 that the YAG laser has a much higher efficiency than the CO_2 laser including a case of a thick corneous tissue. Here, it is worth noting that a repeated treatment would improve a cure rate as confirmed in Ref. (2) using the CO_2 laser. With the YAG laser the repeating method is expected to increase a cure rate more than with the CO_2 laser, although no repeated experiment has been conducted in this study. Ringworms living in a deep corneous tissue, in particular, will be burnt by the repeating method using the YAG laser since a YAG laser has a longer extinction length than a CO_2 laser and is able to penetrate into a deep tissue. Therefore, the combination of the YAG laser with the repeating method will potentially provide a radical cure for *tinea pedis*. A remaining problem for a radical cure by the YAG laser is then to irradiate all the infected area without leaving an unirradiated part. This can be also solved by the repeated treatment.

5. Conclusion

An investigative study on the YAG laser treatment of *tinea pedis* was conducted. It was found that:

1) Compared with conventional medicinal therapy, the YAG laser treatment was very effective; one treatment had a cure rate of about 67% on the average for all subjects, and about half of the subjects showed a cure rate of above 70%.

2) It was desirable to use both the YAG laser and

the CO_2 laser properly, depending on a skin thickness; the YAG laser treatment was particularly effective for a thick skin (above 0.5 mm) and the CO_2 laser for a thin skin (below 0.2 mm).

The YAG laser treatment system is now under works by an industry-university cooperation and in a verification process of a medical appliance at a national hospital, comming up to the standards of the Welfare Ministry.

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