Non-penetrating Corneal Foreign Body Injuries: Relationships between the Distributions of Corneal Foreign Bodies and Their Entering Directions into the Cornea

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ABSTRACT. The purpose of this study was to investigate how foreign bodies enter into the cornea relative to the directions of entrance and to suggest proper protection of the eyes from foreign bodies. Seventy-eight eyes of 78 patients were classified into two groups according to the entering direction of the foreign body: certain and uncertain directions. The real distributions of foreign bodies in the cornea were obtained using photographs of the treated eyes and these were compared with theoretical distributions which were calculated based upon the theory of probability. The group with foreign bodies entering from uncertain directions comprised 16 (20%) of the 78 eyes. In this group, all the foreign bodies were made of iron, and none of them were in the upper half of the cornea. These distributions were significantly different from those in the group with foreign bodies entering from a certain direction. The theoretical probabilities of foreign bodies hitting the lower half increased, as the entering directions decreased. When foreign bodies entered into the cornea from uncertain directions, it is highly possible that they did so from lower directions. This suggests that ordinary glasses can protect the eyes from corneal foreign bodies as an eye protective tool in almost all such cases, although they are open on the temporal and upper sides.

Key words ① **corneal foreign body** ② **localization** ③ **direction** ④ **protection** ⑤ **glasses**

Corneal foreign bodies (FBs), among the most common injuries treated in emergency rooms, have been studied as an aspect of worker health. The total numbers of FBs in the upper and lower halves of the cornea have been compared and FBs have been reported to be localized in the lower half of the cornea1,2. It has also been considered that the localization of the cornea may be the result of the eyelid partially covering the upper half1,2 and that the corneal trauma caused by FBs are generated mostly in work-related environments1-5.

As a tool for protecting our eyes from foreign bodies, various kinds of protective glasses which fulfill industrial standards have been used in work-related environments. However, many FBs still occur almost every day and somewhere in the world. This is because protective glasses are uncomfortable, so workers avoided them. Quite a few FBs also occur also in the process of doing ordinary things in every day life. To properly protect our eyes from corneal trauma in various environments, it is necessary to investigate how

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foreign bodies enter into the cornea.

In this study, the distributions of FBs in the cornea were examined relative to their directions of entrance of into the cornea. According to the entering directions, FBs were classified into two groups: one with a certain entering direction such as from the front and the others with uncertain entering directions. The two groups clearly differed in distributions of FBs. The theoretical relationships between the entering directions and distributions of FBs in the cornea were obtained based upon the theory of probability, and the entering directions in the latter group were calculated using the relationships. Proper protection of the eyes from FB was also discussed.

MATERIALS AND METHODS

Eye materials

Eyes treated from April 1996 through October 2001 in the Department of Ophthalmology, Hamamatsu Rosai Hospital, one of the hospitals founded for workers' health by the Labor Welfare Corporation under the control of the Ministry of Labor (presently, the Ministry of Health, Labor and Welfare) in Japan, were examined retrospectively. Eyes penetrated by FBs were excluded.

Seventy-eight eyes of 78 patients were used in this study. All the eyes had corneal abrasions without regard to corneal rust, and their FBs were more than attached to the corneal surface. The age of the patients whose eyes were treated ranged from 18 to 70 years old, with a mean age of 37.9 years old. All the FBs were fine-granule-like, and they were composed of iron, aluminum, concrete, plastic, and solder alloy. The number of eyes having FBs containing each material were 72 (92.2%), two (2.6%), two (2.6%), one (1.3%), and one (1.3%) of 78 eyes, respectively. Out of the 78 eyes, 74 (94%) were from male patients and 4(6%) from female ones. Forty six (59%) were right eyes and 32 (41%) left ones. Foreign bodies entered the cornea while patients were using a grinder or a sander, soldering, repairing on cars or outer walls, riding on a motorcycle, driving a car, walking, staying in a room, and during other miscellaneous activities.

Real distributions of FBs in cornea

Distributions of FBs in the cornea were obtained using photographs of the eyes, which had taken with each patient's consent. On each photograph, a line was drawn between the corneal center (O) and each FB (F). The length of OF and the clockwise angle between the vertical and OF (θ) were measured for each FB (Fig. 1). The vertical was set as 12:00, and the angle (θ) was expressed in a time scale. The ratio of the length of OF to the radii of the cornea was calculated for each FB, assuming that the cornea was circular. All the FBs were plotted on a diagram using two indices: the ratios and the angles. The positions of the FBs on the left eyes were converted to those on the right ones using a mirror-image-exchange method, since no specific differences between the sides of the eyes in FBs were observed in this study. Then, the cornea on the diagram was divided into upper and lower halves, and the distributions of FBs in both halves were compared with each other. The FBs on the half line were included in the lower half.

Based on entering directions determined using the patients' history, FBs were classified into two groups: ones with a certain entering direction (CED) and the others with uncertain entering directions (UED). In CEDs, FBs entered the cornea from the front when someone was using a grinder or a sander, soldering, repairing cars or outer walls, or riding on a motorcycle at a high speed. On the other hand, in UEDs, the

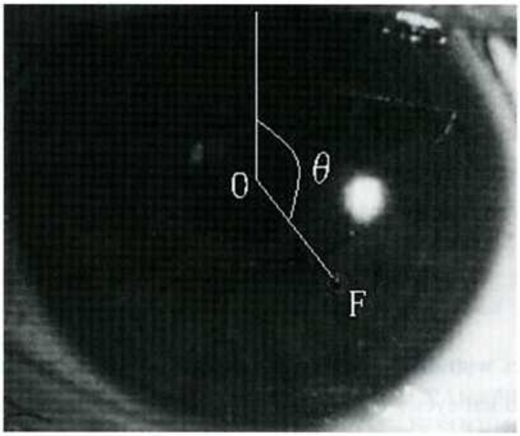

Fig. 1. Determination of the positions of foreign bodies in the cornea. The foreign body (FB) is marked with a red circle. O: corneal center, OF: a line drawn between the corneal center and the foreign body, θ: angle between the vertical and the foreign body.

Equation 1

$$-90 \le \theta \le 0$$

$$p = \int_{-v0}^{v0} h1\,dx \Big/ \int_{-v0}^{v0} h2dx$$

$$= \int_{-v0}^{v0}\{r\cos(-\theta) + r\sin(-\theta)\}dx \Big/ \int_{-v0}^{v0}\{r + r\cos(-\theta)\}dx$$

$$= (\cos\theta - \sin\theta)/(1 + \cos\theta)$$

Equation 2

$$0 \le \theta \le 90$$

$$p = \int_{-v0}^{v0} h1\,dx \Big/ \int_{-v0}^{v0} h2dx$$

$$= \int_{-v0}^{v0}(r - r\sin\theta)dx \Big/ \int_{-v0}^{v0}(r + r\cos\theta)dx$$

$$= (1 - \sin\theta)/(1 + \cos\theta)$$

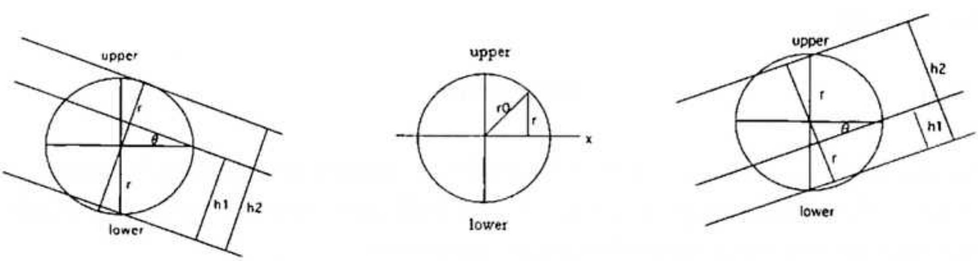

Fig. 2. Equations calculating the probabilities of foreign bodies with entering angles into the lower half of the cornea. Two kinds of equations were used according to the entering angles: (left) Equation 1 when the angle was $-90 \leq \theta \leq 0$ and (right) Equation 2 when it was $0 < \theta \leq 90$. The cornea was assumed to be spherical. r0=corneal radius, p=probability, θ=degree of entering angle. The center is the horizontal integration in each equation.

injuries happened when aperson was walking, looking up at cargo, staying in a working room, driving under a guardrail, or in an uncertain situation. Then the characteristics in CED and UED were compared with, and $\chi 2$ tests were performed to examine the differences in localization between CED and UED.

Theoretical distribution of FBs in the cornea

The theoretical probabilities of FBs hitting the lower half of the cornea with various entering directions into cornea were calculated based upon the theory of probability. That is, first, the lower half and the whole surface of cornea were projected from entering directions of FBs into the cornea, and the ratio of the projected area with the lower half to that with the whole surface was obtained. The theoretical probabilities were proportional to the ratio. Based on the angle (θ) made between the entering direction of an FB into the cornea and the horizon, the projected areas were calculated using the two kinds of equations shown in Figure 2 (Equations 1, 2). The theoretical probabilities were calculated for every five degrees of θ, and the theoretical and real distributions were compared with each other.

RESULTS

No significant differences with the characteristics of the FBs were observed between male and female patients, or between right and left eyes. With regard to protection for the eyes, an FB was observed to have entered the cornea even when ordinary glasses were worn. The other patients had not worn any glasses. There was a patient who had gotten FBs more than once at the same work.

Sixty-two (80%) of the 78 eyes had a CED and 16 (20%) had a UED. With regard to the materials the FBs were composed of, the major material was iron in both CEDs and UEDs. In the case of UEDs, in particular there was no material other than iron. In the case of CEDs, there were various materials such as aluminum, concrete, plastic, and solder alloy as well as iron.

Regarding the real distributions of the FBs in the cornea, most of them were observed in the lower half of the cornea. UEDs had FBs only in the lower half (Fig. 3). The distributions of UEDs were significantly different from those of CEDs ($\chi 2$ authorization $\alpha < 0.05$). As for the theoretical distributions of FBs in the cornea, the relationship between the entering directions of FBs into the corneas and the probabilities of hitting the lower half of the cornea are shown in Figure 4. The theoretical probabilities increased, as the entering directions decreased.

DISCUSSION

More male patients experienced FBs than did females, as reported previously1-3,. Males may either prefer or need to be in environments where FBs can more easily enter the cornea. Differences in male and female roles in a society may be related to these uneven distributions.

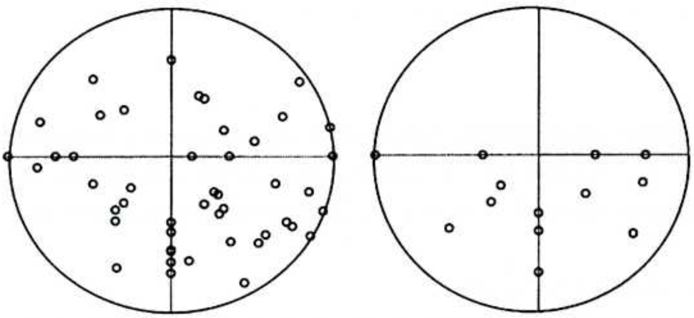

Fig. 3. Distributions of corneal foreign bodies in two groups: (left) one having foreign bodies which entered in certain directions, such as the front, and (right) the other having ones which entered in uncertain directions.

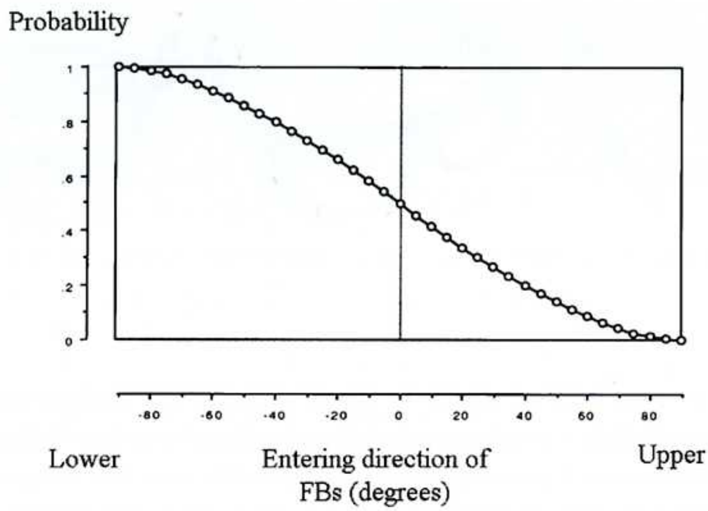

Fig. 4. Theoretical probabilities with entering angles of foreign bodies into the lower half of the cornea. They were calculated using Equations 1 and 2 shown in Figure 2.

Localization of FBs in the lower half of the cornea has been reported previously1,2. In this study, the distributions in CED were compared with those in UED, and localization in the lower half of the cornea was observed more in both groups. What caused this localization? Regarding CED, the patients were using a grinder and/or a sander, soldering, carrying out repairs on cars or outer walls, or riding on a motorcycle at a high speed when the FBs entered the cornea. At the time, it is considered that the patients under these circumstances opened their eyes wide to direct their attention to some objects. It is probable that FBs could get to any location in the cornea. The possibilities of this happening have been considered to be equal, but actually they are not. There may have been something which forces the FBs to enter the lower half of the cornea or prevented them from entering the upper half. Presently, there is no candidate to prevent entrance into the lower half of the cornea, but the eyelids would prevent entrance into the upper half. Therefore, as believed for a half century, this localization seems to have resulted from the existence of the upper eyelid. In UED, the patients were walking, looking up at cargo, staying in a work room, driving under a guardrail or were in an unclear situation when the FBs entered the cornea. It is considered that the patients did not keep directing their attention to any particular source of the FBs, and that their eyes were not always open wide. Therefore, the possibilities for the locations of FBs in UED patients are considered to differ from those in CED patients. In fact, they were significantly different. None of the FBs in UED patients existed in the upper half of the cornea, while some those in CED patients did. How did the presence of the eyelids affect the distribution of FBs in the UED patients? Usually, the lower eyelid is up when the upper eyelid is down. That is, lowering of the upper eyelid to the extent that it covers the upper half of cornea results in the width of the palpebral fissure becoming extremely narrow, and FBs are supposed to be localized near the central line in the cornea. However, actually, FBs were distributed all over the lower half. Therefore, the clear localization in the lower half in UED patients cannot be explained only by the existence of the eyelids. What caused the clear localization? In this study, theoretical probabilities indicated that the directions of entrance affected the distributions of FBs in the cornea. If the cornea were flat, FBs could possibly hit any location in the cornea,

Fig. 5. Various types of glasses for eye protection: (left) ordinary glasses, (center) protective glasses, and (right) protective goggles.

despite the entering directions. However, actually, the cornea is spherical, and the theoretical probabilities of FBs entering the lower half of the cornea increased as the entering directions decreased (Figure 4). That is, as the number of entering directions decreased, FBs more easily entered the lower half of the cornea. Therefore, it is considered that lower directions of entrance in addition to the existence of eyelids may have caused the clear localization in the lower half of the cornea in UED patients.

Today, there are many types of glasses available for eye protection: for example, (1) ordinary glasses, (2) protective glasses, and (3) protective goggles (Fig. 5). In CED patietns, the sources of FBs were identified and the FBs entered cornea from the front. Protective glasses and protective goggles which fulfill an industrial standard are usually used in work-related environments. However, these glasses are sometimes not worn in dangerous environments even though they can protect our eyes almost completely from FBs, because they are not comfortable for some workers. Needless to say that it is necessary to use any protective tools in the environments where FBs may easily enter the cornea even if wearing protective glasses or goggles are disliked.

On the other hand, in UED patients, all the FBs were composed of iron, and it is suspected that iron grids on roads or working sites might have been the sources. In such environments, people do not consider there is any necessity for eye protection, although getting FBs from such sources is possible. The results of this study indicate that it is important to protect our eyes from FBs even in the environments observed for UED patients. Therefore, the protection from lower entering directions is essential. In almost all cases, ordinary glasses can protect our eyes from FBs which are more than attached to the corneal surface although ordinary glasses are open on the temporal and upper sides. In facts, FBs occurred only when patients did not wear any type of glasses with the exception of only one case of UED.

It is workers' duty to use protective gasses or goggles when they are doing work involving sanders, grinders, industrial air guns or other similar equipment. It is also necessary to wear any type of glasses, at least ordinary glasses with or without refraction, including sunglasses, when they are in walking in or staying at working sites, especially at large windblown sites such as an aircraft or automobile factories.

FBs are still among the most commonly treated injuries in emergency rooms. Considering that there was also a patient who had ever got FBs, it is necessary to teach a patient at emergency rooms to wear any type of glasses at the environments where FBs are possible to occur. To protect our eyes properly, protective eys equipments needs to be improved and adequate types of glasses need to be chosen.

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ABBREVIATIONS

FB: corneal foreign body

CED: certain entering direction

UED: uncertain entering direction

REFERENCES

1) Yamagata Y, Mimura O, Shimooku M : Statistic observation on corneal foreign bodies. [English translation] Japanese Review of Clinical Ophthalmology 80(9):1780-1784, 1986

2) Kaye-Wilson LG : Localization of corneal foreign bodies. Br J Ophthalmol. 76:741-742, 1992

3) Yamada Y, Aoyama S, Kitagawa K, et al. : Cases with foreign bodies in the cornea treated in the Kanazawa Medical University Hospital. [English translation] Journal of Kanazawa Medical University 19:350-354, 1994

4) Alexander MM, MacLeod JDA, Hall NF, et al. : More than meets the eye: a study of the time lost from work by patients who incurred injuries from corneal foreign bodies. Br J Ophthalmol 75:740-742, 1991

5) Jayamanne DGR, Bell RWD : Non-penetrating corneal foreign body injuries: factors affecting delay in rehabilitation of patients. Journal of Accident Emergency Medicine 11:195-197, 1994