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INJURY EFFECTS OF LASERS ON EYES

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ABSTRACT:

The injurious effects of different wavelength laser with various operating mode and exposure doses on eyes were reported. Comparision of laser damage effects on eyes was conducted between rabbits with different extent of pigment. The ratio of laser damage threshold for eyes of rabbit, monkey to the yellow race was also discussed.

The eye is an imaging system sensitive to light. An incident laser beam can form an image in a very small retinal area so that the dosage (irradiance or illumination) increases by four to five orders of magnitude; very little incidence can cause serious injuries. Therefore, the emergence of the laser brings about a new topic on medical research into eye effects from exposure to lasers.

In this article, related materials published in China were collected relevant to our work on discussing laser injury effects on rabbit eyes at different wavelengths, different emission approaches (different illumination time), and different dosages.

The injury dosages of rabbit eyes with different pigments were compared. The ratios on injury threshold values for the eyes of rabbits, monkeys, and humans are given.

I. Experimental Conditions

The experimental conditions included laser illumination installations, laser parametric test equipment, experimental animals, and injury observation instruments.

1. Laser illumination apparatus

The article presents data for eight wavelengths, with a total of nine laser illumination apparatus. There are two types of emission methods: continuous and pulsed.

Generally, the continuous laser illumination apparatus includes a continuous output laser device such as He-Ne, Ar^+, CO_2, or CW-YAG; light-switching systems, illumination-time real-time inspection system, dosage-adjustment attenuation system, three-dimensional animal-illumination platform, fixed-point real-time observation apparatus, real-time monitoring power meter, threshold aperture diaphragm, and He-Ne alignment system. Fig. 1 shows the typical optical path.

The pulse illumination apparatus generally include a pulse laser device, such as Nd^{3+}: YAG, ruby, excimer, YAG frequency doubler, pulsed carbon dioxide laser devices, filters ensuring monochromatic light beams, neutral filters for dosage adjustment, threshold-aperture diaphragm, real-time monitoring energy meter, fixed-point illumination and real-time observation system, He-Ne alignment system, and a three-dimensional animal adjustable illumination platform. Fig. 2 shows the typical optical path.

2. Laser parametric test instrument

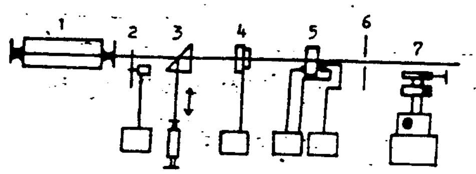

Fig. 1. Optical path diagram of typical apparatus for continuous light illumination ($CW-CO_2$ illumination apparatus)

LEGEND: 1 - CO_2 laser device 2 - dosage adjustment rotating steel net 3 - aligned He-Ne laser device 4 - passing through type power meter for monitoring 5 - shutter and illumination time measurement system 6 - threshold aperture diaphragm 7 - three-dimensional adjustment illumination frame

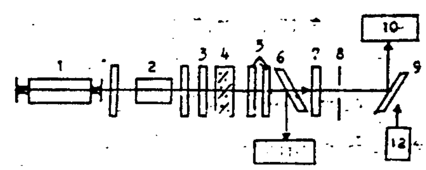

Fig. 2. Optical path diagram of typical apparatus for pulse illumination (YAG frequency doubler)

LEGEND: 1 - aligned He-Ne laser device 2 - YAG laser device 3 - nonsteady cavity compensation lens 4 - frequency doubler 5 - 1.06μm filter beam plate 6 - beam splitter 7 - dosage adjustment filter 8 - threshold-aperture diaphragm 9 - 0.53μm 45° reflective mirror 10 - energy meter (for illuminating eyes) 11 - RJ-7200 energy meter 12 - Topcon ocular fundus lens

In this experiment, there are the following laser parameters to be tested: laser power or energy, pulse duration or illumination time, cornea-incident light spot, and light-beam divergence angle. The laser power and energy were measured, respectively, with an RK-5200 power meter and an RJ-7200 energy meter. The instruments were periodically calibrated in conformity to state measurement standards. The pulse durations were measured with a high-current tube and a model 7904 oscilloscope. The incident light spot measurements involved the threshold-aperture diaphragm diameter placed in front of animal eyes prior to experiments; infrared and ultraviolet rays were used mainly to cause corneal injuries. The diaphragm diameter was OD1mm. The visible light and near-infrared rays with OD5mm were used mainly to cause retinal injuries. The light-beam divergence angle was obtained by using photographic film optical light-spot method (or photographic method).

3. Animals in experiments

Blue-, purple-, and gray-eyed rabbits weighing 2-3kg, as well as Macacus rhesus monkeys weighing 2-7kg were used in the experiments.

4. Eye examination instruments

Handheld eye inspection lens and Topcon eye ground camera were used to examine injuries to the eye ground. A slit lamp was used to examine corneal injuries.

II. Experimental Methods

Generally, each wavelength was divided into five to ten dosage groups. Before the experiments, the related parameters of laser illumination apparatus were measured, as well as the required dosages. Moreover, He-Ne light beam or fixed-point illumination apparatus was used to indicate the position of rabbit eyes to be illuminated. By examining the animal cornea and eye ground, those with normal corneas were experimented on. Before illumination, 0.5% tropine amide was used to dilate the pupils. The animals were immobilized on a three-dimensional adjustment frame. By adjusting the frame, the eye illumination position was adjusted to the designated position of He-Ne light beam or the fixed-point illumination apparatus, for illumination. After illumination, an examination was made immediately and within one hour to produce statistics on injury frequency and the determined extent of injury. In typical cases, photographic and sampling slides were examined under an electron microscope. The injury dosages were given from the real-time monitoring readings. For each wavelength, the dosages were applied group by group, in increasing intensity.

III. Data Processing and Results

In the research, injury effects on blue, purple, and gray eyes of rabbits were observed as caused by lasers with different wavelengths; also observed were different illumination types, (continuous, pulsed, and giant-pulsed); the frequencies of injuries and different injuries with different dosages; ratios of injury dosages of rabbit, monkey, and human eyes; as well as injury dosage comparisons for rabbit eyes with different pigments.

1. Injury effects for lasers at different wavelengths

Table 1 lists the injury threshold values for blue, purple, and gray rabbit eyes due to lasers at eight wavelengths.

TABLE 1. Injury-threshold Values for Rabbit Eyes

波长 1(nm)	照射时间 2(或脉冲)	3 实验物	4 阈值剂量	5 文献
222	8ns	6 兔角膜	$5.44\times10^{-2}J/cm^2$	
308	10—100ns	〃	$8.30\times10^{-1}J/cm^2$	
488	0.145	7 兔眼	$5.04\times10^{-1}W/cm^2$	[1]
530	5ns	〃	$3.92\times10^{-5}J/cm^2$	
530	8ns	〃	$2.32\times10^{-4}J/cm^2$	[2]
632.8	0.125s	〃	$2.15\times10^{-1}W/cm^2$	[3]
694.3	0.32ms	〃	$1.49\times10^{-2}J/cm^2$	
1060	0.1s	〃	$5.42\times10^{0}W/cm^2$	
1060	5ns	〃	$1.21\times10^{-3}J/cm^2$	
10600	0.12s	6 兔角膜	$1.08\times10^{1}W/cm^2$	
10600	180ns	〃	$2.59\times10^{-1}J/cm^2$	

KEY: 1 - wavelength 2 -illumination time (or pulse)
3 - object of experiment 4 - threshold-value dosage
5 - reference 6 - rabbit cornea 7 - rabbit eyes

As mentioned in the article, the threshold value indicates whether or not injuries occur when examined with an eye inspection lens or a slit lamp by two or more experienced scientific technicians immediately and one hour after illumination of each rabbit eye. Different dosages led to different injury frequencies. A wavelength was subdivided into several dosage groups. After illumination, the injury frequencies of different dosage groups at this indicated wavelength were statistically processed, to solve for the corresponding dosage for 50% of the injury frequency. This is called the threshold value, or ED_{50}.

From Table 1, with different wavelength and different injury threshold values, the threshold values were the lowest for 530nm green light.

2. Injury effects due to different illumination times.

Table 2 lists the threshold values for a 1060nm laser for different illumination times. With different illumination times, the threshold values are different. The pulses were narrow and the threshold values are low.

TABLE 2. Injury Effects of Different Illumination Times

1 波长 (nm)	2 照射时间	3 实验物	阈值研究 (J/cm²) 4
1060	1s	5 兔眼	2.52×10^{0}
1060	0.1s	〃	5.24×10^{-1}
1060	150μs	〃	1.46×10^{-2}
1060	5ns	〃	1.21×10^{-3}

KEY: 1 - wavelength 2 - illumination time 3 - object of experiment 4 - threshold-value study 5 - rabbit eyes

Mainly, 1060nm light has a heating effect on the tissues. With compressed pulse duration, the peak value power rose dramatically, therefore the secondary impact function was gradually pronounced due to the light impact function and slight blasting of tissues, thus the injury-threshold value was low when the pulse duration was narrow.

3. Relationship between injury frequency and dosages

Due to factors of individual differences in the animals, at a certain low dosage, not every illumination point resulted in injury. Table 3 cites an example of 1060nm experiments with data on dosage and injury frequencies.

From Table 3, with increase in dosage, the injury frequencies rose. It can be estimated that when the dosage was increased to a certain value, the injury frequency may reach 100%.

TABLE 3. Relationship Between Injury Frequency and Dosage (wavelength 1066nm and pulse duration 5ns)

分组 1	角膜入射剂量 2 (J/cm^2)	损伤发生率 3 (%)
1	9.32×10^{-4}	9.0
2	1.02×10^{-3}	20.0
3	1.16×10^{-3}	41.6
4	1.29×10^{-3}	57.0
5	1.44×10^{-3}	85.0

KEY: 1 - group 2 - incident dosage at cornea
3 - injury frequency

4. Relationship between frequency and dosage

The injury levels can be divided into mild, intermediate, and severe.

Far-infrared and ultraviolet rays mainly caused corneal injuries. Mild injuries may lead to cloudiness in the shallow layer of the cornea. Intermediate injury may lead to white condensation spots in the deep-lying or all corneal layers. Severe injuries may cause condensation and necrosis of the cornea with gasification and holes, deformation of pupillary holes, and even exudation of vitreous humor from the eye chamber, and surface cloudiness in front of the eye crystal.

Visible light and near-infrared light mainly lead to retinal injuries. Mild injuries may lead to condensation and edema of the retina. Such injuries are mild, with rapid resorption, generally not leading to damage to sight. Intermediate injuries may lead to hemorrhagic spots circular in shape or carnation-shaped, with little bleeding entering the eye crystal. As exhibited in tissue pathology, the visual receptors collapsed in the illuminated zone, and bleeding occurred in the outer retinal layer, to form convex-shaped injury foci. Most of such injuries closed over within 1-2weeks, with scars forming. For serious injuries, the corneal lesions with massive hemorrhaging, and the tissues became gasified, forming gas bubbles. Exhibited in tissue pathology the entire retinal layers collapsed with necrosis, forming volcano-shaped foci. The blood that was exuded entered the eye crystal. In such injuries, in 3-4weeks, most of the bleeding was resorbed, and a large scarred area formed in the retina.

Table 4 lists the percentages of different injuries caused by different dosage of a 693.4nm laser.

From Tables 3 and 4 when the dosages were increased, the injury frequencies rose and the injury levels also intensified.

5. Ratios of eye-injury threshold values of rabbits, monkeys, and humans

Since blue, purple, and gray rabbit eyes are similar to those of races other than caucasian, and since these rabbits can

TABLE 4. Relationship Between Injury Level and Dosage (wavelength 694nm and pulse duration 0.32ms)

分组 1	角膜入射能量 (J) 2	网膜爆裂大出血发生率(%) 3	网膜凝固轻度出血发生率 (%) 4
1	9.5×10^{-1}	100	—
2	4.8×10^{-1}	50	50
3	4.1×10^{-1}	90*	10
4	2.0×10^{-1}	30	70
5	9.1×10^{-2}	20	80

LEGEND: * mild bleeding in 60%
KEY: 1 - group 2 - incident energy at cornea
3 - injury frequencies for retinal blast and massive bleeding 4 - mild bleeding frequencies with retinal condensation

be bought at low prices, large amounts of data were obtained by experimenting on blue, purple, and gray rabbit eyes. However, there are certain differences between rabbit eyes and human eyes. How can we apply the data from rabbit eyes to human eyes? In the experiments, few Macacus rhesus monkeys were used because these monkeys have eyes very similar to human eyes. Moreover, investigation and analysis were conducted on human eye cases. Data on eye injury cases in laser treatment were also obtained, as shown in Table 5.

From the table, the ratios of injury-threshold values for rabbit eyes and human eyes are 1:2.7 to 1:4.7.

6. Ratio of injury doses for rabbit eyes with different

pigments

There are different pigments in different human races. For example, there are few pigments in caucasian eyes, but there are many pigments in our yellow race. Therefore, while experimenting on blue, purple, and gray rabbit eyes, comparative experiments were also carried out on white-eyed rabbits with little pigment. The data are listed in Table 6.

TABLE 5. Comparative Values of Injury-threshold Value Dosages of Eyes in Rabbits, Monkeys, and Humans

波长 1	眼损伤阈值 2			兔、猴、人之 3 比值	文献 4
	5 兔	6 猴	7 人		
0.488μm	0.506W/cm²	0.334W/m²	1.75W/cm²	1:1.65:3.47	[4]
〃	6.54W/cm²	13.08W/cm²	17.65W/cm²	1:2:2.7	[1]
1.06μm	97.6W/cm²	333W/cm²	429W/cm²	1:3.4:4.4	[5]
0.53μm	39.2μJ/cm²	187μJ/cm³		1:4.7	

KEY: 1 - wavelength 2 - injury-threshold values for eyes 3 - ratios among rabbits, monkeys, and humans 4 - reference

From Table 6, in the corresponding dosages, the hemorrhaging frequencies in gray-eyed rabbits were higher than in white-eyed rabbits. After statistical treatment, the ED_{50} for gray-eyed rabbits was 73.3muJ; that for white-eyed rabbits, was 104muJ. The threshold value for white-eyed rabbits was approximately 42% higher for gray-eyed rabbits.

TABLE 6. injuries to Rabbit Eyes with Different Pigments by 0.53μm Laser

分组 1	2 灰兔		3 白兔	
	角膜入射能量 4	出血发生率% 5	角膜入射能量 4	出血发生率% 5
1	76.1μJ	51	75.7μJ	0
2	105.7μJ	70	104.0μJ	50
3	138.1μJ	85	137.7μJ	64
4	169.6μJ	79	172.5μJ	79
5			200.2μJ	91

KEY: 1 - group 2 - gray-eyed rabbits
3 - white-eyed rabbits 4 - incident energy at cornea 5 - hemorrhagic frequency in %

IV. Preliminary Conclusions

In approximately five years, we used more than 1000 rabbits and more than 10 monkeys in studying the effects of injuries to eyes at different wavelengths and different illuminations. Observations were also made on the injury frequencies nd different injury levels in rabbit eyes with different pigments, at different dosages. Different injury-threshold values in eyes of rabbits, monkeys, and humans were collected, obtaining data ratios for these three groups. These data provide a biological basis for medical evaluation of acute eye injuries, and prescription of laser safety standards.

Brief resumes of authors: Xu Guidao, see Laser Technology, Vol. 12, No. 1, page 43, 1988, Laser Technology; and Xu Jiemin, female, was born in April 1930. She is a researcher with multiple awards from the Ministry of Public Health and the Liberation Army for accomplishments in science and technology. Presently, she is engaged in laser biological science research and experimental ophthalmology.

Also taking part in the research were Chen Zongli, Qian Huanwen, Wang Denglong, Gao Guanghuang, Shi Liangshun, Zhang Guisu, Hu Fugen, Zhu Shuying, Cao Weijun, and Liu Haifeng.

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