Review of Literature

INTRAOCULAR LENS POWER CALCULATION

The 1.25 D Rule

It depends on the basic refraction of the patient, but it is really guesswork. The ophthalmologist takes a detailed history, examines the patient's old eye glasses, and performs a clinical examination in an attempt to determine the patient's basic refraction prior to the development of significant cataract. When emmetropia is the goal, an 18D. power is used as a basic value that is varied according to the results of the clinical examination. For each diopter of hyperopia or myopia of basic refraction, 1.25 D. of IOL power is added to or subtracted from, respectively, the basic 18D. implant power, ***(Sander, 1987).*** A severe limitation of the rule, however, would be uncertainty about the basic refraction. An increase of the refractive index of the crystalline lens, which may precede or accompany the development of cataract, can change the refraction drastically toward the myopic side. The older the patient's glasses, the better the result. The problem with old glasses is that one eye may not had been corrected fully, as in high anisometropia. To avoid an error on the hyperopic side, it is even advisable to aim at a few diopters of myopia rather than emmetropia ***(Drews, 1975).***

IOL POWER CALCULATION FORMULAS

FIRST GENERATION FOURMULAS

A. THEORETICAL FORMULAS

Optical principles

Those formulas are based on geometric optics. ***(Schechter, 1980).*** In an optical system of thin lenses (or thick lens system reduced to principal planes), the vergence of a light ray, after passing through a lens, is equal to the vergence before the lens added to the lens power. For example: the vergence of a light ray in the plane " F " is defined as the inverse of the distance " L " from the plane " F " to the point where the light ray crosses the optical axis of the system (Fig. 1).

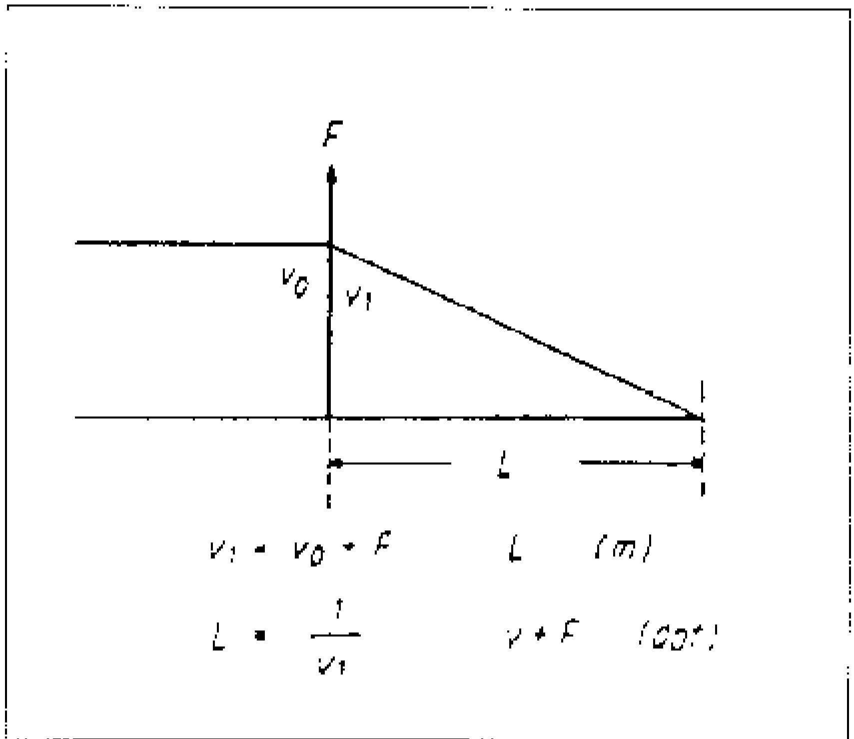

Fig. (1)

Definition of vergence

F	= Lens power.
V_o & V_1	= Vergences of parallel incident light beam before and after passing through a lens with power F
L	– Focal distance at the plane F

(Huber, 1984)

The vergence at any plane " V_2 " can be calculated if the distance from the plane " V_1 " and the vergence at " V_1 " are known. First, the distance " $L_1 = \frac{1}{V_1}$ " is calculated to find out where the light ray crosses the optical axis. The distance " L_2 " from the plane " V_2 " to that point is then " $L_2 = L_1 - d$ " and the vergence at " V_2 " by definition :

$$V_2 = \frac{1}{\frac{1}{F} - d} \qquad \text{(Fig. 2)}$$

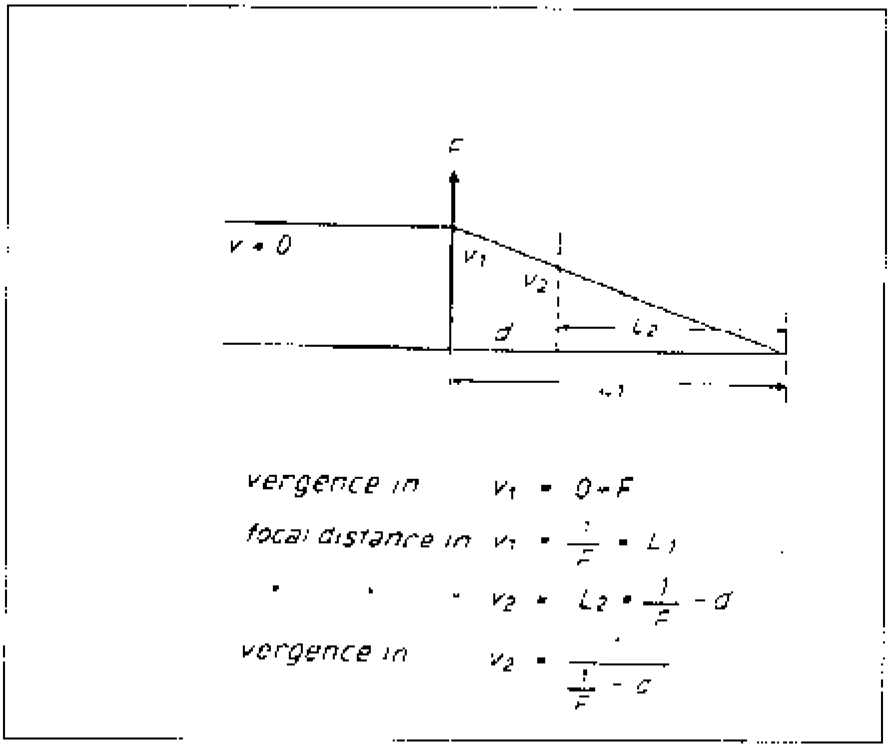

Fig. (2)

Vergence of light beam at a point V2

F	= Lens power
V_o & V_1	= Vergences of parallel incident light beam before and after passing through a lens with power F
V_2	= Vergence of light beam at a point V_2
L_1 & L_2	= Focal distances at V_1 & V_2
d	= Distance from plane V_1 to a point V_2

(Huber, 1984)

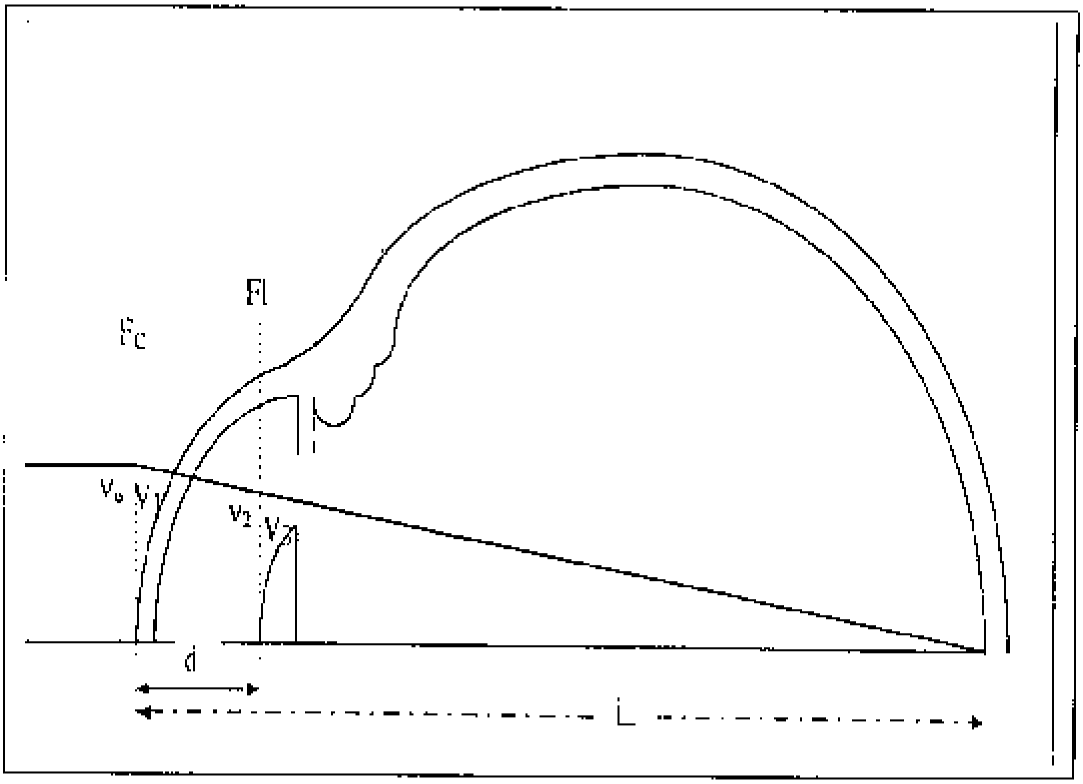

Fig. (3)

Schematic eye with an intraocular lens at V_2

Fc	= Corneal power
F_1	= Power of the intraocular lens.
d	= Anterior chamber depth measured from the corneal epithelium to the convex side of the intraocular lens,
L	= Axial length of the eye.
V_0 & V_1	= Vergences of a parallel incident light beam before and after the plane F_c
V_2 & V_3	= Vergences of the light beam before and after the principal planes of the intraocular lens.

(Huber, 1984)

First Generation Theoretical Formulas

Fyodorov (1967) presented a theoretical formula for calculation of the intraocular lens power. It was based on geometric optics, as applied to schematic eyes using theoretical constants. The axial length was determined by ultrasonography, while the radius of curvature of the cornea was determined by keratometry.

Fyodorov's Formula (1967)

The intraocular lens power = $\dfrac{n\,Pc\,a}{(a - K)\left(1 - \dfrac{PcK}{n}\right)}$

n = the refractive index of the media (aqueous and vitreous)

Pc = Power of the cornea

a = Axial length of the globe

K = Anterior chamber depth.

Colenbrander's Formula (1973)

$$D = \frac{n}{A - d - 0.00005} - \frac{n}{\dfrac{n}{dc} - d - 0.00005}$$

D = refractive power of intraocular lens in diopters

n = refractive index of aqueous and vitreous

d = distance from the anterior surface of the cornea to the anterior surface of the intraocular lens

a = axial length of the eye

Dc = refractive power of the cornea in diopters.

Binkhorst's Formula (1975)

$$D = \frac{1336\,(4r - d)}{(a - d)\,(4 - d)}$$

r = radius of curvature of anterior surface of cornea in mm

D = power of the intraocular lens

d = distance from the anterior surface of the cornea to the anterior surface of the intraocular lens

a = axial length of the eye.

Sanders (1987) suggested that the theoretical formulae are identical except for small correction factors. All those formulae could be algebrically transformed to:

$$P = \frac{N}{(L - C)} - \frac{NK}{(N - KC)}$$

P = the intraocular lens power for emmetropia

N = the aqueous and vitreous refractive index

C = the estimated postoperative anterior chamber depth in mm

L = the axial length of the eye in mm

K = the corneal power in diopters.

B : EMPIRICAL (REGRESSION) FORMULAS

First generation empirical formulas

SRK Formula

Retzlaff (1980) in addition to *Sanders and Kraff (1980)*, published a regression formula for calculation of intraocular lens power. Through regression analysis of their previous results, they observed a relationship between the preoperative variables (axial length and keratometric readings) and the actual results (implant power required to achieve emmetropia). The formula was named SRK according to (Sanders. Retzlaff and Kraff) and it is as follows :

$$\mathbf{P = A - 2.5\ L - 0.9\ K}$$

where,

P = implant power required to achieve emmetropia in diopters

L = axial length in mm

K = average keratometer readings in diopters

A = a specific constant for each lens type and manufacturer.

(Retzlaff, 1980).

The A constant is determined empirically for each implant. The technique uses multiple regression analysis that estimates the relationship between a dependent variable (residual refractive error after surgery) and a set of independent variables (preoperative axial length, keratometry measurement, and power of lens implanted). It depends on the postoperative ACD, lens style and shape, angulation of its haptics, refractive index of its material and intrinsic variations between different surgeons. The A constant is greater the closer the lens implant is to the retina. Therefore it is greatest with posterior chamber lenses, intermediate with iris fixated lenses, and least with anterior chamber lenses. Furthermore, most posterior chamber lenses have haptics that angle forward, pushing the optic posteriorly, which increases their A constant over planar posterior chamber lenses *(Jaffe, 1997).*

SECOND GENERATION FORMULAS

A : THEORETICAL FORMULAS

In the early ***1980s, Hoffer and Binkhorst*** independently replaced the constant ACD in their respective first generation theoretical formulas with one that varied based on the axial length (AL). ***Hoffer (1984)*** used an ACD prediction formula for posterior chamber lenses based on his study, which showed that the measured postoperative ACD was directly proportional to the axial length of the eye (ACD = 0.292 AL - 2.93). Binkhorst II formula ***(Binkhorst, 1978)*** altered the constant ACD as a function of axial length (ACD = AL / 23.45 x ACD). ***Shammas (1982)*** using the Binkhorst I formula, modified the axial length (AL = 0.9 AL + 2.3), which had about the same effect on IOL power as varying the ACD.

B : EMPIRICAL FORMULAS

SRK II formula

Sanders et al.,(1988) introduced a new SRK II formula which had been shown to reduce the prediction error of the original SRK formula in short (< 22 mm) and long (> 24.5 mm axial length) eyes. The SRK II formula is :

if $L < 20$, $A_1 = A + 3$

if $20 \leq L < 21$, $A_1 = A + 2$

if $21 \leq L < 22$, $A_1 = A + 1$

if $22 \leq L < 24.5$, $A_1 = A$

if $L > 24.5$, $A_1 = A - 1$.

where,

L = axial length of the eye in millimeters pre-operatively,

A_1 = recommended A constant for use in calculating IOL power,

A = A constant used with the original SRK formula.

(Sing and Roy, 1989).

THIRD GENERATION FORMULAS

The popularity of the empirical regression methods compared to the early theoretical formulas *(Colenbrander, 1973, Binkhorst, 1973, Fyodorov et al., 1975 and Binkhorst, 1981)* seems to be due to the poor accuracy of the latter formulas initially found in unusually long or short eyes. *(Retzlaff, 1980, Sanders and Kraff, 1980, Hoffer, 1981 and Shammas, 1982).* There is now increasing evidence that this inaccuracy was not caused by the optical approach being insufficient, but by the lack of adequate methods to predict the pseudophakic anterior chamber depth. *(Olsen et al., 1990)*. Rather than making an individual prediction of the pseudophakic anterior chamber depth, the early theoretical formulas recommended a constant value in the IOL power calculation. However, because the pseudophakic anterior chamber depth, among other factors, is correlated with the axial length, ***(Lepper, 1984 and Olsen et al., 1990)***, the use of a constant value for the predicted pseudophakic chamber depth leads to an underestimation of the true chamber depth in a long eye and an overestimation in a short eye. The corresponding error on the refraction will be a hyperopic error in a long eye and a myopic error in a short eye. If, on the other hand, one makes an adequate correction for the axial length dependence, the accuracy can be significantly improved in long and short eyes. ***(Olsen, 1991)***. Third-generation formulas vary the ACD based on the patient's axial length and corneal curvature. ***(Hoffer, 1993)***.

Holladay Formula

Holladay ***(Holladay et al., 1988)*** ushered in the era of third generation formulas. They combined a personalized ACD factor with the Fyodorov ***(Fyodorov and Kolinko, 1967)*** method of using the axial length and K-reading to predict the corneal height (distance from the corneal endothelium to the iris plane). The Holladay ACD was the sum of the corneal height, the thickness of the cornea (0.56 mm), and the distance from the iris plane to the IOL's principle plane. This last value he termed the "Surgeon Factor" (SF). Since the SF could not be known before surgery, it was necessary to calculate it from a series of postoperative eyes of one IOL style using Holladay's formula and the average for that lens style. This formula was more accurate than Hoffer's formula and significantly more accurate than the SRKII.

Table (1) is a mathematical description of the Holladay formula. *(Holladay et al., 1988).*

HOLLADAY FORMULAS AND CONSTANTS

Recommended constant	Measured values
n_c = refractive index of cornea = 4/3	k = average K-reading (diopters)
n_a = refractive index of equeous = 1.336	R = average corneal radius (mm) = 337.5/k
RT = retinal thickness factor = 0.200 mm	AL = measured ultrasonic axial length (mm)

Chosen values

v = vertex distance of pseudophakic spectacles (mm), default = 12mm

Ref = desired postoperative spheroequivalent refraction (diopters)

SF = "surgeon factor" = distance from aphakic anterior iris plane to optical of IOL (mm)

Definitions of other variables

AG = anterior chamber diameter from angle to angle (mm)

ACD = anatomic anterior chamber depth (mm), distance from corneal vertex to anterior iris plane

Alm = modified axial length (mm) = ultrasonic axial length (AL) + retinal thickness factor (RT)

I = power of IOL (diopters)

Aref = actual postoperative spheroequivalent refraction (diopters)

EQUATIONS

Eq 1. Rag = R, if R < 7 mm, then Rag = 7 mm

Eq 2. AG = 12.5 AL/23.45, if AG > 13.5 mm, then AG = 13.5 mm

Eq 3. ACD = 0.56 + Rag - (SQRT (Rag Rag - (AG AG/4)))

IOL power (I) from desired postoperative refraction (Ref)

$$\text{Eq4. } I = \frac{1000 n_a\left(n_a R-(n_c-1)Alm\right)-0.001\ Ref\left(V\left(n_a R-(n_c-1)Alm\right)+Alm R\right)}{(Alm-ACD-SF)\left[n_a R-(n_c-1)(ACD+SF)-0.001\ Ref\left(V\left(n_a R-(n_c-1)(ACD+SF)\right)+(ACD+SF)R\right)\right]}$$

Resultant refraction (Ref) from IOL power (I)

$$\text{Eq5. } Ref = \frac{1000 n_a\left(n_a R-(n_c-1)Alm\right)-I(Alm-ACD-SF)\left(n_a R-(n_c-1)(ACD+SF)\right)}{n_a\left[V\left(n_a R-(n_c-1)Alm\right)+Alm R\right]-0.001\ I(Alm-ACD-SF)\left[V\left(n_a R-(n_c-1)(ACD+SF)\right)+(ACD+SF)R\right]}$$

Reverse Solution "Surgeon Factor" (SF) from IOL power (I) and actual stabilized post - operative refraction (Aref)

Eq 6. AQ = (n_c - 1) - (0.001 Aref ((V (n_c - 1)) - R))

Eq 7. BQ = Aref 0.001 ((Alm V (n_c - 1)) - (R (Alm - V n_a)))) - (((n_c - 1) Alm) + (n_a R))

Eq 8. CQ1 = 0.001 Aref ((V ((n_a R) - ((n_c - 1) Alm))) + (Alm R))

Eq 9. CQ 2 = (1000 n_a ((n_aR) - ((n_c - 1) Alm) - CQ_1)) / I

Eq 10. CQ3 = (Alm n_a R) - (0.001 Aref Alm V R n_a)

Eq 11. CQ3 - CQ2

Eq 12. SF = (((- BQ) - SQRT ((BQ BQ) - (4 AQ CQ)))/(2 AQ)) - ACD

Numeric Example

K	=	46D	V =	12 mm	Ref	=	-0.50000 D
AL	=	22 mm	I =	21.45970 D	Aref	=	-0.5000 D
ALm	=	22.2 mm			SF	=	+ 0.50000 mm

Forward solution for "I" and Ref

Rag	=	R = 7.33696 mm
AG	=	11.72708 mm
ACD	=	3.48676 mm
I	=	21.45970 D
Ref	=	- 0.50000 D

Reverse Solution for "SF"

AQ	=	0.331665	CQ_3	=	218.91391
BQ	=	- 17.22395	CQ	=	63.39617
CQ_1	=	- 0.095853	SF	=	+ 0.5000 mm
CQ_2	=	155.51774			

The use of SF corrects the following possible errors :

1. Lens style has an error range from 0.0 to 3.00 diopters.
2. Lens position has an error range from 0.5 to 1.00 diopters.
3. A-scan unit has an error range from 0.5 to 1.25 diopters.
4. Wound closure & suture has an error range from 0.25 to 1.00 diopters.
5. Keratometer has an error range from 0 to 0.25 diopters.
6. Miscellaneous (Technician, IOL power accuracy, refraction, and postoperative steroids) has an error range from 0 to 0.5 diopters.

SRK/T Formula

Retzlaff et al., (1990) said that it would be valuable to offer a theoretical approach to implant power calculation under the SRK umbrella of formulas. They thought to merge the theoretical and empirical approaches using the best attributes of both to develop the SRK / T (SRK / theoretical) formula. Development of the final SRK / T mode (**Table : 2**) consisted primarily of empirically optimizing (1) postoperative anterior chamber depth (ACD) prediction, (2) retina thickness correction factor, and (3) corneal refractive index.

Table (2) SRK/T formula

Postoperative ACD Computation

(1) Corneal radius of curvature, mm (r) : $r = 337.5/k$

(2) Corrected axial length, mm (LCOR) :

If $L \leq 24.4$, then $LCOR = L$

If $L > 24.4$, then $LCOR = 3.446 + 1.716 \times L - 0.0237 \times L \times L$

(3) Computed corneal width, mm (C_w)

$C_w = -5.41 + 0.58412 \times LCOR + 0.098 \times K$

(4) Corneal height, mm (H)

$$H = r - \sqrt{r \times r - \left((C_w \times C_w)/4\right)}$$

(5) Offset for specific IOL to be implanted :

Offset = ACD_{const} - 3.336

(6) Estimated postoperative ACD for patient :

ACD_{est} = H + offset

Intraocular Lens Power Computations

(7) Constants :

V = 12; n_a = 1.336; n_c = 1.333; n_c ml = 0.333

(8) Retinal thickness, mm (RETHICK) and optical axial length, mm (LOPT) :

RETHICK = 0.65696 - 0.02029 × L

LOPT = L + RETHICK

(9) Emmetropia IOL power, D (IOL_{emme}):

$$IOL_{emme} = \frac{1000 \times n_a \times (n_a \times r - n_c ml \times LOPT)}{(LOPT - ACD) \times (n_a \times r - n_c ml \times ACD)}$$

(10) Ametropia IOL power, D (IOL_{ametr}):

$$IOL_{ametr} = \frac{1000 \times n_a \times \left(n_a \times r - n_c ml \times LOPT - 0.001 \times REFTGT \times \left(V \times (n_a \times r - n_c ml \times LOPT) + LOPT \times r\right)\right)}{(LOPT - ACD) \times \left(n_a \times r - n_c ml \times ACD - 0.001 \times REFTGT \times \left(V \times (n_a \times r - n_c ml \times ACD) + ACD \times r\right)\right)}$$

(11) Expected refraction, D (REFX):

$$REFX = \frac{1000 \times n_a \times (n_a \times r - n_c ml \times LOPT) - IOL \times (LOPT - ACD) \times (n_a \times r - n_c ml \times ACD)}{n_a \times \left(V \times (n_a \times r - n_c ml \times LOPT) + LOPT \times r\right) - 0.001 \times IOL \times (LOPT - ACD) \times \left(V \times (n_a \times r - n_c ml \times ACD) + ACD \times r\right)}$$

Determining ACD-Constant from the A-Constant

(12) ACD_{const} = 0.62467 × A - 68.747

Tailoring, Optimizing the A-Constant

(13) Refraction factor (RF):

If IOL > 16, then RF = 1.25 If IOL ≤ 16, then RF = 1

(14) Short and long eye correction:

If L < 20, then C = 3

If 20 ≤ L < 21, then C = 2

If 21 ≤ L < 22, then C = 1

If 22 ≤ L < 24, then C = 0

If L ≥ 24, then C = -0.5

(15) Individual A-constant (A_{indiv}):

A_{indiv} = IOL + (REF × RF) + 2.5 × L + 0.9 × K - C

(The mean value of A-indiv for a data set is the personalized A-constant for that data set's IOL/surgeon)

VARIABLES

ACD_{const} = constant used for anterior chamber depth in SRK/T formula for specific IOL/surgeon; can be computed from A-constant

ACD_{est} = estimated postoperative anterior chamber depth for a given eye (mm)

A = constant used for SRK/T and SRK II

A_{indiv} = A-constant from postoperative values of an individual eye

C = short and long eye correction factor for SRK II

C_w = corneal width computed from L and K (mm)

H = height of corneal dome (mm)

IOL = power of intended or implanted IOL (D)

IOL_{amet} = power of IOL for given amount of ametropia, for a given REFTGT (D)

IOL_{emme} = power of IOL for emmetropia (D)

K = averged keratometry (D)

L = axial length measured ultrasoically (mm)

LOPT = "optical" axial length (mm) = L + RETHICK

LCOR = axial length with long eye correction; used in height formula

n_a = refractive index of aqueous and vitreous

n_c = refractive index of the cornea

$n_c$ml = n_c minus 1, used in theoretical formula

offset = difference between corneal height of the average eye and the ACD-constant of a given IOL (see Figure 3)

r = averaged corneal radius of curvature (mm)

REF = actual postoperative refraction (D)

REFTGT = targeted or desired postoperative refraction (D)

REFX = expected postoperative refraction (D)

RETHICK = sensory retinal thickness (mm)

RF = refraction factor

Hoffer Q Formula

Holladay recommended that the Hoffer formula (1974) be optimized by personalizing the ACD. This stimulated the creation of the Hoffer Q formula (1992) to predict ACD based on a personalized ACD for any lens style, as well as the axial length and K-reading of the individual eye without using Fyodorov's corneal height formula.

The Hoffer Q formula was written as

Measured Values
A = axial length (mm)
K = K average (D)

Constants
Refractive index of cornea = 1.336
Retinal thickness factor = 0
Vertex distance (glasses) = 12 mm

Calculated Values
P = IOL power (D)
R = refractive error at corneal plane (D)
Rx = refractive error at spectacle (D)
C = chamber depth (ACD) (mm)
pACD = personalized ACD

Hoffer Formula: IOL Power

$$R = Rx/(1 - 0.012\,Rx)$$
$$P = (1336/(A - C - 0.05)) - (1.336/((1.336/(K + R)) - ((C + 0.05)/1{,}000)))$$

Hoffer Formula: Refractive Error

$$R = (1.336/((1.336/((1336/(A - C - 0.05)) - P)) + ((C + 0.05)/1{,}000))) - K$$
$$Rx = R/(1 + 0.012\,R)$$

Hoffer Formula: Axial Length

$$R = Rx/(1 - 0.012\,Rx)$$
$$A = (1336/(P + (1.336/((1.336/(K + R)) - ((C + 0.05)/1{,}000))))) + C + 0.05$$

Hoffer Formula: Personalized ACD

$$N = 1336/(K + R) \qquad R = Rx/(1 - 0.012\,Rx)$$
$$ACD = ((A + N - SQRT\,[(A - N)^2 + 4((N - A)/(P/1336))])/2) - 0.05$$

Hoffer Q Formula: Predicted ACD

$$ACD = pACD + 0.3\,(A - 23.5) + (\tan K)^2 + (0.1\,M\,(23.5 - A)^2\,(\tan(0.1\,(G - A)^2))) - 0.99166$$

If $A \le 23$, $M = +1$, $G = 28$
$A > 23$, $M = -1$, $G = 23.5$
If $ACD > 6.5$, $ACD = 6.5$
$ACD < 2.5$, $ACD = 2.5$
pACD = personalized ACD

where, M and G are correction factors .

The use of the Hoffer Q ACD prediction formula with the basic Hoffer formula (1974) is termed the Hoffer Q formula, which is statistically more accurate than using the basic formula with any constant ACD (first-generation Hoffer formula). ***(Hoffer, 1993)***.