32 An Overview of Intraocular Lens Power Calculation Methods

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Cataract surgery is refractive surgery. Besides removing the dysfunctional cataract, cataract surgery restores and corrects the refractive status of the eye. The success of modern-day cataract surgery is dependent on the refractive outcome. Postoperative refractive surprise is unnecessarily disappointing and frustrating to everyone.

In prescribing the correct glasses, accurate refraction is key to that outcome. In laser cornea refractive surgery, again good preoperative refraction, whether objectively, subjectively, or wavefront-driven, is imperative to a happy result. In cataract surgery, good biometry coupled with good intraocular lens power calculation is crucial to ensure good eventuality. It is akin to accurate refraction in cornea refractive surgery.

In 1949, Harold Ridley implanted a plastic lens in a patient. Despite the less than favorable initial results, he had ushered in a new era of intraocular lenses and indirectly lead to the subsequent development of the science of intraocular lens power calculation.

In the past, IOL power calculation formulas are categorized by generation. However, this can be confusing as formulas evolved and newer methods are being developed. As aptly described by Koch et al., it is opportune to adopt a newer classification based on methodology [1, 2]. However, this has recently been more thoroughly updated by Savini, Hoffer and Kohnen in a recent JCRS Editorial [2].

Historical Methods

Standard Lens Method

Learning from the poor outcomes of the pioneering implantations, the dioptric power of the early lens implants was adjusted to an improved single-lens power for all patients, depending on what type IOL was used (Prepupillary, Iris Plane or Anterior Chamber). The initial gross refractive errors were reduced. This lasted for almost two decades. This overly simplistic method is obsolete due to the inherently poor outcomes.

The Refraction Method

Among the first attempts at calculating IOL power was a simple refraction-based method. The power of the IOL was adjusted by a factor of the preoperative refraction.

$$\text{IOL Power} = 18.00 + 1.25^{*}\ \text{preoperative refraction.}$$

The refraction method has poor outcomes as preoperative refraction with a cataract present is an imprecise method of determining the power

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of the lens. The cataract itself may induce index refractive error that confounds the preoperative refraction.

Theoretical Formulas

In 1967, Fyodorov and Kolonko [3] presented their theoretical formula based on geometric optics. The formula utilizesd keratometry and axial length which was measured with A-scan ultrasonography. That marked the nascency of today's geometrical optics or theoretical formulas.

The eye is essentially a 2-lens system. It consists of the cornea as the first lens that contributes about two-third of the refractive power of the eye; and the crystalline lens that accounts for the remaining one-third of the refracting power of the eye (Fig. 32.1). Theoretical formulas using vergence formulas are based on Gaussian optics.

The geometric formulas of Fyodorov and Kolonko [3] and the other early workers, notably Colenbrander [4], Thijssen [5], Van der Heijde [6], Hoffer [7] and R Binkhorst (Binkhorst, The optical design of intraocular lens calculation [8]) are all applied to schematic eyes using theoretical constants. Basically, these formulas use different correction factors but utilize identical vergence concept of:

$$P = \frac{n}{\mathrm{AL} - \mathrm{ACD}} - \frac{n}{\frac{n}{K} - \mathrm{ACD}}$$

Where P is the IOL power; n is aqueous and vitreous refractive index; and ACD the estimated anterior chamber depth that is adjusted by the individual formulaic correction factors.

The early formulas were good with normal axial lengths of around 23.5 mm (22–24.5 mm) but were less precise with short (<22 mm) or long (>2.5 mm) axial length eyes. Further development on regression and theoretical formulas involved improvement in outcomes in eyes with an expanded range of axial lengths.

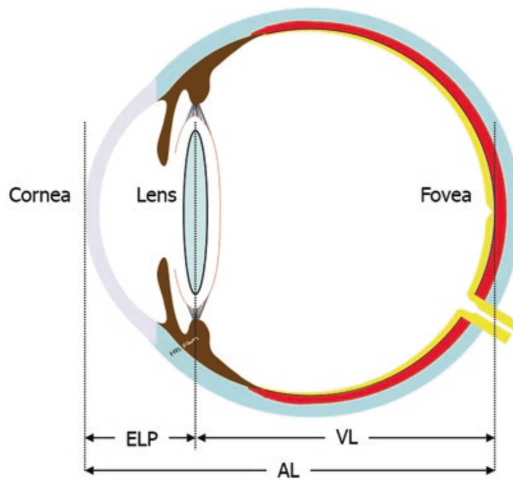

Fig. 32.1 A schematic optical diagram of the eye depicting the 2-lens system of the eye. *ELP* effective lens position (commonly known as the predicted postoperative anterior chamber depth), vl vitreous length (optical vitreous length), *AL* axial length (optical axial length)

The early generation of theoretical formulas assumed fixed postoperative anterior chamber depths. A second generations of theoretical formulas was introduced by Hoffer in 1982, which includes a sub-equation for ELP that mathematically predicts the postoperative effective lens position (ELP) as a function of axial length. The sub-equation (ELP=2.92*AL-2.93) was based on one IOL model and would be best for that model. R. Binkhorst followed with another iteration. (Binkhorst, Intraocular lens power calculation manual: A guide to the Author's TICC-40 Programs, Edition 3 [9], [10] (Hoffer, The effect of axial length on posterior chamber lenses and posterior capsule position [11, 12]). The main difference between these second-generation formulas lies in its prediction of the postoperative effective lens position.

The third generation of theoretical formulas utilizes both AL and keratometry as predictors of preoperative anterior chamber depth (Olsen, Prediction of intraocular lens position after cataract extraction [13]), hence the ELP [14, 15]. All these formulas are based on the Gullstrand eye model.

2-Variables Thin-Lens Vergence Formula: Third Generation Theoretical Formulas

For the last 3 decades, modern theoretical formulas were the commonly used formulas. These were Hoffer Q, the Holladay, and the SRK/T formulas. These 3 formulas make use of the radius of curvature of the anterior cornea and axial length to predict the ELP. Olsen first introduced the use of more variable such as the ACD and LT. Later, Holladay introduced his Holladay 2 (Holladay, Holladay IOL Consultant User's Guide and Reference Manual [16]) which uses up to 7 variables to predict the ELP. Besides corneal radius and axial length, these include preoperative ACD, phakic lens thickness, the corneal diameter (CD), and the patient's age. Hoffer and Savini later introduced gender and race in their Hoffer H-5 formula.

Hoffer Q and Hoffer QST

This formula was published by Kenneth J Hoffer in 1993 (Hoffer KJ, The Hoffer Q formula: a comparison of theoretic and regression formulas [17]). The core vergence formula is the basic Hoffer formula (a major modification of Colenbrander's formula) but with a new ELP prediction equation he called the Q formula which predicted the ELP based on the AL and the Tangent of the K.

Thanks to the studies by Melles [18, 19], Hoffer, Savini, and Taroni have further developed a new formula, the Hoffer QST. This is an evolution of the 1993 Hoffer Q formula with the use of AI to enhance the prediction of ELP and algorithms to improve accuracy in the long eyes. There are several studies now showing the Hoffer QST to be as good or better than all the modern formulas depending on the criteria chosen (MAE, MedAE, SD, %+/-0.50 D, etc) [20]. It is freely available on its website www.HofferQST.com with a Research page allowing lens constant (pACD) optimization and IOL power studies on your data.

Holladay 1 and Holladay 2 Formulas

Holladay's first formula (Holladay 1) is a 3-part formulation [14]. The first part is a set of screening criteria for data. The purpose is to identify the improbable axial length and keratometry measurements and to alert the users to validate the measurements and the possibility of untoward outcomes. He used the Hoffer AJO 1980 study of 7,500 eyes for normal differences in bilateral eyes [21]. This set of useful checklists has persisted and is now part of most biometry systems but with some modifications with the changing times. The second part is the formula proper; this is a further modification of the second-generation theoretical formula to improve on the prediction of the ELP using Fyodorov's Corneal Height equation (using AL and K). Finally, a personalized "surgeon factor" (SF) (his lens constant) compensates for any systematic bias in the individual surgeon's postoperative outcome.

Holladay's Data Screening Criteria [14] to identify unusual measurement and require further validation. Repeat measurement if:

1. Axial length < 22.0 mm or > 25.0 mm
2. Average corneal power < 40.0 Diopters or > 47.0 Diopters
3. Calculated emmetropic IOL power > 3.0 Diopters of average power* for the specific lens type
4. Between eyes, the difference in.
   (a) Average corneal power > 1.0 Diopter
   (b) Axial length > 0.3 mm
   (c) Emmetropic IOL power > 1.0 Diopter

The Holladay 2 formula is unpublished but is available for purchase as part of the Holladay IOL Consultant program (Fig. 32.2). It requires inputs of, besides AL and K, phakic preop ACD, LT, CD and patient's age. Having more parameters enabled the Holladay 2 to appreciate the nuances of disproportionate eyes and render the calculation appropriately.

	Short	Normal	Long
Small	Nanophthalmia *(1.8%)*	Microcornea *(1.5%)*	Microcornea + Axial Myopia *(0%)*
Normal	Axial Hyperopia *(6.9%)*	Normal *(73.4%)*	Axial Myopia *(13.5%)*
Large	Megalocornea + Axial Hyperopia *(0%)*	Megalocornea *(1.5%)*	Buphthalmia *(1.5%)*

Axial Length

Anterior Segment Size	Short	Normal	Long
Small	Nanophthalmia *(1.8%)*	Microcornea *(1.5%)*	Microcornea + Axial Myopia *(0%)*
Normal	Axial Hyperopia *(6.9%)*	Normal *(73.4%)*	Axial Myopia *(13.5%)*
Large	Megalocornea + Axial Hyperopia *(0%)*	Megalocornea *(1.5%)*	Buphthalmia *(1.5%)*

Fig. 32.2 Holladay JT MD. has categorized human eyes into nine categories (Fig. 32.2). This illustrates that the human is not necessarily proportional. This disparity poses a challenge to IOL power calculation, particularly in unusual eyes. Fortunately, most of the eyes are normal. Modern IOL power calculation formulas factored in the above into their algorithms

SRK/T

Using the Holladay 1 formula as a base but modifying so it will use the A constant of the SRK formula, Retzlaff published the SRK/T formula [15] in 1990. The SRK/T is a theoretical formula based on Fyodorov's Corneal Height formula [1] for the postoperative ELP prediction. The retinal thickness correction factor and the corneal refractive index are likewise optimized.

Relationship Between the Third-Generation Formulas and Axial Length

While most third-generation formulas perform well in normal eyes with axial lengths between 22.0 mm to 25.0 mm, these formulas perform less favorably beyond these confines. These formulas tend to have a higher percentage of hyperopic prediction errors in longer axial lengths and conversely, myopic outcomes in shorter axial lengths (Fig. 32.3).

Fam Adjusted

In 2009, Fam et al. [22] published a paper to optimize the relationship between the predicted refractive outcomes and axial lengths as measured by PCI biometry. The concept was based on 2 readjustments. The first readjustment, OAL1, was to reverse the initial calibration by Haigis [23] of the PCI against ultrasound biometry and thereby using the 'actual' optical axial length as measured by the PCI biometer. The second adjustment, OAL2, was converting 'actual optical axial length' to 'true optical path length' using the mean refractive index proposed by Olsen [24]. The smaller annulus keratometry measurement with the PCI biometer was also calibrated to the slightly larger mire of autokeratometry. With these adjustments, the performance of the third-generation formulas on longer eyes improved (Fig. 32.4).

Wang-Koch Adjustment

Wang et al., in 2011 [25], proposed a set of adjustment equations to optimize the outcomes in eyes longer than 25 mm. The adjustments were shown to reduce the risk of hyperopic outcomes in patients with long eyes. It has been modified since then.

The T2 Formula

The T2 formula was described by Sheard, in 2010 [26]. Using a larger and more up-to-date database, Sheard was able to correct the non-physiological behavior of the quadratic function of the corneal height prediction of SRK/T first pointed out by Hoffer and then Haigis [27].

Haigis Formula

Haigis realized the importance of lens geometry on the ELP [28]. Thin lens formulas, by having just a single constant, neglect the effect of changing lens geometry with different IOL power, curvatures, thickness, and styles. In unusual eyes where the almost linear relationship between the ELP and axial length starts to deviate, the perfor-

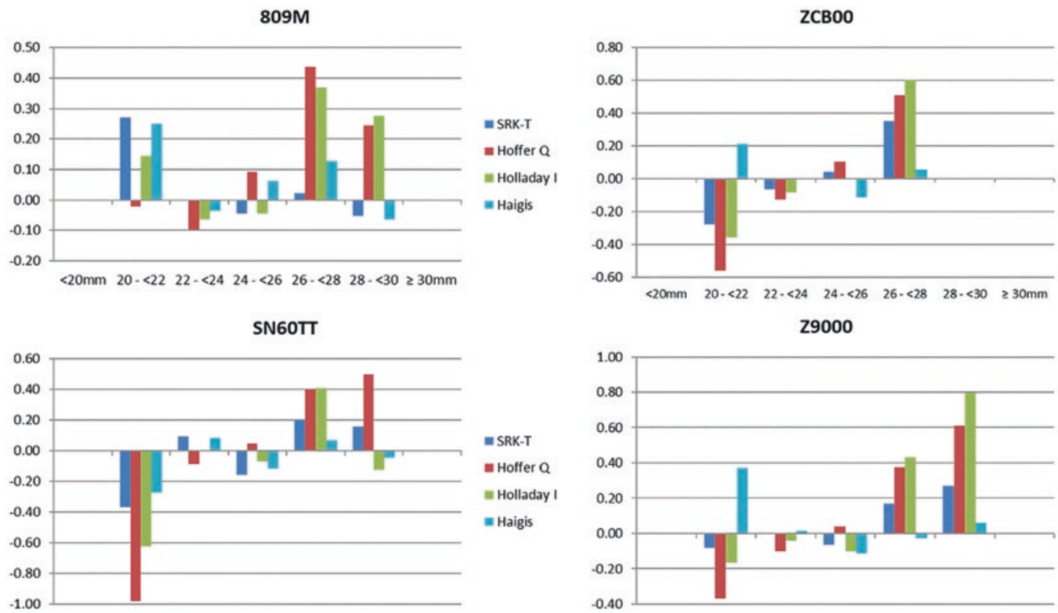

Fig. 32.3 The effect of axial lengths on the prediction errors of 4 theoretical formulas on 4 different IOLs. 3 of the 4 formulas showed hyperopic prediction errors with long axial lengths. Conversely, the same 3 formulas showed myopic tendency with shorter axial lengths with 3 IOLs

mances of these formulas start to falter. The Haigis formula, without resorting to the complexity of thick lens formulas, uses 3 lens constants (a_0, a_1 a_2) instead of one; and using the preopertive measured ACD instead of K as a variable which overcomes some of the problems of thin lens vergence formulas with short and long eyes.

In the Haigis formula, there are 2 types of constant optimization:

1. Classical optimization where one constant a_0 is optimized but not the other two. In this case, the formula performs as good, if not better than the other popular thin lens vergence formulas.
2. Full optimization where all three constants are optimized. This is when the full potential of the formula for wider ALs and lens types is achieved.

Regression Versus Theoretical Models

Regression formulas are entirely based on regression with a large database of postoperative outcomes. The larger the database, the better their predictability. More importantly, are the quality and integrity of the database. In theoretical formulas, regression with real-world postoperative results is utilized to refine its predictability. This is notably so in predicting the effective lens position and is embedded in the constants and correction factors of the formulas. Pure regression formulas (SRK and SRK II) are no longer recommended or used today.

Thin Lens Formula

The popular 3rd generation formulas for IOL power calculation like the Hoffer Q, Holladay 1, and the SRK/T are based on thin lens optics. A normal lens has a thickness and two refracting surfaces. In thin lens optics, the thickness of the lens is ignored, and its two refracting surfaces are reduced to a single plane thin lens. It is assumed that all refractions of light occur in that single plane. The advantage of the thin lens formula is that it simplifies the calculation and circumvents the difficulty of measuring certain parameters often not obtainable.

The popular formulas of Hoffer Q [17], Holladay 1 [14], and SRK/T [15] are based on thin

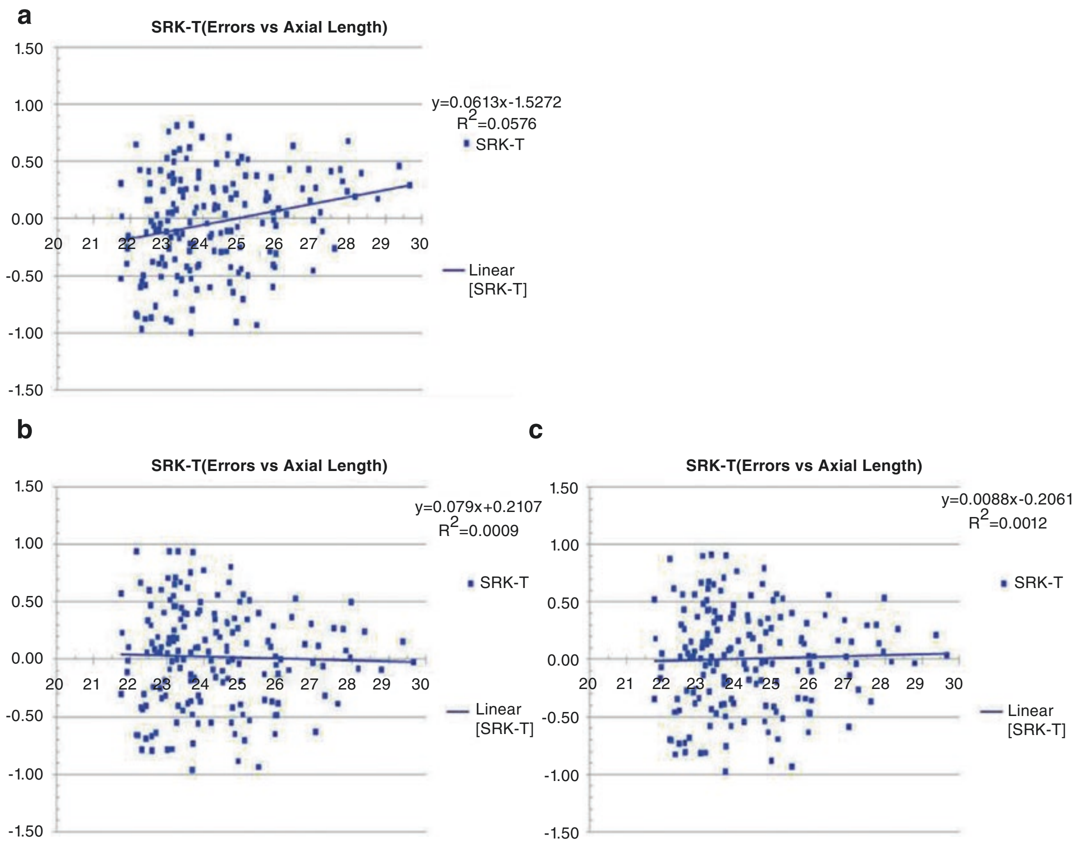

Fig. 32.4 (**a**) SRK/T outcomes with inputs from PCI. (**b**) SRK/T outcomes with OAL1-K readjustment and (**c**) SRK/T outcomes with OAL2-K readjustment. The abscissas are axial length in mm and the ordinates the prediction error

lens optics. Haigis [28] subsequently developed an improved thin lens formula by using a thick lens algorithm and regressing the ELP with preoperative data. Unlike the other 3 formulas, Haigis' ELP is derived ELP from the measured axial length and the preoperative anterior chamber depth.

The Impact of Optical Biometry

In ultrasound biometry, axial length measurement error alone accounted for 54% to 68% of the total prediction error according to Olsen [29]. With the availability of optical biometry, the source of error from axial length measurement decreased substantially from 0.65 D to 0.43 D or 30 to 40% of the total prediction error according to Olsen [30]. The repeatability of optical biometry was reduced from an SD of ±0.11 mm to ±0.03 mm [31]. Despite the improvement in AL measurement, this precision is not reflected in reducing prediction error according to Olsen [30]. This less than encouraging improvement was probably overshadowed and supplanted by the ACD prediction error, a function of IOL power calculation formulas [31].

Newer formulas can leverage the ever improving accuracy of biometric measurement and the quantum leap improvement in computational power to improve the precision and sophistication toward better outcomes and predictability.

In the last decade, many new and better formulas have emerged, making use of the heightened accuracy of the newer biometers and increasing computational power. It is not feasible to go through all the formulas and this article does not claim to be exhaustive.

Ladas Super Formula (LSF) 1.0

The Hoffer Q, Holladay 1, and SRK/T formulas have different optimal ranges for better outcomes, first proven and published by Hoffer in 1993. The Ladas Super Formula blends the proven popular formulas of Hoffer Q, Holladay 1 (with and without Wang-Koch adjustment [25], Haigis and SRK/T using a 3-dimensional model to determine the best power for each eye [32] based on its 2 to 3 variables inputs. This formula was originally developed by Ladas and subsequently included Siddiqui, Devgan, and Jun. The method has now been enhanced with artificial intelligence. www.iolcalc.com.

Kane Formula

Developed by Jack X Kane, [33–35] the Kane formula is an unpublished formula based on theoretical optics with refinements through both regression and artificial intelligence. It was developed using approximately 30,000 eyes from various cataract practices. The required parameters are AL, K, ACD, and gender with LT and CCT being optional. Various studies have reported excellent outcomes with this formula. The formula is available on www.iolfomula.com.

Panacea

This is a thin lens vergence formula developed by David Flikier. It is a 5-variable calculator using AL, K, ACD, LT; and to date the only formula that can utilize the asphericity Q value of the anterior corneal curvature and the anterior-to-posterior corneal curvature ratio [36]. It uses a demographic to statistically data screen the quality of the various inputs. This formula is available only for downloading at www.panaceaiolandtoriccalculator.com.

VRF-G

The VRF is a published vergence-based thin lens formula by Voytsekivskyy [37]. The VRF-G is a newer improved unpublished formula [38, 39]. The latter formula is based on theoretical optics with ray-tracing components; further refined through regression. This is an 8-variables formula.

Castrop

Castrop is a hybrid thin and thick lens formula [40]. It considers the cornea as a thick lens. It uses a constant like the Olsen C constant and readjusts the axial length based on Cooke's sum-of-segments approach. Finally, besides the IOL constant that is integral to the equation, it uses a second constant, offset R to the final dioptric power. The formula requires mandatory AL, ACD, and K inputs, with CCT and Post K being optional.

Thick Lens Formula

The third-generation formulas are simple thin lens formulas that do not require complex calculations. A simple calculator would be sufficient for the formula to be executed. Thin lens formulas are based on the Gullstrand eye model that assumed a fixed ratio of anterior to posterior corneal curvature and a keratometric index of refraction of 1.3375. The systematic deviations of these thin lens assumptions are compensated by the IOL constants. A thin lens formula assumed all the IOL powers of the same IOL model to have the same lens constant. This works reasonably well for the average eye requiring the average IOL power. Despite being the same IOL model, as the IOL power changes: its two curvatures, the ratio of its curvatures, and the lens thickness change. These changes will shift the ELP of the IOL.

Similarly, as the measuring devices become more accurate and comprehensive, more parameters can be measured accurately and be included in the computation of IOL power, without the risk of increasing the errors of propagation.

Barrett Universal II and EVO are thick lens formulas. In simpler terms, these formulas, like the third-generation formulas, predict the ACD of the IOL in the eye. After determining the initial ACD for the eye, the formulas iterate to determine the final ELP and thence the final IOL power for the eye. These iterative calculations are far more complex and require the power of modern-day computers.

Barrett Universal II (BUII) Formula

The concept behind the Barrett Universal formula was first described by Barrett himself in 1987 [41] and further elucidated in 1993 [42]. The Barrett Universal II (BUII) is a further refinement of the Barrett Universal formula and includes the use of more variables such as ACD, LT, and radius of curvature of the posterior cornea. These latter additional parameters have reached a high level of precision (with today's optical biometers) to be used confidently.

The BUII heralded in a new era of IOL power calculation formulas, with improved and consistent performances [43]. AL and K inputs are mandatory with ACD, LT, and CD being optional. With the accessibility to corneal thickness (CCT) and posterior corneal curvature (PK) in newer biometers, these variables are now additional optional variables for the formula.

Næser Formula

Conceptualized by Kristian Næser, this is a paraxial, step-along formula that considers the IOL a thick lens. The difference between Næser 1 [44] and Næser 2 [45] are on the source of the IOL architecture. Næser 1 uses the available information on the IOL architecture from the manufacturers (Cutting Card), whereas Næser 2 derived this information from open, commercial but non-proprietary sources. Also, the measured AL is optimized for different axial lengths.

EVO

Emmetropia Verifying Optical (EVO) formula is a thick lens formula developed by TK Yeo. The formula is based on the emmetropization concept of a normal eye and is constantly updated and improved. Presently, it requires mandatory AL and K inputs, with ACD, LT and CCT being optional, has recently been updated to include posterior cornea curvature.

PEARL-DGS

This is a thick lens IOL formula that relies on artificial intelligence of machine learning and modeling to predict ELP and fine-tuning of outputs for extreme biometric values. This formula was developed by G. Debellemanière, D. Gatinel and A. Saad. The formula is accessible at iol-solver.com.

Ray Tracing

Ray tracing is a method for calculating the path of individual rays through the various elements in an optical system. These various elements, with their surfaces and refractive indices, bend and change the passing light path. These individual rays are traced and calculated as they are refracted at each of these surfaces according to Snell's law [46]. Ray tracing may be limited to just the paraxial rays or cover any area on the pupil. The former neglects higher-order aberration, while the latter takes account of them and allows predicting the IOL power that provides the best visual quality.

Olsen Formula

First published by Olsen in 1987 [47], this formula has undergone many upgrades and refinement over the years [48, 49]. The latest is based on thick-lens ray-tracing optics. The uniqueness of this formula is the C constant concept [50] that generates the ELP based on the preoperative measurements of ACD and LT but can be additionally tweaked by AL and K, if desirable. The Olsen formula is available as an option in the LenStar biometer or as a standalone PhacoOptics program for purchase (www.phacooptics.net). The Olsen formula (Olsen2P = Olsen 2 parameters) that is preinstalled in biometers uses 2 parameters: ACD and LT to predict the C constant. The Olsen formula (Olsen4P) in the standalone PhacoOptics program uses 4 parameters, besides ACD and LT, AL, and K as well.

Okulix

Okulix is a standalone computer program that calculates IOL power based on ray-tracing the optical path of single rays that pass through the ocular structure. It uses measured parameters that are fed directly via computer interfacing from the biometers and corneal tomographers. Parameters can also be entered manually, where interfacing is not available. The program includes a compilation of IOL geometry of commonly used IOLs.

CSO Method

Two corneal tomographers (developed by the Italian company CSO) include a software module that performs IOL power calculations based on exact ray tracing: Sirius is a Scheimpfug-Placido device, and MS 39 is an OCT-Placido instrument. Corneal surfaces as well as actual IOL data are raytraced to calculate the optical performance of the eye and select the IOL power that will produce the targeted refraction or the best visual quality.

Regression Methods

To improve the accuracy of the early 2nd generation (R Binkhorst, regression formulas were born). The regression formulas are derived empirically from analyzing the relationship between the preoperative biometric measurements and the postoperative refractive outcomes. Using a large outcomes database, the relationship below was established.

$$P \propto A + bK + c\mathrm{AL}$$

Where P is the IOL power, A is the A constant; b and c are constants; K is the keratometry power and AL is the axial length.

It was first introduced by Thomas Lloyd (a technician with James Gills) [51] and followed first by John Retzlaff [52, 53] and then by Donald Sanders [54] & Manus Kraff. After the latter 3 combined forces, the SRK formula by Sanders, Retzlaff, and Kraff became the most established regression formula. It underwent subsequent revision (SRK II by Sanders) to compensate for the non-linear relationship between the intraocular lens power and the axial length. The SRK II was popular during the 1980s. It was superseded by the later more accurate 3rd generation theoretical formulas.

Artificial Intelligence (AI)

AI examines huge data efficiently and differently from how we humans do; it identifies relationships, patterns, and trends that escape us. AI has been used in medicine, but these are mainly for image classification and object recognition. IOL power calculation is now benefiting from AI as well.

Critical to the success of AI is a large and sound “training” dataset. AI learns from its dataset through interpreting and unraveling, to achieve the desired goal. An accurate and consistent dataset is indispensable to good machine learning. With a large and accurate dataset, AI can figure out the complex relationships between the many biometric parameters that may not fit traditional eye models or Gaussian optics.

Datasets from different devices may have to be interpreted differently, or at the very least adjusted and optimized to the device. Newer IOLs with novel optical structures that have yet to attain a sufficient sizable dataset may pose a challenge for AI. As AI learning capabilities improve, it may be able to adapt to parameters from different devices and bridge newer IOLs.

Despite these challenges, the future of AI is bright. It has already markedly improved outcomes as shown by some formulas such as RBF 3.0, Hoffer QST and PEARL-DGS. As the datasets get larger, these formulas improve further as typified by the version numbers. More and more parameters are being utilized as the neuronal circuits are refined and expanded.

Radial Basis Function (RBF)

Developed by Hill and his team, this formula is based on radial basis function (RBF), a machine-learning form of artificial intelligence. RBF with its multidimensions pattern recognition and adaptive neural learning process is appropriate to these real-world challenges of IOL power calculation. The formula is constantly being updated as more and more data is available to refine the process. At last look, the formula has been updated to version 3.0 with an expanded domain.

RBF is available as an option on some devices as well as online at www.rbfcalculator.com. The required variables are AL, K, and ACD with LT, CCT, and CD as options.

BART

This update on the development of Bayesian Additive Regression Trees (BART) [55] was described by Clarke et al. in 2020. This is an AI method using a machine-learned algorithm that sums decision trees. It gauges its accuracy using Monte Carlo simulations and generates intervals of possible lens powers with a probability density. Over a fivefold cross-validation process, the result of BART was an SD of 0.242 D compared to 0.416 (Holladay 1), 0.569 D (RBF 1.0), 0.575 D (SRK/T), 0.936 D (Hoffer Q), and 1.48 D (Haigis). The results were without optimizing the constants (which might be unfair to some of the formulas). MedAE was 0.204 D (BART), 0.416 D (Holladay 1), 0.676 D (RBF 1.0), 0.714 D (SRK/T), 0.936 D for Hoffer Q, and 1.204 D for Haigis. BART prediction achieved 89.5% within +/-0.50 D of prediction error, RBF 1.0 was 61.4%, and SRK/T with 52.0%.

Ladas Super Formula (LSF) 2.0

This formula uses machine learning algorithms to refine the prediction of the original LSF 1.0. using AL, K, and ACD as inputs. In a sample of 101 eyes implanted with the same IOL Taroni found in 2020, that this formula was one of the best performers among several modern formulas with a median absolute error of 0.22 D [56].

Intraoperative Aberrometry

ORA

Optiwave Refractive Analysis (ORA) is a methodology first proposed by Ianchulev in 2005 [57, 58]. This intraoperative Talbot-Moiré interferometry measures the ocular wavefront aberrations after removal of the crystalline lens in surgery. The captured real-time wavefront information is used to determine the aphakic spherical equivalent of the eye and thence calculate the proper desired IOL power. The system is independent of AL and K.

Conclusion

Today, there is an explosion of new IOL power calculation formulas and methods. This is a welcome development, as today patients are expecting better refractive outcomes. The newer formulas have shown to be more accurate than the once eminently popular third-generation formulas. As the hardware and computational power improve, we can expect even better formulas [1].

References

1. Koch D, Hill W, Abulafia A, Wang L. Pursuing perfection in intraocular lens calculations: 1. Logical approach for classifying IOL calculation formulas. J Cataract Refract Surg. 2017;43:717–8.
2. Savini G, Hoffer KJ, Kohnen T. IOL power formula classifications (Guest Editorial). J Cataract Refract Surg. 2024;50(2):105. https://doi.org/10.1097/j.jcrs.0000000000001378.
3. Fyodorov S, Kolonko A. Estimation of optical power of the intraocular lens. Vestnik Oftalmologic (Moscow). 1967;4:27.
4. Colenbrander M. Calculations of the power of an iris clip lens for distance vision. Br J Ophthalmol. 1973;57:735–40.
5. Thijssen J. The emmetropic and iseikonic implant lens: Computer calculation of the refractive power and its accuracy. Ophthlmologica. 1976;171:467–86.
6. van der Heijde G. The optical correction of unilateral aphakia. Trans Am Academy Ophthalmol Otolaryngol. 1976;81:80–8.
7. Hoffer KJ. Intraocular lens calculation: the problem of the short eye {Hoffer Formula}. Ophthalmic Surg. 1981;12(4):269–72.
8. Binkhorst R. The optical design of intraocular lens calculation. Arch Ophthalmol. 1981;99:1819–23.
9. Binkhorst, R. (1984). Intraocular lens power calculation manual: A guide to the Author's TICC-40 Programs, Edition 3. New York.
10. Shammas H. The fudged formula for intraocular lens power calculations. J Cataract Refract Surg. 1982;8:350–2.

11. Hoffer K. The effect of axial length on posterior chamber lenses and posterior capsule position. Curr Concept Ophthalmol Surg. 1984a;1:20–2.
12. Hoffer K. The effect of axial length on posterior chamber lenses and posterior capsule position. Curr Concept in Ophthal Surg. 1984b;1:20–2.
13. Olsen T. Prediction of intraocular lens position after cataract extraction. J Cataract Refract Surg. 1986;12(7):376–9.
14. Holladay J, Prager T, Chandler T, Musgrove K. A three-part system for refining intraocular lens power calculations. J Cataract Refract Surg. 1988;14:17–24.
15. Retzlaff JA, Sanders DR, Kraff MC. Development of the SRK/T intraocular lens power calculation formula. J Cataract Refract Surg. 1990;16:333–40. Errata: 1990;16:528 and 1993;19(5):444–446
16. Holladay J. Holladay IOL consultant user's guide and reference manual. Houston: Holladay LASIK Institute; 1999.
17. Hoffer KJ. The Hoffer Q formula: A comparison of theoretic and regression formulas. J Cataract Refract Surg. 1993;19(11):700–12. Errata: 1994;20(6):677 and 2007;33(1):2–3
18. Melles R, Holladay J, Chang W. Accuracy of intraocular lens calculation. Ophthalmol. 2018;125:169–78.
19. Melles R, Kane J, Olsen T, Chang W. Update on intraocular lens calculation formulas. Ophthalmol. 2019;1226:1334–5.
20. Savini G, Di Maita M, Hoffer K, Næser K, Schiano-Lomoriello D, Vagge A, et al. Comparison of 13 formulas for IOL power calculation with measurments from partial coherence interferometry. Br J Ophthalmol. 2021;105(4):484–9. https://doi.org/10.1136/bjophthalmol-2021-316193.
21. Hoffer KJ. Biometry of 7,500 cataractous eyes. Am J Ophthalmol. 1980;90(3):360–8., Erratum: 1980;90(6):890. https://doi.org/10.1016/S0002-9394(14)74917-7.
22. FAM H, Lim K. Improving refractive outcomes at extreme axial lengths with the IOLMaster: the optical axial length and keratometric transformation. Br J Ophthalmol. 2009;93:678–83.
23. Haigis W, Lege B, Miller N. Comparison of immersion ultrasound biometry and partial coherence interferometry for intraocular lens calculation according to Haigis. Graefes Arch Clin Exp Ophthalmol. 2000;238:765–73.
24. Olsen T, Thorwest M. Calibration of axial length measurements with Zeiss IOLMaster. J Cataract Refract Surg. 2005;31:1345–50.
25. Wang L, Shirayama M, Ma X. Optimizing intraocular lens power calculations in eyes with axial lengths above 25mm. J Cataract Refract Surg. 2011;37:2018–27.
26. Sheard R, Smith G, Cooke D. Improving the prediction accuracy of the SRK/T formula: the T2 formula. J Cataract Refract Surg. 2010;36:1829–34.
27. Haigis W. Occurrence of erroneous anterior chamber depth in the SRK/T formula. J Cataract Refract Surg. 1993;19:442–6.
28. Haigis W, Waller W, Duzanec Z, Voeske W. Postoperative biometry and keratometry after posterior chamber lens implantation. Eur J Implant Ref Surg. 1990;2:191–202.
29. Olsen T. Sources of error in intraocular lens power calculations. J Cataract Refract Surg. 1992;18:125–9.
30. Olsen T. Improved accuracy of intraocular lens power calculation with the Zeiss IOLMaster. Acta Ophthalmol Scand. 2007;85:84–7.
31. Norrby S. Sources of error in intraocular lens power calculation. J Cataract Refract Surg. 2008;34:368–76.
32. Ladas J, Siddiqui A, Devgan U. A 3-D "Super Surface" combining modern intraocular lens formulas to generate a "Super Formula" and maximize accuracy. JAMA Ophthalmol. 2015;133:1431–6.
33. Kane J, van Heerden A, Atik A, Petsoglou C. Intraocular lens power formula accuracy: comparison of 7 formulas. J Cataract Refract Surg. 2016;42:1490–500.
34. Kane J, van Heerden A, Atik A, Petsoglou C. Accuracy of 3 new methods for intraocular lens power selection. J Cataract Refract Surg. 2017;43:333–9.
35. Reitblat O, Gali H, Chou L, Bahar I, Weinreb R, Afshari N, Sella R. Intraocular lens power calculation in the elderly population using the Kane formula in comparison with existing methods. J Cataract Refract Surg. 2020;46:1501–7.
36. Savini G, Taroni L, Hoffer K. Recent developments in intraocular lens power calculation methods - update 2020. Ann Transl Med. 2020c;8(22):1553.
37. Voytsekhivskyy O. Development and clinical accuracy of a new intraocular lens power formula (VRF) compared to other formulas. Am J Ophthalmol. 2018;185:56–67.
38. Hipólito-Fernandes D, Luis M, Gil P, Maduro V, Fejiao J, Yeo T, et al. VRF-G, a new intraocular lens power calculation formula: a 13 formulas comparison study. Clin Ophthalmol. 2020a;14:4395–402.
39. Hipólito-Fernandes D, Luis M, Serras-Pereira R, Gil P, Maduro V, Feijóão J, Alves N. Anterior chamber depth, lens thickness and intraocular lens calculation formula accuracy: nine formulas comparison. Br J Ophthalmol. 2020b;0:1–7.
40. Wendelstein J, Hoffmann P, Hirnschall N, Fischinger I, Mariacher S, Wingert T, et al. Project hyperopic power prediction: accuracy of 13 different concepts for intraocular lens calculation in short eyes. Br J Ophthalmol. 2021;0:1–7.
41. Barrett G. Intraocular lens calculation formulas for new intraocular lens implants. J Cataract Refract Surg. 1987;13:389–96.
42. Barrett G. An improved universal theoretical formula for intraocular lens power prediction. J Cataract Refract Surg. 1993;19:713–20.
43. Turnbull A, Hill W, Barrett G. Accuracy of intraocular lens power calculation methods when targeting low myopia in monovision. J Cataract Refract Surg. 2020;46:862–6.
44. Naeser K. Intraocular lens power formula based on vergence calculation and lens design. J Cataract Refract Surg. 1997;23:1200–7.

45. Naeser K, Savini G. Accuracy of thick-lens intraocular lens power calculation based on cutting-card or calculated data for lens architecture. J Cataract Refract Surg. 2019;45:1422–9.
46. Preussner P, Wahl J, Lahdo H, Burkhard D, Findl O. Ray tracing for intraocular lens calculation. J Cataract Refract Surg. 2002;28:1412–9.
47. Olsen T. Theoretical approach to intraocular lens calculation using Gaussian optics. J Cataract Refract Surg. 1987;13:141–5.
48. Olsen T, Corydon L, Gimbel H. Intraocular lens power calculation with an improved anterior chamber depth prediction algorithm. J Cataract Refract Surg. 1995;21:313–9.
49. Olsen T. Prediction of effective postoperative (intraocular lens) anterior chamber depth. J Cataract Refract Surg. 2006;32:419–24.
50. Olsen T. C Constant: new concept for ray tracing-assisted intraocular lens power calculation. J Cataract Refract Surg. 2014;40:764–73.
51. Gills J. Minimizing postoperative refractive error. Cont Intraocular Lens Med J. 1980;6:56–9.
52. Retzlaff J. A new intraocular lens calculation formula. J Cataract Refract Surg. 1980a;6:148–52.
53. Retzlaff J. Posterior chamber implant power calculation: regression formulas. J Cataract Refract Surg. 1980b;6:268–70.
54. Sanders D. Improvement of intraocular lens power calculation using empirical data. J Cataract Refract Surg. 1980;6:263–7.
55. Clarke G, Kapelner A. The Bayesian Additive Regression Trees formula for safe machine learning-based intraocular lens predictions. Front Big Data. 2020;3:572134.
56. Taroni LHK-L. Outcomes of IOL power calculation using measurements by a rotating Scheimpflug camera combined with partial coherence interferometry. J Cataract Refract Sur. 2020;46(12):1618–23.
57. Ianchulev T, Salz J, Hoffer K. Intraoperative optical refractive biometry for intraocular lens power estimation without axial length and keratometry measurements. J Cataract Refract Surg. 2005;31:1530–6.
58. Raufi N, James C, Kua A, Vann R. Intraoperative aberrometry vs preoperative formulas in predicting intraocular lens power. J Cataract Refract Surg. 2020;46:857–61.