Minimal spot size on the retina formed by the optical system of the eye

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Abstract

A knowledge of the quality of the ocular optical system is of primary importance in light- and laser-photocoagulation of the fundus. A study was therefore undertaken to determine the minimal spot size of a Helium-Neon laser focused on the retina of rabbits: freshly enucleated eyes were carefully mounted in a specially designed eye holder. A small hole was then trepanized throug the sclera and neural retina in the macular region. A minimal spot was produced on the retina and the spot size was measured by scanning the intensity distribution of an enlarged image. It was shown that a diffraction limited spot size can be obtained under certain circumstances. The light scattering out of the focus, however, is about fifty percent.

Introduction

A consideration in light and laser photocoagulation of the fundus is the concentration of incident light by the optical media of the eye. A knowledge of the quality of the ocular optical system is therefore of great importance.

The goal of these investigations was first to measure the minimal spot size on the retina and second to estimate the part of the incident energy which is concentrated within the focus. Therefore, it was necessary to develop a method which allowed direct measurement of both focus intensity distribution and energy.

This paper reports on experiments in which the focus of a He-Ne-laser on the retina was measured directly by scanning the profile of the beam transmitted through a trepanized opening in the sclera.

Materials and methods

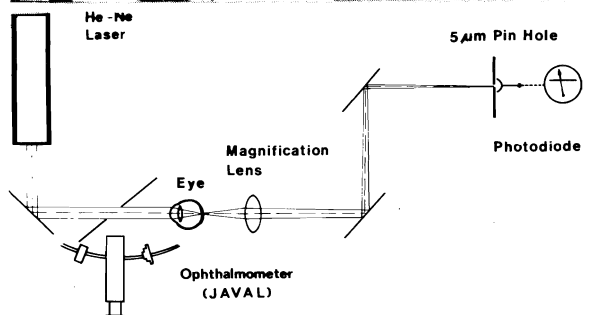Figs. 1a and 1b show a photograph and a schematic diagram of the optical set-up. A He-Ne-laser beam
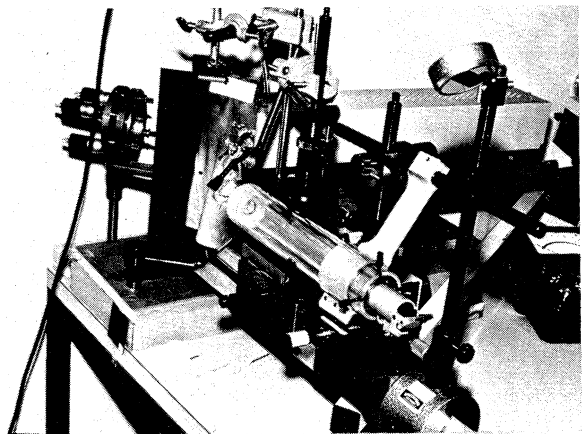
Fig. 1a and b: Experimental set-up for measurement of the spot size on the retina

The various steps of preparation can be seen in Figs. 2a and 2b. After enucleation, the eye is put in a specially designed plexiglas eye holder (Fig. 3). A hole is cut through the sclera, choroid and retina at the macular region using a motorized 6 mm diameter trepan. The hole is then closed with an optical quality plexiglas cover. The mydriasis is maintained with Adrenaline during the preparation and measurement procedures; the cornea is irrigated with Ringer solution.

The experimental eyes were examined carefully with a slit lamp. The curvature of the cornea of each eye was measured with a Javal ophthalmometer in vivo and in vitro during the experiment. Only eyes with a normal slit lamp examination statement and a corneal radius changes throughout the experiment of less than 0.3 mm were used. The maintenance of the natural geometry of the eye was guaranteed by the stability of the curvature of the cornea.

The optical conditions of 38 eyes of 22 chinchilla rabbits were measured. Minimal or near minimal spot sizes of reasonably Gaussian profile were obtained in 17 cases.
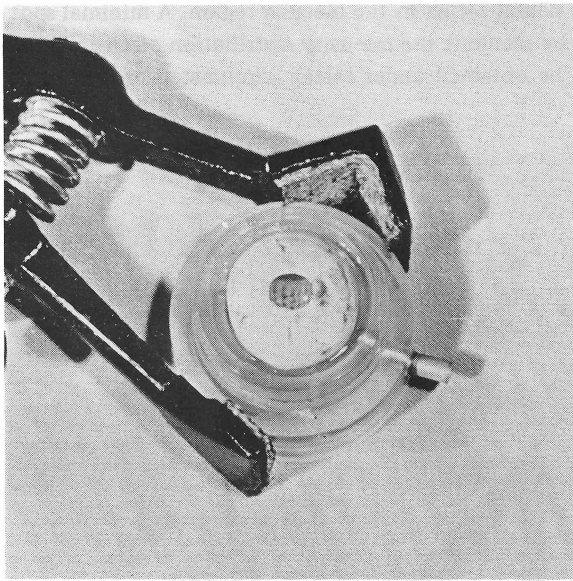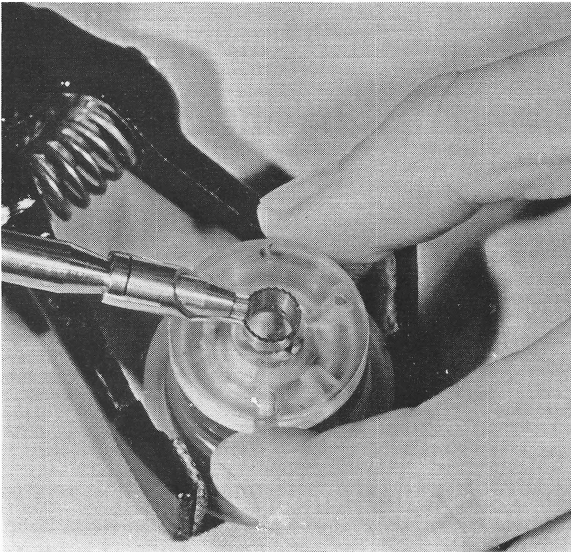

Fig. 2a and b: Enucleated eye in the eye holder with a trepanized hole of 6 mm diameter in the central part of the fundus.

1.2 mm in diameter is directed into the examined eye through a perforated mirror. The focus formed by the optical system of the eye is enlarged with a magnifying lens located behind the eye. The intensity distribution and the total energy within the enlarged image of the focus can then be measured directly with a scanning 5 μm pin hole and a diaphragm opened to equal the enlarged spot size diameter respectively.
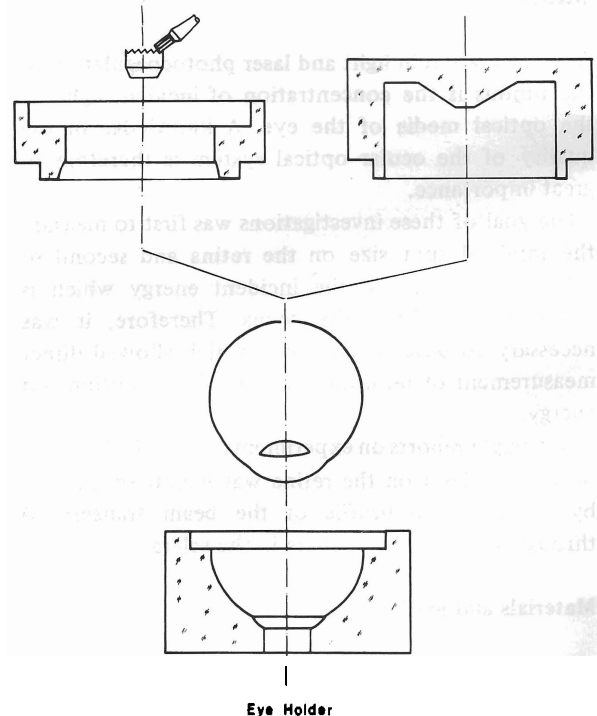

Eye Holder

Fig. 3. Schematic diagram of the eye holder.

Results

The optical set-up was tested by measurement of the light intensity distribution of the focus formed by a glass lens with a refraction power of 100 D which is similar to the refractive power of the rabbit eye. The result is shown in Fig. 4. The diameter at the $1/e^2$ intensity of 7.0 μm insures that the experimental device can form a diffraction limited focus.

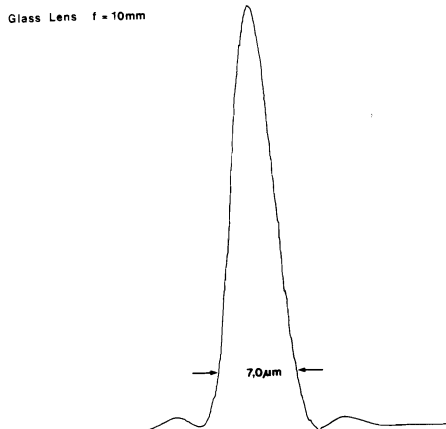Glass Lens f = 10mm

7,0μm

Fig. 4. Intensity distribution of the focus of a 100 Diopters glass lens.

Results obtained from a typical rabbit eye are shown in Figs. 5a and 5b. After the preliminary rough adjustment, the intensity distribution exhibited may be a result of interferences caused by inhomogenities in the optical path (Fig. 5). A diffraction limited focus could be obtained when it was possible to find a clear path through the pre-retinal medica (see Fig. 5b). The focus diameter in this case is 7.1 μm at the $1/e^2$ points of the maximum intensity. The results of the 17 eyes are listed in Table 1.

Measurements of the energy concentration in the focus were taken on 7 eyes. The results show that only 50% of the energy reaching the fundus is concentrated in the focus. The remaining 50% is scattered out of the focus. The maximum intensity of the scattered light is less than 5% of the maximum intensity in the focus.

Discussion

The variation of the spot size of the various eyes, as shown in Table 1, cannot be explained by the individual variation of the refractive power.

Rabbit 5 li
R_{HH} = 7,2mm

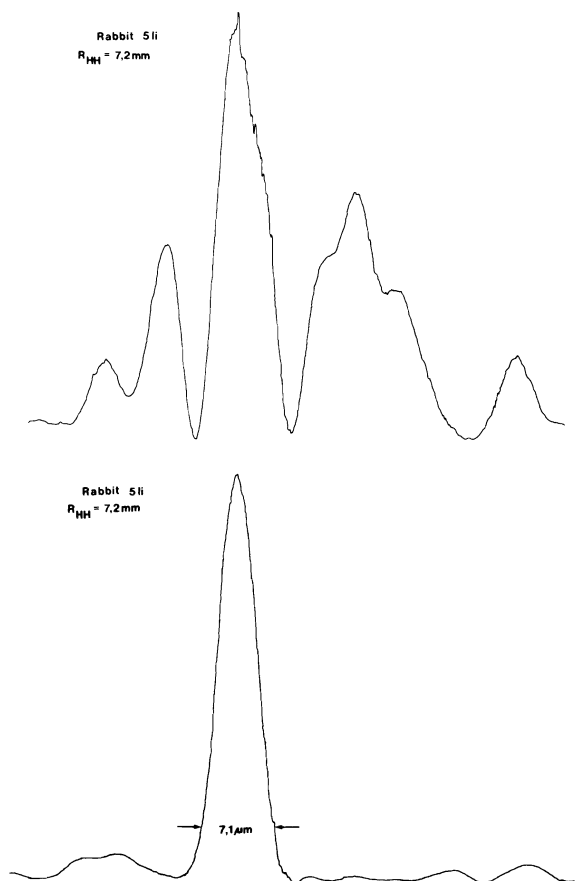Rabbit 5 li
R_{HH} = 7,2mm

7,1μm

Fig. 5a and b: Intensity distributions on the fundus of a rabbit eye before (a) and after (b) an optimal adjustment.

The difficulties in finding a clear path through the eye indicate that small inhomogenieties contribute to the variation of spot size. In any case, the results show that the rabbit eye can in principle form a diffraction limited focus. This has previously been observed by others with indirect measurements in human eyes (2, 3).

The energy concentrated in the focus is of particular importance for determination of laser threshold values where minimal spot sizes are realized on the retina. Previous calculations of thermal models, without consideration of the scattering in the ocular media, yield retinal temperatures of 150° C and more (4, 5, 6). If the scattering of energy out of the focus is taken into account, the retinal temperatures for threshold values become realistic and agree with the common ideas of thermal denaturation processes (1).

Table 1. Results of the 17 eyes with minimal retinal spot sizes of the laser focus.

Eye No.	R_{Cornea} in vivo (mm)	Cornea in vitro (mm)	Focus Diameter (μm)	Fraction of energy within the focus
1 li	7.6	7.5	11.3 μm	––
2 re	7.3	7.1	13.0	––
3 re	7.0	6.9	10.5	––
3 li	7.0	7.2	9.6	––
4 re	7.4	7.4	12.1	––
4 li	7.9	7.6	10.7	––
5 re	7.2	7.0	8.8	––
5 li	7.2	7.2	7.1	––
6 re	7.9	7.7	9.8	––
6 li	7.9	7.9	11.7	52 %
7 re	7.5	7.4	6.8	52 %
8 re	7.0	6.9	9.4	34 %
8 li	7.0	6.8	8.8	63 %
9 re	7.7	7.8	10.2	––
10 re	7.4	7.4	10.2	51 %
10 li	7.3	7.2	10.7	46 %
11 re	7.7	7.6	15.1	59 %
Mean values and standard deviations		7.3 ± 0.3 mm	10.3 ± 2 μm	51 ± 9 %

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