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# Deformation of Yellow Spot Area by Compulsory Increase of Eye Pressure

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*Abstract*— **The deformation characteristics of yellow spot of retina under a compulsory eye pressure increase is discussed for both normal and glaucoma eyes. We impart the force corresponding to 50[mmHg] of eye pressure to eyelid through a contact probe with force gauge. We analyze the deformation of yellow spot area for three different layers. An interesting observation is that yellow spot suffered by glaucoma has thinner layer and smaller deformation than that of normal subjects, especially the characteristics is enhanced in both the surface and the bottom layers.**

## I. INTRODUCTION

A high eye pressure may damage the optic nerve in a human eye and result in gradually loss his (or her) eye sight due to a partial death of the eye nerve system. This disease is called glaucoma. It is the most common cause of loss eyesight in Japan. Once we suffer from this disease, we are obliged to use a special eye lotion and in an extreme case, we are treated with surgery that can suppress a further increase of the eye pressure. However, the treatment to completely restore a field of vision that we lost is not possible. In addition, there are many cases to develop terminal symptoms before we notice it. The eye pressure defined as the external pressure makes cornea a certain amount of flat[1] is an important index for diagnosing the disease[2]. Due to the principle of measurement, however, the eye pressure measurement is sensitive on cornea stiffness, which makes it difficult to evaluate eye pressure[3]-[5]. While there are many works discussing the cornea stiffness, few works on evaluating the stiffness of retina in-vivo have been done so far. Retina is composed of multilayered nerve cells and most involved in converting visual information into electric signal. We believe that a remarkable change on stiffness characteristics in retina may occur for patients suffered by glaucoma. This is the motivation why we challenge to evaluate the deformation characteristics of retina for compulsory increase of eye pressure. While retina covers a large area, we particularly focus on the area of yellow spot[2], where photoreceptor cells are exposed directly without the optic nerve layer of the surface and the photosensitivity is pretty high. Through experiments, we found that yellow spot suffered by glaucoma has thinner layer and smaller deformation than that of normal subjects, especially the characteristic is enhanced in both the surface and bottom layers, while it is not in the middle layer.

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Fig. 1. An overview of experiment

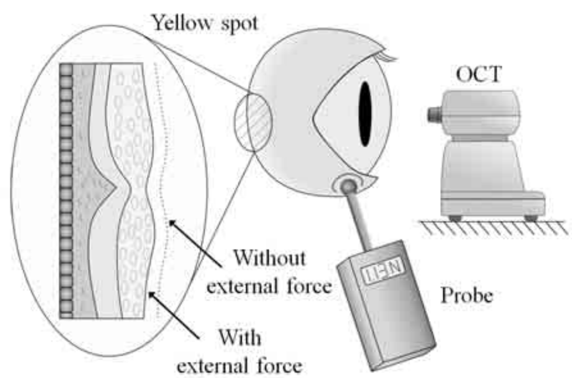



Fig. 2. Scematic view of experiment system

## II. RELATED WORKS

Optical Coherence Tomography (OCT) is becoming popular as one of the powerful tools for inspecting the inside of human eye[6]. By using the system, we can examine not only the precise profile of retina but also the depth information with the resolution of less than 10[$\mu$m], by which we have more chance to discover new pathologic change of the retina. By using OCT, Younes and others have challenged to measure the tissue displacement of an optic disk when raising the eye pressure compulsorily[7], but they have measured the displacement of an optic disk only. Since the area of retina yellow spot includes many photoreceptor cells, we can expect a new discovery by measuring the

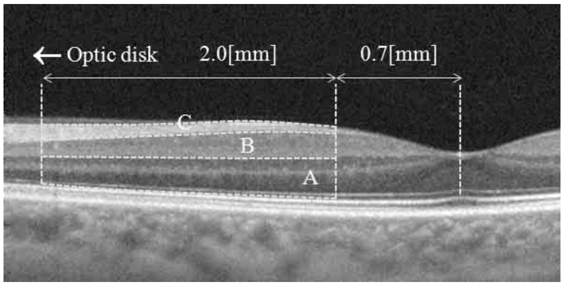



Fig. 3. OCT image

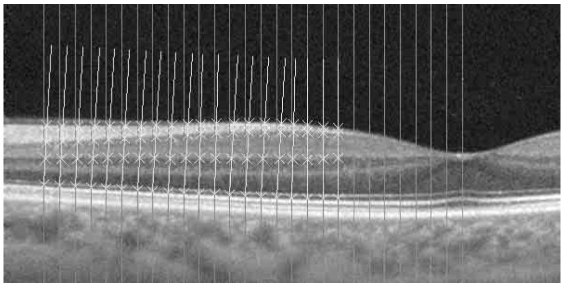


Fig. 4. Image of analysis

displacement under a compulsory increase of eye pressure. As far as we know, there has been no work focusing on the displacement in the area of retina yellow spot.

## III. EXPERIMENTS

### A. Experimental System

Figure 1 shows an overview of the experimental system where an assistant is imparting a compulsory eye pressure through a probe with force gauge. Figure 2 shows a figure of the system including retina with three layered model. A digital force gauge Z2-5N made by Imada, Inc, is used for measuring the applied force to eyelid. The gauge can sense forces in the range of $\pm$ 5[N] with the resolution of 0.001 [N]. The probe attached to the gauge has the dimensions of 10 [mm] in diameter and 110 [mm] in length, respectively. A sponge is pasted up at the tip as a cushion with 10 [mm] in diameter and 3 [mm] in thickness for avoiding damage to skin.

OCT is an imaging instrument using the theory of optical interference. An OCT image is constructed from the reflections of infrared light emitting into the media. By using OCT, we can obtain images of a living body tissue underneath skin in high resolution. In this paper, we utilize the technique to gather the images of the tissue where optic disc and yellow spot are located. The OCT used in this experiment is made by TOPCON CO. whose resolution is 2.62 [$\mu$m].

In order to investigate how the optic disc and yellow spot react to different IOPs, we can control the IOP by pressing on the eyelid with a force gauge as shown in Fig. 1. Through the calibration test, we obtain the relationship between the force gauge and the tonometer. As a result we can increase the IOP of subject with 50 [mmHg], by appropriately pressing the force gauge to eyelid.

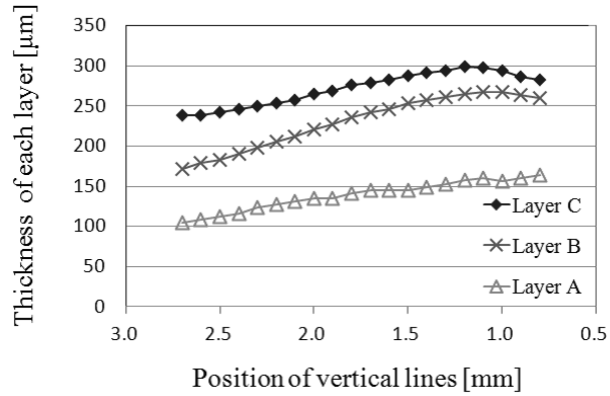
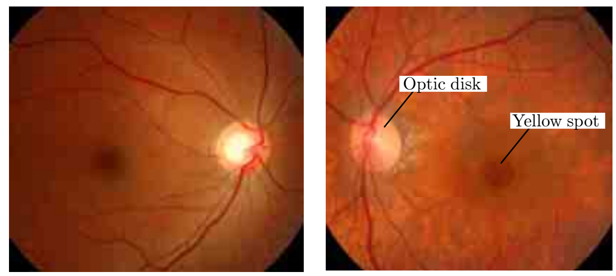



Fig. 5. Thickness of each layer




(a) Normal Eye (b) Glaucoma Eye

Fig. 6. Ocular fundus

### B. EXPERIMENTAL PROCEDURE

The experimental procedure is described as follows:

1) The OCT image is taken for a naked eye before pressing.
2) The IOP manually increases to 50 [mmHg] by using the force probe.
3) The second OCT image is taken.

The interval between every two tests is 30 minutes, so the tested eye has enough time to recover to its original condition.

### C. Region of Interest

Figure 3 shows an example of OCT image of yellow spot area where the yellow spot is defined as the circular area centered at the hollow point with the radius of 2.7 [mm] , while the central fovea is the circular area centered at the same point with the radius of 0.7 [mm] in average. There are three layers in the tissue, and are labeled as Layer A, Layer B and Layer C in Fig. 3, respectively. Layer A is the visual cell layer where the light is converted into electric signals. Layer B is the middle cell layer which is an intermediate layer transmits the signals by synaptic connection to Layer C. Layer C is the layer of ganglion cells which transmits the signals to brain.

In this paper, we are interested in the region containing all three layers. It is known that the Layer C is not developed in a central-fovea portion. We focus on the ring area which is centered at the hollow point with the radius from 0.7 to 2.7 [mm] as shown in Fig. 4.

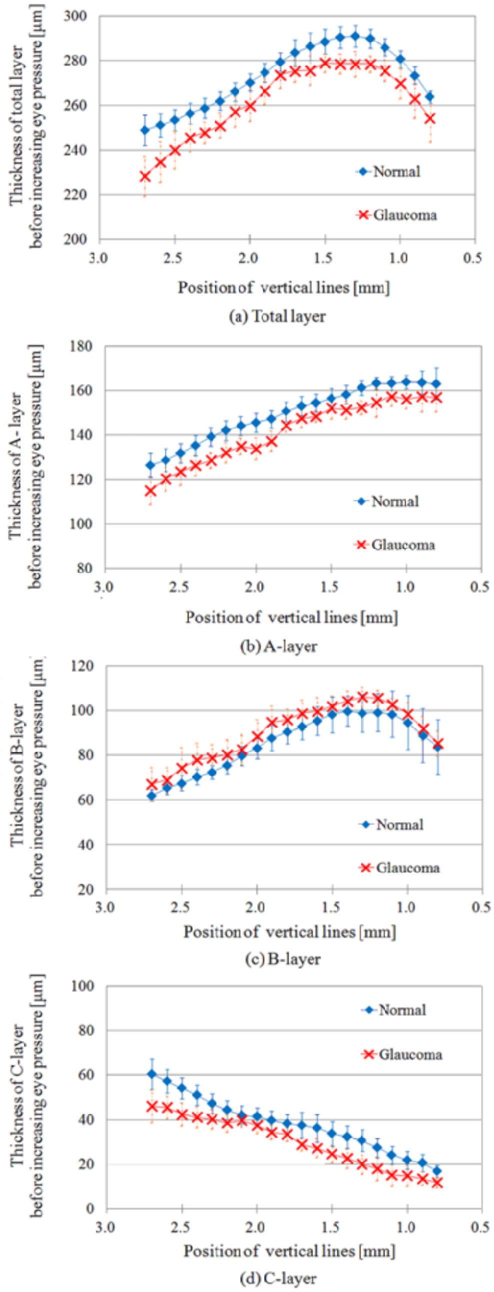



Fig. 7. The distribution of thickness before pressing

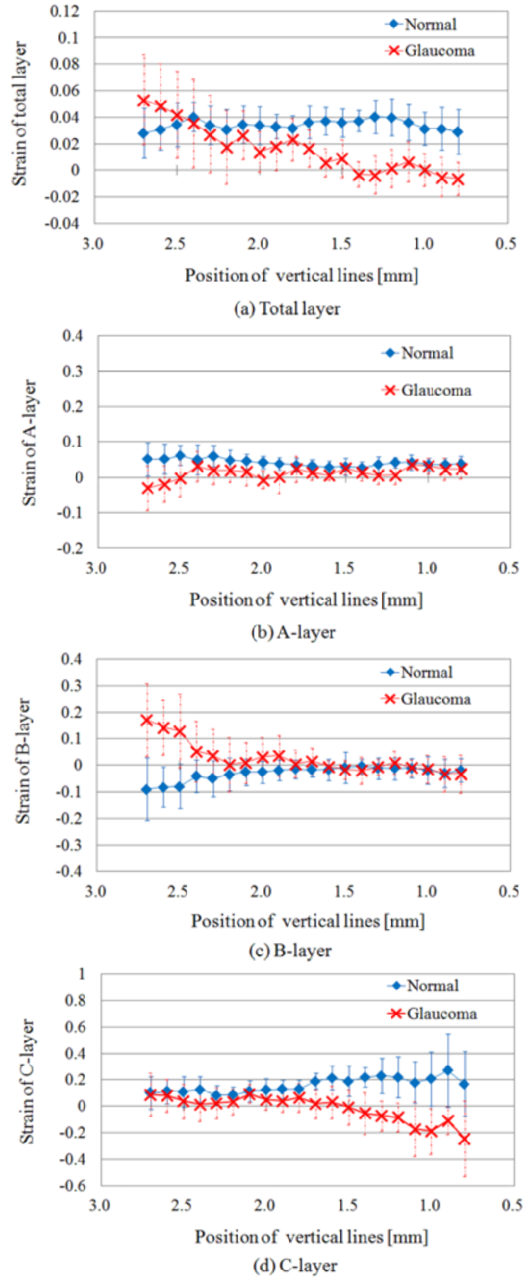



Fig. 8. The distribution of strain of each layer

### D. Subjects

Four subjects, 2 healthy subjects and 2 glaucoma patients, were tested, and all of them consent to the documents specified by the Ethics Committee after receiving a description about the experiment outline. The healthy subjects are a 22 year-old male and a 23 year-old male. The glaucoma patients are a 41 year-old female and a 57 year-old male, and both their left eyes are suffered from glaucoma. Five healthy eyes and two glaucoma eyes were tested in total. Figure 6 shows two examples of photos where Fig. 6(a) and (b) are the left eye of normal and the right eye of glaucoma eye, respectively. The yellow spot corresponds to the center area whose color is light black.

## IV. EXPERIMENT RESULTS

### A. Thickness of the tissue before pressure

The experimental results before pressing are shown in Fig. 7. Figure 7(a) shows the total thickness of three layers combined with respect to different locations. Figures 7(b), (c), (d) show the thickness of Layer A, B and C, respectively. The data presented in Fig. 7 are the average values of all the measured data from the experiments. From the results, we found that the average thickness of healthy eyes is always greater than the ones of glaucoma eyes, except for the Layer B. The statistical T-test is applied to the results, and the significance value, P, of the tests were found all smaller than 0.01 for the whole layer as well as for the individual layers.

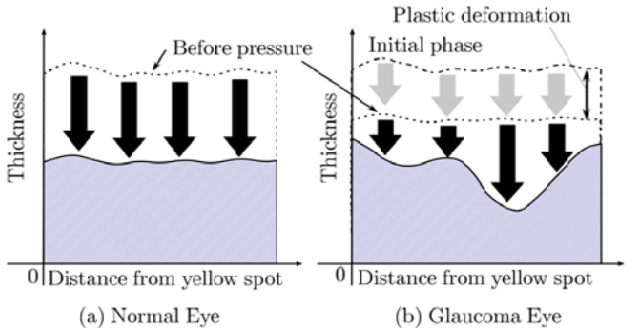



Fig. 9. The thickness before and after force impartment

This means that the difference of the thickness between healthy subjects and patients is significant, and we can distinguish healthy eyes from glaucoma eyes according to the results.

### B. Strain of the tissue after pressing

The experimental results of the strain of whole yellow spot and individual layers after pressing are shown in Fig. 8, where the horizontal axis indicates the location of the measurements and the vertical axis indicates the strain of the deformation. The strain is computed by

$$\varepsilon = \frac{L}{L_{\text{before}}} \qquad (1)$$

where $\varepsilon$, $L$ and $L_{\text{before}}$ are the strain, the amount of deformation and the undeformed thickness, respectively.

The results show that the strains of healthy eyes are evenly distributed in different locations while the strains of glaucoma eyes are not. As for the results of glaucoma, there is a noticeable tendency, where the strains in Layer B and C are not evenly distributed with respect to position. For example, the strain in Layer B increases as the position is away from the central fovea, while that in Layer C decreases as the position is close to the central fovea.

## V. DISCUSSION

### A. Thickness of healthy eyes and glaucoma eyes

From the experimental results as shown in Fig. 7, we found that the glaucoma eyes tend to have smaller thickness comparing to healthy eyes. According to [2], the patients suffered from glaucoma usually have a relatively high IOP. Thus, the retina tissue of glaucoma eyes is continuously compressed with high pressure over years due to such a high IOP. This may be the reason for thinner layers of glaucoma eyes is due to the high IOP of glaucoma patients.

### B. The tissue stiffness of healthy eyes and glaucoma eyes

As shown in Fig. 8, the experimental results of strain of layers under pressing shows that the strain of glaucoma eyes is smaller in average. It means that while the same IOP (50 [mmHg]) is applied to the eyes, glaucoma eyes deform less comparing to healthy eyes. When we compare with 57 year-old male's right eye and left eye which is suffered from glaucoma, we found this tendency. So this tendency is not only due to the age. One possible reason for explaining such phenomenon is the change of characteristics in retina tissue of glaucoma eyes. The idea can be explained by using Fig. 9 where Figures 9(a) and (b) are the deformation characteristics of normal and glaucoma eyes, respectively. The vertical and horizontal axes are the thickness from the base and the distance from the yellow spot, respectively. Suppose that both normal and glaucoma subjects have the same thickness, respectively. Also suppose that the tissue of retina for glaucoma eye results in plastic deformation through the continuous eye pressure increase in the past, as shown in the gray allows in Fig.9(b), while this is not the case for normal eye. Due to such historical process already brought into the retina, the deformation when a force increase with 50[mmHg] is imparted is perhaps smaller in glaucoma eye than that in normal eye.

## VI. CONCLUSIONS

What we have done through this work are summarized as follows.

- The yellow spot tissue of the a glaucoma eye is thinner than the one of a healthy eye in general.
- The deformation of a glaucoma eye after pressing with an external force is smaller than the deformation of a healthy eye with the same amount of force.
- A glaucoma eye has an uneven distribution of strain responding to a pressure over yellow spot tissue while the strain distribution is evenly distributed for a healthy eye.

We believe that we can make sure this tendency by increasing the sampling for both normal and glaucoma eyes in the future.

## ACKNOWLEDGMENT

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## REFERENCES

[1] W. Kluwer Health, L. Williams, Wilkins, "*Manual of ocular diagnosis and therapy*", Philadelphia, Vol. 6 (2008).

[2] The Tajimi Study report 2, "*Prevalence of primary angle closure and secondary glaucoma in a Japanese population*", Ophthalmology, 112 (2005), pp. 1661-1669.

[3] Y. Kurita, R. Kempf, Y. Iida, J. Okude, M. Kaneko, H. K Mishima, H. Tsukamoto, I. Sugimoto, S. Katakura, K. Kobayashi, Y. Kiuchi, "*Contact Based Stiffness Sensing of Human Eye*", IEEE Transactions on Biomedical Engineering, Vol.55, No.2 (2008), pp. 739-745.

[4] A. Elsheikh, Wang D, Pye D, "*Determination of the modulus of elasticity of the human cornea*", Journal of refractive surgery, Vol. 23 (2007), pp. 808-818.

[5] G. J. Orssengo, D. C. Pye, "*Determination of the true intraocular pressure and modulus of elasticity of the human cornea in vivo*", Bulletin of Mathematical Biology, Vol. 61 (1999), pp. 551-572.

[6] G. Strouthidis, B. Fortune, H. Yang, A. Sigal, F. Burgoyne, "*Longitudinal Change Detected by Spectral Domain Optical Coherence Tomography in the Optic Nerve Head and Peripapillary Retina in Experimental Glaucoma*", Investigative. Ophthalmology & Visual Science, Vol. 52, No. 3 (2011), pp.1206-1219.

[7] Y. Agoumi MD, Glen P. Sharpe MSc, M. Hutchison BSc, T. Nicolela MD, Paul H. Artes PhD, Balwantray C. Chauhan PhD, "*Laminar and Prelaminar Tissue Displacement During Intraocular Pressure Elevation in Glaucoma Patients and Healthy Controls*", Ophthalmology, Vol. 118 (2011), pp. 52-59.