IS THERE A LINK BETWEEN CORNEAL STRUCTURE AND THE 'CORNEAL CROSS'?

BARBARA K. PIERSCIONEK[1] and ROBERT A. WEALE[2,3]

SUMMARY

The 'corneal cross', observed when polarised light is reflected from the cornea and viewed through a crossed analyser, has been attributed to the fine anisotropic structure of the cornea causing birefringence or, alternatively, multiple reflections. But when plane polarised light is similarly reflected from isotropic curved surfaces and viewed through a crossed analyser, isogyres are also seen. Moreover, they vanish with a gonioscopic lens neutralising corneal curvature. This suggests that the corneal cross is not a specific attribute of corneal birefringence.

Polarised light is useful for the study of the optical properties of transparent and reflecting substances. It can yield information on structural detail and optical parameters. The living human cornea has been studied in this manner by a number of authors, referenced in Cope *et al.*,[1] and the mechanism of its light transmission in general has also been elucidated.[2] Polarised light illuminating the living human cornea produces patterns attributed to birefringence. This is a property of highly ordered structures, such as crystals, the refractive index varying with the direction of light travel and so causing a relative retardation of light rays which may be travelling along different paths. The unambiguous measurement of birefringence requires a knowledge of that retardation, obtainable with circularly polarised light, which is the only form of polarised light to produce a pattern linked exclusively to retardation.

Because of this, van Blokland and Verhelst[3] employed circularly polarised light passing through the eye in order to learn more about corneal birefringence. They avoided the use of linearly polarised light because it masks the relevant retardation patterns.

However, viewing the cornea between crossed linear polarisers gives rise to the appearance of a characteristic dark cross (isogyres) imaged against the iris, and not observed when circularly polarised light is used. Following statements made in a very early study (cited in Nyquist[4]) the 'corneal cross' has been associated with corneal birefringence. Cope *et al.*[1] suggested that 'the optical mechanisms of the corneal polarisation cross involve both the corneal curvature . . ., and the distribution of the corneal collagen fibrils'. In other words, they explain the corneal cross as the cumulative result of rotation and retardation of light due to the collagenous corneal layers. But Stanworth and Naylor[5] state that there is no birefringence in the [feline] corneal centre since the [human] central lamellae are randomly orientated.[6]

The issue addressed here is not whether the cornea is birefringent or not, but rather whether isogyres can be used as an indicator of its birefringence. It may be noted that a similar figure observed in highly refracting, isotropic (non-birefringent) structures placed between crossed polarisers has been shown to result purely from refraction, which causes a rotation of the plane of polarisation of obliquely incident rays.[7–9] This can be explained by Fresnel's laws,[8–10] which describe the relation between the amplitudes of incident, refracted and reflected rays in terms of their directions. In the case of linearly polarised light, they predict a verifiable change in direction of the plane of polarisation after refraction.

Now these laws make an analogous prediction also for reflected light, and accordingly may serve to explain the formation of the corneal isogyres. If this is true then one should observe isogyres in the absence of birefringence, following reflection at a convex surface placed between crossed polarisers. The following study sought to test this.

METHODS

Human corneae from two subjects were photographed using a Topcon SL5 photo-slip-lamp with

From: [1]Department of Electronic Engineering, La Trobe University, Bundoora, Victoria 3083, Australia; [2]Age Concern Institute of Gerontology, London, UK; [3]Moorfields Eye Hospital, London, UK.

Correspondence to: R. A. Weale, Age Concern Institute of Gerontology, King's College London, Cornwall House, Waterloo Road, London SE1 8WA, UK.

Eye (1997) 11, 361–364

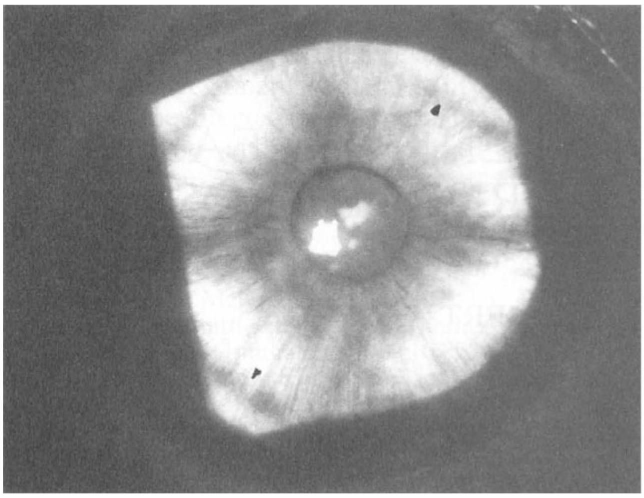


Fig. 1. *Corneal isogyres seen against the background of the iris in an eye viewed through a slit-lamp with crossed polarisers. The arrows mark a ring caused by corneal birefringence.*

two modifications. One polariser (axis horizontal) was placed above the slit-lamp mirror and another (axis vertical) was placed in front of the microscope. The polarisers were Lee camera filters (linear type butyrate-based polarisers).

In addition, the corneae of four glaucoma patients were viewed through crossed polarisers, as described above, both without and with a gonioscopic lens. However, no photograph was taken through the gonioscope.

The above situation was mimicked as follows for three reflecting objects: a glass lens of refractive index $n = 1.495$ as measured with an Abbe refractometer at a wavelength of 589 nm; a chromium-coated steel button with $n = 2.97$ for the same wavelength; and a gelatin hemisphere, similarly with $n = 1.511$. The illumination was obtained from a 16 V incandescent filament lamp, and the light reflected from the test objects was photographed with a Minolta 7000i camera with a 100 mm f/2.8 macrolens. The film used was Kodak Tmax 400. The film speed was maintained at 400 ASA for the test objects, but increased, during development, to 800 ASA for the film containing the corneal images.

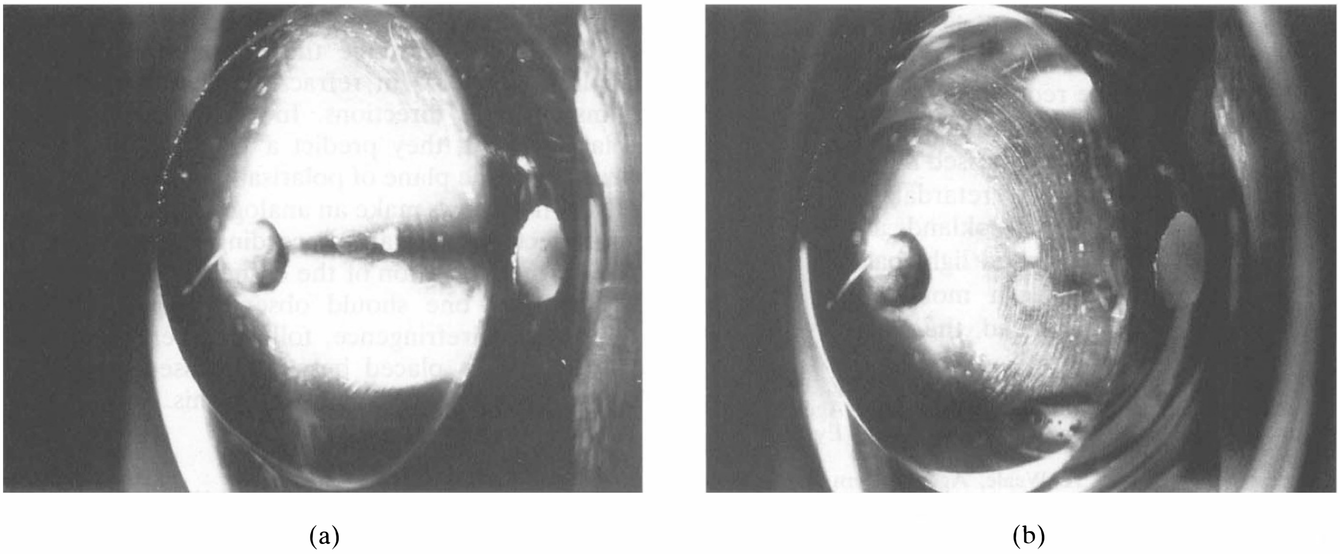
Following Cope *et al.*[1] a retarder, namely a quarter-wave plate (wavelength 550 nm), was inserted between the polariser and the reflecting surface and the effect on the cross following rotation of the quarter-wave plate, in a plane parallel to the polarisers, was noted.

RESULTS

A representative set of corneal isogyres is shown in Fig. 1. The dark cross is clearly visible against the background of the iris. The arrows indicate coloured rings, called isochromatics, which vanish when one or both polarisers are removed.

Fig. 2 shows the glass lens (a) between crossed polarisers, and (b) in natural light. The isogyres were easiest to photograph at an angle of about 45°, since the glass surface was highly reflecting: hence only the proximal isogyre arm is shown (Fig. 2a). The lump of modelling clay seen on the left served to eliminate glare due to reflection of the filament of the lamp.

Figs. 3 and 4 show analogous results for the crossed polarisers used in connection with the hemispherical gelatin shell and the chromium-coated button respectively. The gelatin surface reflected less regularly than the glass lens, and so, although the isogyre contrast is reduced, there was no veiling glare, thus allowing all four isogyre arms to be photographed. In Fig. 4 reflections from the surface of the button clearly show the isogyre pattern. Being a function of the curvature, the isogyres are here thicker, so that the dark section, which is almost diamond-shaped, extends over a large part of the



(a) (b)

Fig. 2. *Light reflected from a glass lens photographed (a) between crossed polarisers, (b) without polarizers.*

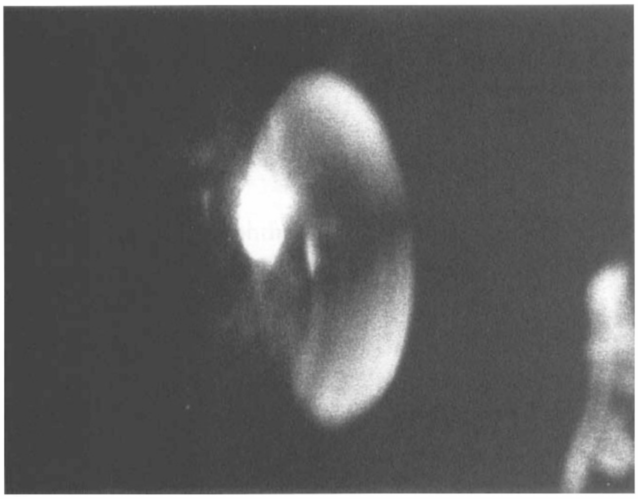


Fig. 3. *Light reflected from a hemispherical gelatin shell photographed between crossed polarisers.*

surface: the illuminated sections of the quadrants are confined to the outer edges of the surface. Fig. 4, like Fig. 2, shows only the proximal section of the pattern because of the angle at which the photograph was taken.

When the fast axis of the quarter-wave plate was parallel to the axis of either polariser no change occurred in the isogyre pattern. As the angle between the fast axis of the quarter-wave plate and either polariser axis increased from zero, the cross changed to two hyperbolae located in diagonal quadrants and aligned along the direction of the fast axis, as had been earlier observed also for transmitted light.[1]

To test further whether rotation of the plane of polarisation, caused by reflection at a curved surface, is the reason for the appearance of the isogyres, observations through crossed polarisers were made with the corneal curvature neutralised with a gonioscopic lens. While the isochromatics persist, the dark cross vanishes or else degenerates into a nondescript grey area, much as can be seen in strongly flattened excised lenses.[11] More particularly, the insertion of the gonioscope transforms the appearance of the cornea from one characterised by the cross to one having the appearance of van Blokland and Verhelst's[3] photographs which show no cross but characteristics of biaxial crystals together with one or more coloured rings in the corneal periphery.

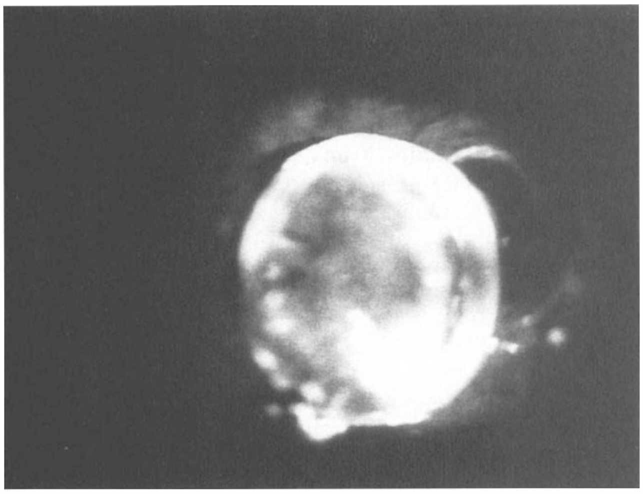


Fig. 4. *Light reflected from a chromium-plated button photographed between crossed polarisers.*

DISCUSSION

The three test objects – glass lens, steel button and gelatin hemisphere – are all non-birefringent structures with curved surfaces. Because the reflecting surfaces are curved there are variations in the directions of reflection of the incident plane polarised rays and hence in the amounts of rotation of their planes of polarisation, as predicted by Fresnel's equations.[12] The extent of rotation governs the amount of light which will pass through the second polariser (analyser) and the resultant pattern is that of the dark cross. The corneal surface is also highly reflective and consequently the isogyre pattern seen in Fig. 1 can result from the rotation of reflected plane polarised light. Hence there is no need to base the existence of the isogyre pattern on birefringence or multiple reflections.[13] This does not negate or dispute the notion of corneal birefringence but serves to point out that it is not a prerequisite for the formation of the isogyres (as had long been assumed until recent work on the lens showed otherwise[7]), and conversely that the cross pattern provides no measure of birefringence.

Cope *et al.*[1] have suggested that the isogyres are the cumulative result of rotation and retardation of light as it passes through the layers of the cornea. The authors viewed an *in vitro* cornea placed between linear polarisers. Our results show phenomena similar to those observed by the authors with transmitted light can also be observed when the light is reflected from curved surfaces. They concluded that the cornea is birefringent from observations of changes to the isogyre pattern following the insertion of a retarder between the analyser and the cornea. However, similar observations, employing a retarder, can be made for non-birefringent objects such as those used in this study. This is because a retarder can also rotate the plane of a polarised beam and in this way alter the isogyre pattern. The test object does not have to be birefringent for such an alteration to occur.

Here the notion of corneal birefringence is not under discussion. What is suggested is that the isogyres (i.e. the corneal cross) may be explained in terms of Fresnel's equations relating to the reflection of plane polarised light at a curved surface, and that the corneal cross is due to the presence of a reflecting surface no matter what else it may also indicate.

The authors thank Professor Hugh Taylor for the facilities kindly made available at the Royal Victorian Eye and Ear Hospital, Melbourne, and Mr K. Sharma, FRCS, FRCOphth, Dr G. Seth and Mr Mark Westcott, FRCS, FRCOphth, Moorfields Eye Hospital, for assistance with the observations with the gonioscope. B.K.P. thanks Essilor and the National Health and Medical Research Council of Australia for support.

Key words: Cornea, Corneal reflexion, Polarisation, Isogyres.

REFERENCES

1. Cope WT, Wolbarsht ML, Yamanashi BS. The corneal polarisation cross. J Opt Soc Am 1978;68:1139–41.
2. Maurice DM. The structure and transparency of the cornea. J Physiol (Lond) 1957;136:263–86.
3. van Blokland GJ, Verhelst SC. Corneal polarisation in the living human eye explained with a biaxial model. J Opt Soc Am 1987;4:82–90.
4. Nyquist GW. Stress-induced birefringence of the cornea. Am J Ophthalmol 1968;59:398–404.
5. Stanworth A, Naylor EJ. The polarisation optics of the isolated cornea. Br J Ophthalmol 1950;34:201–11.
6. Kokott W. Über mechanisch-funktionelle Strukturen des Auges. Graefes Arch Ophthalmol 1938;138:424–85.
7. Pierscionek BK. Explanation of isogyre formation by the eye lens. Ophthalmol Physiol Opt 1993;13:91–4.
8. Pierscionek BK, Chan DYC. Mathematical description of isogyre formation in refracting structures. Ophthalmol Physiol Opt 1993;13:212–5.
9. Charman WN. Explanation for the observation of isogyres in crystalline lenses viewed between crossed polarisers. Ophthalmol Physiol Opt 1993;13:209–11.
10. Lekner J. Isogyre formation by isotropic refracting bodies. Ophthalmol Physiol Opt 1995;15:69–72.
11. Weale RA. The eye and aging. Interdiscipl Top Gerontol 1978;13:1–13.
12. Born M, Wolf E. Principles of optics. Oxford: Pergamon Press, 1970.
13. Mishima S. The use of polarised light in the biomicroscopy of the eye. Adv Ophthalmol 1960;10:1–31.