Power of the prepupillary pseudophakos

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The following considerations and calculations are exclusively related to the so-called "iris clip lens" and "irido-capsular lens" designed by the author (Binkhorst, 1959, 1967a,b). The optical part of both types of lens is made of polymethylmethacrylate (refractive index $n_2 = 1.490$) and is of simple planoconvex design. Its centre thickness (t) is about 0.5 mm.

We will discuss both the pseudophakos that makes the eye emmetropic (emmetropizing pseudophakos) and the pseudophakos that makes the eye isekonic with the fellow phakic eye (iseikonic pseudophakos).

(1) Emmetropizing pseudophakos

The power of any emmetropizing pseudophakos (F_L) can be calculated from the relationship between the power of the cornea (F_c), the corneal vertex distance of the pseudophakos (v), and the axial length of the eye (l). Several authors have presented useful formulae (Le Grand, 1965; Maria, Bonnet, and Cochet, 1958; Fyodorov; Colenbrander, in press; Gernet, Ostholt, and Werner, 1969). A diagram based on Colenbrander's formula is easy to read and is available on request.

It has to be recognised that in substituting the necessary data we have to work with questionable values. There are the usual errors of measurement. The corneal power (F_c) is subject to surgical change and there is no absolutely reliable method of predicting the corneal vertex distance (v) of the pseudophakos exactly.

The axial length (l) of the eye can be determined by ultrasonography or in cases of aphakia with a clear pupil it can be calculated from the power of the cornea (F_c) and the aphakic spectacle correction (D) at the anterior focal point (Fig. 1).

FIG. 1 Calculation of axial length (l) of aphakic eye from the spectacle correction (D) at the anterior focal point and the power of the cornea (F_c)

$$x \cdot x' = f_c \cdot f_c' \quad \text{and} \quad l = \frac{1.336}{F_c^2} (F_c - D)$$

hence $\frac{1}{D} \left(\frac{1.336}{F_c} - l \right) = \frac{1}{F_c} \times \frac{1.336}{F_c}$

(2) Iseikonic pseudophakos

In many instances the aim should be iseikonia rather than emmetropia.

Iseikonia and at the same time emmetropia or any other precataractous refraction can be achieved only when the pseudophakos normalizes all cardinal points of the eye. Dudragne (1955) was the first to recognize this fact, and he calculated a concavo-convex pseudophakos that fulfilled this requirement. Such a pseudophakos can easily be made, and has indeed been used by us in a few instances (Binkhorst, 1961), but it had to be abandoned because the shape of the design could not be adapted to the anterior chamber without risk of damage to the corneal endothelium. The idea of Boeder was to use a lens system. Troutman (1962) calculated several types of a so-called "air-space doublet" based upon Boeder (1938), but this design has never been put to practical use.

The prepupillary plano-convex design of the author cannot normalize all cardinal points and thus cannot re-establish both iseikonia and emmetropia or any other precataractous refraction. We shall first demonstrate what this means for the schematic eye and then try to find the best solution to the problem for the living eye.

ISEIKONIC PSEUDOPHAKOS FOR THE SCHEMATIC EYE

There will be iseikonia between the schematic pseudophakic eye and the schematic phakic eye when the focal lengths of both eyes are identical (Fig. 2).

FIG. 2 Schematic phakic eye (a) and schematic iseikonic pseudophakic eye (b)

P_E first equivalent plane
 P_E^1 second equivalent plane
 f_E anterior focal length
 f_E^1 posterior focal length

We used the following relationship for the focal length.

$$f_E = \frac{f_c \cdot f_L}{f_L + f_c^1 - d}$$

in which f_E = anterior focal length of complete eye (-17.055 mm.).

f_c = anterior focal length of cornea (-23.227 mm.).

f_c^1 = posterior focal length of cornea (31.031 mm.).

d = distance of first equivalent plane of pseudophakos from second equivalent plane of cornea (3.5506 mm.).

f_L = focal length of pseudophakos.

The value for d can be calculated from Fig. 3. We assumed a corneal vertex distance of $v = 3.5$ mm.

FIG. 3 Relative position of pseudophakos and cornea

Vertex distance (v) between pseudophakos and cornea = 3.5 mm.

Second equivalent plane of cornea (P_C^1) = -0.0506 mm.

Distance (d) of first equivalent plane of pseudophakos (P_L) from second equivalent plane of cornea (P_C^1) = 3.5506 mm.

The focal length of the schematic isekonic pseudophakos (f_L) turned out to be 75.921 mm., which gives a radius of the anterior surface (r_1) of 8.751 mm.* and an equivalent power of the pseudophakos (F_L) of 17.6 D†. A pseudophakos with a power of 17.6 D at a corneal vertex distance of 3.5 mm. is thus isekonic with Gullstrand's schematic crystalline lens of 19.11 D (Gullstrand, 1924).

The pseudophakos is in a more forward position than the crystalline lens which means that the equivalent planes of the pseudophakic eye are further forward than those of the phakic eye. If the focal lengths are the same this results in a more forward position of the posterior focal point and plus ametropia. For the schematic pseudophakic eye we can calculate the anterior displacement of the second equivalent plane and the correlated myopia as follows:

The distance of the second equivalent plane of the pseudophakos (P_L^1) from its posterior surface is $-n_1 \cdot \frac{t}{n_2} \cdot \frac{F_L^1}{F_L} = 0.448$ mm., in which t is the centre thickness of the pseudophakos (0.5 mm.), n_1 is the refractive index of the aqueous (1.336), n_2 is the refractive index of the pseudophakos (1.490), and $F_L^1 = F_L$. The corneal vertex distance of the second equivalent plane of the pseudophakos is thus $3.5 + 0.5 - 0.448 = 3.552$ mm.

The distance of the second equivalent plane of the schematic pseudophakic eye (P_E^1) from the second equivalent plane of the pseudophakos (P_L^1) equals $\frac{d \cdot f_L}{d - f_L - f_c^1} = -2.607$ mm., in which d = distance of first equivalent plane of pseudophakos (P_L) from the second equivalent plane of the cornea P_C^1 (3.5506 mm.), f_L focal length of pseudophakos (75.921 mm.), and f_c^1 posterior focal length of cornea (31.031 mm.). The corneal vertex distance of the second equivalent plane of the pseudophakic eye is therefore $3.552 - 2.607 = 0.945$ mm.

Compared with the corneal vertex distance of the second equivalent plane in Gullstrand's schematic phakic eye of 1.602 mm., the second equivalent plane of the schematic isekonic eye is in a 0.657 mm. more forward position. Calculation with Newton's object image relation $x \cdot x' = f \cdot f'$ shows that this corresponds with a 1.69 D myopia at the anterior focal point (Fig. 4, opposite).

ISEKONIC PSEUDOPHAKOS FOR THE LIVING EYE

Standard of power

This should be based upon the average power of the crystalline lens, which was calculated by Stenström (1946) for 1,000 eyes in the age group 20 to 35 years. The average agreed

* $r_1 = \frac{1.49 - 1.336}{1.336} \cdot f_L$

† $F_L = \frac{1.49 - 1.336}{r_1}$

FIG. 4 Calculation of corresponding myopia in schematic isekonic pseudophakic eye

$$x \cdot x' = f \cdot f'$$

hence $\frac{1}{D} \times 0.000657 = -0.017055 \times 0.022785$ and $D = -1.69$ dioptres

closely with Gullstrand's schematic power of 19.11 D. The power of the schematic isekonic pseudophakos (17.6 D) could therefore be used as standard power for the age group 20 to 35 years.

For other age groups little is known about lens power values. It is unlikely that lens power is greatest in the first years of life, then decreases to a minimum at the age of 20 to 35 years, and thereafter gradually increases. For the treatment of predominantly unilateral senile cataract, a standard pseudophakos of 19.5 D has been adopted by us on an empirical basis, and has proved to be acceptable in hundreds of implantations. This was borne out by binocularity tests and measurements with Ames's space-eikonometer (Binkhorst and Gobin, 1964; Binkhorst and Leonard, 1967).

A slight increase in power seems to be justified at any age in view of a possible postoperative flattening of the cornea. Little uniform information is given about the effect of cataract surgery on the cornea, which is dependent on the surgeon and his technique. Floyd (1951) found a tendency to flattening. In a study of 28 patients we found increased curvature as well as flattening, the average being a flattening of 0.55 D.

In early youth, however, this power is too low and in young adults it is too high. We estimate that the standard isekonic pseudophakoi for different age groups should be powered as indicated in the Table.

Table Standard isekonic pseudophakoi for various age groups

Age (yrs)	Dioptres
1-3	22.5
3-10	20.5
10-20	19.0
20-35	18.0
35-50	19.0
50-	19.5

The standard lens aiming at iseikonia for the eye with an average-powered crystalline lens should produce approximately +1.69 D ametropia.

Individual power

Isekonic power should be calculated or read from data obtained from both eyes. In order to make both posterior focal lengths equal, we use the axial length of the fellow eye,

corrected with -0.657 mm. in the case of a phakic fellow eye, and uncorrected in the case of a pseudophakic fellow eye.

This is combined with the corneal power of the eye under treatment corrected with a value equivalent to the spectacle correction of the fellow eye.

Discussion

For those who aim at emmetropia it should be clear that emmetropia is hard to achieve. This is due to errors in calculation, in keratometry, in the predicted corneal vertex distance of the pseudophakos, in the surgical effect on corneal power, but above all in the ultrasonographic determination of the axial length of the eye. Additional spectacle correction, either plus or minus, will be the rule. With this in mind it would therefore seem better to aim at a slightly myopic eye rather than at emmetropia.

Calculation of the axial length of the eye from the aphakic spectacle correction is possible only when the pupil is clear. It implies implantation in a second stage. However, in the majority of cases, it is an advantage to perform the cataract operation and implantation at the same session (Binkhorst and Leonard, 1967; Binkhorst, Gobin, and Leonard, 1969; Binkhorst and Gobin, 1970). Giving up this advantage in order to calculate the axial length of the eye cannot be justified. Only in those rare cases of pre-existing aphakia in which implantation is necessary may calculations on the aphakic eye be valuable. An intact capsular membrane in such cases is such an advantage during implantation that surgery of the capsular membrane before implantation is not justified (Binkhorst and others, 1969).

In unilateral cases, the emmetropic pseudophakic eye is rarely the ideal partner of the phakic fellow eye, as it usually produces aniseikonia. In such unilateral cases, iseikonic lenses should be used. Yet these can only approximate the ideal as they are subject to the same errors as mentioned above for emmetropic lenses. Aniseikonia as a consequence of maldetermination of the corneal vertex distance and of the surgical effect on the cornea has been calculated on a schematic pseudophakic eye with varying corneal power and varying

vertex distance. We used the focal length relation $f_E = \frac{f_c \cdot f_L}{f_L + f_c - d}$ and found a 1.6 per

cent. aniseikonia per dioptre corneal power, and 0.9 to 1 per cent. aniseikonia per mm. corneal vertex distance. Moreover, the "iseikonic standard pseudophakos" is based on the average power of the crystalline lens in a given age group. Stenström (1946) found a standard deviation of ± 1.38 D in the age group 20 to 35 years. For "iseikonic standard pseudophakoi" this implies aniseikonia, which with schematic values we calculated at a standard deviation of ± 1.9 per cent. aniseikonia. The advantage of the "iseikonic standard pseudophakos", however, is its availability and the fact that it does not require ultrasonographic equipment.

An iseikonic pseudophakos is indicated not only in unilateral cataract but also in "predominantly unilateral" cataract. If the second eye also has to be implanted later, iseikonic power should again be used. In *a priori* bilateral implantations emmetropizing or preferably slightly myopizing pseudophakoi can be used in both eyes only if the axial lengths are equal. In the case of unequal axial length, the eye with the shorter length should be given an emmetropizing pseudophakos and the fellow eye an iseikonic power; the residual myopia of the latter has to be corrected with glasses. Only in this way is it possible to keep eyes iseikonic, and even in cases of pre-existing aniseikonia it is possible to provide the patient with iseikonia.

Finally it must be stressed that in cases of unilateral pseudophakia iseikonia will inevitably develop into aniseikonia as time goes by because of the changes which are bound to occur in the power of the crystalline lens in the phakic eye. This time-induced aniseikonia has been calculated for the schematic eye at 1.4 per cent. per dioptre power change corresponding to a 2 per cent. aniseikonia per dioptre change of spectacle correction. The patient's tolerance of aniseikonia must therefore always be our ally.

Summary

The author describes his methods of determining the power of prepupillary intraocular lenses (pseudophakoi) in various circumstances. Emmetropizing pseudophakoi are sometimes useful, but iseikonic pseudophakoi are most often used. The use of "iseikonic standard pseudophakoi" and of "individual iseikonic pseudophakoi" is discussed.

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