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INJURY THRESHOLD OF RUBY LASER IRRADIATION ON HUMAN SKIN

BY: Chen Ji, Wang Jun, Lu Shanfen, Xu Guidao, Shi Liangshun
Qian Huanwen, Wang Denglong

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This paper reports experimental results of human skin exposed to ruby laser light. By statistical analysis of the erythema produced within 24 hours post-exposure, ED_{50} about $4.6J/cm^2$ was obtained.

There have already been reports and evaluations in foreign countries concerning damage to human skin from ruby laser irradiation^[1-4]. However, all of these reports were on the skin of people from the Caucasus and of blacks. Their skin lesion threshold values are fairly high, and are not completely appropriate for asians.

On the basis of experiments with pig skin, this article uses the same ruby laser to irradiate human skin, observing the erythema occurrence rate, and through statistical processing, calculates the dosage for 50 percent erythema reaction.

I. Experiments

The ruby laser has a multimode pulse output. Its pulse width is 0.32 ms, and angle of dispersion is 28-29mrad. It has a maximum output of 18J, and an aperture of 0.5 cm. The output energy stability within was $\pm 5\%$. The radiation energy measurements were taken through live time measurements of the rear chamber output. The energy receivers were a JNK-1 model optical carbon energy measuring device and a metal plated inverse pile energy measuring

device, both of which had been calibrated.

The average temperature in the laboratory was $30.1 \pm 1.4^\circ\text{C}$. The testing group consisted of 15 people, all of which were Han Chinese and averaged 39.5 ± 8.9 years of age. Prior to irradiation we conducted the necessary physical examination and EKG. There were no abnormal changes before or after laser irradiation. The first irradiation point was three centimeters below the horizontal crease in the center of the inside of the elbow, and every two centimeters there after for five points, using different radiation doses (averaging 0.52-2.8J). A total of ten test points were used on the left and right forearms, distributing the different radiation doses into five groups in order to obtain a 50 percent erythema dosage (ER_{50}). Immediately after irradiation we observed the skin reaction at the irradiated area and the occurrence of erythema. Thereafter, observations were conducted at 2, 12, 24 and 48 hours post-exposure.

II. Results

Tab. 1 Erythema occurrence rate with ruby laser irradiation of human skin

1 组 别	2 照射剂量均值 $\pm S_x$ (J/cm ²)	3 吸收剂量均值 $\pm S_x$ (J/cm ²)	4 照射点数 (个)	5 红斑发生率 (%)
1	14.01 ± 0.72	8.63 ± 0.61	29	100
2	7.01 ± 0.56	4.32 ± 0.30	30	90
3	5.45 ± 0.25	3.37 ± 0.24	33	57.6
4	3.92 ± 0.31	2.43 ± 0.24	30	36.7
5	2.63 ± 0.08	1.62 ± 0.11	30	6.7

1. Group. 2. Radiation dosage $\pm S_x$ (J/cm²). 3. Average absorption value $\pm S_x$ (J/cm²). 4. Number of irradiation points. 5. Erythema occurrence rate (%).

Occurrence of Erythema: There were a total of 152 effective exposure points in this experiments distributed among five radiation dosage groups. Each group had about 29-33 samples (see Table 1). We can see from Table 1 that the erythema occurrence rate dropped as the radiation dosage was decreased. The time of the occurrence of erythema changed with the radiation dosage (see Table 2). With large dosages of radiation, the erythema occurred very quickly, and the occurrence rate was very high. With low radiation dosages, the erythema occurrence rate was lower. As the table shows, with a reduced radiation dosage, the erythema occurrence time was delayed.

Tab. 2 Erythema occurrence rate and disappearance rate of skin on inside forearm

1 组 别	2 红斑发生率(%)		5 红斑消退率(%)		
	3 5分钟内	4 6分钟~1小时	6 2~12小时内	7 13~48小时内	8 3天以上
1	96.6	3.4	10.3	20.7	69.0
2	66.7	33.3	18.5	48.1	33.4
3	36.8	63.2	47.4	52.6	—
4	27.3	72.7	63.6	18.2	18.2
5	50.0	50.0	100	—	—

1. Group. 2. Erythema occurrence rate (%). 3. Within five minutes. 4. Six minutes to one hour. 5. Erythema disappearance rate (%). 6. Two to twelve hours. 7. Thirteen to 48 hours. 8. Over three days.

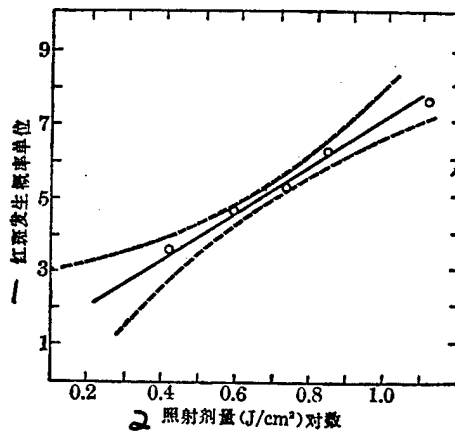
2. Disappearance of erythema. The length of time for the disappearance of the erythema following irradiation depended on the dosage (see Table 2). This indicates that with higher dosages of exposure, the longer the erythema remained, and the smaller the dosage of exposure, the shorter the length of time the erythema remained.

3. Follow-up observations: At different intervals following laser radiation, observations were made of the exposed areas and the skin reactions. (1). Severe erythema reaction (about 20.7 percent). Slightly elevated above the surface of the normal skin forming small itchy bumps, and even some blisters, with scabs forming one to two days later, and the scabs falling off in six to seven days following exposure. In some of the cases of severe erythema, there was no visible blistering, but scabs formed on the surface of the skin. (2). Relative severe erythema: Not visibly elevated, no bumps and no blisters. In the early stages the skin was red, and then gradually turned purple to dark purple. The boundaries were distinct and remained for a long time, generally disappearing four to five days following exposure. (3). Moderate reaction. Visible redness, distinct boundaries, no swelling, no bumps, even with the surface of the normal skin. Not easily visible at the start, but gradually becoming more distinct after a certain length of time. Within test group 2, only group member eight had dry scab formation, which occurred three days after exposures. These disappeared later. The other erythema cases were either slight or very slight reactions: no bumps, no blisters and the area remained even with the level of normal skin. In there early stages there was a slight reddening which later became red. The boundaries were either distinct or indistinct. The third and fourth dosage groups all had slight or very slight erythema reactions, with slight reddening, usually in a circular pattern with distinct boundaries. The fifth dosage group had two cases of erythema. One was five minutes after exposure and the other 30 minutes after exposure. both were slight erythema reactions and both disappeared two days after exposures, with only a slight discoloration remaining. In pretesting, when we used dosages of less than $2.5\text{J}/\text{cm}^2$ (such as $2.4\text{J}/\text{cm}^2$) laser exposure, we did not note any occurrence of erythema, so $2.6\text{J}/\text{cm}^2$ serves as the practical lower threshold.

Calculating fifty percent erythema dosage (ED_{50}): Under the conditions of these experiments, each group data was statistically processed using the Bliss Method to weight the iterative regression calculation, solving the equation and ED_{50} and its 95 percent credibility.

$$ED_{50} \approx 4.7J/cm^2$$

Fig. 1 Relationship between occurrence of human skin erythema and ruby laser irradiation



1. Erythema occurrence rate units. 2. Radiation dose (J/cm^2) logarithm.

The 95 percent credibility limit is between 4.217 and $5.147J/cm^2$. Testing with χ^2 , $\chi^2=1.8683$, thus $\chi^2_{0.05}=7.8405$, $P>0.05$, indicating that the calculation model conforms with actual measured values. These experimental results are acceptable (see Figure 1).

III. Conclusions

In the same dosage group, due to the different reflectivity of

the human skin, there was differences in the absorption of laser energy. Thereby resulting in differing degrees of skin erythema effects. The greatest ruby laser reflectivity of the forearms of the subjects in these experiments was 43.8 ± 1.9 percent and the lowest was 32.5 ± 1.8 percent, with the average being 38.8 ± 3.6 percent. Therefore, in the highest dosage group, those having lower reflectivity absorbed more laser energy and the erythema reaction was more severe. In the lowest dosage group, it was possible to induce erythema in those subjects with lower reflectivity, but not in those subjects with higher reflectivity. Therefore, the deepness of the color of the skin and the amount of reflectivity has a very large effect on the skin erythema effect.

Tab. 3 Comparison of experimental results on the injury threshold of human skin

	本实验参试者	黑人	高加索人
参试人数(人)	15	2	4
照射点数(个)	152	105	100
辐照量(J/cm ²)	2.6~14.0	0.5~8.0	5.0~30.0
皮肤反射率(%)	32~44	30~41	52~62
红斑发生率(%)	57.9	32.4	72
ED ₅₀ (J/cm ²)	4.7	2.2~6.9	11~20

1. Subjects in our experiments. 2. Blacks. 3. People from the Caucasus. 4. Number of subjects. 5. Number of exposure points. 6. Exposure dosage (J/cm²). 7. Skin reflectivity (%). 8. Occurrence of erythema (%).

Through statistical processing of the results obtained in these experiments, using the Bliss method to weight the iterative regression, we calculated the ED₅₀ to be about 4.7J/cm². It is 2.3 to 4.3 times of people from the Caucasus and 0.5 to 1.5 that of blacks. We can thus see that the skin of Chinese people is closer to that of blacks. The effective dosage is also close to that of

blacks, about 1.4J.

ANSI stipulates that the maximum permissible exposure (MPE) of visible light radiation to the skin is 150mJ/cm². The ED₅₀ obtained in these experiment compares to an MPE of 31. That is to say that the skin of Chinese people has an injury threshold which is fairly close to the MPE. When drafting laser safety and protection standards, consideration should be given to this factor.

We would like to take this opportunity to express our gratitude to Comrade Tang Zhongming for his assistance in the statistical processing.

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RETINAL INJURY THRESHOLD BY CW Nd³⁺:YAG LASER LIGHT

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ABSTRACT

One hundred Chinchilla rabbit eyes were exposed to CW Nd³⁺:YAG laser light. Using ophthalmoscopic criteria for retinal injury, the intraocular injury points (ED₅₀) were 2.52 W/cm² and 5.42W/cm² for exposure times of 1.02 and 0.12 seconds respectively.

This article used a continuous wave (CW) Nd³⁺:YAG laser at the eye injury threshold for the purpose of providing a biological reference basis for determining safety standards.

I. Experimental equipment and methods

For our experiments the radiating equipment was composed of a JQY-1 model CW Nd³⁺: YAG laser, an exposure time monitor, an electrical high speed shutter, a He-Ne laser and a beam limiting aperture. The laser maximum output power was 9.5 W. After the laser light beam angles of dispersion were compressed by a 16 mrad three power telescope lens and a 3 mrad one-way lens. The power output had a stability of less than $\pm 5\%$. The beam limiting aperture was 5mm in diameter. The radiating equipment and optical circuit are shown in Figures 1 and 2.

The animals used in the experiments were chinchilla rabbits. They weighted between two and three kilograms. Their retinas were

checked and all were normal prior to the experiments. None were farsighted more than 2.25D and none were nearsighted more than 1.00D. No corrections were made.

Figure 1. CW Nd³⁺:YAG laser radiating equipment

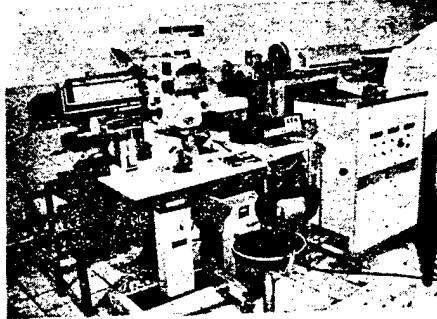
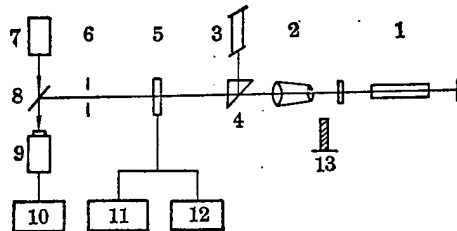


Fig. 2. CW Nd³⁺:YAG laser power measuring optical circuit



1. CW Nd³⁺:YAG laser. 2. transmitting telescope lens. 3. He-Ne laser. 4. Right-angle prism. 5. High speed shutter. 6. Aperture. 7. TOPCON retina camera. 8. Mirror. 9. RKP-545 probe. 10. RK-5200 laser power rater. 11. Timer. 12. Time monitor. 13. Shield.

The laser radiation portion was restricted to the central optical area at the extreme rear portion of the rabbits' eyes. Each eye was exposed to ten samples and given an ocular examination one hour and 24 hours after exposure, with two or more persons concurring. Vivisection was performed on some animals with the eyeball removed and given a pathological tissue examination.

II. Results of the experiment

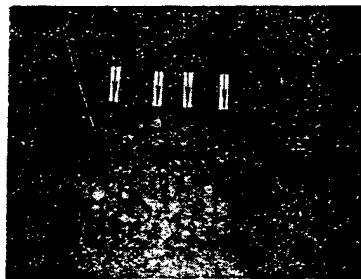
The range of radiation in this experiment averaged 2.02 to 9.09W/cm². The average times of exposure were 1.02 and 0.12 seconds. Five dosage groups were exposed each time. A total of 100 rabbit eyes were exposed for a total of 1000 sample points.

1. Appearance of retina damage

With the radiation dosages in this experiment, the retina damage was slight. One hour after exposure an ocular examination noted small circular and oval light gray or whitish gray spots with a small number of small black dots around the periphery and in the middle. Around the peripheries of some there were light gray-white edema rings. Some of the more serious reactions had black burn spots the size of the point of a needle and some showed bleeding from a small spot in the middle of the injury.

An examination 24 hours after exposure showed that the injury had enlarged and the black grains around the periphery had increased markedly. Three to five days later the edema had decreased, and five to ten days later the injury had shrunk, forming a light gray discolored spot.

Fig. 3 Rabbit eye retinal injury following 0.1 second 5.09W/cm² irradiation by CW Nd³⁺:YAG laser



Retinal injury following irradiation by the Nd³⁺:YAG laser is shown in Figure 3.

2. Relationship between Laser radiation dosage, radiation times and incidence of rabbit retinal damage

There were a total of 10 dosage groups in this experiment, with groups one through five averaging exposure time of 1.02 seconds and groups six through ten averaging exposure time of 0.12 seconds. The laser radiation dosage and exposure times and incidence of retinal injury are shown in Table 1.

Tab. 1 CW Nd³⁺:YAG laser radiation dosage, exposure times and incidence of retinal injury in rabbit eyes

实验 分组 1	平均照 射时间 (s) 2	平均角膜入射剂量 ³		损伤发生率 ⁴	
		(W)	(W/cm ²)	损伤数/ 样点数 ⁵	(%)
1	1.019	6.30×10^{-1}	3.21	92/100	92
2	1.022	5.62×10^{-1}	2.87	73/100	73
3	1.023	4.99×10^{-1}	2.55	53/100	53
4	1.019	4.50×10^{-1}	2.30	33/100	33
5	1.020	3.96×10^{-1}	2.02	11/100	11
6	0.116	1.78	9.09	91/100	91
7	0.117	1.27	6.47	67/100	67
8	0.118	9.98×10^{-1}	5.09	44/100	44
9	0.119	8.37×10^{-1}	4.27	28/100	28
10	0.118	6.97×10^{-1}	3.56	13/100	13

1. Experimental group. 2. Average exposure time (seconds). 3. Average corneal exposure dosage. 4. Incidence of injury. 5. Injuries/sample points.

We can see from this table that the incidence of retinal injury increases as the density of corneal exposure power density is increased. The necessary corneal exposure power required drops as exposure time is lengthened. With an average exposure time of 1.02 seconds, and an average corneal exposure of 2.02 to 3.21 W/cm², incidence of injury was 11 to 92 percent. With an exposure time of 0.12 seconds and an average corneal exposure of 3.56 to

9.09 W/cm², the incidence of injury was 13 to 91 percent.

3. Calculating the injury threshold for CW Nd³⁺:YAG laser light

We made our statistical calculations using the Bliss incidence unit weighted iterative regression method, solving for the logarithm (X) of the Nd³⁺:YAG laser light radiation dosage and the units (Y) of incident of rabbit eye retinal injury. The regression equation and ED⁵⁰ are as follow:

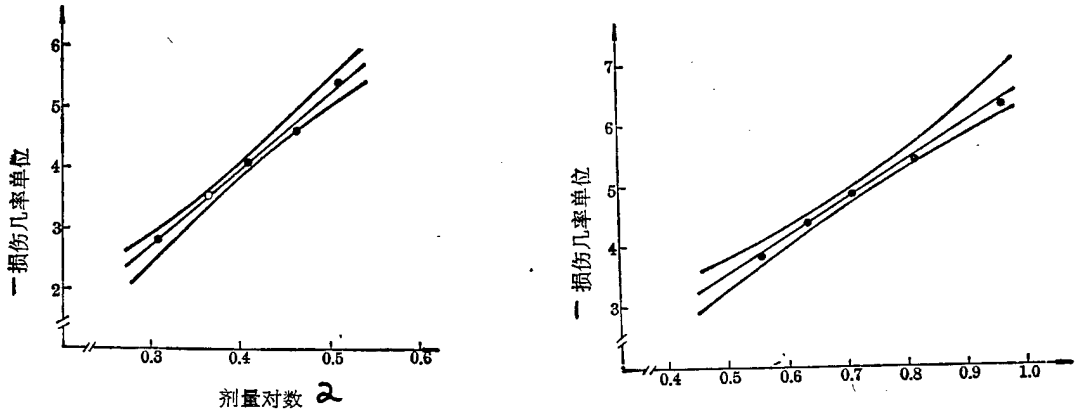
The regression equation for average exposure time of 1.02 seconds is: $\hat{Y} = 1.2.45X + 0.0065$, and $ED_{50} = 2.52W/cm^2$. (95 percent credibility limit is 2.46~2.58W/cm².)

When exposure time averages 0.12 seconds, the regression equation is $\hat{Y} = 5.950X + 0.6335$, and $ED_{50} = 5.42 W/cm^2$. (95 percent credibility limit is 5.16~5.69 W/cm².)

The regression line is checked by X^2 . When exposure times were 1.02 seconds and 0.12 seconds, the two group X^2 values were 1.0401 and 0.1695 respectively, both of which are clearly below $X^2_{0.005}$ value of 7.8045 ($P > 0.05$). This indicates that under the two exposure conditions, there is a good linear relationship between the dosage logarithm and incidence of retinal injury. The regression lines are shown in Figures 4.

Fig. 4. Relationship between rabbit eye incidence of injury and dosage logarithm

a. Exposure time one second b. exposure time 0.12 second



1. Incidence of injury units. 2. Dosage logarithm.

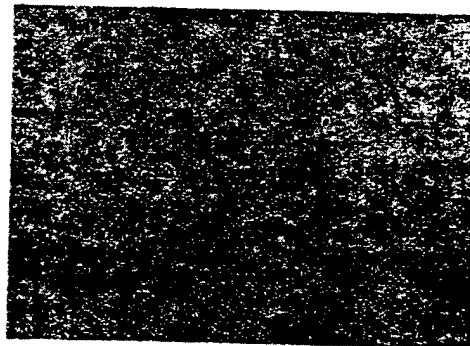
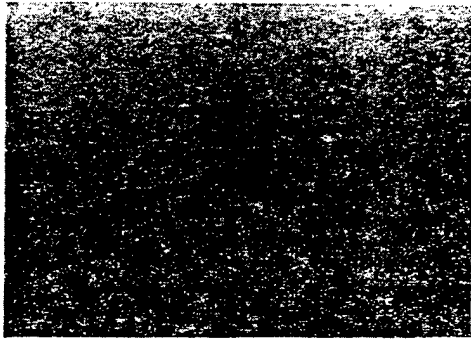
4. Pathological indications of Retinal injury from CW Nd³⁺:YAG laser irradiation

In this experiment, the dosage was close to threshold values, when exposure time averaged 10.2 seconds, radiation dosage averaged 2.55~3.21 W/cm². When exposure time averaged 0.12 seconds, retinal dosage averaged 5.09 W/cm², and there were the following indications of retinal injury.

Below the retinal membrane there was granular exudate and a gassified region, causing a slight elevating of the affected area. The gassified area was located between the liquid exudate and the external granule layer. It was circular and expanded on all sides, like a mesh, with various sized gaps. At times the nuclei of detached cells from external granular layer could be seen.

Fig. 5 Rabbit retinal injuries from CW Nd³⁺:YAG laser exposure

- (a). Subretinal Exude, gassification (exposure time 1s, 2.55W/cm²)
- (b). Subretinal exude, pigment floatation, gassified area internal, external granular Layer, exposure time 1s, 5.09W/cm²



Some pigment epithelial cells were highly swollen or even burst. The black pigment granules were dispersed and floating or massed together to form black strips. Many of the external segments of the visual cells in the injury area were broken off, but the internal and external granular layers were still orderly arranged. The typical injury was 200~300 μ m long (see Tables 5 (a) and (b)).

IV. Conclusions

In this experiment we used a JQY-1 model CW Nd³⁺:YAG laser to irradiate 100 chinchilla rabbit eyes. We made 1000 sample exposures. Using the Bliss probability weighted iteration regression method we solved for the exposure times averaging 1.02 seconds and 0.12 seconds, the retina injury thresholds, the ED₅₀ being 2.52W/cm² and 5.42W/cm² respectively. This article describes the injuries and pathological changes.

The computer statistical processing of the data in this paper

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was done with the assistance of Comrade Tang Zhongming, and we take this opportunity to thank him.

Bibliography (omitted).

RETINAL INJURY THRESHOLD OF LONG PULSE RUBY LASER LIGHT

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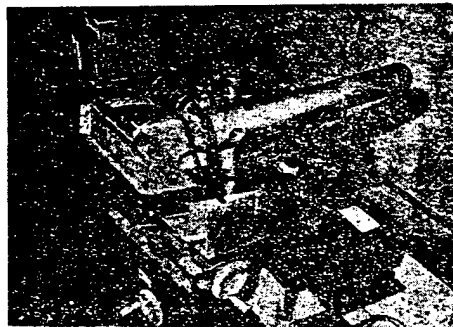
ABSTRACT

Threshold of observable retinal injury was determined for chinchilla rabbits exposed to long pulse ruby laser light irradiation. The threshold, ED_{50} was $14.9\text{mJ}/\text{cm}^2$ and its 95 percent confidence limit was $13.6\text{--}16.5\text{nH}/\text{cm}^2$ for intraocular energy density.

The red ruby laser had a wave length of 6943\AA . The eye injuries were primarily to the retina. This article studies the rabbit retina injury threshold for long pulse ruby laser light, and it provides reference for drafting laser safety standards.

I. Experimental equipment and methods

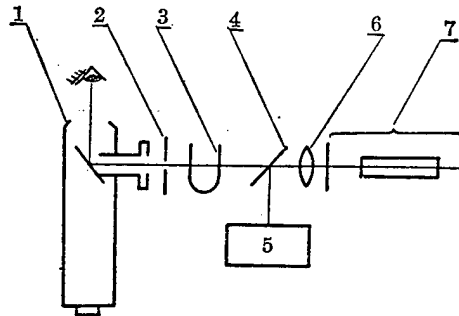
Fig. 1 Ruby Laser radiation equipment



The irradiation equipment used in these experiments included a ruby laser, laser positioning irradiation equipment, copper sulfate attenuated solvent quartz chromometer, output energy measuring system, light beam dispersion angle suppression lens and

a shutter (see Figures 1 and 2).

Fig. 2 Ruby laser radiation optical circuit diagram



1. Laser positioning irradiation equipment.
2. Shutter.
3. Attenuation ring.
4. Beam splitting lens.
5. Measuring equipment.
6. Compression lens.
7. Ruby laser.

Laser output energy was 0.1~1.8J/pulse, pulse width was 0.6ms, output energy stability was $\geq 6.6\%$, experiment light beam angle of dispersion was 4.5mrad and light beam diameter was 5mm.

We using laser fixed point radiation equipment to observe the animal's eye fundus and chose the necessary locations for fixed point irradiation. This equipment was composed of an observation, inverse image and illumination system. Magnification was 1.44 power, the field of view angle was 64° and the resolution was 0.5mm.

The measuring device used the thermal type NJ-J₂ model energy measurer. It has a light receiving surface 10mm in diameter. Its wave length reaction range is from ultraviolet to far infrared. It has a repeatability of better than 0.5 percent. Within the measurement range its reaction was always linear. It was monitored with an integrated ball energy graph. We took measurements of a total of five experimental groups, totalling 240 irradiation

points. Based on measurement statistics of 23 groups and 115 points, the beam splitting to monitoring ratio error is less than eight percent, indicating that the measurement method was reliable.

For our experiments we used chinchilla rabbits weighing between two and 2.9 kilograms. Their eye fundus were checked and were normal, for refractive error, and that for far sightedness they did not exceed 2.25D and near sightedness they did not exceed 1.0D. No vision corrections were made. An ocular examination was performed one hour and 24 hours after exposure. Some of the eyeballs were extracted for pathologic tissue examination. A total of 77 rabbit eyes and 240 sample points were irradiated.

II. Results of the experiment

The radiation dosage of the experiment was corneal irradiation of 11.7~25.0mJ/cm², with five experimental groups.

1. Indications of retinal injury: An ophthalmoscopic examination revealed light gray or gray-white circular injury spots, around the periphery of which were tiny dispersed black pigment granules. There were circles of edema around some, and within a few injury spots there could be seen black burn points the size of the point of a needle. The injury spots had enlarged slightly after 24 hours, and the edema receded. Within three to five days, black pigment deposits remained in most cases, or a small white circular scar had formed.

2. Relationship between radiation dosage and the incidence of retinal injury. See Table 1 for the radiation dosage and the incidence of retinal coagulation injury. We can see from this table that the incidence of retinal injury increases with the energy density introduced. An ophthalmoscopic examination one hour

after exposure observed injuries at 138 of the 240 test points (57.5%). After 24 hours, an examination noted an incidence of 80.6%.

Tab. 1 Ruby laser light dosage and incidence of injury to rabbit retinas

实验 分组	2 平均角膜入射剂量		3 损伤发生率	
	(J)	(J/cm ²)	4 损伤数/样点数	(%)
1	4.91×10^{-3}	2.50×10^{-2}	42/48	87.5
2	3.65×10^{-3}	1.86×10^{-2}	35/54	64.8
3	3.25×10^{-3}	1.66×10^{-2}	26/52	50.0
4	2.74×10^{-3}	1.40×10^{-2}	18/42	42.9
5	2.30×10^{-3}	1.17×10^{-2}	17/44	38.6

1. Experiment group. 2. Average corneal dosage. 3. Incidence of injury. 4. Number of injuries/number of sample points.

3. Calculating the retinal injury threshold of long pulse ruby laser light: The eye injury threshold to laser light usually refers to the radiation dosage required for 50 percent probability of ophthalmoscopic detection of visible injury one hour following retinal exposure (also called ED_{50}). Based on the results of this experiment, using the Bliss method of probability unit weighted iterative regression method, we solved for the regression equations and ED_{50} of the logarithm of the long wave ruby laser light radiation dosage and the probability unit (\hat{Y}) for rabbit retina coagulative injury.

$$\hat{Y} = 4.332X - 0.937$$

$$ED_{50} = 14.9 \text{ mJ/cm}^2$$

(95 percent confidence limit is 13.6~16.5mJ/cm²)

4. Pathologic changes of the injuries: The pathologic changes of injuries from radiation doses near the threshold were primarily to the outer layer of the retina. There was sub-retinal edema exudation, causing the entire injury to be slightly elevated. The inner and outer segments were broken off. The pigmented upper cells were swollen or burst, resulting in floatation of black pigment granules. In the outer granular layer and in the exudated liquid under the retina there were "gassified areas" at the injuries., forming mesh type gaps. There was pyknosis of the nuclei of some of the outer granular layer cells, and some had fallen into the gassified area. There were individual cases of swelling or necrosis of the nerve section cells, and of empty cells without cytoplasm. However, the outer cellular membrane was intact, and no obvious abnormalities were noted in the choroidea or sclera in the injury area. A typical injury is shown in Figure 3.

Fig. 3 Rabbit retinal injury from ruby laser light



Sub-retinal exudation, free pigment cells and cell swelling, (average irradiation of $16.6\text{mJ}/\text{cm}^2$)

For this experiment we used a modified model JLX ruby laser slit-lamp microscope to irradiate 76 rabbit eyes, for a total of

240 irradiation points. Using the Bliss probability unit weighted iterative regression method, we solved for the ruby laser light retinal coagulative injury threshold value, its ED_{50} was $14.9\text{mJ}/\text{cm}^2$. Its 95 percent confidence limit was $13.6\text{--}16.5\text{mJ}/\text{cm}^2$. This article also describes the indications of injuries and the pathologic changes.

Comrade Tang Zhongming assisted in the computer statistical processing of the data in this paper, and we take this opportunity to express our gratitude to him.

STUDY OF RETINAL THRESHOLD FOR Nd:YAG FREQUENCY
DOUBLED LASER LIGHT

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ABSTRACT

When the eyes of chinchilla rabbits and Rhesus monkeys were exposed to a laser pulse at the wavelength of $0.53\mu\text{m}$, the ED_{50} values obtained were $39.2\text{uJ}/\text{cm}^2$ and $187\text{uJ}/\text{cm}^2$ for intraocular energy density respectively. The results of the experiment demonstrate that monkey fundus is considerably more sensitive than that of rabbits.

This paper reports a study of the injury threshold value for Nd^{3+} :YAG frequency doubled laser light irradiation of rabbit and monkey eyes in order to provide reference for drafting laser safety standards.

I. Irradiation equipment and experiment methods

In this experiment we used an Nd^{3+} :YAG laser composed of one level oscillation. We used KD^*P to adjust λ , output was $1.06\mu\text{m}$ base frequency light. We used a KDP multiplier, with out being 0.53μ green light. The pulse width was 5ns. The beam dispersion angle was less than 0.5mrad , and output was monomodal.

The irradiation equipment and its basic optical circuit is shown in Figures 1 and 2. Different multiple attenuation chips were used before and after the multiplier crystal and the beam divider (1.06 and $0.53\mu\text{m}$), and by matching the charging voltage and changing the composition of the filter, it was possible to obtain

the required laser light radiation dosage.

The laser exposure dosage was provided by interocular energy injection. We used beam splitting for real time monitoring, measuring the radiation dosage of 1,382 experimental samples in 13 groups. There were 45 groups, 496 data statistics, with a measurement error of 1.7 to 4.8 percent, meeting the minute energy precision requirements for biological effect experiments.

Fig. 1 Nd³⁺:YAG frequency doubled laser retinal injury irradiation equipment

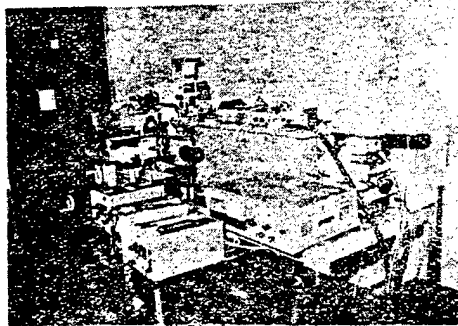
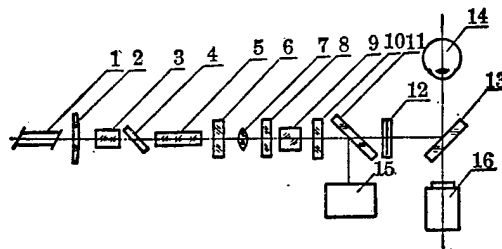


Fig. 2 Nd³⁺:YAG frequency doubled laser light retinal injury irradiation equipment optical circuitry



1. He-Ne Laser. 2-7. uneven surface unstable chamber laser. 8, 12. Attenuation chips. 9. frequency multiplier crystal. 10. 1.06 μ m light filter. 11. Wave splitting lens. 13. Mirror. 14. Animal irradiated eye. 15. Energy measuring device. 16. TOPCON fundus camera.

For the animals of our experiments, we selected chinchilla rabbits weighting two to three kilograms and rhesus monkeys

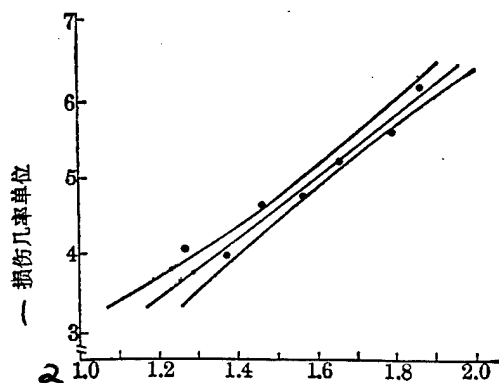
weighing two to seven kilograms. We checked the animal eyes prior to the experiment and all were normal. One and 24 hours following exposures we inspected the fundus of the eyes, with two or more people concurring on the results. There were a total of 530 irradiation points in 70 rabbit eyes and 220 irradiation points in ten rabbit eyes in this experiment.

II. Results of the experiments

1. Study of rabbit retina injury threshold

The density range of rabbit eye irradiation energy averaged $14.4\sim 70.1\mu\text{J}/\text{cm}^2$. The energy range averaged between 2.83 and $13.7\mu\text{J}$. The indications of retinal injury ranged from the slightest injury of a small circle of pigment or an accumulation of pigment, which mostly disappeared 24 hours later. Another type of slight damage was a circular light gray congealed edema spot, which might have some pigment sediment at the center, and the boundaries not being very distinct as shown in Figure 3. Some of the injuries disappeared within 24 hours, but most formed pigment spots in 72 hours. As the dosage was increased, a small number of slightly bleeding spots appeared, which were circular or flower shaped.

Fig. 3 Relationship of rabbit eye retina injury probability and laser irradiation dosage



1. Injury probability unit. 2. Dosage logarithm.

The results of the experiments indicate that the incidence of

retinal injury caused by Nd³⁺:YAG laser light increased as the energy density increased. The relationship between dosage and incidence of retinal injury within one hour is shown in Table 3. Using the Bliss probability unit weighted iteration regression method, we solved for the regression equations of irradiation logarithm (X) and the probability unit (Y) of the incidence of retinal injury and the threshold value ED₅₀:

$$\hat{Y} = 3.838X - 1.116$$

$$ED_{50} = 39.2 \mu\text{J}/\text{cm}^2$$

(95 percent credibility limit of 36.5~42.1 μJ/cm²)

The regression graph of the probability unit of rabbit retina damage and dosage logarithm is shown in Figure 3.

Tab. 1 Relationship between rabbit retinal injury probability unit and dosage logarithm with Frequency doubled Nd³⁺:YAG laser light

实验 分组	2 平均角膜入射剂量		3 损伤发生率	
	(J)	(J/cm ²)	损伤数/样点数	(%)
1	2.83 × 10 ⁻⁶	1.44 × 10 ⁻⁵	0/22	0
2	3.61 × 10 ⁻⁶	1.84 × 10 ⁻⁵	7/44	15.9
3	4.44 × 10 ⁻⁶	2.27 × 10 ⁻⁵	7/48	14.6
4	5.54 × 10 ⁻⁶	2.83 × 10 ⁻⁵	20/58	34.5
5	7.04 × 10 ⁻⁶	3.59 × 10 ⁻⁵	37/91	40.7
6	8.64 × 10 ⁻⁶	4.41 × 10 ⁻⁵	47/80	58.8
7	1.09 × 10 ⁻⁵	5.55 × 10 ⁻⁵	74/107	69.2
8	1.37 × 10 ⁻⁵	7.01 × 10 ⁻⁵	69/80	86.2

1. Group. 2. Average corneal input dosage. 3. Injury incidence.
4. Injuries/number of samples.

2. Study of monkey retina injury threshold

The range of radiation energy density used on the monkey eyes averaged 210~327 μJ/cm², and the energy range was 412~642 μJ. With

this dosage, the injuries were all slight, seen as a small circular light gray congealed spot or dot with distinct boundaries. In this experiment, we irradiated 220 sample points. After one hour there were 52 congealed injury spots, and after 24 hours some of the injuries disappeared, but another 13 injury spots appeared.

Tab. 2 Frequency doubled Nd³⁺:YAG laser radiation dosage and incidence of monkey retina injury

实验 分组	2 平均角膜入射剂量		3 损伤发生率	
	(J)	(J/cm ²)	损伤数/样点数	(%)
1	4.12×10 ⁻⁶	2.10×10 ⁻⁵	1/59	1.69
2	9.13×10 ⁻⁶	4.66×10 ⁻⁵	2/54	3.70
3	1.78×10 ⁻⁵	9.08×10 ⁻⁵	4/31	12.9
4	3.42×10 ⁻⁵	17.5×10 ⁻⁵	27/54	50.0
5	6.42×10 ⁻⁵	32.7×10 ⁻⁵	18/22	81.8

1. Experimental group. 2. Average cornea dosage. 3. Incidence of injury. 4. Number of injuries/number of sample points.

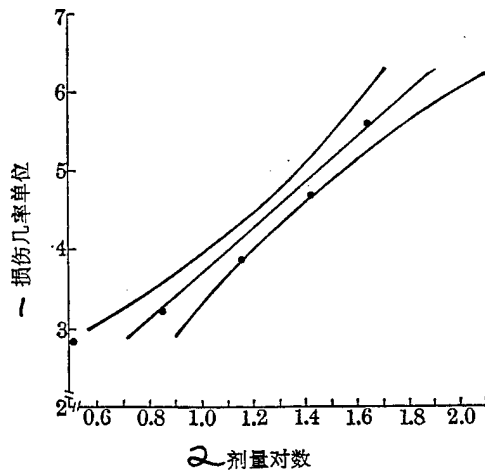
Table 2 shows the monkey retina injury incidence within one hour of irradiation with 0.53μm laser light. Using the Bliss probability unit weighted iteration regression method, we solved for the regression equation for the retina congealed injury probability unit (Ŷ) and the radiation dosage logarithm (x) and the ED₅₀ as follow. The regression graph is shown in Figure 4.

$$\hat{Y} = 2.804x - 1.373$$

$$ED_{50} \approx 187\mu\text{J}/\text{cm}^2$$

(95 percent credibility limit is 156~238μJ/cm²)

Fig. 4 Relationship between monkey retina injury probability unit and Nd³⁺:YAG laser light dosage logarithm

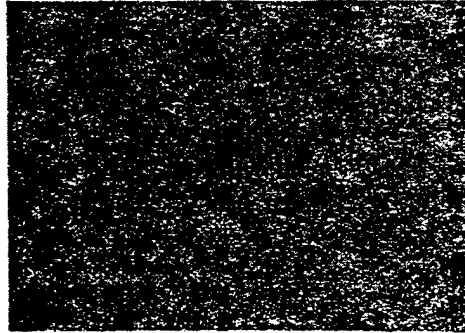


1. Injury probability unit. 2. Dosage logarithm.
3. Pathological observations of retina injuries

The typical manifestations of retinal injuries from near threshold radiation dosages include visible sub retina exudation, swelling of pigmentation cells, black granules floating, breaking off of external segments, edema exudation and gassification areas bursting the external granular layers, appearance of nucleus pyknosis within the internal and external granular layers, and slight elevation of the overall injury. The filling and expansion of blood vessels of the choroidea could be seen as shown in Figure 5. The typical damage to the monkey retina was also primarily congealment and edema exudation, sub-retina exudation of fluids, causing the external granular area cells to be elevated, a marked edema exudation between the outer and inner plexiform layers, nucleus pyknosis in the external granular layer and pyknosis within the center of the injury forming something that looks like the mouth of a volcano (see Figure 6). However, we did not note any lesions of the internal limiting membrane. Inside the concave center of some injuries there were visibly raised granular layer

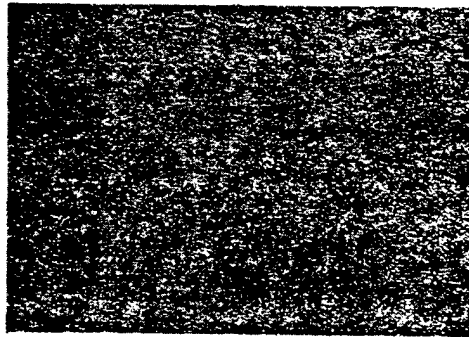
cell nuclei from gas impact. There was no visible change in the choroid.

Fig. 5 Rabbit retinal injury from Nd:YAG laser light



Injury (magnified 126 times) (Sub-retinal exudation, pigmentation floating, external granular layer exudation of gaseous area, corneal irradiation of $7.28\mu\text{J}$)

Fig. 6 Monkey retinal injury from Nd^{3+} :YAG laser light



Injury (magnified 63 times) (sub-retinal exudation, inner layer pyknosis).

Bibliography (omitted).