

improve the procedure, and it may be that we shall also have to change some of our concepts. But the chief purpose of this paper will be fulfilled even if the hypothesis and the calculations which I have presented are erroneous, for my principal aim is to show that an efficient prevention of glaucomatous field damage is only possible by a *quantitative* determination of visual field sensitivity against intraocular pressure.

### Summary

The central problem of simple glaucoma is to establish the connection between intraocular pressure and visual function decay in every individual case as early as possible. Such a connection can only be a quantitative one, either by attaining statistically "normal" values achieved in certain test experiments or by evolving formulae which allow us to determine "critical limiting pressure values" for every case from a short examination.

### COMMENTARY

#### THE APPEARANCE OF THE DISC IN EARLY OPEN-ANGLE GLAUCOMA

The harder one tries to distinguish the glaucomatous disc from the normal disc, the less one seems able to distinguish between the different types. However, one principle that Dr. Anderson and Dr. Kirsch of Miami have found very useful is that in the glaucomatous cup there is a tendency for cupping to extend towards the upper and lower portions of the disc. It does not matter whether it is a very small cup but it does seem to be the vertical orientation that is associated with glaucoma. On the other hand, a perfectly round cup with a perfectly even rim can be considered normal, even if large.

## Aetiology of angle-closure glaucoma

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The shallow anterior chamber and the angle which can and does close are well-accepted properties of the eye with angle-closure glaucoma. References will be found, for example, in Shaffer (1956) and Duke-Elder (1969b). The size and shape of the anterior chamber must result directly from the characteristics of the structures bordering it, and indirectly from the influences which determine *their* size, shape, position, and function. The *marked* shallowness in angle-closure glaucoma is, I suggest, due to a *summation of quantitatively* lesser abnormalities in other individual structures which will be considered *seriatim*.

### I. CRYSTALLINE LENS

In angle-closure glaucoma, the pupil is on a plane considerably more anterior than that of the periphery of the iris, unlike the situation in the normal eye: this produces iris *bombé* and must be due to a relatively more anterior position of the anterior surface of the lens than is usual. Three lens-related factors are very probably involved:

(a) *Thickness*

The axial thickness is greater than normal and this is probably the main contributory factor (Aizawa, 1960; Gernet and Jürgens, 1965; Lowe, 1969; Delmarcelle, Luyckx-Bacus, and Weekers, 1969). In our series (Storey, 1968a; Storey and Phillips, 1971a), careful control for age, sex, and refractive error, all of which affect lens thickness, was applied and still the lens was significantly thicker than in normal subjects.

(b) *Intraocular position of the lens*

Because the eyeball is small over-all (see below) it seems likely that the notional plane of the lens will be nearer the front of the eye in absolute terms than in the normal eye, and it may also be disproportionately further forwards. Delmarcelle and others (1969) and Lowe (1969, 1970a) have produced some evidence to confirm this and to suggest that it increases with age (as happens in the normal eye: Raeder, 1923; Weale, 1962). An indirect approach by a study of lens mobility and in prone and supine patients may help to confirm this (Storey and Phillips, 1971b). Delmarcelle, Collignon-Brach, and Luyckx-Bacus (1970) have also considered the part played by the plane of the insertion of the crystalline lens in determining the depth of the normal anterior chamber.

The position of the plane of the iris-lens diaphragm may vary quite quickly as choroidal blood volume and aqueous production fluctuate.

(c) *Growth of lens*

It is fundamentally important in anterior chamber glaucoma that the lens goes on increasing in axial thickness with age (as in the normal); hence the tendency for the disease to affect the elderly and its great rarity in young adults. This characteristic of the lens was first observed by Priestley Smith (1883). The wide variability in age at onset is, however, probably explained by the variable initial congenital handicap inherited by the patients. The increasing axial thickness will very probably have a direct effect on the depth of the anterior chamber, but the increasing *diameter* which is also likely to occur probably slackens the inelastic suspensory ligament; this will allow the lens to move forwards as a whole with an additional shallowing of the anterior chamber. These two effects of growth of the lens will produce a further narrowing of the angle, aggravated by an increased iris *bombé* due to the increased pupil block.

(The close contact between lens and iris along with the increasing immobility of the iris with increasing age is an important factor in the production of *posterior* synechiae after peripheral iridectomy (Phillips and Snow, 1967)—and in iridocyclitis in the patient with a shallow anterior chamber.)

## II. CORNEA

(a) *Diameter*

It is surprising that Priestley Smith (1890), when angle-closure and open-angle glaucoma were not differentiated, found the average normal corneal diameter to be 11.6 mm. whereas in "primary" glaucoma it was 11.2 mm. Very similar results were reported by Grieten and Weekers (1962), *viz.* 11.63 mm. for normal subjects and 11.15 mm. for angle-closure glaucoma. Ortlepp (1966) found the radius of curvature and corneal diameter less in angle-closure glaucoma than in normal subjects. The average difference we found (Storey, 1968b: see Storey and Phillips, 1971a) was 0.25 mm., *i.e.* about half that of the previous workers, probably because our series was carefully controlled for age, sex, and refractive error.

Other things being equal, a small corneal diameter (excluding any effect from a thick lens and iris *bombé*) would contribute to a narrow angle, as is shown by the Figure (p. 252). It would also account for some shallowing of the anterior chamber. We have calculated, to take one arbitrary example, that a difference in corneal diameter of 1 mm. would account for a difference of  $5^{\circ} 25'$  in the angle, if radius of curvature were the same (see Storey, 1968b; Storey and Phillips, 1971a). In this calculation we could not estimate in degree the angle enclosed by curved cornea so we used a concept of "notional angle", *viz.* the angle between the plane of the base of cornea (corresponding to a flat iris) and a tangent to the cornea at its base.

However, such an oversimplification has to be modified by three considerations:

- (i) Effect of increase in corneal thickness towards periphery, especially if this is different in smaller compared with larger corneae.
- (ii) Effect of flattening of curvature of peripheral cornea, especially if more marked in smaller corneae.
- (iii) Effect of a tendency for corneae with smaller diameters to have steeper curvatures.

For want of any data on (i) above, one assumes that small and large diameter corneae thicken proportionately to the periphery (Martola and Baum, 1968). Furthermore, we are obliged to consider external diameter and external curvature even though we are more interested in their internal dimensions. The application to eyes with angle-closure glaucoma of the new technique of photography of corneal profiles would be useful in this connection (Collignon-Brach, Papritz, and Prijot, 1966; Collignon-Brach, 1969) especially in the vertical plane.

Radius of curvature (see *iii* above) can be incorporated with corneal diameter to give the resultant *viz.*:

- (b) *Height, i.e.* distance from the apex of the cornea to the plane of base of cornea.

We calculated a series of corneal heights in which for simplicity corneal curvature was assumed to be the same. To take one arbitrary example, a difference of 1 mm. in corneal diameter gave a difference in corneal height and therefore in anterior chamber depth of 0.36 mm. (Storey and Phillips, 1971a). The formula used for this calculation was (Storey, 1968c; see Storey and Phillips, 1971a):

$$h = r_2 - \sqrt{r - (d/2)^2}$$

where  $h$  = corneal height,  $r$  = radius of corneal curvature, and  $d$  = corneal diameter, and it can be easily derived. It has also been independently derived by Delmarcelle and others (1969).

However, in real life that difference of 0.36 mm. would not be so great, because a small cornea tends to have a steeper curvature. We calculated corneal heights from corneal diameters and radii of central curvature in our series of angle-closure glaucoma, normal subjects, and open-angle glaucoma, and found that the difference between the normal and angle-closure glaucoma was still significant (Storey and Phillips, 1971a). Delmarcelle and others (1969) also found a lower corneal height in angle-closure glaucoma compared with normal subjects.

#### *Reciprocity between iris elevation and corneal height*

Logically it seems likely that, in any given series of cases of angle-closure glaucoma, lens-based effects (producing an anterior position of the pupil, *i.e.* iris elevation) may contribute

more or less to the disease if corneal height contributes less or more respectively. Some evidence for reciprocity has been calculated (Storey and Phillips, 1971a).

However, to the surprisingly large variability of depth of anterior chamber associated with angle-closure glaucoma (see, for example, Törnquist, 1956; Storey and Phillips, 1971a), other static and dynamic properties probably contribute, *e.g.* point of origin of iris from ciliary body, accommodation, angle of trabecular meshwork in relation to periphery of iris, hydration of lens, choroidal blood volume, slackness of suspensory ligament, aqueous production and drainage, posture of head, etc.

### III. ASYMMETRY OF ANGLE

Narrowness is more marked superiorly (Barkan, 1938; François, 1955; Phillips, 1956a). I think this is still a valid observation, although gonioscopic artefacts probably do occur (Schirmer, 1967; S. C. Becker, 1969), especially as Törnquist (1959) found that the depth of the anterior chamber at the mid-point of the iris was less superiorly than elsewhere. The explanation may be the smaller vertical than horizontal diameter of the cornea (especially the upper half, although the weight of the upper lid may be a factor). McLenachan and Loran (1967) have presented evidence of a greater incidence and higher degree of inverse astigmatism in closed-angle glaucoma than in normal subjects. Goniosynechiae tend to occur more often superiorly in acute and subacute glaucoma (Phillips, 1956b) and in chronic closed-angle glaucoma (Bhargava, Leighton, and Phillips, 1971). In retrospect I think that the cases called chronic closed-angle glaucoma by Phillips (1956b) and showing an even distribution of goniosynechiae all round the angle should probably have been called "advanced" cases.

These considerations, *coupled with the fact that the lens increases in size with age*, gave rise to the suggestion (Phillips, 1956a) that closure of the angle evolved gradually from above downwards, at first by reversible irido-trabecular contact which was often later converted into permanent goniosynechiae. I think this mechanism must be important in the evolution of chronic *angle-closure glaucoma* (due to irido-trabecular contact and treatable by iridectomy alone—see Foulds and Phillips, 1957) and chronic *closed-angle glaucoma* (due to goniosynechiae)—see also Kolker and Hetherington (1970a). But I think it also applies in acute glaucoma, especially in cases with a history of subacute attacks. This is a different mechanism from the posterior→anterior "creeping" closure suggested by Kessler (1958), Gorin (1960), and Lowe (1964, 1966).

Self-limiting cases may arise, probably because of the asymmetry (Phillips, 1956a; Phillips and Woodhouse, 1963).

I should like to make a plea for giving up *numerical* labels for grouping angles—or any other continuous biological variable, for that matter—according to narrowness. The main reason is that it is immediately fairly clear what a very narrow, narrow, or medium-narrow and so on angle is, whereas "Grade I", etc., is not immediately obvious (Kolker and Hetherington, 1970b); a closely related reason is that confusion may arise from the classification of Scheie (1957) in which Grade IV was the narrowest and Grade I the widest angle. The ideal of course would be to work in degrees to avoid arbitrary cut-off points on continuous variables. Also angle classifications should take account of asymmetry of angles.

I should also like to make a plea for giving up the term "primary" in glaucoma, if not in all other disease processes.

## IV. AXIAL LENGTH

The axial length of the eyeball is less in cases of angle-closure glaucoma than in normal subjects (Gernet and Jürgens, 1965; Lowe, 1969), an observation which we have confirmed (Storey, 1968d; Storey and Phillips, 1971a). However, if corneal height is less in angle-closure glaucoma than in normal subjects (see above), then *axial length of scleral envelope* rather than of eyeball should be compared; after deducting a calculated corneal height from axial length, we found that the difference still remained significant (Storey and Phillips, 1971a).

An hypothesis being currently investigated in my department is of some interest at this point. Abdalla and Hamdi (1970) found that, in most age groups between 11 and > 50 years, myopes had a significantly higher mean applanation tension than emmetropes. Tomlinson and Phillips (1970) found in a group of 26 to 72-year-olds that myopes had a significantly higher pressure than hypermetropes (with emmetropes mid-way between) and that the longer the axial length the higher the ocular tension. By analogy, we reach the paradoxical hypothesis that an abnormally low tension may be an important (? inherited) determining factor in the small stature of the eye predisposed to angle-closure glaucoma. (The explanation of course could be that the small stature might somehow cause the low tension.) If it turns out to be true, it suggests that the combination of open-angle glaucoma plus closed-angle glaucoma may be much rarer than one might expect on grounds of pure chance.

## SUMMARY AND SYNTHESIS

The most obvious characteristic of the eye with, or predisposed to, angle-closure glaucoma is a *markedly* shallow anterior chamber. That is closely related to the dangerously narrow or closed angle, and it results from a *summation* of *lesser* anatomical differences:

- I. (a) Axially thicker crystalline lens, which increases with increasing age.
- (b) A more anterior position of lens, and therefore pupil, than IV below can explain, and which increases as lens diameter increases to loosen suspensory ligament. These result in iris elevation (*i.e.* anterior position of pupil in relation to iris periphery) and hence iris *bombé*.
- II. Corneal abnormalities, *viz.*
  - (a) Smaller corneal diameter, producing
  - (b) Lower corneal height, in spite of
  - (c) Steeper corneal curvature.

This contributes to the narrow angle: see Figure.

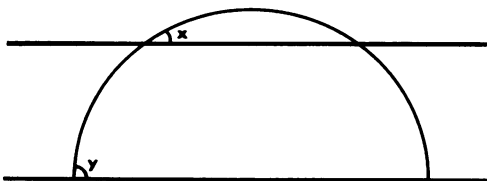


FIGURE Diagram to show that, other things being equal, a smaller corneal diameter will cause a narrower angle. Note that it will also reduce the depth of the anterior chamber

III. Asymmetry of the angle. The angle is narrower superiorly so that this area tends to close first as the axial thickness of the lens increases with increasing age. A slow evolution of closure explains the quite common cases of *chronic* closed-angle glaucoma (due to permanent goniosynechiae) and the occasional case of *chronic* angle-closure glaucoma (due to irido-trabecular contact): it may well also account for reversible subacute attacks.

IV. Shorter axial length of scleral envelope, implying smaller over-all dimensions except, of course, for lens thickness (and thickness of wall).

In individual cases of angle-closure glaucoma each of the above may contribute in different amounts—especially there may be a reciprocity between I and II.

The basic common inherited determinant of all these properties is probably the small eyeball (IV). However, another aggravating inherited factor may well be, paradoxically, a low intraocular pressure which prevents a given eye reaching its full potential for growth.

Other static and dynamic factors, such as point of origin of iris from ciliary body, accommodation, angle of trabecular meshwork in relation to periphery of iris, hydration of lens, choroidal blood volume, slackness of suspensory ligament, aqueous production and drainage, and posture of head, may contribute, especially to the acute attack.

## COMMENTARY

### CAUSE OF SUDDEN CLOSURE OF THE ANGLE OF THE ANTERIOR CHAMBER

In addition to the gradual process of lens change, Mr. Fisher\* described the theoretical changes in the periphery of the human lens which he felt to be the reason for the sudden closure of the angle in acute angle-closure glaucoma. The human lens curvature may be described by a complex curve related to an ellipse. Thus, apart from changes in thickness and radius of the lens, the shape of the lens also alters and this can be measured by a "curvature coefficient". This coefficient is an additional variable which changes with age. Although it is of paramount importance in understanding what occurs at the periphery of the lens, it cannot be measured by ultrasonic studies.

Not only does the lens increase in thickness but its periphery also bulges and approaches the angle, causing the iris to come into contact with the lens surface even when the pupil dilates. This area of iris contact increases discontinuously with age in an eye with a shallow anterior chamber. Thus, should the pupil dilate, there is no decrease in the differential pressure between the aqueous behind and in front of the iris since the iris does not leave the surface of the lens. If this dilation of the pupil occurs, and the iris becomes slack at the periphery, the angle will suddenly close, and an acute attack of glaucoma be initiated.

### EFFECTS OF MEDICATION ON THE ANTERIOR CHAMBER

There was some evidence that phospholine iodide, Tosmilen, and other powerful miotic agents could reduce the axial depth of the anterior chamber (Romano, 1968).

### SPONTANEOUS CURE OF CLOSED-ANGLE GLAUCOMA

During an acute attack, the pupil often became drawn up. This was sometimes enough to eliminate pupil blocks, to open the angle, and to cause permanent self-limitation of the glaucoma (Woodhouse and Phillips, 1963). However, it is not safe to assume that a spontaneous cure is permanent and a peripheral iridectomy should be performed.

\* see p. 200