INFLUENCE OF SOFT AND HARD CONTACT LENSES ON THE CORNEA

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ABSTRACT

Various problems regarding contact lenses can be classified into two categories, one is on the application to the eye and the other is on the optical properties.

In order to clarify the effects of contact lens wear on the cornea, clinical research is insufficient and research based on fundamental experiments is necessary.

The present paper describes briefly the fundamental information obtained through the experiments on the relation of contact lens wear and the cornea.

INTRODUCTION

The most important criterion for the contact lens is that it has the least influence on the eye or the cornea. Up to the present the contact lens has been improved mainly by the accumulation of clinical experience.

In order to minimise the influence of contact lenses on the eye, the authors thought it essential to obtain fundamental information about contact lenses on the eye. Thus the effect of contact lenses on the cornea has been investigated for more than ten years. In the present paper the information obtained through our research is reported briefly.

EFFECT OF CONTACT LENSES ON THE CORNEAL EPITHELIUM

Morphological Study

Histochemical analysis

Smelser *et al* (1953) have originally reported the morphological change of epithelial cell on wearing contact lens and since then many reports have been published concerning this subject. We have also made experiments on rabbit eyes with hard and soft lenses (1972).

In the rabbit cornea which wore a hard lens for 17 hours glycogen granules disappeared in the epithelial cells. The disappearance occurred in the basal cell within 4 hours and nearly completely in the whole layer within 8 hours of wearing the hard lens. In this case the epithelial cells were swollen and their arrangements were disturbed.

After 17 hours wearing a soft lens glycogen granules still remained in the surface layer of cornea. The arrangement of epithelial cells was almost normal. After wearing a high water content soft contact lens continuously for one month, the existence of glycogen granules was evidently observed in the cornea.

The decrement of glycogen is thought to be induced by the interruption of oxygen supply from the atmosphere, and epithelial cells do anerobic glycolysis and as a result glycogen in the epithelium is consumed.

The variation of activity of lactate dehydrogenase has also been examined histochemically for contact lens wear

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(Hamano *et al*, 1972). The activity in the epithelium of a normal eye was highest in the basal cells as reported by Ehlers (1970). The activity after 24 hours of wearing hard lenses was found to decrease in the basal cells covered by a lens. On the other hand, with silicon rubber lenses having higher gas permeability, strong enzyme activity was still observed under the same condition.

Scanning electron microscope analysis

In order to investigate the influence of contact lenses on the fine structure of the surface layer of corneal epithelium, a scanning electron microscope, or SEM, was employed. The SEM image of the surface of normal human or rabbit cornea showed that the outermost epithelium was composed of rather regular pentagonal or hexagonal cells with uniform distribution of microvilli.

After 17 hours of wearing hard lenses of 9.5 mm diameter, the SEM image of epithelial cells revealed that tight junctions became loose and microvilli disappeared partly. In the case of soft lens wear for 17 hours, the epithelial cells showed nearly normal structure. Similar experiments were conducted under various conditions and a good reproducibility was attained. Yoshida (1972) made a comparison of eyes wearing soft lenses using a transmission electron microscope, and good agreement was obtained with our results.

From the above experimental results, it is possible to mention that by wearing hard lenses for more than 10 hours some structural hindrance is induced in the cornea, whereas with soft lenses the effect is less or none.

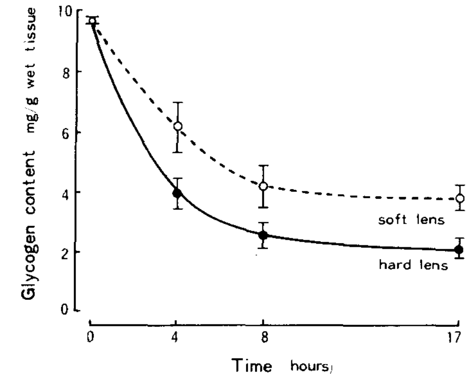
Cellular Function Study

Biochemical analysis

The measurement of the amount of glycogen was made after the method of Kishida and Ootori (1971) for the eyes with hard and soft lenses. As shown in Fig. 1, the glycogen content decreases rapidly to about the half of normal value within several hours of wearing contact lenses. With hard lenses the value after 17 hours decreases to about 20% of normal value, whereas with soft lenses the decrement is smaller and this result agrees with the histochemical result.

Trans-corneal potential analysis

To study the function of epithelium more precisely, the trans-corneal potential was measured. Fig. 2 shows a cotton wick electrode and the circuit diagram for measuring the potential. Fig. 3 is the result of measurements and depicts the



(Hamano, Hori & Hirayama 1972)

Fig. 1. Glycogen content with respect to the wearing time of contact lenses.

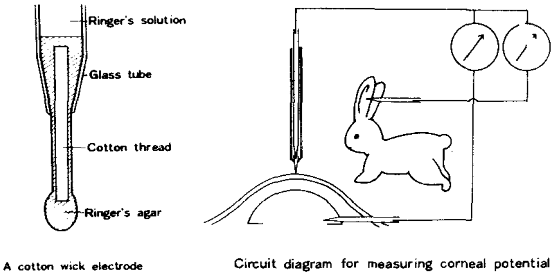


Fig. 2. Schematic circuit diagram for measuring trans-corneal potential.

recovery of trans-corneal potential of a living rabbit's eye at various locations and instants after 10 hours of hard lens wear. The region which had been covered by a lens is the left half of the cornea as shown in the lower part of the figure. By removing the lens the potential resumes the normal value within 4 or 5 hours.

Fig. 4 describes the change of trans-corneal potential of a rabbit with respect to the wearing time of contact lenses, the

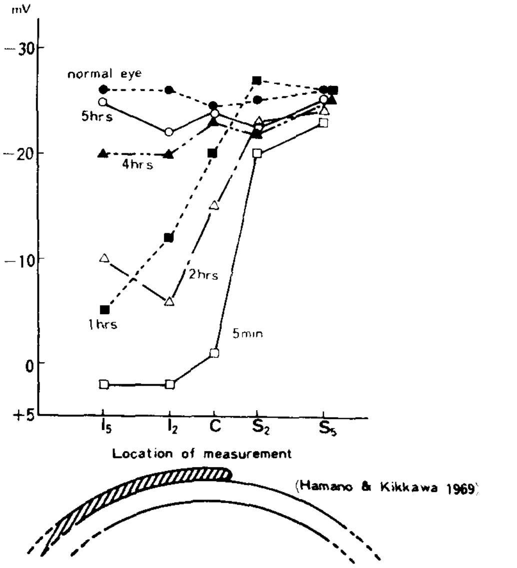


Fig. 3. Recovery of trans-corneal potential after removal of hard lens.

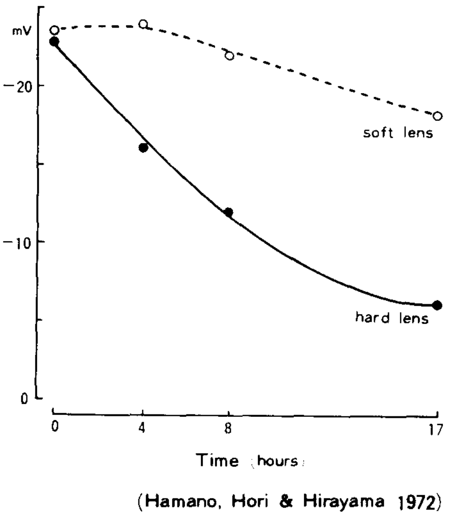


Fig. 4. Change of trans-corneal potential with wearing time of contact lens.

hard lens is on the left eye and the soft lens on the right eye. It can be observed that with hard lenses the potential decreases linearly with time of wearing, and after 17 hours it drops from 23 mV to about 5 mV. In contrast, with soft lenses the potential decreases only several mV.

Fig. 5 shows the recovery process of trans-corneal potential on removal of hard lenses or soft lenses after wearing for 6

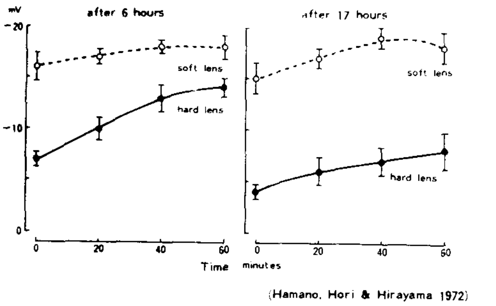


Fig. 5. Recovery of trans-corneal potential on removal of contact lens after 6 and 17 hours of wearing.

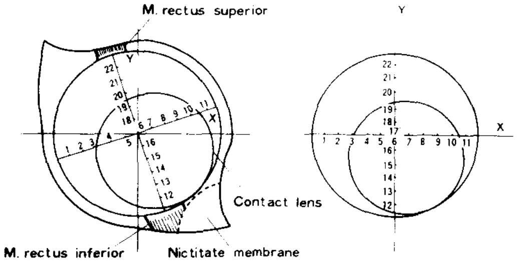


Fig. 6. Locations of measurements on the corneal surface by a glass micro-electrode.

and 17 hours. In the case of wearing hard lenses for 6 hours, potential recovers considerably within 60 minutes, but the degree of recovery for 17 hours is very poor. In the case of soft lenses, the initial potential variation is small both for 6 and 17 hours of wearing and after 60 minutes the potential resumes the normal value.

Intra-cellular potential analysis

To study the effect of contact lenses on the characteristics of epithelium in more detail, the intra-cellular potential of rabbit eyes was measured by a glass micro-electrode.

The measurements of potential were conducted during one hour after enucleation along the co-ordinates shown in Fig. 6, and eyes with and without contact lenses were compared under the same condition. Fig. 7 is the results of measurements. At positions covered by hard lenses of 9.5 mm diameter for 21 hours, the potential drops of 5 to 31 mV are observed.

Figs. 8 and 9 show the variations of intra-cellular potentials of 6 rabbit eyes after 6 hours of wearing hard lenses and 6 eyes after 17 to 22 hours of wearing hard lenses, respectively. All the plots are made with respect to the average potential of reference normal eye, which is designated as 100%. Slight drop of potential is observable in Fig. 8 at region where there was a lens, and in Fig. 9 remarkable potential drop is observed at the central part of the hard lens. In contrast, with soft lens wear, no potential drop was realised after more than 17 hours of wearing.

Thus hard lens wear of more than 17 hours does hinder the characteristics of corneal epithelial cells; however, soft lens wear under the same condition does not harm the characteristics.

EFFECT OF CONTACT LENSES ON THE CORNEAL STROMA

Corneal Thickness Study

The increase in thickness of the cornea by the wear of contact lenses has been reported by Smelser *et al* (1955) for the marmot cornea with scleral lenses. Recently, Kikkawa (1973) reported that there is a diurnal change in the corneal thickness.

We have also measured the corneal thickness with and without contact lenses and the results are shown in Fig. 10. The thickness of a rabbit's cornea was found to increase by 20% with 17 hours of hard lens wear and about 5% with soft lens. Taking into account the diurnal change of corneal thickness, swelling of more than 20% after 17 hours of hard lens wear is beyond the normal variation. In contrast the swelling of about 5% with soft lens can be mentioned as being within the physiological variation.

Oxygen Tension Study

It has been of great interest to study the problem of oxygen supply to the cornea when its surface is covered by a contact lens. Hill and Fatt (1963, 1970) have measured the oxygen consumption of corneal epithelium by polarography. Polse and Mandell (1970) have made various experiments for the gas exchange on the corneal surface and Mishima *et al* (1969) made anoxia experiments. Thus the outline of the physiological metabolism of cornea has been clarified.

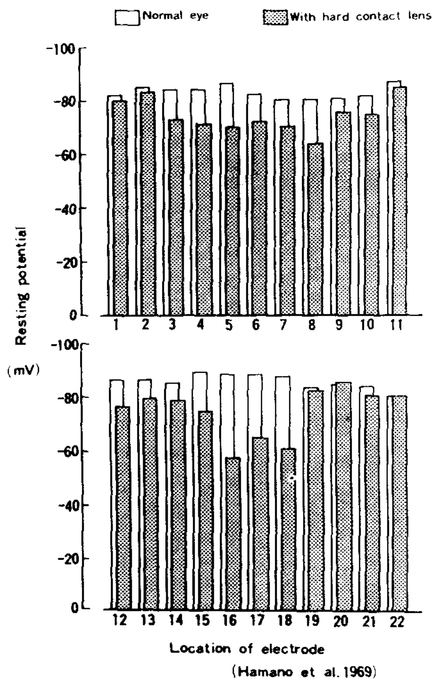


Fig. 7. Change of intra-cellular potential by wearing contact lenses.

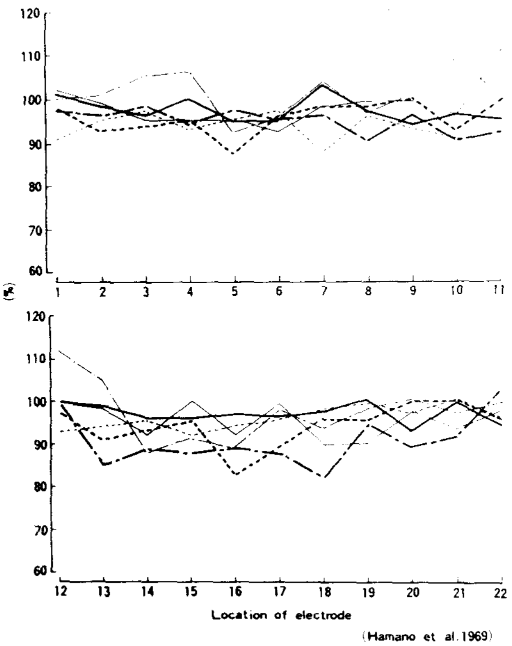


Fig. 8. Per cent variation of intra-cellular potential of 6 rabbit eyes after 6 hours of wearing hard lenses.

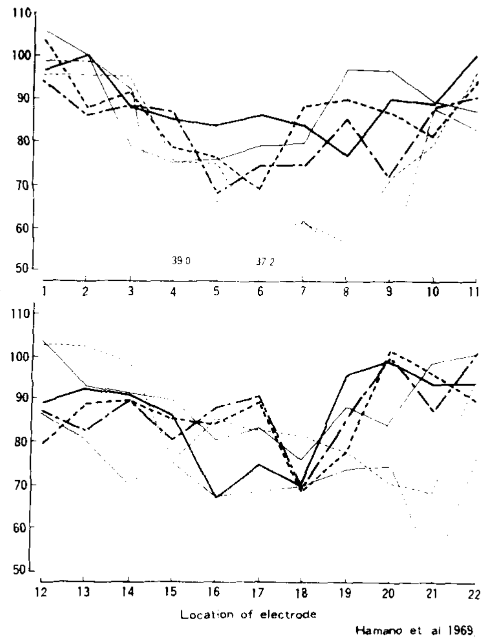


Fig. 9. Per cent variation of intra-cellular potential of 6 rabbit eyes after 17 to 22 hours of wearing hard lenses.

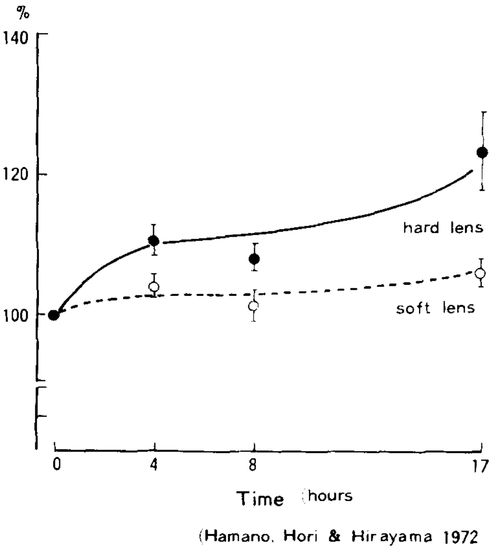


Fig. 10. Change of thickness of cornea on wearing contact lenses.

We have also investigated the oxygen tension in the stroma and in the anterior chamber at the time of contact lens wear and at the time of gas exchange on the corneal surface by embedding the Yagi's copper enamelled wire electrode in the stroma and in the anterior chamber. The circuit diagram of the measuring system is shown in Fig. 11.

Fig. 12 shows the variation of oxygen tension in the stroma of a living rabbit eye with a hard lens. On wearing the hard lens, rapid current drop occurs and in about 2 minutes the current becomes nearly zero and attains the plateau. When oxygen is blown on to the corneal surface

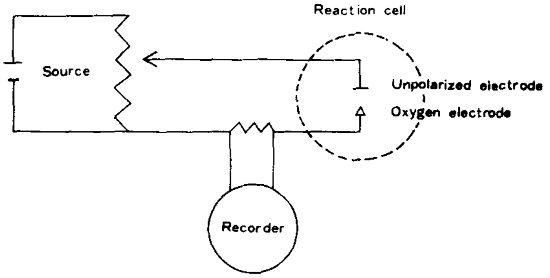
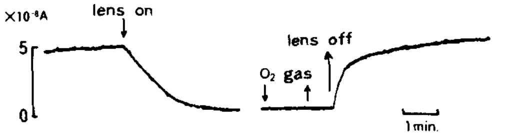


Fig. 11. Circuit diagram of Yagi's polarometrical oxygen electrode.



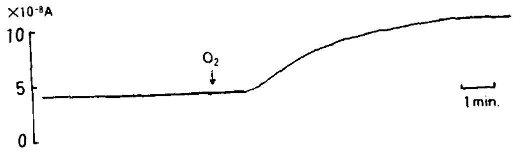
(Hamano, Hirayama & Hori 1973)

Fig. 12. Change of oxygen tension in stroma of a living rabbit cornea with hard lens.

covered by a hard lens, the current does not change. This signifies that the lens is not permeable to oxygen, and that oxygen does not go around to the stroma under the lens from surrounding structures.

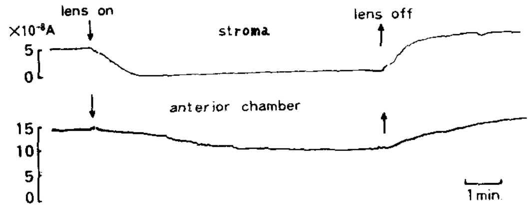
In the case of a soft lens, it is observed that oxygen tension in the stroma drops to about zero as in the case of hard lens wear. However, the rate of decrement of oxygen tension of stroma is smaller than in the case of hard lens wear.

Fig. 13 depicts the change of oxygen tension in the stroma of enucleated eye with silicone rubber lens. It can be seen that the oxygen tension does not change on wearing the silicon rubber lens and that on blowing oxygen a rapid increase in current is observed. Thus the high



(Hamano, Hirayama & Hori 1973)

Fig. 13. Change of oxygen tension in stroma of nucleated eye with silicon rubber lens.



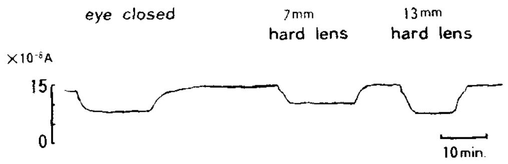
(Hamano, Hirayama & Hori 1975)

Fig. 14. Change of oxygen tension in stroma and in anterior chamber on wearing hard lens (living eye).

oxygen permeability of silicon rubber lens was proved.

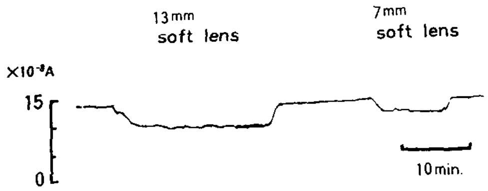
The effect of contact lens wear on the oxygen tension in the anterior chamber was studied and Fig. 14 shows the result of simultaneous recording of currents from electrodes in the stroma and in the anterior chamber with hard lens. The oxygen tension in the anterior chamber decreases gradually on wearing contact lenses, whereas that in the stroma decreases rapidly. On removing the hard lens oxygen tension in anterior chamber increases gradually. From this experiment it can be anticipated that the variation of oxygen tension in the anterior chamber is affected by the area of corneal surface covered by a lens, and further experiments were conducted with hard lenses and soft lenses of 7 and 13 mm diameter.

Figs. 15 and 16 show the results of experiments on oxygen tension in anterior chamber with hard lenses and with soft lenses respectively. Oxygen tension decreases gradually both for 7 and 13 mm lenses from the instant of contact lens wear. However, comparing both figures, it can be seen that variation is widest for a hard lens of 13 mm diameter. Also it can be noticed that the oxygen tension in the anterior chamber decreases at the time of



(Hamano, Hirayama & Hori 1975)

Fig. 15. Variation of oxygen tension in anterior chamber of rabbit eye with hard lens.



(Hamano, Hirayama & Hori 1975)

Fig. 16. Variation of oxygen tension in anterior chamber of rabbit eye with soft lens.

eye closure, and the decrement is about the same order of magnitude as in the case of soft lens wear or 7 mm hard lens wear.

From the above experiments of thickness measurement and oxygen tension measurement a clear difference between hard and soft lens wear was realised, as related to corneal epithelium.

OTHER EFFECTS OF CONTACT LENSES ON THE CORNEA

Study of the Temperature of Corneal Surface

As the surface of cornea is exposed to the atmosphere, it can be easily imagined that the surface temperature is affected by the changes in the atmospheric conditions. The same kind of phenomenon is supposed to be occurring on the surface of an eye wearing a contact lens.

The surface temperature is one of the most interesting problems and several measurements have been undertaken. By thermography, a pattern of temperature distribution can easily be obtained, but the information is limited only to an instant and is not sufficient to obtain successive change. With an infra-red radiation thermometer, successive change can

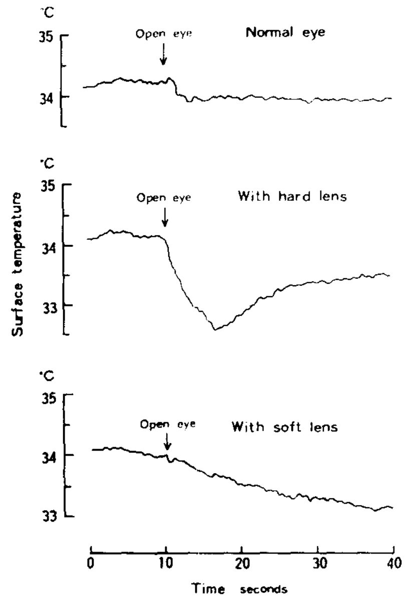


Fig. 17. Variation of temperature of human corneal surface without blinking for 30 seconds (room temperature: 23.5°C, humidity: 68%, age: 27, female).

be obtained, but the uncertainity remains from what part the information on temperature is obtained.

For the above reasons we employed the medical infra-red radiation thermometer with spot marker, the sensor of which is lead titanate (Model ER-2005, Matsushita Communication Industrial Co., Ltd., Japan). The measurements of surface temperature were conducted with this apparatus on the eye of one person with and without a contact lens, and the results are shown in Fig. 17. After closing the eye for 10 seconds, measurements were made for 30 seconds on the open eye. In the case of the eye without a lens the temperature decreased about 0.3°C and during 30 seconds the temperature remained almost constant. In contrast, for the eye with a hard lens, the temperature decreased about 1.5°C during first 7 seconds and later the temperature increased gradually. This phenomenon can be interpreted as follows: at first the tear film on the lens surface evaporated and due to the heat of vaporisation, temperature decreased. Later, as the surface of the lens became dry, it was warmed up by the thermal conduction from the cornea. In the case of soft lens wear, the temperature decreased rather monotonously. The reason may be as follows: the temperature was measured after 10 minutes of wearing soft lens and as the time passed the water content decreased, so that the temperature started to decrease gradually. However, temperature increase during measurement as in the case of the hard lens was not observed.

Fig. 18 shows the result of temperature measurement at the time of natural blinking after closing the eyes for 10 seconds. For the normal eye the temperature decrement was small on opening eye and

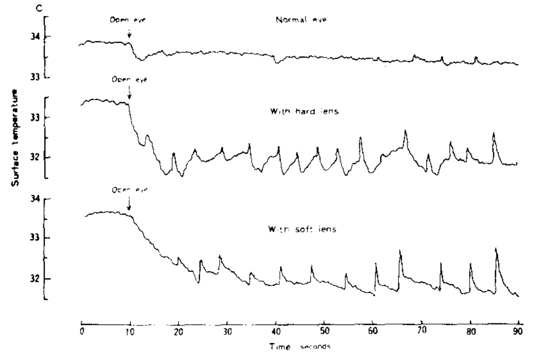
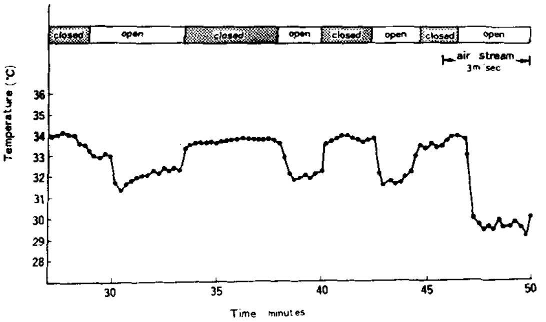


Fig. 18. Variation of temperature of human corneal surface. (room temperature: 23.5°C, humidity: 68%, age 27, female).

afterwards temperature decreased very slowly, so the effect of blinking can hardly be noticed. In contrast, with a contact lens, the effect of blinking appears as pulses on the curve and every time one blinks the temperature changes in a small step. Comparing the effect of hard lenses with soft lenses, it can be mentioned that the temperature drops just after opening the eye and that the shape of the blink pulse and the interval of blinks are different.

These measurements would give us not only the knowledge of surface temperature, but also information on the wetting condition of the surface, on the properties of tear liquid and on the number of blinks.

As the surface temperature of contact lenses has been successfully measured, it becomes necessary to know the temperature on the inner side of a contact lens. For this purpose we have developed a device to measure the temperature on the inner surface of a contact lens. The hard lens employed here has a diameter of 11.9 mm and a ceramic condenser is embedded on the inside as a detector of temperature. The result of measurement is given in Fig. 19. It can be observed even under a contact lens that the temperature



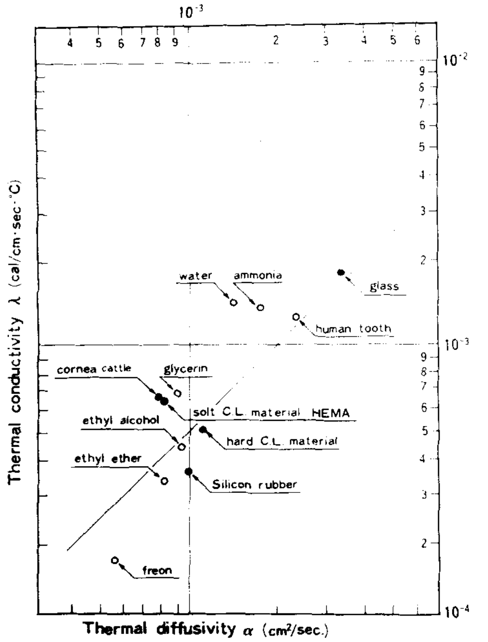
Hamano, Murata & Nishigori 1964)

Fig. 19. Temperature at inner surface of a hard lens (ambient temperature: 20°C, oral temperature: 36.7°C, age: 24, female).

varies sensitively by closing or opening of the eye, or by the wind in the surroundings. Therefore, it would be possible to mention that the temperature of the cornea itself is also affected somehow by a contact lens, although direct measurements are impossible.

Fig. 20 shows the thermal properties of various materials, including the cornea from cattle and contact lens materials. HEMA, which is the material of the soft lens, is found to have a very similar thermal conductivity and thermal diffusivity to cattle cornea. Glass, silicon rubber and methacrylic material for hard lenses have different thermal properties from those of cornea. Therefore, it can be imagined easily that the soft lens is very adaptive to the cornea from the standpoint of thermal properties and that the temperature difference at the contact point of soft lens and cornea would be smaller compared to that when other lens materials are employed.

As a next step it would become necessary to know the effect of thermal properties of various lenses on the surface temperature of the cornea. Naturally, the thickness and the size of the contact lens would affect the corneal temperature. Also the outer surface of the lens is affected by blinking and thermal radiation. Thus this problem is a non-steady state problem with complex boundary conditions. So far



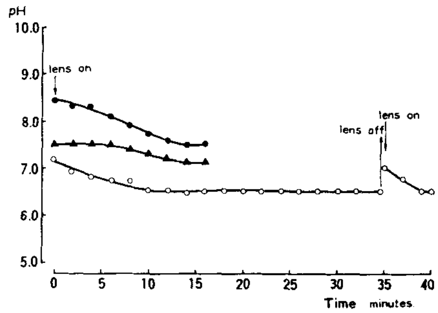
(Hamano, Miyabe & Mitsunaga 1971)

Fig. 20. Correlation of thermal conductivity and thermal diffusivity for various materials (at 20°C, 1 atm).

we have not analysed the problem completely, however, it would be an important problem to be solved in future, for the enzyme activity and metabolism of epithelial cells are temperature dependent.

Study on pH of Corneal Surface

The pH value of corneal surface depends on that of tears and it is commonly accepted that pH of tears is about 7.4 (Rexed, 1958). Fig. 21 shows the results of pH measurements of human eye with hard lens by a pH glass tube electrode.



(Hamano, Murata & Nishimoto 1966)

Fig. 21. Continuous measurement of pH of human eye through embedded electrode in a hard lens.

The initial pH value of the eye was sometimes around 8.0 and this is on the alkaline side compared with the reported data of pH of tears. On wearing a contact lens pH value shifts to the acidic side, that is, lowering of pH occurs by 0.5 to 1.0, and after about 10 minutes it attains a stable value.

Recently, to study the relationship between contact lens wear and pH of tears in more detail, a micro glass tube pH electrode having the diameter of 1.8 mm (Fuji Kagaku Keisoku Inc., Japan) was developed and the variation of pH was examined on the corneal surface. Fig. 22 shows the result of measurement of pH by

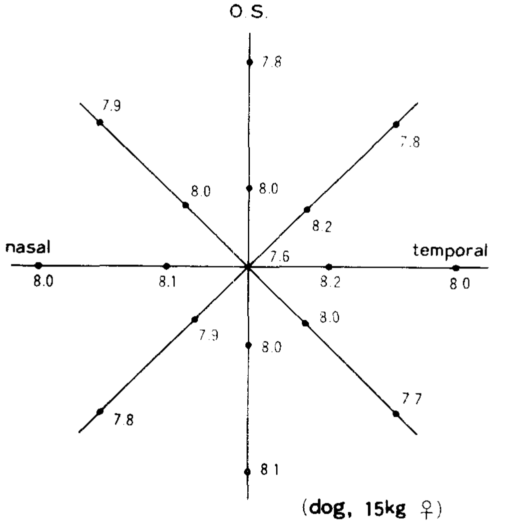


Fig. 22. pH at various positions of dog cornea.

this electrode at various positions on the dog cornea. pH values are in the range of 7.6 to 8.1.

To know the diurnal change of pH, normal eyes of ten guide dogs for the blind, which are extremely regularly trained, were examined. The measurements were made every hour and a half from 8 a.m. to 8 p.m. The result of measurement is shown in Fig. 23. It can be seen both for 5 male and 5 female dogs that pH value becomes acidic in the a.m. and it reaches minimum at noon and becomes alkaline in the p.m. The same kind of phenomenon is observed both for right and left eyes. Further the same tendency is recognised for the measurements made on different days. Fig. 24 is the histogram indicating the diurnal deviation from the average pH value of each sample dog for time zone of 1.5 hours. It is evident that there is a regularity for the variation of corneal surface pH.

From these experimental data for dogs it can be deduced that more reliable data of variation of pH on wearing contact lenses would be obtained at a constant time interval than for long duration measurement.

From such a standpoint the variation of corneal surface pH of human eyes with and without contact lenses was examined. Fig. 25 shows the results of measurements during 13:00 to 16:00 hours on 16 normal eyes of 8 persons, on 23 eyes with hard lenses for 14 persons and on 17 eyes with soft lenses for 10 persons. All persons in this experiment are inexperienced with contact lenses and the time of wearing lenses is limited to one hour. As the figure shows, pH value decreases from the initial

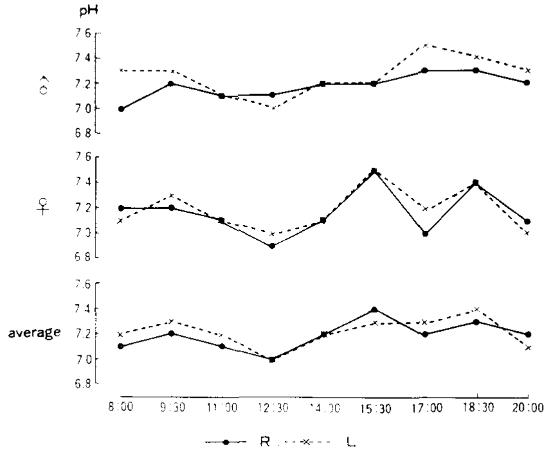


Fig. 23. Diurnal variation of corneal surface pH of 10 dogs.

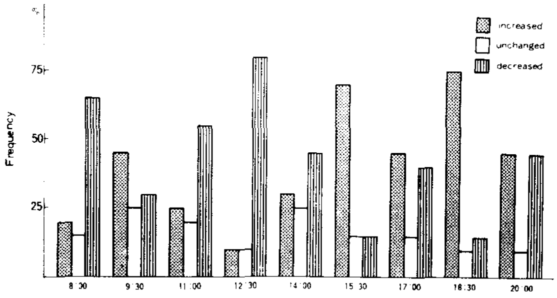


Fig. 24. Histogram indicating the diurnal deviation of corneal surface pH from the average value of each sample dog.

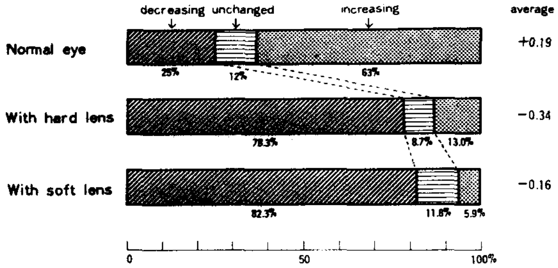


Fig. 25. Change of corneal surface pH on wearing contact lenses for one hour (human eye, during 13:00 to 16:00).

value for 25% of normal eyes, 78.3% of eyes with hard lenses and 82.3% of eyes with soft lenses. Thus, the corneal surface pH becomes acidic for most eyes with contact lenses. However, when compared with pH just before wearing lenses, the range of variation of pH becomes —0.34 and —0.16 for eyes with hard and soft lenses, and this signifies that the eye with a hard lens is more acidic.

Study on Radius of Corneal Curvature

It is widely known that the radius of corneal curvature is affected by wearing contact lenses, and many investigations have been undertaken on this subject. However, information on the peripheral region of the cornea has not been obtained so far.

Recently, we have succeeded in measuring the radius of curvature of the human cornea with one hour of contact lens wear with the PEK camera (Mark IIIA, Wesley Jessen Co., U.S.A.).

The measurements were made for 20 eyes of 10 females whose ages were between 23 and 27. Among them, 6 girls were accustomed to hard lenses and their refractive errors were in the range of —4.00 to —6.00 D, and 4 other girls inexperienced in contact lens wear. By the usual methods, the best fit hard lens was adapted to the right eye and the best fit soft lens applied to the left eye. Photographs were taken by the PEK camera just before the application of lenses and after 30 and 60 minutes of wearing them.

Fig. 26 shows the variation of the radius of curvature of the central part of the cornea for experienced and inexperienced eyes with hard or soft lenses. When girls experienced in contact lenses wear hard lenses for 30 minutes a fairly large drop of the radius of curvature is observed and the cornea becomes steep. This tendency is more evident in the direction of the horizontal axis, and the result agrees with those reported by many investigators. When these girls wear soft lenses, the variation of radius of curvature becomes smaller than in the case of hard lens wear and after about 60 minutes the radius of curvature becomes stable or even shows a tendency to recover. Further, it can be seen for the eye with a hard lens that the deviation seems to be larger for the adapted eye than for the unadapted eye.

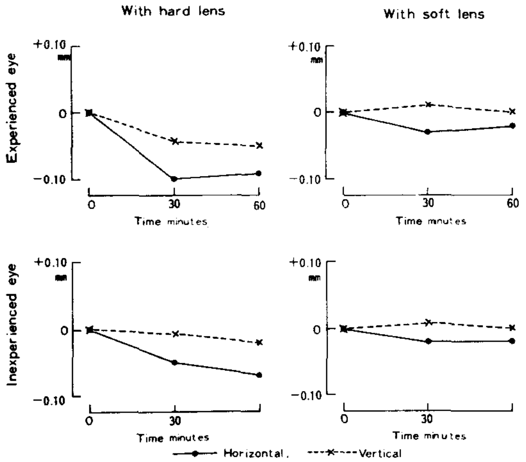


Fig. 26. Variation of radius of curvature at paracentral part of human cornea.

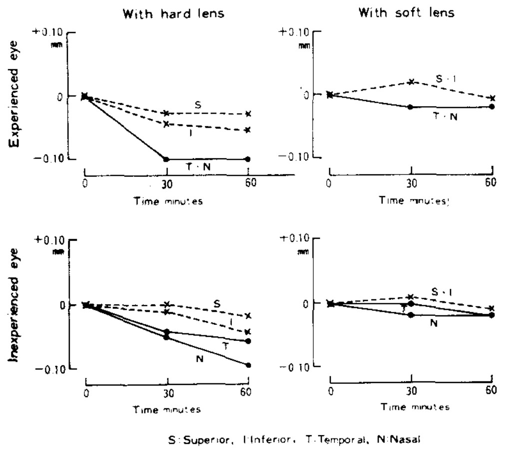


Fig. 27. Variation of radius of curvature at paracentral part of human cornea.

In the case of soft lenses, the deviation is not so significant as in the case of hard lenses.

Fig. 27 shows the variation of radius of curvature of para-central part of human cornea. The para-central part means the region which is covered even by a hard lens. The calculations of curvature are made at the inner fourth ring out of 7 rings of a keratograph and those points lie about 3 mm from the centre of the cornea. Comparing this figure with Fig. 26, it is found that the deviation of radius of curvature in the para-central part is very close to that in the central part. The similarity of this tendency is recognised for all 20 eyes without any exception.

The measurement of corneal curvature has been successfully done after 60 minutes of contact lens wear. Naturally, it is interesting to know the variation of curvature for a much longer time interval, but in this case it becomes quite necessary to know beforehand the diurnal change of corneal curvature in normal conditions. Unfortunately the reliable data on the corneal curvature have not been published yet, but hereafter by the progress and development of precise measuring methods, such as PEK, it can be anticipated that more fundamental and clinically beneficial information regarding the shape of the cornea will be obtained.

SUMMARY

The effects of contact lenses on the cornea have been studied through fundamental research and almost all our experimental results show that the soft lens has less influence on the cornea.

Naturally, the hard lens and the soft lens have their own suitable application and there are still many problems to be solved with regard to the soft lens, for example, sterilization, sediment, mechanical properties and visual correction of astigmatism or keratoconus.

However, judging from our fundamental experiments, the soft lens would be improved for continuous wear and prevail more in the near future.

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