Determination of the power of a convex-plano intraocular lens in situ from the dioptric keratometer reading of its front surface: extension table for the Javal-Schiøtz ophthalmometer

C D BINKHORST, M C COLENBRANDER, AND L H LOONES

From Terneuzen, The Netherlands

SUMMARY The size of the reflex image of keratometer mires can be used to determine the power of an intraocular lens (IOL) inside the eye (in situ). The dioptric scale reading from the front surface of a convex-plano intraocular lens in cases of unknown power is compared with computed values. The accuracy of the method is demonstrated in a series of patients with known IOL power. Though in our study we have assumed convex-plano lenses are in use, the same procedure can sometimes be applied to lenses of different forms. To interpret scale readings below 30 dioptres and over 60 dioptres we compiled an extension table, suited to the ophthalmometer of Javal-Schiøtz (Haag-Streit), making use of low-powered minus and plus auxiliary lenses in front of the tube of the instrument.

Intraocular lens (IOL) power is controlled by the manufacturer to a high degree of accuracy before packing. Simple methods are available to the surgeon to check IOL power on the operating table before implantation.^{1,2} Determination of the power of an IOL once it is inside the eye (in situ) may therefore seem to be a merely theoretical problem. However, there may be instances in which the determination of the power in situ acquires a practical interest—for example, when there is doubt about the IOL power used and other important data are lacking or are not reliable.

In our study we made use of the size of the reflex image produced by the front surface of a convex-plano IOL. Reflex images of the surfaces of an IOL are much clearer than the third and the fourth Purkinje images of the crystalline lens.

We used the ophthalmometer of Javal-Schiøtz (Haag-Streit) with a slightly increased target illumination by stronger bulbs. The instrument is built for the measurement of the reflex image of its mires produced by the surface of the cornea in air. But with the same instrument it is possible to observe the reflex image of the mires produced by the front

surface of an IOL in situ. It should be understood, however, that the reflex image is observed through the magnifying system of cornea and aqueous. Neither the millimetre scale nor the dioptric scale of the instrument can directly be applied to the IOL. However, if we compare the dioptric scale reading from the front surface of a convex-plano IOL in situ with the values computed for variable IOL power in eyes with variable corneas and variable corneal vertex distances, this reading can be used to determine the power of the IOL. This method was presented for the first time at the first meeting of the European Intraocular Implantlens Council in 1982.³

Computation of the dioptric scale reading from the front surface of a convex-plano IOL in situ

Colenbrander⁴ has demonstrated that the regression line for variations of the corneal refraction and the regression line for variations in depth of the anterior segment of the eye are for practical purposes straight lines. Therefore we selected as variables only three values (38, 43, and 48 dioptres) for the power of the cornea (F_c), three values (2.5, 3.5, and 4.5 mm) for the distance (d) between the apex of the cornea and the apex of the IOL, and five values (10, 15, 20, 25,

Correspondence to C D Binkhorst, MD, Axelsestraat 54, 4537 AL Terneuzen, The Netherlands.

and 30 dioptres) for the power of the IOL in situ (F_1).

There are thus three variables: F_c , d , and F_1 . We executed a computation for the standard combination ($F_c=43$ D, $d=3.5$ mm, and $F_1=20$ D), and for the combinations of the above mentioned variations of only one variable in turn, combined with the standard values of the other two variables.

For these computations we made use of the principle of the 'equivalent mirror.' This principle states that a spherical surface (in this case the anterior surface of the IOL) seen through an optical system (in this case the cornea) is equivalent to a spherical surface in air, of which the position of the apex and the centre of curvature are the images formed by the cornea of the corresponding real points.

The computation and their results are shown in Appendix 1.

The results enable us to frame the following set of instructions.

Instructions for the determination of a convex-plano IOL in situ (refractive index 1.4917) having a refracting power within the eye between 10 and 30 dioptres

(1) Read with the ophthalmometer the dioptric value for the reflex image from the IOL inside the eye.

(2) Adjust this dioptric value to the corresponding value for the standard eye. This means: (a) if the dioptric power of the cornea is more (less) than 43 D, lower (raise) the dioptric value for the IOL by 0.53 D for each dioptre of difference; (b) if the depth of the anterior segment of the eye is more (less) than 3.5 mm, lower (raise) the dioptric value by 2.8 D for each mm of difference.

(3) Use Table 1 to convert the dioptric value in situ, adjusted for the standard eye, into the refracting power of the IOL.

Appendix 2 gives the comparison of the computed and the actual dioptric power of the IOL in a series of 11 patients.

Extension table for the Javal-Schiötz ophthalmometer (Haag-Streit)

The Javal-Schiötz ophthalmometer (Haag-Streit) is calibrated to read the front curvature of the cornea from 30 dioptres to 60 dioptres. However, with the use of the ophthalmometer to determine the apparent curvature of the front surface of an intra-ocular lens inside the eye, dioptric values under 30 D and over 60 D may be encountered. Moreover, corneal curvatures under 30 D may occur in rare cases of cornea plana. On the other hand corneal curvatures over 60 D occur in cases of advanced keratoconus. Because the ophthalmometer scale

Table 1 Conversion of the dioptric reading with the ophthalmometer from a convex-plano IOL in the standard eye (cornea 43 D, anterior segment depth 3.5 mm) into the refracting power of the IOL in situ. *I*=Reading of the ophthalmometer in dioptres. *II*=Corresponding power of the IOL in situ, in dioptres.

<i>I</i>	<i>II</i>	<i>I</i>	<i>II</i>	<i>I</i>	<i>II</i>
10	10.1	25	16.7	40	23.3
11	10.5	26	17.1	41	23.7
12	10.9	27	17.5	42	24.1
13	11.4	28	18.0	43	24.6
14	11.8	29	18.4	44	25.0
15	12.3	30	18.9	45	25.5
16	12.7	31	19.3	46	25.9
17	13.1	32	19.7	47	26.4
18	13.6	33	20.2	48	26.8
19	14.0	34	20.6	49	27.2
20	14.5	35	21.1	50	27.7
21	14.9	36	21.5	51	28.1
22	15.3	37	21.9	52	28.6
23	15.8	38	22.4	53	29.0
24	16.2	39	22.8	54	29.4
25	16.7	40	23.3	55	29.9

does not allow the reading of these values, extension of the reading on both sides became necessary. We therefore developed an extension table for the Haag-Streit ophthalmometer, using a minus 2.5 D, a minus 1.25 D, or a plus 1.25 D auxiliary lens in front of the ophthalmometer tube. Stronger lenses cause difficulties with the forward and backward shift of the instrument.

An explanation of the method of computation is given in Appendix 3. The results are given in Table 2.

Table 2 Conversion of scale readings with an auxiliary lens to the true values in dioptres

With a minus 2.5 D auxiliary lens (conversion factor 0.5138)		With a minus 1.25 D auxiliary lens (conversion factor 0.7416)		With a plus 1.25 D auxiliary lens (conversion factor 1.2855)	
Reading	True value	Reading	True value	Reading	True value
30	15.4	30	22.2	45	57.8
31	15.9	31	23.0	46	59.1
32	16.4	32	23.7	47	60.4
33	17.0	33	24.5	48	61.7
34	17.5	34	25.2	49	63.0
35	18.0	35	26.0	50	64.3
36	18.5	36	26.7	51	65.6
37	19.0	37	27.4	52	66.8
38	19.5	38	28.2	53	68.1
39	20.0	39	28.9	54	69.4
40	20.6	40	29.7	55	70.7
41	21.1	41	30.4	56	72.0
42	21.6	42	31.1	57	73.3
43	22.1	43	31.9	58	74.6
44	22.6	44	32.6	59	75.8
45	23.1	45	33.4	60	77.1

Table 3 Results of the computations on the various combinations of eye and IOL power

	Data		Results (F_c) Diff.		
	$F_c(D)$	$d(mm)$	$F_I(D)$	(D)	(D)
Variation in F_c	38	3.5	20	35.26	0.53
	43	3.5	20	32.58	0.52
	48	3.5	20	29.97	
Variation in d	43	2.5	20	35.47	2.9
	43	3.5	20	32.58	
	43	4.5	20	29.81	2.8
Variation in F_I	43	3.5	10	9.88	2.27
	43	3.5	15	21.23	2.27
	43	3.5	20	32.58	2.27
	43	3.5	25	43.93	2.27
	43	3.5	30	55.28	2.27

The last column shows that indeed the differences per unit are nearly constant. The values of 0.53 D per dioptre difference of F_c and of 2.8 D per mm difference of d are inserted in the instruction. Results = readings on the ophthalmometer (F_o). Diff. = difference per unit (D or mm).

Appendix 1. Computation of the dioptric scale reading from the front surface of a convex-plano IOL in situ

Here follows, as an example, the complete computation for the standard combination.

In order to be in accordance with dioptries, distances have to be measured in metres. However, we expressed distances in millimetres so as not to handle extremely small numbers, and in accordance multiplied the refractive indices by 1000.

The direction of the light rays is from within the eye to outside the eye. Distances behind the cornea are therefore negative.

I. First, we want to know the position of the image (d') of the apex (d) of the IOL. The formula used is $A + F = A'$ or $(1000 n/d) + F_c = (1000 n'/d')$. $n = 1.336$; $n' = 1$; $F_c = 43$ D; $d = -3.5$ mm. $(1336/(-3.5)) + 43 = (1000/(-2.952))$. Thus $d' = -2.952$ mm.

II. Secondly, we want to know the radius (r_1) of the front surface of the IOL. The formula is $F_1 = 1000\Delta n/r_1$. $F_1 = 20$ D. $\Delta n = n' - n = 1.4917 - 1.336 = 0.1557$. $20 = 155.7/7.785$. Thus $r_1 = 7.785$ mm, or in the computation -7.785 .

III. The (real) position of the centre of curvature (c_1) of the anterior surface of the IOL is $c_1 = d + r_1 = -3.5 - 7.785 = -11.285$ mm.

IV. Its image (c_1') is found along the same lines as in section I by the equation $(1000 n/c_1) + F_c = (1000 n'/c_1')$ or $(1336/(-11.285)) + 43 = (1000/(-13.265))$. Thus $c_1' = -13.265$ mm.

V. The radius of the equivalent mirror (r_c) is $-(c_1' - d')$ or $13.265 - 2.952 = 10.313$ mm.

VI. Just as with the cornea this corresponds with a power F_c . $F_c = (1000\Delta n)/r_c = (1336 - 1000)/10.313 = 32.58$. Thus $F_c = 32.58$ D. This means that, if the ophthalmometer reading is 32.58 D, the IOL in the standard eye has a refracting power of 20 dioptries.

The same computations were made for the other combinations. The results are shown in Table 3.

Appendix 2 Comparison of the computed and the actual dioptric power in situ of the IOL in a series of 11 patients

F_c = Mean of the highest and the lowest reading (if there is corneal astigmatism) of the power of the cornea.

d = Distance from the apex of the cornea to the apex of the lens.

F_o = Reading on the ophthalmometer of the IOL in situ.

Corr. F_c = Correction for the variation of F_c .

Corr. d = Correction for the variation of d .

F_s = Adjusted reading for the standard eye.

$F_{I.1}$ = Corresponding power of the IOL (D).

$F_{I.II}$ = Actual power of the inserted IOL (D).

Patient no.	F_c D	d mm	F_o D	Corr. F_c	Corr. d	F_s D	$F_{I.1}$ D	$F_{I.II}$ D
1	43.75	3.5	26.6	-0.4	+0.0	= 26.2	17.2	18.0
2	44.1	3.2	36.0	-0.6	+0.8	= 36.2	21.6	21.0
3	45.0	3.3	35.1	-1.1	+0.6	= 34.6	20.9	22.0
4	42.75	3.0	32.25	+0.1	+1.4	= 33.75	20.5	20.0
5	43.4	3.4	36.0	-0.2	+0.3	= 36.1	21.5	21.5
6	44.5	3.4	24.75	-0.8	+0.3	= 24.25	16.3	16.5
7	45.5	3.5	29.5	-1.3	+0.0	= 28.2	18.1	19.5
8	47.5	3.4	31.0	-2.4	+0.3	= 28.9	18.4	19.5
9	43.4	3.2	23.9	-0.2	+0.8	= 24.5	16.4	16.0
10	43.0	2.7	33.75	-0.0	+2.2	= 35.95	21.5	19.5
11	44.75	3.15	31.25	-1.0	+1.0	= 31.25	19.4	19.5

Appendix 3 Computations for the extension table for the Haag-Streit ophthalmometer

The distance from the plane of focus of the Haag-Streit instrument to the front of the tube for an emmetropic observer and the eyepiece in the emmetropic position is 126 mm. The distance from the focal plane to the auxiliary lens is therefore 125 mm. The divergence of the light rays coming from the focal plane at this position is exactly 8 dioptries. This is the divergence that the instrument requires at this spot in all circumstances.

A lens of +1.25 dioptries needs a divergence of 9.25 dioptries on entering the lens in order to obtain the divergence of eight dioptries when leaving the lens. The focal plane is then at $1/9.25$ D = 108.11 mm distance and the shift is 16.89 mm forward.

In the same way the distance to the focal plane with a -1.25 lens will be $1/6.75$ dioptries = 148.15 mm and the shift 23.15 mm backward.

With the forward shift and backward shift of the instrument in the reading position known, its influence on the size of the reflex images, and thus on the dioptric scale of the ophthalmometer, can be calculated. This influence is twofold: (a) a change of the angle with which the ophthalmometer mires present themselves to the patient's eye; and (b) a change of the observation angle of the reflex images. Both aspects can be expressed in terms of magnification, and thus the final magnification can be calculated.

In an ophthalmometer the coloured objects and the tube are linked together. They go both to and fro. But suppose for a moment that they were not linked. Then it would be possible to move only the objects forwards, which gives a real magnification of the reflex images, and see them in the normal way. Or it would be possible to move only the tube with the plus lens forwards. Then we should have reflex images of normal size, seen enlarged. However, if both the objects and the tube are shifted forwards, there must be a twofold magnification. Each of these magnifications is equal to the proportion of the distances to the focal plane without and with the additional lens. The normal distance from the coloured objects to the focal plane is 168 mm. Thus the magnification with the plus 1.25 D lens is:

$$\text{for the shift of the coloured objects } M_1 = \frac{168}{168 - 16.89} = 1.112,$$

$$\text{and for the tube } M_2 = \frac{125}{125 - 16.89} = \frac{9.25}{8} = 1.156,$$

and for both $M_1 \times M_2 = 1.112 \times 1.156 = 1.2855$. The magnification with the minus 1.25 dioptre lens is:

$$\text{for the shift of the coloured objects } M_3 = \frac{168}{168 + 23.15} = 0.879,$$

and for the tube $M_4 = \frac{125}{125+23 \cdot 15} = \frac{6 \cdot 75}{8} = 0 \cdot 844$,

and for both $M_3 \times M_4 = 0 \cdot 879 \times 0 \cdot 844 = 0 \cdot 7416$.

In the same way the magnification with a $-2 \cdot 5$ D lens is $0 \cdot 7473 \times 0 \cdot 6875 = 0 \cdot 5138$.

These magnification factors are applicable only to the Haag-Streit keratometer and not to other instruments. However, the same method could be applied to other makes, if the relevant dimensions were measured or obtained from the manufacturers. The results of this computation are shown in Table 2.

We acknowledge with thanks critical comments made by Mr A G Bennett on a draft of this paper.

References

- 1 Mc Reynolds WL, Snider NL. The quick measurement of intraocular lens power and lens resolution at surgery. *Am Intraocular Implant Soc J* 1978; **4**: 15.
- 2 Miller D, Manning W, Miller R, West W, Ullen R, Stenowski J. Intraocular lens power check. *Am J Ophthalmol* 1981; **91**: 462-4.
- 3 Loones LH. Intraocular lens power 'in situ.' First meeting of the European Intraocular Implantlens Council, 30 Sept-2 Oct 1982, The Hague, Netherlands.
- 4 Colenbrander MC. Calculation of the power of an iris clip lens for distant vision. *Br J Ophthalmol* 1973; **57**: 735-40.

Accepted for publication 31 July 1986.