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Measurement of Eyeball Deformation due to Variation of Intraocular Pressure by Holographic Interferometry

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ABSTRACT

Rabbit eyeball deformation caused by intraocular pressure is quantitatively measured by double-exposure holographic interferometry. The eyes of white rabbits are enucleated and deformation of its sclera is measured. Holographic interferograms illustrate a dependence of the distribution of deformations on the intraocular pressure. It is necessary for diagnosis in opthalmology that retina is observed directly through cornea. But the method may by useful for basic investigation of eyeball deformation.

I. Introduction

In as much as the eye is a hollow sphere as shown in Fig. 1[1], its interior pressure must exceed that of the surrounding atmosphere to prevent collapse. Intraocular pressure (**IOP**) is determined physiologically by the relative rates of aqueous inflow and outflow. **IOP** changes gives morphological and functional influences on the ocular system[2–4]. Therefore, the measurement of deformation of eyeballs caused by change of **IOP** is important in opthalmological investigation of glaucoma, intraocular surgery and ametropia. In our study, experimental measurements of the scleral deformation following variations of **IOP** are obtained by holographic interferometry[5]. The deformations of sclera with the lapse of time are observed under constant **IOP**. Eyeballs of white rabbits are used. As **IOP** normally has a slow fluctuation daily, diurnal variation is measured for used rabbits by means of a tonometer. In the stage of lower **IOP**, the local distension could found at the area of optic nerve head. In the stage of **IOP** near the diurnal variation, the fringe pattern showed complex deformation of sclera.

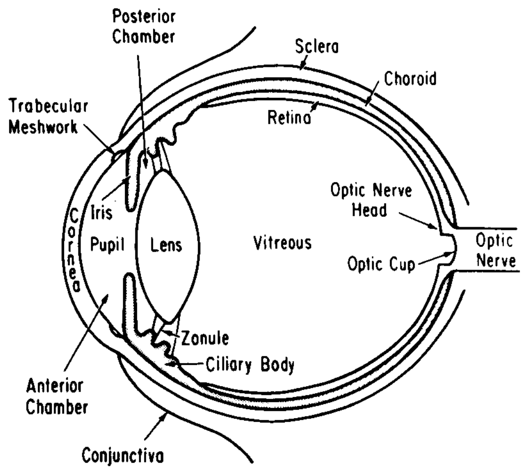

Fig. 1 Schematic diagram of the eyeball.

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II. Experiments

The Perkins hand held applanation tonometer is used to measure **IOP** of rabbit in the experiment[6]. The tonometer can measure easily **IOP** more than other tonometer for rabbit. The tonometer is designed for human eye. It is necessary therefore, to calibrate the tonometer. As preliminary study, the calibration curve is estimated as the standard in the regular study. The eyes of white albino rabbits are removed under sodium pentobarbital anesthesia (Nembutal®). Then a teflon tube, which is 1.1mm in outer diameter and has a stainless steel needle in it, is stabbed into the anterior chamber at the limbus as shown in Fig. 2. After drawing out the inner needle, the eyeball is fixed with adhesive (Aron Alpha®) at its limbus in a hole which had been made on a metal plate in the fitting size.

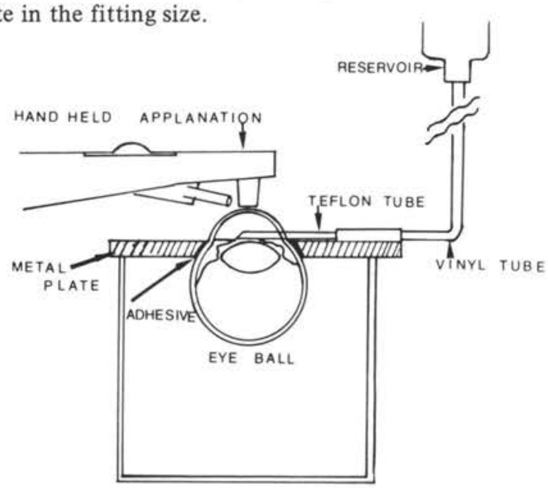


Fig. 2 Device to obtain calibration curve between applanation tonometry and manometry.

In the figure, a teflon tube is inserted into the anterior chamber and is connected to a reservoir filled with physiologic saline solution. Changing height difference between the eyeball and the reservoir, applanation tonometry is repeatedly performed and the calibration curve is used as the standard in the regular study.

Diurnal variation of **IOP** of normal rabbits in living state is measured, including its upper and lower limits. Variations of **IOP** of 6 rabbits are measured during 24-48 hours in livings state by using applanation tonometer under instillation anesthesia.

Figure 3 shows optical system for recording double-exposure hologram by means of holographic interferonetry. He-Ne laser having power of 50mw is used as light source. Light beam is divided into two waves by beam splitter (BS). The transmitted beam becomes parallel wave by collimating lens (Ls).

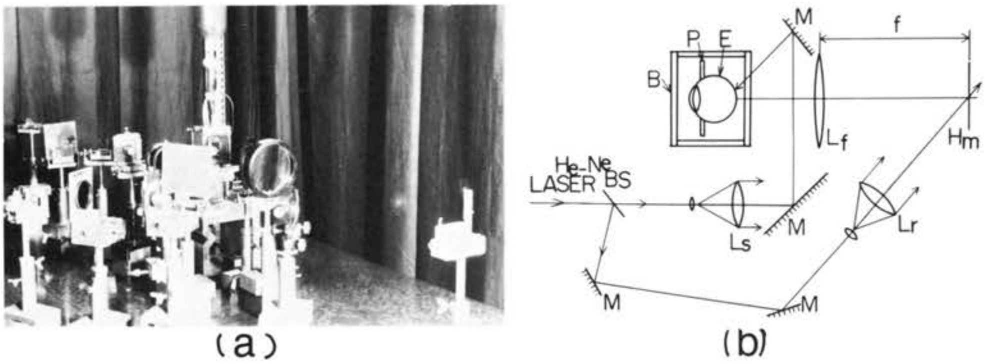


Fig. 3 Optical system. (a) and (b) show practical and schematic optical systems, respectively.

The wave is reflected by mirrors (M) and illuminates the rear of eyeball (E) fixed to the metal plate (P). The direction of illuminating beam makes 20 degrees with it of observing direction to prevent reflecting wave from the glass plate of immersing chamber (B). The wave reflected from the object transmits Fourier transform lens (Lf) and is focused on the photographic plate (Hm) located at its focal point (focal length (f)). The size of hologram is very small and clear reconstructed image can be observed by using laser beam[7). Reflected beam from the beam splitter is called reference beam and it becomes parallel wave by collimating lens (Lr) and illuminates obliquely the photographic plate (Hm).

The eyeball is enucleated from white albino rabbits of 2500-3000g in body weight. As eyeballs of different rabbits have various sizes, several plates with a hole of various sizes are prepared. A teflon tube, which is 1.1mm in outer diameter and a stainless steel needle in it, is inserted into the anterior chamber at the limbus of cornea through a metal guide tube of 1.5mm in inner diameter which has been set towards the center of the hole on the metal plate. After the trochar was withdrawn, the eyeball is cemented at the limbus in a tapered hole of the fitting size on a metal plate with the adhesive. In order to protect any mechanical deformation of eyeball accompanied with the movement of the teflon tube, the tube is fixed to a metal guide tube with the adhesive. The metal plate, on which the eyeball and the teflon tube are mounted, is immersed in the chamber as shown in Fig. 4.

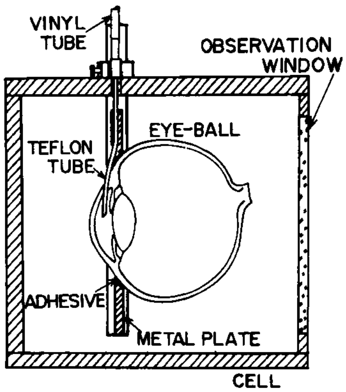


Fig. 4 Test chamber. The chamber is filled with physiological salt solution. The vinyl tube is connected to a manometer to change intraocular pressure.

The cell has an observation window which consists of a parallel glass plate and is filled with physiological salt solution. The teflon tube, which is stabbed at the limbus, is connected to the reservoir containing physiological salt solution in it with the long vinyl tube and this device operates as a manometer, so that IOP can be adjusted to a desired pressure by changing the height of the reservoir as shown in Fig. 2.

Giving various values of IOP, we measure the deformation of the sclera for small increment of the pressure from the rear of the eyeball through the window of the chamber by double-exposure holographic interferometry. The first exposure of holography is done at the same IOP as that just after the enucleation. The second exposure is done after 10mm upward shift of the reservoir (equivalent to pressure increment of 0.7mmHg), so a hologram of double-exposures is made. This procedure is repeated about 20 times until IOP is elevated to about 28mmHg, so about 20 double-exposure holograms are obtained. Thus the deformation of sclera produced by every pressure increment of 0.7mmHg is presented by making interference patterns.

III. Results and Discussions

The Perkins tonometer was used to measure **IOP** of rabbit. But the tonometer was designed for human eye[8]. It was necessary therefore, to calibrate the tonometer for rabbit. Figure 5 shows the calibration curve for rabbit.

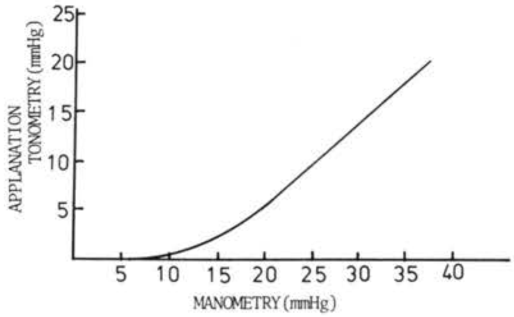


Fig. 5 Calibration curve of the Perkins tonometer for rabbit.

Figure 6 shows an example of diurnal variations obtained for 6 rabbits. The difference between the data of both eyeballs of an individual rabbit was small. From these results, the upper and lower limits were 22mmHg and 15mmHg, respectively. The diurnal variation was 7mmHg. **IOP** in the figure shows the pressure transfered to manometric reading by using Fig. 5.

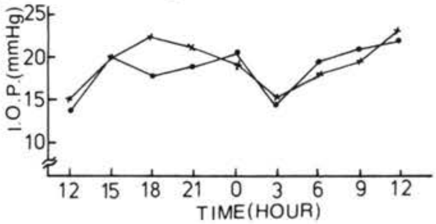


Fig. 6 Diurnal variation of intraocular pressure. · ; right eyeball, x; left eyeball.

One of reconstructed images is shown in Fig. 7. In this figure, interference fringe pattern indicates the deformation of sclera for pressure increment of 0.7mmHg from **IOP** of 9.6mmHg.

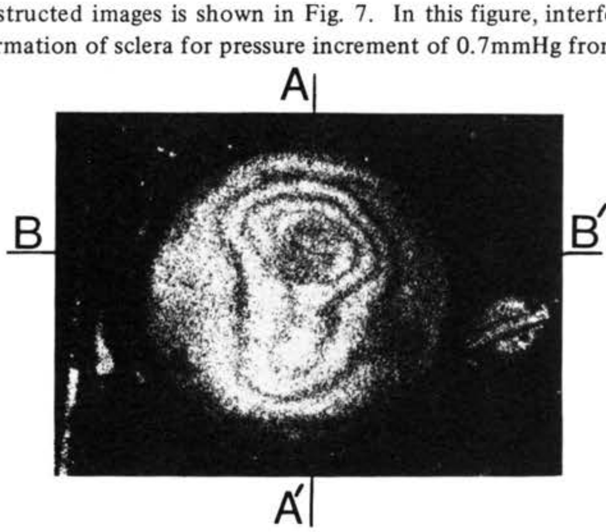


Fig. 7 The interference fringe pattern caused by deformation of the sclera. The optic nerve head is located at the intersection of *A–A'* and *B–B'*. Each fringe corresponds to a displacement of 0.24μm of the sclera.

Figure 8 shows the distribution of the relative displacement component in the direction bisecting the illuminating and observing directions. Diagrams (a) and (b) are calculated from the pattern correspond to the deformation along A–A' and B–B' lines through the optic nerve head in Fig. 7, respectively.

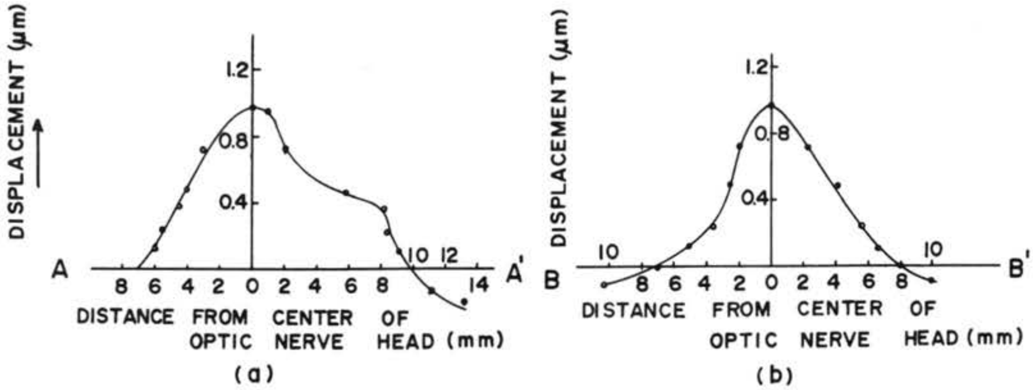


Fig. 8 Relative displacement of the sclera given for an 0.7mmHg change in intraocular pressure (**IOP**). The lines *A–A'* and *B–B'* are shown in Fig. 7.

Judging from Figs. 7 and 8 and fringe patterns obtained for other pressures, it is found that the deformation in the neighbourhood of optic nerve head is larger than that in other region of the sclera. As the deformation of eyeball is originally the three dimensional, three holograms are necessary from three observing directions[9]. The interference fringe patterns obtained for various stages in **IOP** were shown in Fig. 9. These patterns shows the deformation of sclera produced by every pressure increment of 0.7mmHg.

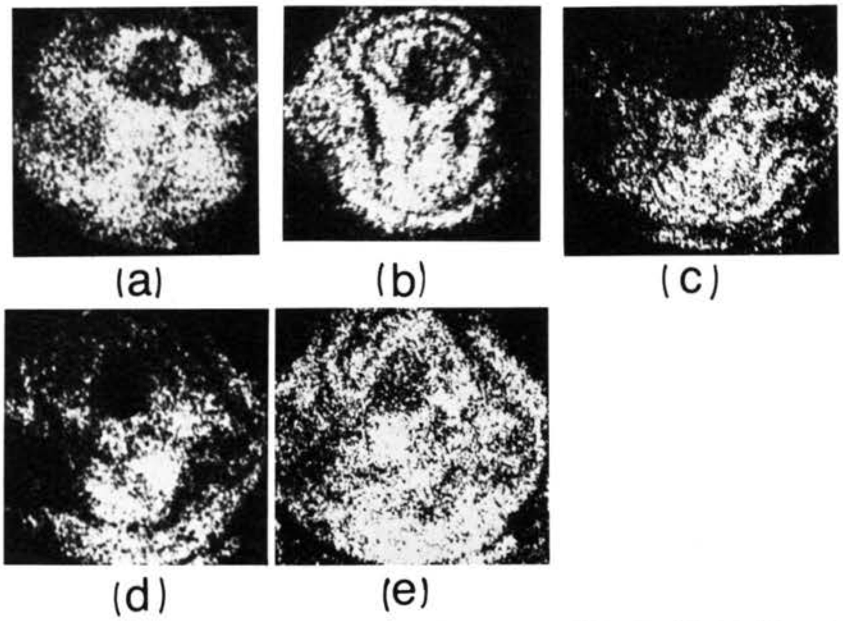
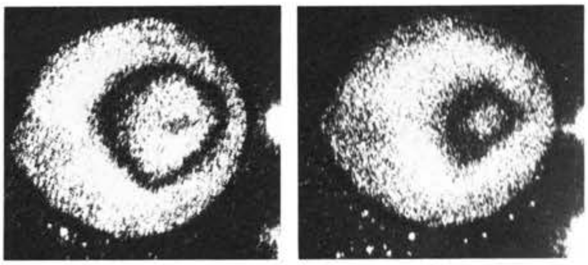


Fig. 9 The interference fringe patterns obtained for various stages in **IOP**. (a), (b), (c), (d), and (e) show the interference fringes of sclera for pressure increment of 0.7mmHg from **IOP** of 6.6mmHg, 17.6mmHg, 19.9mmHg and 26.5mmHg, respectively.

In the stage of lower **IOP** (Fig. 9 (a) and (b)), the interference fringes were closely arranged. This shows the sclera has a steep displacement gradient. The local distension at the area of optic nerve head could found as indicated in Fig. 8. In the stage of **IOP** near the diurnal variation (Fig. 9 (c) and (d)), the fringe pattern shows the complex deformation although number of fringes decreased. In the stage of higher **IOP** (Fig. 9 (e)), the number of fringes obviously decreased, indicating lesser deformation of the sclera.

As the eyeball has vitreous and anterior chamber, it is judged that it shows visco-elastic property for dynamic response. Therefore, the eyeball shows various patterns with the lapse of time under the constant **IOP**. After **IOP** was increased 0.7mmHg from 20mmHg, two holograms were recorded at 6 minutes and 26 minutes, respectively. Figure 10 shows the reconstructed images. The time between the first and second exposures was 15 seconds. It is shown that the deformation continues for about 30 minutes.



(a) (b)

Fig. 10 Interference fringe patterns obtained with the lapse of time under the constant **IOP**. (a) and (b) show the fringes recorded after 6 minutes and 26 minutes, respectively, after **IOP** was increased 0.7mmHg from 20mmHg.

IV. Conclusions

Deformations of eyeball due to change in **IOP** were measured quantitatively by double-exposure holographic interferometry. Results have been very useful in physiological study. It is necessary for diagnosis in opthalmology that retina is observed directly through cornea.

We intend to carry out measurement of scleral deformation by pressure change in vitreous humor and to clarify more precisely the effect for the visual system due to the variation of **IOP**.

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