Studies on CO_2 Laser Treatment of *Tinea Pedis*

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An experiment on the treatment of *tinea pedis*, common athlete's foot, infections was done using a pulsed CO_2 laser having an output energy of 3 joule/pulse and pulse duration of 0.5 μsec. Based on the results by the culture experiment, the ratio of the number of the samples having a cure rate of above 70% to all the samples is about 0.55 for thin skin and 0.35 for thick skin. The itchiness on the blistered infected parts virtually disappers within a few hours after the laser irradiation and the vesicles almost completely disapper within about 2 days.

I. INTRODUCTION

In an earlier study [1] we examined the influence of N_2 laser irradiation on eumycetes and the practical effect of the irradiation on *tinea pedis* lesions. It was found that the N_2 laser can be used in the medical treatment for dermatomycosis. However, the output of the N_2 laser light is too low to be used practically; it takes a few hours to treat the entire sole of a foot suffering from *tinea pedis*. Furthermore there is a risk that cutaneous cancer may develop when the N_2 laser treatment is employed.

The purpose of the present study is to examıne whether or not the use of the CO_2 laser in place of the N_2 laser might prove to be a practical treatment for superficial dermatophytosis, but one without these two disabvantages. The lethal effect of the N_2 laser assumed to be mainly due to the UV effect. On the other hand, the lethal effect of the CO_2 laser is mainly due to the thermal effect. The energy of the CO_2 laser light is almost entirely transferred to heat, and further, 90% of the heat energy is absorbed within 0.05 mm from the surface of the skin[2]. The heat energy absorbed within such a thin layer is then gradually conducted into an inner tissue. The pulsed CO_2 laser is therefore preferable to the CW CO_2 laser for local heating of the epidermis, where ringworms live, because the heat energy can be held at the epidermis for only a short time after the pulse shot. The pulsed CO_2 laser may then be used effectively to burn the ringworm to death without affecting the corium and the subcutaneous tissue.

II. LASER SYSTEM

The laser system used in this study is shown in Fig. 1. Figure 1 (a) shows a photograph of the system and 1 (b) a schematic diagram. The system consists of three discrete assemblies; the laser itself (①) to generate the laser beam, the beam delivery (②, ③) to deliver the beam through the aperture (④) and focusing lens (⑤) to the infected part, and the laser control (⑥) which houses operator controls and monitors the laser performance on every pulse. The laser is a high power, pulsed TEA CO_2 laser. The output energy is about 3 joule/pulse with a pulse duration of 0.5 μsec. The cross-sectional area of the beam is about 3 cm × 3 cm at the exit of the laser. In order to obtain optimum conditions for the laser cure, the energy density on the irradiated surface can be varied form a few joule/cm^2 to 30 joule/cm^2 by

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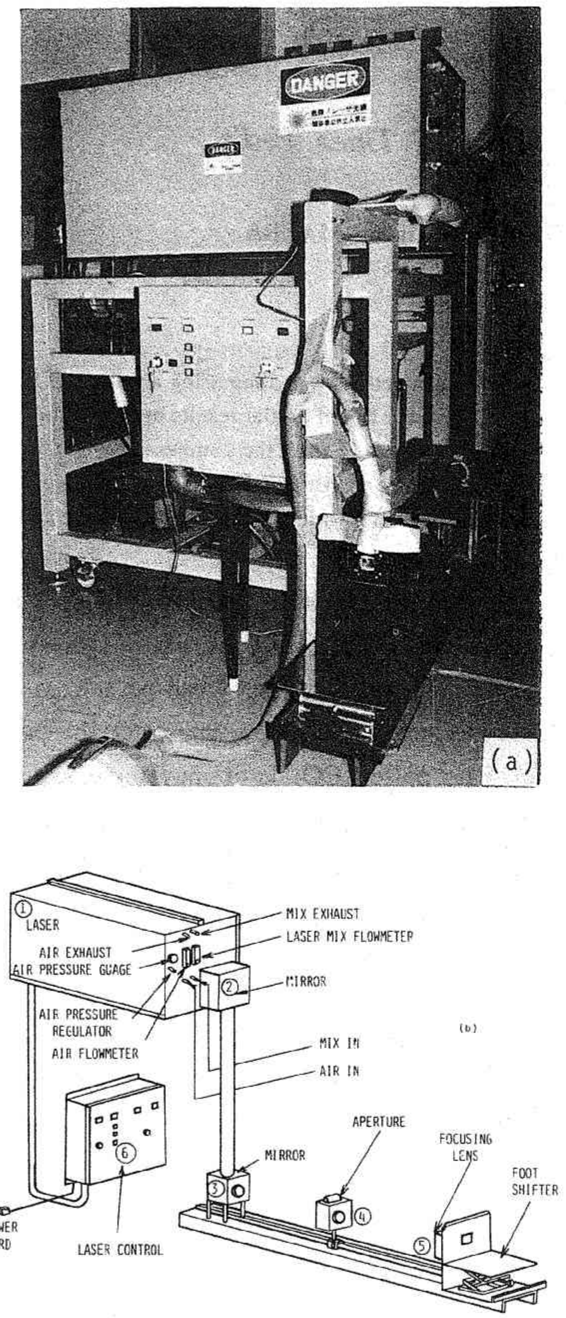

Fig.1 The laser system used for this experiment. (a) Photograph. (b) Schematic Diagram.

changing the aperture size or the distance form the focusing lens to the irradiated part. The triggering of the laser is done by hand at the proper repetition rate. Smoke, loose fragments of skin and other waste products resulting from the irradiation are removed by a vacuum cleaner. This is necessary to prevent air breakdown due to the high electric field at the focusing point of the laser beam.

III. EXPERIMENTS AND RESULTS

A. Biopsy using rat tissue

In order to examine how the laser irradiation has an effect on the epidermis, a preliminary experiment was done using the rat (Donryu strain of 80 days age). The back of the living rat was irradiated with laser light of about 10 joule/cm^2 energy density on the skin surface and an irradiation area of 7mm × 7mm. Pulse shots of 2,5 and 50 pulses were used at a pulse repetition rate of 2 Hz and 0.5 Hz. Figure 2 shows samples removed by

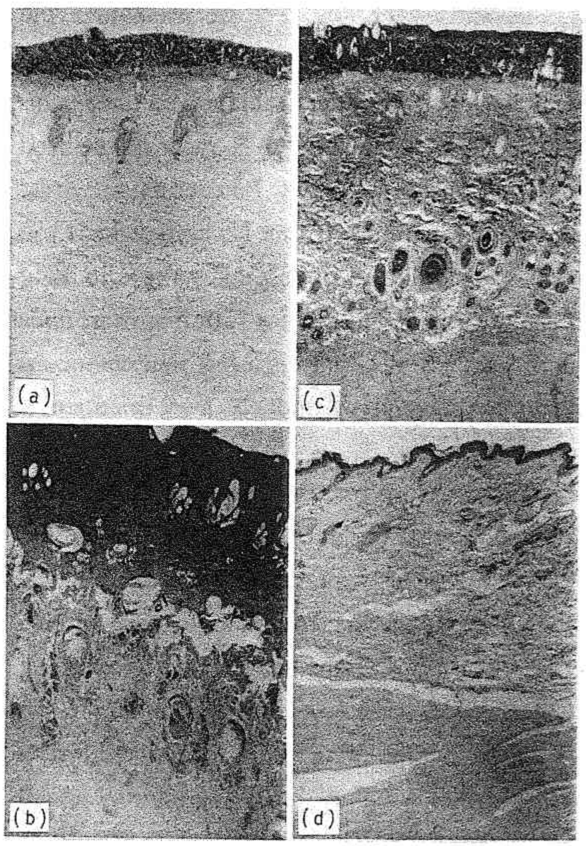

Fig.2 Injury of the skin tissue due to exposure to CO_2 laser light examined by biopsy of rat. (a) Result exposed to 2 pulse shots at 2 Hz. (b) 50 pulses at 2 Hz. (c) 50 pulses at 0.5 Hz. (d) Control (no irradiation). The epidermis of the irradiated area shows necrosis in (a), (b) and (c). (magnification = 50x)

biopsy two days after the irradiation. In all cases except the control, an inflammation is observed within the corium and at the most ranges over the upper part of the subcutaneous tissue, as shown in Fig. 2 (b). Further it may be concluded from a series of these experiments that the injury is mainly influenced by the repetition rate. These facts mean that almost all the laser energy is transferred to heat in the extreme upper layer of the skin and that the accumulation of heat in that layer becomes large as the repetition rate increases.

B. Semi-clinical study

A semi-clinical experiment was done using small pieces of skin resected from the infected part of the sole of a foot.

First, in order to determine the thermal death point for ringworm, small pieces of the skin (2mm × 2mm) were immersed in heated water (50-90°) for 1 to 10 seconds and then cultured for one week on Sabrouraud's nutrient agar medium at 25°C. Table I shows the lethality of the ringworm against temperature of the heated water and time duration of the immersion in the heated water. The lethality was observed a week after the immersion in heated water. It is seen that the ringworm population was greatly reduced at temperature of 70°C, at which necrosis of the tissue is observed[3].

Table I Lethality of the ringworm[%] against temperature of the heated water and time duration of the immersion in the heated water.

TIME (SEC) \ TEMPER (°C)	50	60	70	90
1	14	25	67	100
5	30	43	90	100
10	60	87	92	100

Table II Lethality of the ringworm against the irradiation dose. The dose in this case means a number of the pulse shot at 2 Hz.

IRRADIATION DOSE (PULSES)	LETHALITY (%)
2	45
4	78
6	100

Next, we examined the lethal effect of the laser irradiation on ringworm using small samples taken from an infected part of the sole of a foot. The samples (5mm × 5mm) were fixed on starch so that the rise in temperature in the samples would be in the same as in the clinical experiment. The energy density of the laser pulse was 10 joule/cm^2 on the sample, at 2 Hz. The thickness of the samples were 0.35 to 0.45 mm. After laser irradiation the samples were divided in two; one part was used in microscopic observation and the other in tissue culture. Table II shows the lethality of the ringworm against the irradiation dose. A dose of 4 to 6 pulses burns alive a large part of the ringworm within the skin. The results in Tables I and II suggest that the sterilizing effect is due to the thermal action of the laser light.

C. Clinical study

A clinical experiment was done using 50 volunteers suffering from *tinea pedis* infections to various degrees. The efficacy of the laser treatment may largely be affected by the thickness of the stratum corneum, in which ringworm lives, because about 90% heat energy of the laser light is absorded within 0.05 mm of the surface of the skin. The infected region was then divided into parts of 2cm × 3cm; the thickness of the stratum corneum in each separate part may be considered almost uniform within that part. After laser irradiation, eight small samples (2mm × 3mm) were resected from each part. The samples was further divided into two pieces; one was used for microscopic observation and the other for the tissue culture. The laser irradiation was done twice with an interval of 5 to 8 days between sections. The energy density of the laser irradiation was about 5 to 10 joule/cm^2 on the skin surface with the irradiation area of 7mm × 7mm. The laser pulse was shot at a repetition rate of 1 to 2 Hz up to 5 times, or as many times as the patient could bear the heat or pain. At the instance of the irradiation the patients felt a little pain as well as heat and at the same time the skin burned and carbonized to white as shown in Fig. 3. However, the burn was confined to a very thin layer and healed within a day.

Table III shows a result of the laser treatment which was used as a basis for the results below, for an example. In this table, both microscopic and cultural data shown in each row were obtained by examining the samples in a same day. The results by microscopic observation were obtained immediately after each laser irradiation; the results

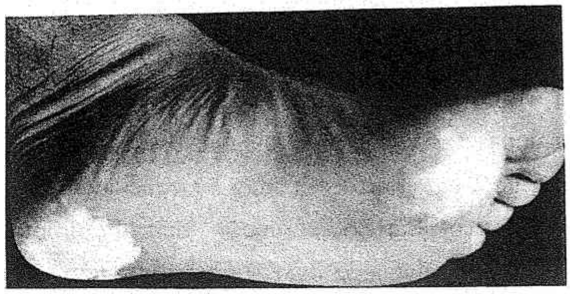

Fig.3 An example of carbonization of the skin (the white area) by CO_2 laser irradiation.

after each laser irradiation were identical to the ones before each laser irradiation. Then, an existence rate of the ringworm before laser irradiation, which is defined by the ratio of "+" sample numbers to all the sample numbers, is 7/8 in the case shown. The survival rate after each laser irradiation is defined by the ratio of "+" sample numbers to all the sample numbers of the corresponding laser irradiation. Then the survival rate after second laser irradiation, for an example, is 2/8, which is obtained by the results in a row of two weeks after the first laser irradiation. The cure rate after the second laser irradiation, is then 71% by the calculation of $100 \times (1-(\frac{2}{8}/\frac{7}{8}))$. On the other hand, the results by the culture experiment

Table III An example of the results concerning the laser treatment. In this figure, "+" shows the case that the ringworm was observed microscopically in the samples numbered 1 through 8 or grew in the culture and "−" shows the case that the ringworm was not observed microscopically or did not grow in the culture. The results by microscopic observation was obtained immediately after each laser irradiation and the one by culture was obtained a week after each laser irradiation.

AFTER 1st LASER IRRADIATION (WEEKS)	SAMPLE NO. / METHOD	1	2	3	4	5	6	7	8
0	MICRO	+	+	+	+	+	+	+	−
	CULTURE	+	+	+	+	+	−	−	−
1 (2nd LASER IRRADIATION)	MICRO.	+	+	+	+	−	−	−	−
	CULTURE	+	+	+	−	−	−	−	−
2	MICRO.	+	+	−	−	−	−	−	−

were obtained a week after each laser irradiation. The survival rate after the second laser irradiation, for an example, is then 3/8, which is obtained by the results in a low of the second laser irradiation. The cure rate after the second laser irradiation by culture experiment is then 57% by the calculation of $100 \times (1-(\frac{3}{8}/\frac{7}{8}))$.

Figure 4 shows the efficacy of the laser treatment in various infected part of the foot. When the existence rate before laser irradiation was greater than 50%, the cure rate was grouped into three classes: highly effective (cure rate of above 70%), medially effective (cure rate of 20-69%), and ineffective cases (cure rate of 0-19%). When the existence rate was less than 50%,the cure rate was grouped into two classes:

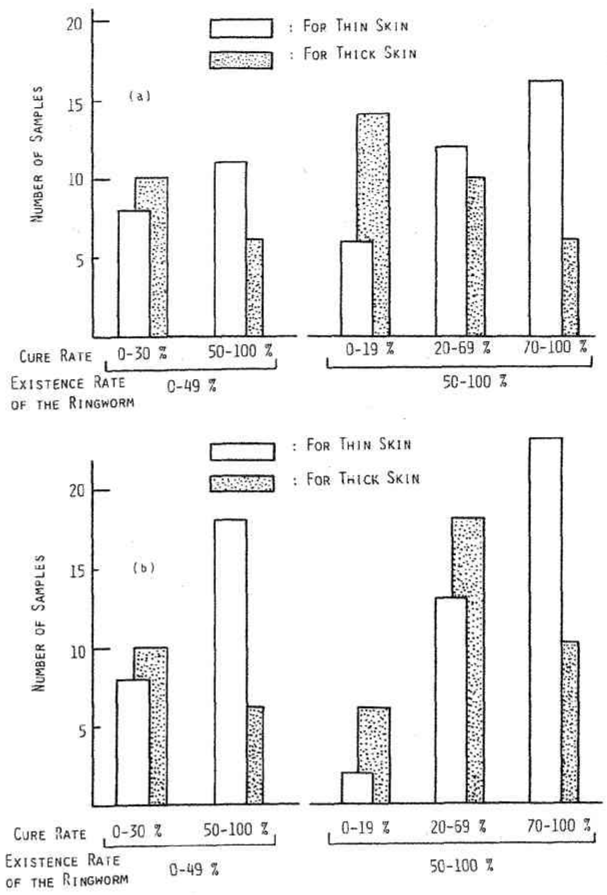

Fig.4 Efficacy of laser treatment for various infected parts. (a) Results by microscopic observation. (b) Results by culture experiment.

effective (cure rate of above 50%) and ineffective cases (cure rate of 0-30%). The infected area was also classified into two large groups: those regions having thick corneous tissue (for example, the heel) and those regions having thin corneous tissue (for example, the arch of the foot). The efficacy by the microscopic experiment is slightly lower than that determined by the culture experiment. This may be due to the fact that the ringworm burned alive is still observed microscopically but cannot, of course, be cultured. In both experiments, the laser cure seems more effective in thin skin as opposed to thick skin.

Table IV shows the change rate from "+" to "−" examined by the culture experiment, which is the mean value of all the samples in each laser irradiation. The change rate of the thin skin is large compared to that of the thick skin. This is attributed to the fact that the ringworm which lives in the deep corneous tissue of th thick skin may not be burnt alive because the greater part of the CO_2 laser energy is absorbed in the very thin layer of the corneous tissue.

Figure 5 shows the effect of the second treatment on the cure rate. The second treatment has some effect on the cure rate, particularly for the infected part where the corneous tissue is thin. But it is uncertain whether or not further repeated treatment will result in a radical cure, and if so, how many treatments would be necessary. It is preferable, from the clinical point of view, to

Table IV The lethality of the ringworm examined by the culture, which is a mean value of all the samples in each laser irradiation.

THICKNESS (mm)	0.3-0.6	0.6-1.2
LETHALITY (%)	46	35

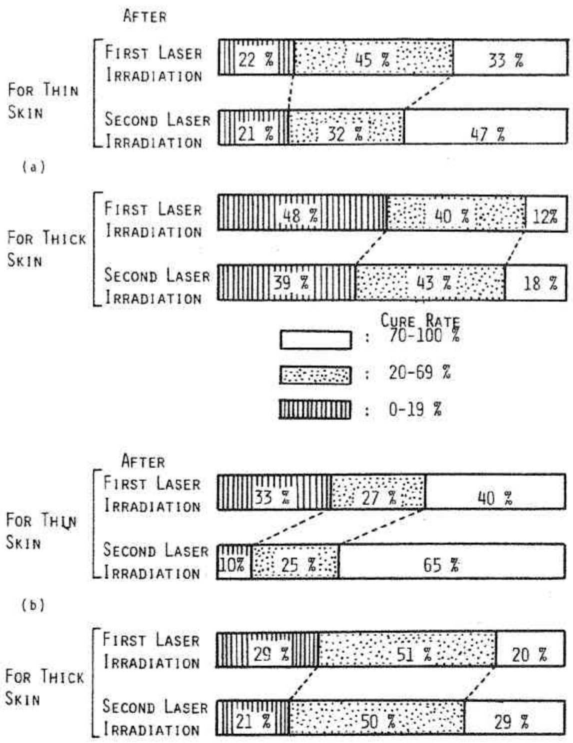

Fig.5 The effect of second treatment on the cure rate. The treatment was done with one session per week for two weeks. (a) Results by microscopic observation. (b) Results by the culture experiment.

make thick corneous tissue thin by resecting it, rather than to repeat the treatment.

It can be observed with the naked eye that the rough skin infected by *tinea pedis* is cured into a fresh complexion within one to two weeks after the laser irradiation. The usual itch also ceases soon after the laser irradiation. However, the examination of cultured ringworm shows that all the ringworm in the stratum corneus have not necessarily been burnt alive, rather, the activity of the ringworm has been suppressed by the irradiation.

IV. CONSIDERATIONS

The thermal death point of the ringworm is about 90°C as shown in section 3-B. We now estimate the rise in temperature, $\triangle T$, in corneous tissue due to the laser irradiation. The light energy of the CO_2 laser, E, is assumed to be converted to heat within a small volume Sd (S, area; d, depth), and the heat conduction within the pulse duration may be ignored. The rise in temperature is roughly calculated by

$$\Delta T = \frac{E(1-R)}{S d \rho C}$$

where R shows the reflexibility of the laser light on the irradiated surface, ρ the density of the tissue and C the specific heat. Substituting typical values in this experiment, $E=3$ [J] and then, $E=3/4.18$ [cal], $R=0.1$, $S=0.5$ [cm^2], $d=0.01$ [cm], $\rho=1$ [g/cm^3] and $C=0.9$ [cal/g°C], we obtain $\triangle T=140$ [°C]. The value is quite sufficient for our purpose. The actual rise in temperature, however, may be lowered considerably because a part of the heat energy is used for the evaporation of water in the tissue. But the temperature is assumed to be raised above 90°C, based on the fact that a sharp stab of pain is felt at the instance of the laser irradiation. The carbonization and the coagulation of the skin tissue takes place approximately in a depth of 100 μm from the skin surface. However, the tissue degeneration will, in fact, range over the corium and the subcutaneous tissue, based on the results in section 3-A.

There are some problems in our laser treatment. From the clinical point of view it is difficult to cure the infected part having a thick horny layer. The use of Nd-YAG laser in place of CO_2 laser may prove to be a promising solution for this problem since it has a penetration length of 0.8 mm for skin[4]. Further, it will be necessary to develop a beam delivery system which make it possible to change the illumination direction easily or to develop a shifter controllable by the operator's hand. Finally, it will be necessary to develop a laser system of small size.

V. CONCLUSION

The CO_2 laser was successfully used for the treatment of ringworm. It was found that:

1) Compared with conventional medicinal therapy, a much shorter period of treatment is possible (one session per week for two weeks). Also, the time required for each session, 20 to 30 minutes to treat all the infected parts of a foot, is much shorter than that required for N_2 laser therapy.

2) Based on the results by the culture experiment, the ratio of the number of the samples having a cure rate of above 50% to all the samples examined is about 0.74 for thin skin and is 0.4 for thick skin and that of the samples having a cure rate of above 70% to all samples is about 0.55 for thin skin and 0.35 for thick skin. Each ratio further increases by about 10 to 20% if these values are obtained only from the samples of the subjects who are able to bear the heat at the laser irradiation.

3) This treatment has an outstanding effect on the blistered itchy infected parts; the itchiness virtually disappears within a few hours after the laser irradiation and the vesicles almost completely disappear within about 2 days. But according to an examination of cultured ringworm, these facts do not always mean that all the ringworm in the corneous tissue have been burnt alive, but rather the activity of the ringworm has been suppressed, and the itchiness therefore contained.

The CO_2 laser treatment system is in the works under industry-university cooperation and is under verification at a national hospital as medical appliances which comes up to the standards for the Ministry of Public Welfare.

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