CO2 Laser Treatment System of Tinea pedis

CO_2 Laser Treatment System of *Tinea pedis*

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ABSTRACT

The CO_2 laser treatment system 'Melase 1000' has been developed for the treatment of Tinea pedis *and the efficacy of the treatment using the system and its optimum irradiation condition are studied. The present system enables us to make the healing time of* Tinea pedis *treatment far shorter than conventional pharmaceuticals. This is in spite of using heat levels low enough for patients not to feel discomfort. Features offered by the system are a safe-and-easy operation and a stable laser power for a prolonged use. The efficacy of the present therapy is excellent; only two treatments a week for three weeks, i.e. six consecutive treatments, attained an improvement rate of 71·8% in the skin findings and a 'usefulness' of 66·2% determined from cases rated as 'useful' or 'better'. The optimum laser irradiation condition for a single treatment found in this experiment is a light fluence of about $3\ J/cm^2$ and four laser pulses with a time interval between pulses of 1 s for a typical horny layer thinner than 0·5 mm.*

1 INTRODUCTION

In a previous study on the laser treatment of *Tinea pedis*, a N_2 laser was used by Maeda *et al.*,[1] a CO_2 laser by Ueda *et al.*[2,3] and a YAG laser by Ueda and Kagawa.[4] Although all the lasers showed a lethal effect to ringworm, the N_2 laser had too small an output energy and the YAG laser had too long an extinction length to use practically. The YAG laser showed a better cure rate especially for a skin thickly cornified by serious *Tinea pedis* infections, but it is likely to overheat tissues other than the stratum corneum where ringworms live. The CO_2 laser, however, had a proper extinction length for typical *Tinea pedis* infections where thickness of a stratum corneum was thinner than about 0·5 mm.

In this paper, a CO_2 laser treatment system will be described and its treatment effect and optimum condition for the treatment are also discussed. The system 'Melase 1000' has been approved by the Ministry of Health and Welfare in Japan as medical equipment.

2 OPTIMUM CONDITION FOR THE TREATMENT

The treatment method has been developed by accounting for the fact that ringworms live only in the stratum corneum (normally 100–800 μm thick; mean thickness is about 400 μm) of the epidermis, that most of these ringworms are killed by temperatures of 70 °C or more, and that heat-sensing nerves extend only to the corium, not to the stratum corneum. When the diseased part of the skin is exposed to a far-infrared CO_2 laser light, most of the thermal energy (above 90%) is absorbed in the outer 50–100 μm of the skin surface.[5] The laser can, therefore, kill the ringworms by heating only the stratum corneum, causing no damage to the corium. For this treatment to be effective, it is necessary to use a pulsed CO_2 laser and raise the temperature of only the stratum corneum to above 70 °C. The optimum conditions for this laser treatment, that is, laser irradiation condition, can be determined by the temperature rise of the skin samples due to the pulsed laser irradiation.

Figure 1 shows the experimental set-up for the temperature measure-

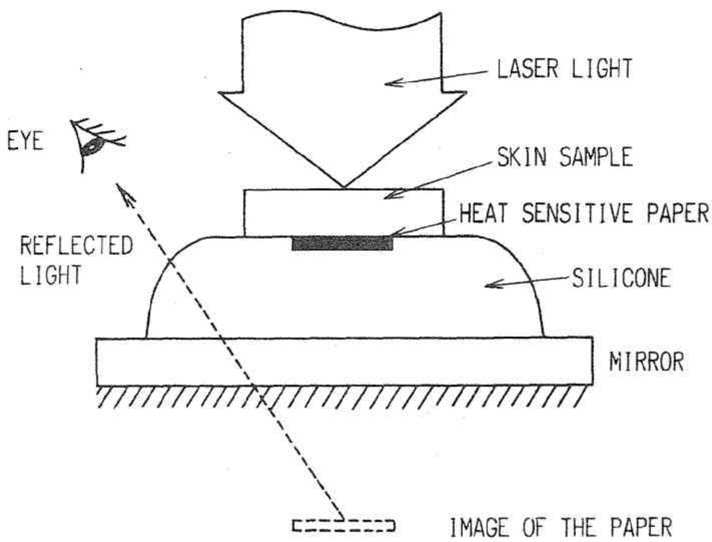

Fig. 1. Set-up for the measurement of skin temperature rise by pulsed CO_2 laser irradiation.

ment of a skin sample from the sole of an infected human foot. A piece of heat sensitive paper (3 mm × 3 mm) was attached to the back of the sample (about 5 mm × 5 mm) to monitor its temperature change. Three different papers were used for the measurement for which color-change temperatures were 60, 65 and 71 °C. A skin sample with the attached paper was supported by a translucent silicone bed maintained at 30 °C so that the heat transfer from a sample would be similar to that *in vivo*. A mirror beneath the sample was used for the color observation of the heat sensitive paper as shown in Fig. 1. The temperature rise of a sample depends on the irradiation parameters of the laser, i.e. light fluence I, irradiation dose $I \times N$ (N = the number of laser pulses), the time interval S between laser pulses, and the sample thickness d. In this experiment, the light fluence on the skin surface was fixed at 3·4 J/cm^2 for clinical reasons. The number of laser pulses was defined as the total pulse number necessary for discoloring heat sensitive paper.

Table 1 summarizes data obtained in this experiment. Figure 2

TABLE 1
Data for the Temperature Rise

Interval between laser pulses (s)	*Thickness of the sample (mm)*	*Temperature (°C)*	*Number of laser pulses*
1	0·34	60	3
	0·36	65	4
	0·35	71	4
	0·49	60	4
	0·47	65	4
	0·47	71	5
	0·70	60	5
	0·68	65	5
	0·68	71	6
	0·92	60	6
	0·94	65	6
	0·89	71	8
0·5	0·40	60	3
	0·39	65	3
	0·38	71	4
	0·45	60	3
	0·45	65	3
	0·43	71	4
	0·65	60	4
	0·65	65	5
	0·66	71	5
	0·89	60	6
	0·90	65	6
	0·93	71	7

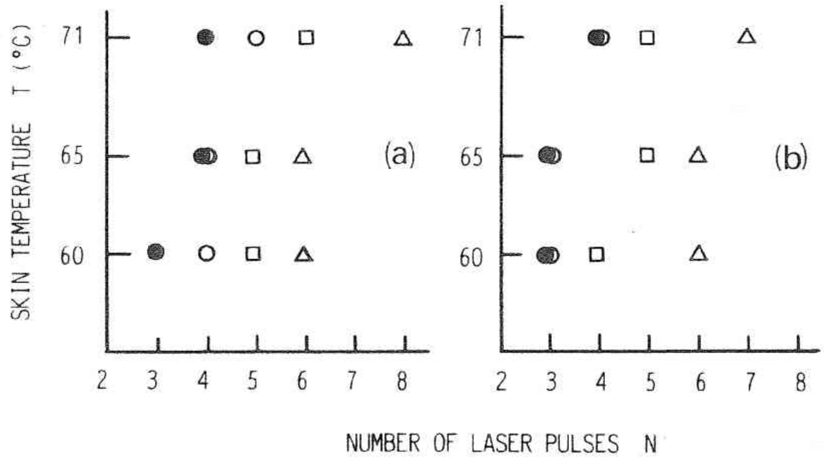

Fig. 2. Relationship between skin temperature T and the number of laser pulses N. (a) For the time interval between each laser pulse, $S = 1$ s, (b) for $S = 0{\cdot}5$ s. ● Shows the data for $d = 0{\cdot}37$ mm, ○ for $d = 0{\cdot}47$ mm, □ for $d = 0{\cdot}67$ mm and △ for $d = 0{\cdot}91$ mm.

illustrates the effects of various parameters on the temperature rise; in this figure, the number of laser pulses N is plotted against the sample temperature T, where the time interval S between laser pulses and the sample thickness d are fixed. From these results it is found that: (i) the number of laser pulses (and thus the total irradiation dose) required to obtain a given temperature rise is roughly proportional to the temperature rise; (ii) that the number of laser pulses required for a given temperature rise is roughly proportional to the sample thickness; and (iii) that the number slightly decreases for a sample thicker than 0·5 mm when the time interval is shortened from 1 to 0·5 s.

The temperature rise ΔT, by a single laser pulse irradiation is roughly estimated[3] by eqn (1):

$$\Delta T = \frac{E(1-R) - E'}{Ad\rho C} \times 10 \quad [^\circ\mathrm{C}] \tag{1}$$

where E is the incident energy, E' the absorbed energy for the evaporation of the water in the skin tissue, R the reflectivity of the laser light on the irradiated surface, A the irradiation area of the laser light, d the thickness of the skin sample, ρ the density of the skin tissue, and C the specific heat. The above equation can further be simplified by the relation $E = IA$ and $E' = I'A$, where I and I' are the light fluence, as

$$\Delta T = \frac{I(1-R) - I'}{d\rho C} \times 10 \quad [^\circ\mathrm{C}] \tag{2}$$

The units for each quantity are J/cm^2 for I and I', joule for E and E', mm for d, cm^2 for A, g/cm^3 for ρ, and cal$(=4{\cdot}18$ J$)$/g °C for C. Figure 3 shows the temperature rise calculated from eqn. (2). As an example, we can obtain $\Delta T = 11{\cdot}7$°C for $I = 3{\cdot}4$ J/cm^2, $I' = 0{\cdot}3I$, $R = 0{\cdot}05$,

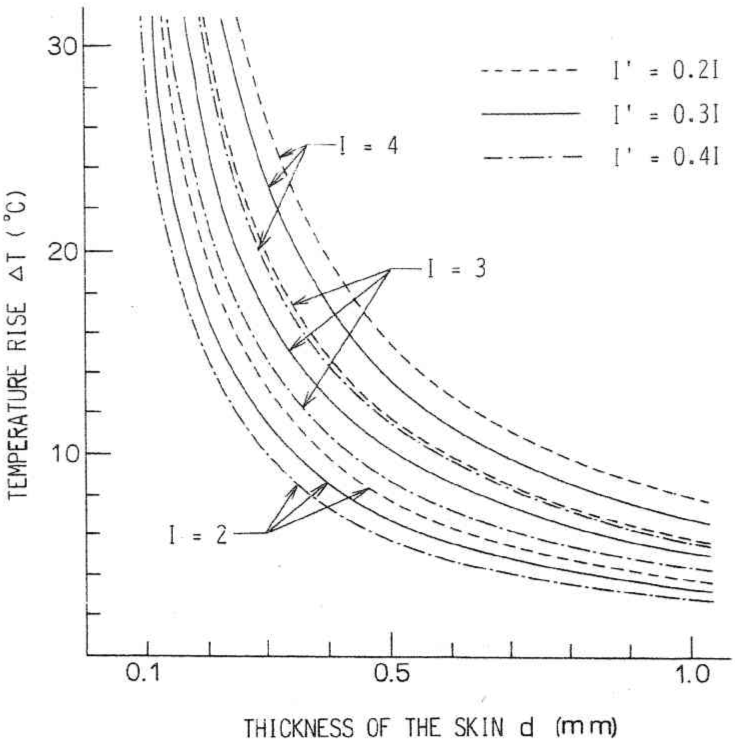

Fig. 3. Temperature rise ΔT calculated from eqn (2) as a function of skin thickness d for $R = 0{\cdot}05$, $\rho = 1$ g/cm^3, and $C = 0{\cdot}9$ cal/g °C. I shows the light fluence (J/cm^2) and I' the light energy per unit area absorbed for the evaporation of water in the skin tissue.

$d = 0{\cdot}05$ mm, $\rho = 1$ g/cm^3, and $C = 0{\cdot}9$ cal/g °C. Therefore, we need four laser pulses (theoretically 3·4 laser pulses) to heat the skin sample above 70 °C if we assume that the temperature of the clinical skin tissue is 30 °C. This result agrees with the data obtained in our experiment (see Table 1).

From the above discussion, the following is found to be the optimum condition for a typical horny layer thinner than 0·5 mm: a light fluence of about 3 J/cm^2 and four laser pulses with a time interval between pulses of 1 s.

3 CO_2 LASER TREATMENT SYSTEM

The CO_2 laser treatment system was developed in collaboration with Fukui University and Shibuya Kogyo Co., Ltd. This laser treatment system, named 'Melase 1000', has been approved for manufacture in Japan as 'Laser therapy apparatus' (Approval No. 60B-726).

Figure 4(a) shows a photograph of the system and 4(b) the schematic diagram. The laser oscillator is built vertically in the main body and provides compactness to the system. The laser light is conducted through a manipulator and a handpiece to infected skin parts. Figure 5(a) shows a manipulator and 5(b) a handpiece. The easy-to-use

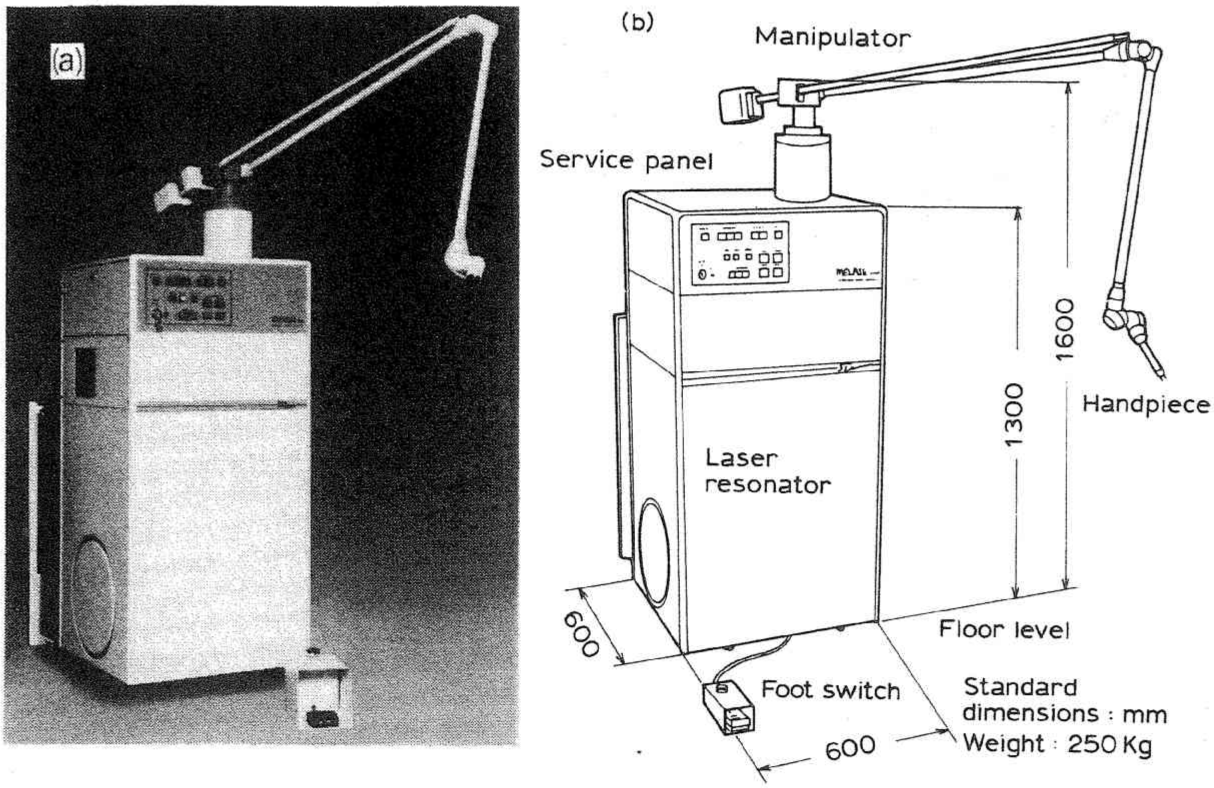

Fig. 4. The CO_2 laser treatment system 'Melase 1000'. (a) Photograph, (b) schematic diagram.

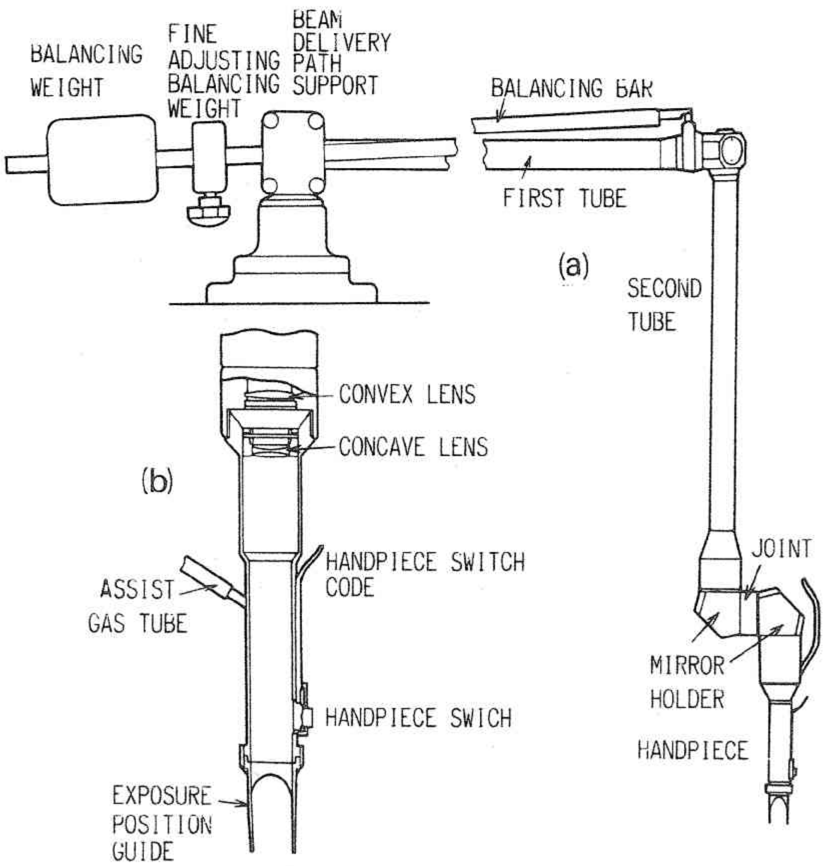

Fig. 5. Manipulator and handpiece of the system. (a) Multi-articulated arm manipulator, (b) handpiece.

multi-articulated arm manipulator can transmit the laser light to any affected site. Also, this manipulator's specially designed joints prevent any distortion of the laser light even in frequent operations. As shown by Figs 5 and 6, the handpiece is equipped with an exposure guide which can easily be changed to fit the skin site being treated and also a finger operated switch to emit the laser light. Lenses are incorporated in the handpiece so that a constant exposure area is maintained. A control panel is shown in Fig. 7; it is equipped with a keylock switch turning on and off for safety, a service-call pilot lamp for an emergency

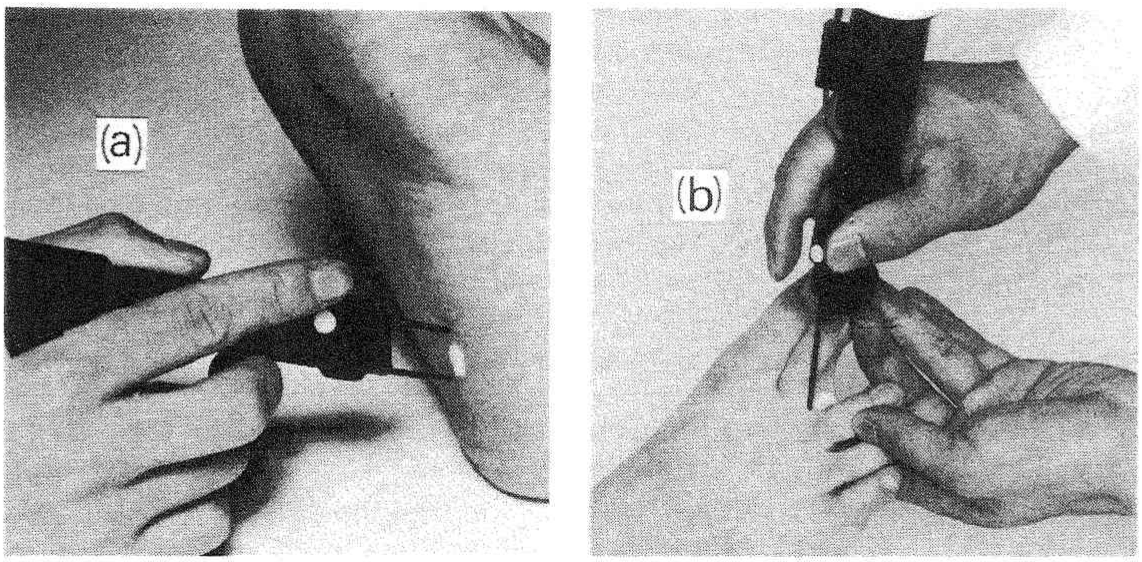

Fig. 6. Photographs of an exchangeable exposure guide.

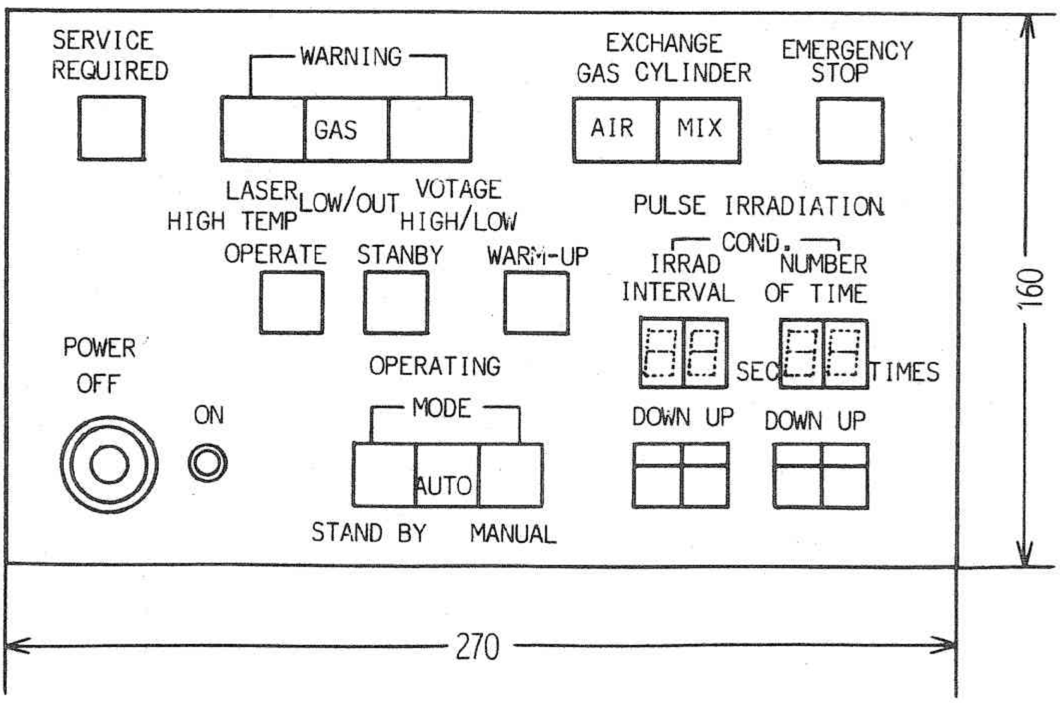

Fig. 7. Diagram of a control panel.

requiring service by a technician, pulse condition display lamps displaying a laser pulse interval and a laser pulse number, and alarm lamps indicating abnormal conditions such as overheating of the laser resonator, a gas pressure drop and line voltage fluctuations. The self-diagnosis system assures an easy and safe operation. Continuous pulse irradiation with a specified interval is also available by setting both the desired irradiation interval and a laser pulse number, depending on an individual case, where the laser output is stable even over a long period of use. Safety in the operation of Melase 1000 is enhanced by adding a dual interlocking system consisting of the handpiece switch shown in Fig. 6 and the foot switch shown in Fig. 8;

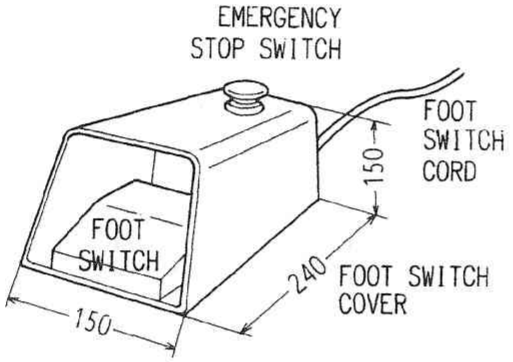

Fig. 8. Schematic diagram of a foot switch.

the laser light is emitted only when the handpiece switch is depressed (ON position) while holding the foot switch down (ON position). In an emergency the laser emission can be immediately terminated by depressing the emergency switch mounted on the foot switch cover.

Table 2 shows the specifications of Melase 1000. As shown in the table, the system is capable of generating an extremely short irradiation period of the order of a micro-second giving little pain to a patient.

4 EFFICACY OF LASER TREATMENT

The clinical results of treatment of *Tinea pedis* using the described system were obtained at the dermatology departments of the National Kanazawa Hospital (hereafter called 'the National Hospital') and Social Insurance Naruwa General Hospital (hereafter called 'the Naruwa Hospital').[6] Thirty-four patients were treated at the National Hospital and 37 patients at the Naruwa Hospital; all of these patients were male and all were treated for *Tinea pedis* of vesicular type. The energy fluence of the laser irradiation used in the treatment was about $3{\cdot}4\ \mathrm{J/cm^2}$ at the skin surface with an irradiation area of between

TABLE 2
Specifications of Melase 1000

Property	*Specification*
Type of laser	CO_2 laser
Wavelength of lasers	10·6 μm
Power of laser	2–4 J/cm^2
Radiation mode	Pulsed mode
Pulse duration	10^{-6} s
Exposure area	25–75 mm^2
Gas mixture	Mix of CO_2, N_2, He and CO. One 10·5 liter gas cylinder (good for approximately 70 h continuous operation at 2·7 J average power)
Air	Clean air for clinical use. One 10·5 liter gas cylinder (good for approximately 28 h continuous operation at 2·7 J average power)
Manipulator	Multi-articulated arm type by mirror reflection. Number of joints = 6, Horizontal reach = 2000 mm
Electric power	AC 100 V ± 10%, 50/60 Hz, 700 VA
Weight	Approximately 250 Kg

Remarks: The environment for installation of this system should be between 4 and 40 °C and between 10 and 90% relative humidity.

6 mm × 6 mm–9 mm × 9 mm. The laser pulse was shot four times with a pulse interval of 1 s. Results of the laser treatment were attained after only two treatments a week for three weeks, that is, six consecutive treatments.

Figure 9 shows the clinical examples of *Tinea pedis* of plantar and between-toes lesions. In Fig. 9(a), some vesicles and many squamae are observed before the laser treatment (left), but vesicles are eliminated and squamae are distinctively reduced after the laser treatment (right). In Fig. 9(b), light rubefaction and squamae are observed before the laser treatment (left), but lesions have almost disappeared after the laser treatment (right). Figure 10 shows the structure of human plantar skin prior to (a) and after (b) exposure to laser light by the present laser treatment system. In Fig. 10(b), upper parts of stratum corneum are burned, but heat effects by laser light on stratum spinosum, stratum basale and corium are not observed at all. Figure 11 shows the results at both hospitals. The efficacy of the Melase 1000 therapy in the treatment of plantar lesions (vesicular type) caused by Trichophyton can be summarized as follows. The improvement rate in the skin findings was

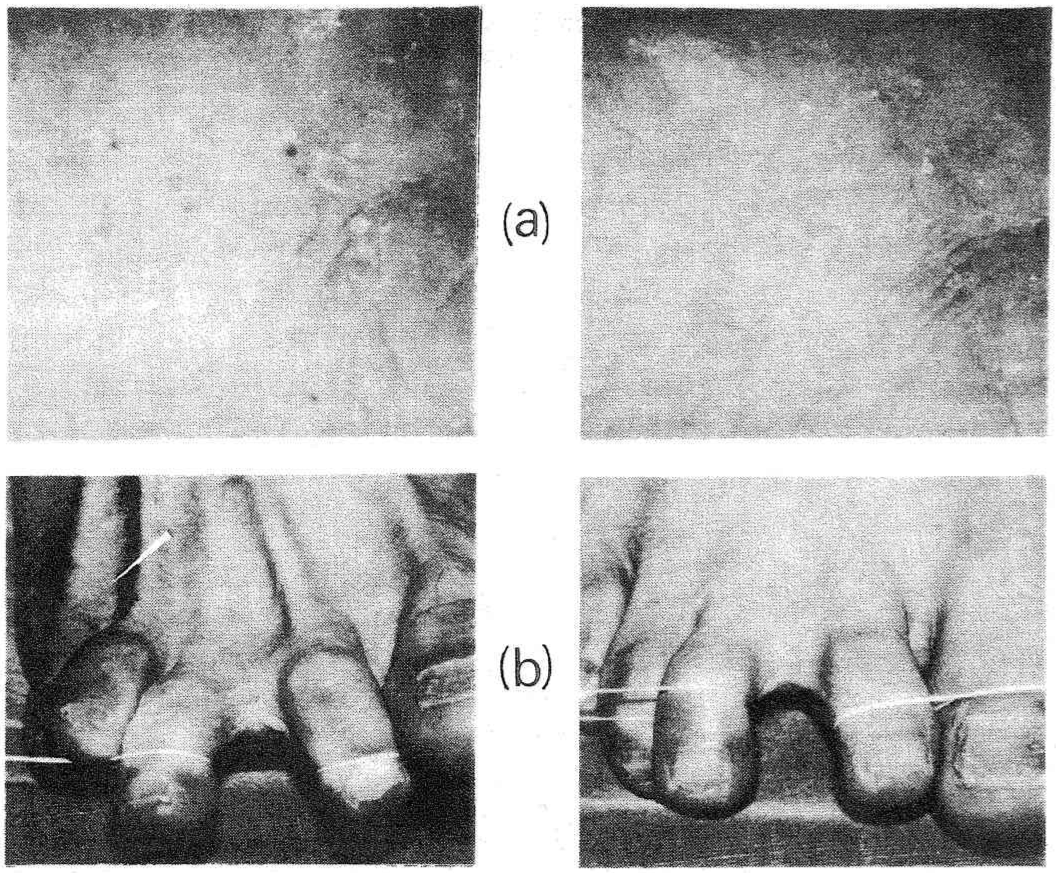

Fig. 9. Clinical example of *Tinea pedis* (vesicular type). (a) For plantar lesions, (b) for between-toes lesions. The left corresponds to the one prior to laser treatment and the right to the one after laser treatment.

71·8%; the combined efficacy rate of the fungi-eliminating rate and the improvement rate in the skin findings was 60·6%, and the usefulness rate based on cases rated as 'useful' or 'better' was 66.2%. From these results it can be concluded that the Melase 1000 therapy is safe and useful. Furthermore, it was found that this treatment was especially effective in preventing itching of the vesicular lesions, and eliminating this annoying symptom.

5 CONCLUSIONS

The CO_2 laser treatment system of *Tinea pedis*, which was approved for manufacturing in Japan as a 'Laser therapy apparatus' has been described, including its treatment efficacy and the optimum condition for the laser irradiation.

The main advantages of this laser treatment method are that the treatment is highly safe, that treatment time for healing is dramatically reduced compared to conventional pharmaceutical agents, and that

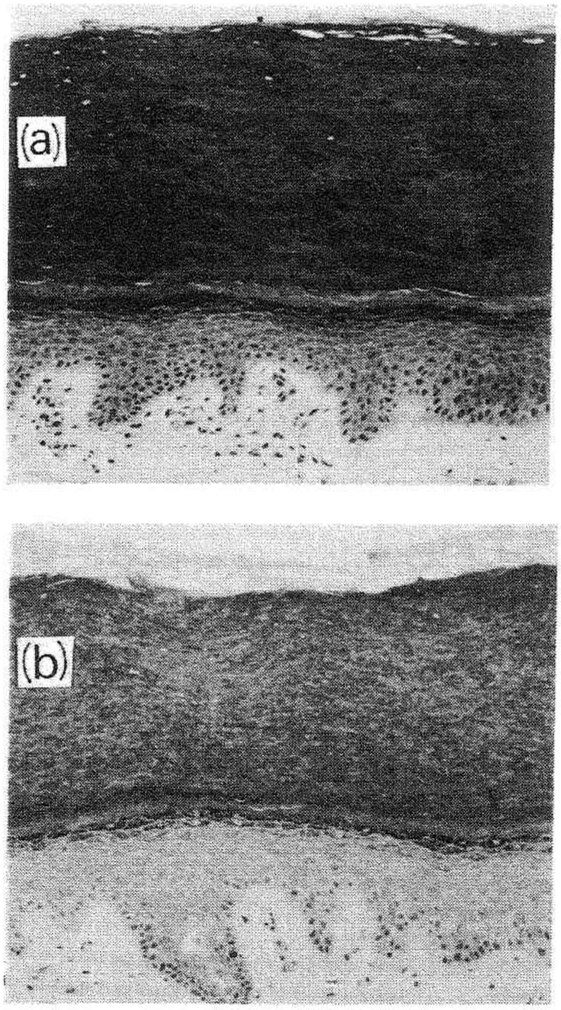

Fig. 10. Structure of human plantar skin. (a) Prior to laser light exposure, (b) after exposure to three pulses of laser light. These were obtained by the light fluence of 3·4 J/cm^2 and exposure interval of 1 s.

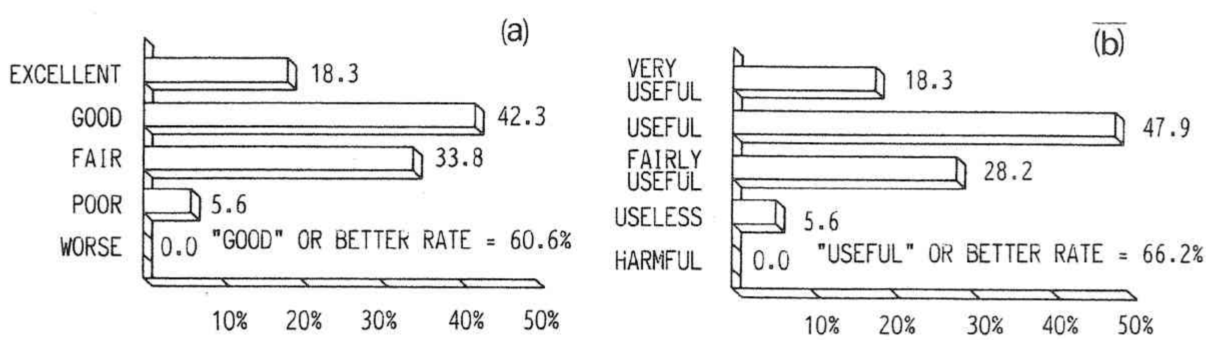

Fig. 11. Clinical data of the *Tinea pedis* treatment by Melase 1000. (a) Final overall effect judged from KOH test results and skin findings. 'Excellent' means that fungi are eliminated and diseased skin parts are completely or almost eliminated; 'good' means that fungi are eliminated and diseased skin parts are remitted; 'fair' means that fungi remain and diseased skin parts are slightly remitted or fungi are eliminated and diseased skin parts are unchanged; 'poor' means that fungi remain and diseased skin parts are unchanged; and 'worse' means that fungi remain and diseased skin parts deteriorate. (b) Results of usefulness. Usefulness was determined on the final test day judging from improvement rates and side effects in the whole test process. In case of a discontinuation of the treatment due to healing or deterioration, usefulness is determined at that point in time.

patients feel very little discomfort thanks to laser treatment by pulses that last only one millionth of a second. The present treatment system is compact, safe and easy-to-operate and the laser resonator incorporated in this system maintains a stable power for prolonged use.

The clinical data on *Tinea pedis*, which were attained after only six consecutive treatments, that is, twice a week for three weeks, show that the improvement rate in the skin findings was 71·8% and the usefulness rate on cases rated as 'useful' or 'better' was 66·2%. The optimum condition for the laser treatment is a light fluence of about 3 J/cm^2 and a laser pulse number of four with a time interval between pulses of 1 s for a typical horny layer thinner than 0·5 mm.

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