Closed-angle glaucoma. Theoretical considerations

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The success of a peripheral iridectomy in the treatment and prevention of closed-angle glaucoma (CAG) has tended to obscure the fact that the events preceding an acute attack are in most instances unknown. The generally accepted view (Curran, 1931; Barkan, 1938; Chandler, 1952) can be crudely expressed by the formula $AC \propto (pbf) (ps)$ where pbf = pupil blocking force, ps = pupil size, and AC = angle closure. It is further argued that a miosed pupil is relatively safe, since a taut iris will not easily become *bombé*, and that a widely dilated pupil is also safe, since the block is broken. There remain the mid-pupillary states and it is suggested that the inception of CAG occurs over this range.

No systematic attempt has been made to explore the implications of this hypothesis. The reasons are no doubt various, but a major stumbling block to an experimental analysis is the absence of quantitative data that can be experimentally manipulated. The purpose of this paper is to devise a theoretical model of the events contributing to pupil block and from this to design experiments that test its conclusions.

Forces involved in normal pupillary activity

In previous papers (Mapstone, 1968, 1970), the forces generated by an iris strip during the pupillary play of the light reflex are analysed and measured in arbitrary units (λ the elastic modulus of iris stroma). Fig. 1 reproduces the results and shows that the forces due to the sphincter (S) and iris stroma (E) decrease in a linear fashion as the pupil dilates, the tonus of the dilator (D) remaining constant at 0.23λ . The maximum values of S and D were shown to be 1.19 and 0.62λ respectively. The relevance of this to the size of the pupil blocking force is as follows:

Consider a strip of iris (Fig. 2) with pupil diameter constant at any value, say d mm. During the pupillary play of the light reflex $S = D + E$ and $D = 0.23\lambda$. Now, if D were to increase to a maximum (0.62λ), then the same pupil diameter would be maintained if S increased by an equivalent amount. Again, if D decreases to zero, then to retain the same pupil size S must decrease by an equal quantity. Hence, at any given pupil size, E is constant but S and D can vary over a wide range. This means that the forces available for block at a given pupil diameter are not constant, but can increase or decrease according to the size of S and D .

Pupil blocking force from an iris strip

Three separate forces contribute to pupil block.

(1) SPHINCTER PUPIL-BLOCKING FORCE (S)

To say that, at a pupil size of d mm., the sphincter is pulling with a force of S units is not to say that all this force is available for pupil block. In Fig. 3 (overleaf), S is the sphincter force, and its component pulling the iris back onto the lens is $S \cos a$. Assuming that the radius of curvature of the anterior lens surface is 10 mm., then the component of S available for block depends on pupil size, since $\cos a$ is $d/20$. The values of S pbf during

FIG. 1 Variations in sphincter (S), dilator (D), and iris stretch (E) forces during the pupillary play of light reflex

FIG. 2 Range of values for sphincter (S), dilator (D), and iris stretch (E) at a given pupil diameter D_0 = sympathetic inhibited

the pupillary play of the light reflex can therefore be calculated from Fig. 1, and are shown in Fig. 4 (overleaf).

As was demonstrated above, however, S at a given pupil diameter is not constant, but can have a range of values, a minimum when D is completely inhibited and a maximum when D is contracting to a maximum. These values can be simply calculated and are reproduced in Fig. 4. The graphs indicate that in miosis and dilatation, S pbf is at a minimum but that around the range of 3–5 mm. it is at a maximum.

It is apparent that a prerequisite for pupil block is iris/lens contact, but that an anterior displacement of the lens will not increase S pbf (Mapstone, 1968).

(2) PUPIL BLOCKING FORCE FROM THE DILATOR MUSCLE (D) AND IRIS STROMA (E)

As soon as the anterior lens surface touches the posterior surface of the iris block commences,

FIG. 3 Effect of sphincter contraction is a force S acting at right angles to the antero-posterior lens axis. Its component pulling the iris onto the lens is $S \cos a$

FIG. 4 S pbf varies with pupillary diameter and strength of dilator contraction. Its values during normal, maximal, and zero sympathetic activity are illustrated

and it has been shown previously (Mapstone, 1968) that the greater the anterior displacement of the lens, the greater is the component of D and E available for block. Two main theoretical situations occur (Fig. 5).

- (a) Lens advancement relative to the iris plane of approximately 1 mm.; here the D and E contribution to pbf is negligible (see below).
- (b) Lens advancement of 2 mm., or greater; here the D and E contribution to pbf is significant.

The size of D and E pbf in these two situations is illustrated below. The calculations are based on the following assumptions:

- (i) Radius of curvature of anterior lens surface 10 mm.
- (ii) Diameter of iris plane, *i.e.* from iris root insertion at 12 o'clock to 6 o'clock, is 12.2 mm. (Mapstone, 1970).
- (iii) The D and E forces act in a straight line from the point of pupil margin/lens contact to the iris root insertion).

DILATOR pbf

At a given pupil diameter D can vary from zero to 0.6λ , Fig. 6a shows the calculated pbf when D is 0.23λ and 0.6λ for a 1 mm. lens advancement. It can be seen that above 4 mm. D pbf is negative, *i.e.* actually pulling the iris away from the lens and so tending to break block. Below 4 mm. a positive pbf is present but insignificant. Similarly Fig. 6b shows pbf with a 2 mm. advance; here pbf is of consequence—at a maximum in miosis, decreasing in an almost linear fashion as the pupil dilates.

IRIS STROMA pbf

Force E is constant at a given pupil diameter but the E component varies with pupil size and lens position. Fig. 7 shows E pbf at a 1 and 2 mm. lens advance. Again it can be seen that pbf is at a maximum in miosis and decreases as the pupil dilates.

Total pupil blocking force (pbf)

The total pbf is the sum of the S , D , and E contribution. Figs 8 and 9 show this for a 1 and 2 mm. lens advance respectively, relative to the iris plane. In each Figure (a)

FIG. 5 Force due to dilator contraction (D) and stromal stretch (E) has a component $(D + E) \cos b$ pulling the iris onto the lens. The component increases with anterior lens displacement (angle b smaller)

FIG. 7 Stromal stretch (E) component for a 1 and 2 mm. lens advance

FIG. 8 Total pbf from dilator and sphincter muscles and stromal stretch. Sphincter component shown by solid line. Lens advance 1 mm. (a) Dilator inhibited by thymoxamine; (b) During pupillary play of light reflex; (c) Dilator contracting to a maximum

represents pbf when D is zero, (b) during the pupillary play of the light reflex, and (c) when D is contracting to a maximum.

It can be seen that with a 1 mm. advance almost the whole of pbf comes from S ; above a pupil diameter of 4 mm. the D and E contribution is negative, *i.e.* pulling the iris away from the lens. Block is still present, however, since the positive contribution of S is greater. In Fig. 9 (overleaf) the contribution of D and E is greater, and so too is the total pbf.

Conclusions

Theoretically there are two major types of phakic block;

(1) S BLOCK

With a small lens advancement relative to the iris plane the major contribution to pupil block comes from the sphincter muscle (Fig. 8). D and E contribute a little between 2 and 4 mm., but at larger pupil diameters their components are negative—pulling the iris away from the lens and tending to break block. If pbf (at certain pupillary diameters)

FIG. 6 (a) Dilator component for a 1 mm. lens advance relative to the iris plane. Values shown when D is contracting normally and when stimulated to a maximum

FIG. 6 (b) Dilator component for a 2 mm. lens advance. Values shown when D is contracting normally and when stimulated to a maximum

FIG. 9 Total pbf from dilator and sphincter muscles and stromal stretch. Sphincter component shown by solid line. Lens advance 2 mm. (a) Dilator inhibited by thymoxamine; (b) During pupillary play of light reflex; (c) Dilator contracting to a maximum

is both necessary and sufficient to explain the initiation of angle closure, *i.e.* increasing pbf produces AC whilst a reduction opens the angle, then such an anterior segment would have the following characteristics:

- (a) pbf is zero or small with a widely dilated pupil, whether obtained by maximal para-sympatholytic or sympathomimetic activity. Angle closure in this pupillary position is therefore unlikely (Fig. 8).
- (b) pbf is at a maximum when *S* and *D* co-contract to a maximum, *e.g.* after the instillation of pilocarpine and phenylephrine (Fig. 8)—AC therefore more probable.
- (c) pbf is at a maximum in miosis and decreases in an almost linear fashion as the pupil dilates (Fig. 8), *i.e.* the smaller the pupil, the greater the danger of angle closure (but this ignores the effect of a taut iris in miosis).
- (d) pbf is at a minimum when sympathetic tone is inhibited, *e.g.* by thymoxamine (Fig. 8a). Hence the danger of angle closure is lessened.

(2) *S.D.E.* BLOCK

Here the anterior lens displacement is greater, and consequently both *D* and *E* add a significant contribution to pbf. It has the same characteristics as *S* block with the exception that dilatation with a sympathomimetic drug is—theoretically—dangerous (Fig. 9c). Pbf is also approximately twice as large as in *S* block (*cf.* Figs 8 and 9).

These conclusions are tested experimentally in subsequent papers.

Summary

A theoretical model is derived of pupil blocking force variations during differing anterior segment situations. The events that precipitate and prevent angle closure are described.

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