An estimate of the size and shape of the human lens fibre in vivo

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SUMMARY The size and shape of the lens fibres were estimated by specular reflex photography. The fibres were measured in three separate regions. Peripheral fibres have a mean width of 10.2 μm , the central fibres 11.9 μm , and the central fibres with suture 15.8 μm . Measurements were made of the taper (becoming narrower towards the suture) and flare (becoming wider towards the suture). The peripheral fibres have a mean taper of 0.3 μm per 100 μm . The central fibres have a mean flare of 0.6 μm per 100 μm , and the central fibres with suture have a mean flare of 2.4 μm per 100 μm . These differences are highly significant ($p < 10^{-6}$). From these measurements the overall shape of the average lens fibre was estimated. This fibre tapers as it passes forward from the equator to the peripheral extent of the lens sutures and then flares increasingly as the junction with the lens suture is approached. A mean increase in peripheral lens fibre width with age at 0.028 μm per year was demonstrated. This is significant ($p = 0.042$). No difference in fibre width was found in diabetics and non-diabetics.

The lens fibres of the human eye run an elliptical course from their termination at a suture line anteriorly to their other termination at a suture line posteriorly. Their length has been estimated by examination of the lens in vitro at 8-10 mm by Salzmann,¹ and this figure has been widely quoted since.² This figure appears perfectly acceptable and cannot be confirmed in vivo. Kuzsak *et al.*³ observed in vitro that the fibres are wider at their posterior ends than at their anterior ends. In-vivo observation by specular photography can give information on the lens fibre width and how this changes in various regions of the anterior part of the fibre only.

Vogt⁴ observed in vitro that the fibres tapered from the equator towards the peripheral extent of the lens sutures and then flared towards their insertions in the sutures. The electron microscope studies of Kuzsak *et al.*³ showed no taper in the fibres of human lenses and that the fibre is flared in the proportion of 1:1.7 in its course from the equator to the suture.

The lens fibre width was estimated in vitro by Salzmann as 8-12 μm and there appear to have been no further estimates until the specular photographic studies of Laing and Bursell,⁵ who estimated the

width as 8 (SD 2) μm and Bron and Matsuda,⁶ whose estimate was 7.8 to 17.4 μm with a mean of 13.7 μm . Bron and Matsuda's figures are uncorrected for the corneal magnification and it is not stated whether Laing and Bursell's figures are corrected.

A variety of specular reflex images can be obtained from the anterior lens surface with the slit-lamp microscope or with the macro camera. The appearance depends on the angles of illumination and viewing and on the depth to which the camera or microscope is focused in the eye. The anterior corneal shagreen (Fig. 1) is easily demonstrated. The next appearance to be demonstrated is an arrangement of fine spots (Fig. 2) representing the lens epithelium. (A specular reflex study of the lens epithelium has been submitted for publication.) With the focus at a slightly deeper level, a pattern of fine parallel lines (Fig. 3) is seen, and these lines represent the borders between the lens fibres. The fibres are seen to be near parallel sided in the periphery (Fig. 4) and flaring markedly as a suture is approached (Fig. 5). This appearance is seen in exaggeration (Fig. 6) when the lens fibres are swollen by oedema in a newly acquired traumatic cataract.

The recognition that several types of cataract take their form from the organisation of the lens fibres⁷

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Fig. 1 The anterior lens shagreen.

Fig. 2 The specular reflex image of the lens epithelium.

makes it particularly relevant to try to understand the structural form of the lens fibre.

The present study aims to estimate the width of the lens fibre in vivo and the extent of the taper and flare in the various regions of the fibre to give an overall picture of the shape of the typical human lens fibre on the anterior surface of the lens.

Material and methods

Sixty-five subjects were studied, ranging in age from 11 to 75, including 20 diabetics and two acromegalics. Twelve of the subjects had cataract. The observations were confined to one eye of each subject to reduce the effect of similarity between the left and right eyes detracting from the results. Recruitment of older subjects was limited by the difficulty in demonstrating the lens fibre specular reflex image, which could be found more reliably in young subjects. This image was also difficult to demonstrate in cataract, especially when there was any anterior subcapsular involvement. The eyes were photographed with a macro camera,⁸ with the primary magnification increased to approximately 15:1. Experiments with an artificial eye⁹ fitted with a graticule to represent the anterior lens surface showed that the magnification was increased by the effect of the cornea and with a camera viewing angle of 20° to the optic axis; the measured magnification was 14.8 horizontally and 17.0 vertically, giving a mean magnification of 15.9 times. The horizontal magnification of 14.8 was applied to the measurement of the fibre width of vertically running lens fibres. The vertical magnification of 17.0 was applied to the measurement of the fibre width of horizontally running lens fibres, and the mean magnification of 15.9 was applied to the measurement of obliquely running lens fibres. Most of the fibres satisfactorily demonstrated by the specular reflex image were horizontal or oblique.

The pupils were dilated with cyclopentolate 1% and phenylephrine 10% eye drops, and the subjects were seated at a Zeiss photo-slit lamp fitted with a Brown macro camera. The angles of illumination and viewing were adjusted to show the lens fibre specular reflex image. This was usually best demonstrated with broad slit focal illumination 20° off the optic axis on one side and the camera at 20° off the optic axis on the other side. The illumination and camera could be moved together to the left or right in order to demonstrate specular reflex images in the central or peripheral parts of the anterior lens surface. The peripheral images were identified by the presence of the pupil margin towards the edge of the frame. The pupil diameters varied from 6 to 8 mm.

The aperture on the 25 mm Leitz Photar macro lens was *f*5.6 and the film used was Ilford XP1, which

Fig. 3 *The specular reflex image of the lens fibres.*

combines fine grain with extended exposure latitude. An orange filter, Wratten 22, was used to increase image contrast, probably by reducing scatter from subjacent layers of the lens.

The negatives were projected on to paper with a Zeiss (Jena) Documator at a measured magnification of 17.0 times. The borders of the lens fibres were seen in the projected negative image as near parallel dark

Fig. 4 *The specular reflex image of the lens fibres in the periphery of the lens.*

Fig. 5 *The lens fibres are seen to curve and to flare as they approach the lens suture, which is seen as a broad dark line.*

Fig. 6 The flare of the lens fibres as they approach the sutures is seen in exaggeration when they are affected by oedema in a recent traumatic cataract.

lines. These were drawn on to the paper with a fine pencil and the distance between the pencilled lines measured with a comparator, an instrument with a 10 times magnifying lens and a graticule scaled in 0.1

Fig. 7A Percentage distribution curves of fibre widths from the three regions of the lens.

mm divisions. In each fibre that could be traced for a distance of 100 μm or more, width measurements were made at 100 μm intervals. From these figures the state of fibre vergence could be calculated. This is stated as tapering (converging in the direction of the suture) or flaring (diverging in the direction of the suture): 1420 fibres were measured.

The measured fibres were arranged into three population groups: (1) peripheral fibres, identified by the image of the pupil margin towards the edge of the frame; (2) central fibres; (3) central fibres in region of a visible suture. The peripheral fibres were estimated to lie in the region of 3 to 3.75 mm radius of the anterior surface of the lens, the central fibres in the region of 1.5–2.5 mm radius, and the central fibres with suture in the region of 1–2 mm radius. In 29 eyes a second satisfactory negative of the same region of the lens was available, allowing calculations of the standard deviation for the method.

Results

The three population groups from the different regions of the anterior surface of the lens were found to show different characteristics. The mean width of the peripheral fibres was 10.2 μm , the central group 11.9 μm , and the central group with suture 15.8 μm . One-way analysis of variance showed that differences in the means for the three groups were highly significant ($p < 10^{-6}$).

The range of fibre sizes found in each of these populations also differed. Those in the peripheral group were the most homogeneous and those in the

Fig. 7B Percentage distribution curves of fibre taper (-) and flare (+) from the three regions of the lens.

Fig. 8 The change in lens fibre size with age in peripheral fibres.

central group with suture showed the widest variation in size. These results are shown in the percentage distribution curves in Fig. 7A. The vergence also differed between the three fibre groups with the peripheral fibre group showing a mean taper of $-0.3 \mu\text{m}$ per $100 \mu\text{m}$, the central group a mean flare of $+0.6 \mu\text{m}$ per $100 \mu\text{m}$, and the central group with suture showed a mean flare of $+2.4 \mu\text{m}$ per $100 \mu\text{m}$. One-way analysis of variance showed that differences in the means of the three groups were highly significant ($p < 10^{-6}$).

In each negative examined both tapering and flaring fibres could commonly be found in any one region of the lens, but one or other type would predominate. Individual fibres tend either to taper or

to flare, but sometimes showed these characteristics separately in different regions of the same fibre. The percentage distribution curves for fibre taper and flare are shown in Fig. 7B.

The effect of age on the fibre size is shown graphically in Fig. 8. The mean peripheral fibre width in individual eyes was plotted against age. It is seen that there was a small ($0.028 \mu\text{m}$ per year) mean increase in lens fibre width with age. The regression analysis showed that this was significant ($p < 0.042$).

Eleven diabetic subjects were matched for age and sex with non-diabetics. The mean age for the diabetic subjects was 52.4 and for non-diabetics 52.7. The mean width of the peripheral lens fibres in the diabetics was $10.38 \mu\text{m}$ and in the non-diabetics $10.56 \mu\text{m}$, showing no significant difference ($p.63$).

The standard deviation for measuring the mean lens fibre width in a particular region of an individual lens was calculated from 29 eyes in which there were paired observations of the same region of the lens. This gave a standard deviation of $0.4 \mu\text{m}$. Thus it is seen that the change in lens fibre size with age (Fig. 3) exceeds the standard deviation for the method.

ESTIMATION OF THE SHAPE OF THE LENS FIBRE

From the observations of the lens fibre width in various regions of the lens and from the observations of the degree of taper or flare of the lens fibre in these regions it has been possible to construct a diagram of the typical lens fibre (Fig. 9). It is assumed that the adult lens has a diameter of approximately 10 mm, which is based on the calculations of Storey and Rabie,¹⁰ who estimated the diameter of the young adult lens unaccommodated at 9.6 mm. With good mydriasis the pupil diameter reaches 8 mm, so that the iris covers the peripheral 1 mm of the lens. The typical peripheral lens fibre has a width of $10 \mu\text{m}$ as it emerges from under the iris at a radius of 4 mm, tapering to $9 \mu\text{m}$ at 3.2 mm radius, and then running a near parallel sided course until becoming affected by progressively increasing flare as the suture is approached, with a final width of $20 \mu\text{m}$ reaching the suture. Thus the typical fibre flares by $9\text{--}20 \mu\text{m}$, a ratio of about 1:2. It is also seen (Fig. 9) that the fibre curves as it approaches the suture, except for those fibres that run to a suture bifurcation, which remain straight. The overall shape of groups of 25 typical lens fibres is shown in Fig. 9 (it is necessary to show a group of 25 fibres, since it is not feasible to draw single fibres).

From the estimated average fibre width of $10 \mu\text{m}$ at a diameter of 8 mm it is calculated that there are on average 2500 fibres in the most superficial shell of fibres.

Fig. 9 The estimated shape of the typical lens fibre. Groups of 25 fibres are drawn.

a Intersutural arc length

b Equatorial arc length

Fig. 10A A hypothetical lens fibre system in which the fibres curve sufficiently to join the sutures perpendicularly. This system requires that the fibres flare by 1:4.

ANALYSIS OF ERRORS

The method is subject to error owing to the observer having to identify the borders between adjacent fibres, which may occasionally lead to the false identification of non-adjacent fibre borders and the measurement of two fibres as one. Thus this may occasionally cause overestimation of the lens fibre width.

The fibres are observed through the cornea, and the distortions imposed by that structure have been allowed for by the use of an artificial eye, but the effect of various anterior chamber depths was not examined.

Discussion

The present in-vivo study confirms the observations by Vogt¹ on the fibre shape which he observed in a

Fig. 10B A hypothetical lens fibre system in which the fibres run a straight course to join the sutures at an angle of 14° . The fibres in this system do not need to flare.

single lens of a child's eye in vitro. It is shown that the fibre tapers slightly in the periphery of the lens and then runs a gradually increasingly flaring course towards the suture. In addition it has been possible to estimate the width in various regions of the fibre. Recent studies³ appear to have concentrated on the central flaring region of the lens and have not demonstrated the existence of a taper from periphery to centre.

The key to the mechanism of fibre taper and flare is the dimensions of the lens suture system. The sutures in the adult human eye show an extensively branched system¹¹ (Fig. 9). The peripheral terminations of the sutures are some distance from the equatorial periphery of the lens; thus the arc length between the termination of one suture and the next one is less than the arc length of the same segment of the lens at the equator (Fig. 10A). Then the fibres must taper as

Fig. 10C A diagrammatic representation of the actual human lens fibre system in which the fibres curve to join the sutures at an angle of 30° and flare by 1:2.

they pass from the equator to enter the bottleneck between the suture terminations. The shape of the fibres in the next part of their course is determined by the difference in the arc length between the suture terminations and the lengths of the sutures themselves. This varies somewhat in different regions of the lens depending on the degree of suture branching in that region. The differences are at their most extreme for fibres that run towards the apex of the lens (Fig. 9) and least for fibres that terminate near the peripheral extent of the sutures. The ratio of the arc length between the suture termination to the length of the sutures themselves in Fig. 9 is 1:4. This could be taken to imply that each fibre should flare by a factor of 4, which is approximately twice the value that measurement of the fibres has shown. The fibres would have to flare by a factor of 4 if they were each to curve sufficiently to join the suture perpen-

dicularly, as is shown diagrammatically in Fig. 10A. But this is not the case, as is seen in the specular photograph (Fig. 5), which shows the fibres joining the suture obliquely. No fibre flare at all would be required if the fibres were to run a straight course and to join the suture at an acute angle of 14° (Fig. 10B). The measured flare at 2:1 is achieved when the fibres curve sufficiently to meet the suture at an angle of 30° (Fig. 10C), which demonstrates the typical arrangement in the human lens.

The lens fibre and its relationship to the suture presents a most intriguing shape, with evident variation between individual fibres and between the fibres in various regions of the lens. It appears that versatility of the lens fibre allows a beautifully geometrically symmetrical lens to be assembled from a very asymmetric fibre and suture system.

An increase in the lens fibre width with age would occur if the total number of lens fibres in the anterior superficial shell (estimated at 25000) remains constant, and this appears to be the case.

No differences in lens fibre width between normal persons and diabetics have been demonstrated, though the number of diabetic lenses that could be satisfactorily measured were small. This suggests that it is not a wider lens fibre that accounts for the greater lens fibre size for age that has been observed in the diabetic.¹²

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