Emmetropia Verifying Optical (EVO) Formula

40

Tun Kuan Yeo

The Emmetropia Verifying Optical (EVO) formula, currently in version 2.0, consists of a suite of algorithms for intraocular lens (IOL) power and toric prediction, as well as post-myopic laser vision correction IOL power and toric prediction. The formula is based on the theory of emmetropization, hence its name, and is freely available online [1].

History

In the middle of 2015, while researching toric IOL calculations, a theoretical method for the prediction of posterior corneal astigmatism was discovered and created. While this posterior corneal astigmatism algorithm could be applied directly and successfully to existing third-generation IOL formulas for toric predictions, there was a desire to create a new IOL formula that could fully utilize it. The aim subsequently was to develop a formula of high accuracy that could leverage the advances in measurements using optical biometry, be devoid of any axial length or corneal power bias and combine with the new posterior corneal astigmatism algorithm. In June 2016, the EVO formula (version 1.0) for IOL power was therefore completed together with its toric counterpart, the EVO toric formula. This version of the formula utilized axial length, corneal power (K), anterior chamber depth (ACD), lens thickness (LT) and horizontal Corneal Diameter (CD) measurements as its input parameters, with the latter two being optional. The formula was first presented at the European Society of Cataract and Refractive Surgeons Meeting in 2016 in a comparative study of 817 eyes and showed that it had the lowest mean absolute error (MAE) and median absolute error (MedAE) when compared to the Barrett Universal II, Haigis, Hill-RBF v1.0, Hoffer Q, Holladay I and SRK/T formulas, with no significant bias against axial length and K (Fig. 40.1) [2].

In June 2019, the formula underwent an update to version 2.0, with improved accuracy and added several additional functionalities including prediction for post-myopic laser vision correction eyes with or without clinical history, or Total Keratometry measurements from the IOLMaster 700 (Zeiss, Jena, Germany), in addition to an option for the Argos (Movu, Santa Clara, USA) biometer. The input parameters were changed to axial length, K, ACD, LT and central corneal thickness (CCT), with the latter two being optional. However, it was also recognized that there are cases where only the axial length and K measurements could be used, such as patients with aphakia or eyes with subluxated cataracts where the ACD would have deviated from its physiological value. Therefore, the for-

---

T. K. Yeo (✉)
Department of Ophthalmology, Tan Tock Seng Hospital, Singapore, Singapore

© The Author(s) 2024

J. Aramberri et al. (eds.), *Intraocular Lens Calculations*, Essentials in Ophthalmology,
https://doi.org/10.1007/978-3-031-50666-6_40

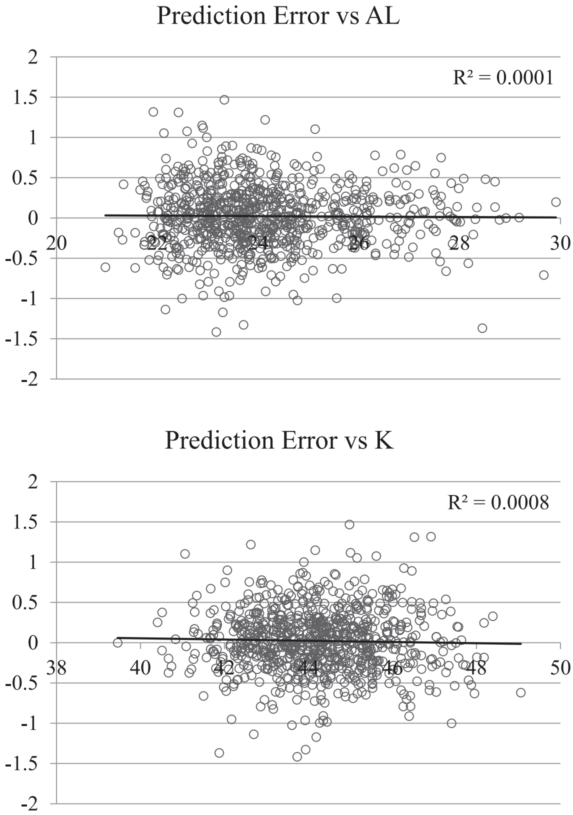

Fig. 40.1 Graphs of the prediction error of the EVO formula against axial length (top) and K (bottom) with corresponding trend lines show no significant bias in a study of 817 eyes

mula was designed to be capable of calculations with just two parameters, axial length and K, as well.

Description

The EVO formula is a thick lens formula based on Gaussian optics principles and therefore takes into account the anterior and posterior corneal curvatures, central corneal thickness, as well as the geometry of the IOL. The decision to base the formula on thick lens optics rather than thin lens optics was to improve accuracy by modelling the formula in close approximation to the optics of the actual physical eye, allowing flexibility in changing the geometry of the IOL for different lenses and enabling easy scalability in future updates of the formula. This is because new measurement parameters can be more readily incorporated into a thick lens formula compared to a thin lens formula. An example would be the posterior corneal radius from either optical coherence tomography (OCT) or Scheimpflug machines. The basic equation for a thick lens formula is

$$P = \frac{n}{L - d2} - \frac{n}{\frac{n}{K} - d1}$$

P = IOL power.

n = 1336.

L = axial length.

K = corneal power.

$d1$ = distance from the anterior corneal vertex to the first principal plane of IOL.

$d2$ = distance from the anterior corneal vertex to the second principal plane of IOL.

Axial Length

From the equation above, we can see that axial length is one of the most important variables in IOL power calculations. In the past, axial length was measured using ultrasound A-scan, which is the distance from the anterior cornea to the internal limiting membrane (ILM) of the retina. With the introduction of optical biometry in 1999, it was then possible to measure the retinal pigment epithelium (RPE) with higher resolution and repeatability. However, at that time, it was not possible to measure lens thickness, and difficult to ascertain the actual refractive indices of the different media of the eye relative to the wavelength of the optical biometer. Furthermore, IOL formulas then were ultrasound based. Therefore, Dr. Wolfgang Haigis derived a regression equation to convert the optical path length obtained in the IOLMaster (Zeiss, Jena, Germany) to an immersion ultrasound equivalent. For EVO v2.0, its axial length is derived using Cooke's modified axial length (CMAL) [3] with further adjustments to suit the model of the formula and account for retinal thickness. The resulting axial length therefore represents an optical axial length to the RPE. CMAL is an elegant solution that adds variability to the axial length as a function of lens thickness change, which cannot be attained using the Haigis regression.

$$CMAL = 1.23853 + 0.95855 * AL - 0.05467 * LT$$

CMAL = Cooke's modified axial length.
AL = traditional axial length.
LT = lens thickness.

Corneal Power

Another important factor in IOL calculations is of course corneal power. The corneal power for the EVO formula is derived using Gaussian thick lens equations. The anterior corneal radius is utilized to derive a predicted posterior corneal radius with the Gullstrand ratio of 0.883. A fixed corneal thickness of 540 μm is assumed when a CCT value is not available, otherwise, the measured CCT value is used. The fixed corneal thickness is the average central corneal thickness obtained from the EVO development dataset. With the information above, the total corneal power and the corneal principal planes can then be calculated with the equations below:

$$Ant\,K = \frac{376}{r}$$

$$Pos\,K = -\frac{40}{0.883 * r}$$

$$Total\,K = Ant\,K + Pos\,K - \left(\frac{CCT}{1000}\right) * Ant\,K * Pos$$

$$C1 = \left(\frac{CCT}{1376}\right) * \left(\frac{Pos\,K}{Total\,K}\right) * 1000$$

$$C2 = -\left(\frac{1.336 * \left(\frac{CCT}{1000}\right)}{1.376}\right) * \left(\frac{Ant\,K}{Total\,K}\right) * 1000$$

r = anterior corneal radius.
Ant K = anterior corneal power.
Pos K = posterior corneal power.
CCT = central corneal thickness.
Total K = total corneal power.
$C1$ = first principal plane of the cornea.
$C2$ = second principal plane of the cornea.

Lens Geometry

Another benefit of thick lens optics is the ability to model different IOLs. Not all IOLs are the same and the lens geometry of certain models can differ significantly. The EVO formula provides four options to represent four commonly used IOL models of different lens geometry on its website, namely 'Standard', 'Tecnis', 'AR40e/E/M' and 'MA60MA'. The 'Standard' option represents the majority of IOLs such as SN60WF (Alcon, Texas, USA). With this model, the formula assumes a biconvex lens configuration with a 1:1 anterior-to-posterior ratio. The formula also predicts the anterior and posterior lens radii and

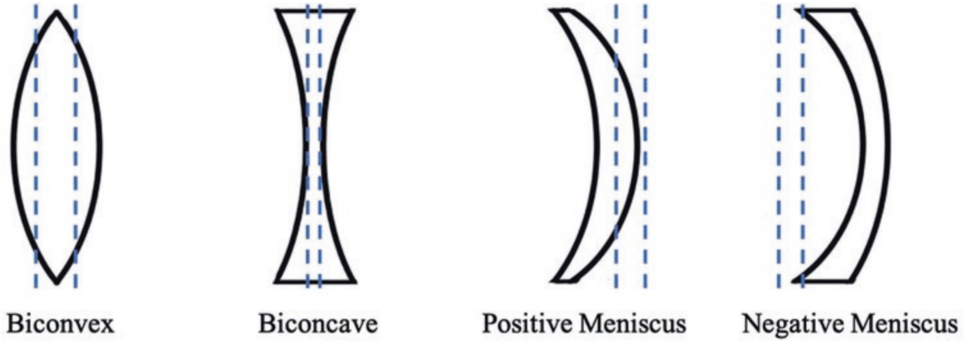

Fig. 40.2 Different lens shapes and their respective principal planes

the change in IOL thickness as the power of the IOL changes. The principal planes of the IOL can then be calculated and combined with the predicted pseudophakic lens position to be applied to the basic thick lens formula shown above in deriving the predicted lens power. The 'Tecnis' option is modelled for IOLs of the Tecnis platform such as ZCB00 (Johnson & Johnson, Florida, USA). I believe that the IOLs of the Tecnis platform differ from most standard IOLs, based on back-calculated clinical results and physical evaluation of the IOL. The 'AR40e/E/M' and 'MA60MA' options represent the IOL models AR40e, AR40E and AR40M (Johnson & Johnson, Florida, USA), and MA60MA and MA60MN (Alcon, Texas, USA), respectively. Although usually grouped with having the same lens constants for each version of the IOL, these are in fact different IOLs of different lens geometry. While the AR40e and MA60MA have a biconvex structure, the AR40M and MA60MN are instead meniscus. The latter are low or minus diopter IOLs and contribute to some of the hyperopic errors seen in traditional thin lens formulas in long eyes. This is mainly due to the significant change in the principal planes of the IOL when transitioning from a biconvex to meniscus structure. The EVO formula, however, models this change in lens geometry and principal planes for these IOLs, to avoid similar issues (Fig. 40.2). It is important to note that not all low or minus diopter IOLs are in a meniscus structure. An example would be the 409 M IOL (Zeiss, Jena, Germany), where the 'Standard' option should be used.

Effective Lens Position

We often use the term effective lens position (ELP) to describe the predicted position of the IOL for a formula. However, ELP is probably more suited to describe thin lens formulas, and I prefer the term pseudophakic lens position for thick lens formulas. This is because the ELP in a thin lens formula roughly equates to the second principal plane of the IOL. However, the structure of the EVO formula is such that it predicts the pseudophakic lens position and then derives the principal planes of the IOL, rather than predicting the second principal plane directly. Anatomically and functionally, this appears to be more logical. Predicting where the IOL sits within the eye is the core of any IOL formula. The EVO formula is based on the theory of emmetropization, to predict its pseudophakic lens position. It is postulated that the main driver for the process of emmetropization is the cornea, and the shape of the cornea does not change significantly after infancy, as opposed to the axial length. Therefore, the formula uses the corneal power as a reference and suggests that for any particular corneal power, there is a fixed lens position and axial length to attain emmetropia. Not all eyes attain emmetropia in adulthood, either due to genetic or environmental factors. If for a particular corneal power, the axial length differs from the emmetropic axial length, then there should be a corresponding change in the lens position in relation to the axial length. With this, an 'emmetropia factor' could be derived to describe every eye. Since we are unable to obtain the actual crystalline lens power or shape of an eye before cataract development, the predicted pseudophakic lens position is also adjusted using ACD and LT. LT serves mainly to correct the ACD measurement as the lens changes in thickness with cataract development, which would impact the ACD parameter. Hipolito-Fernandes et al. in their paper systematically illustrated the importance of the LT parameter, in determining what is the actual physiological ACD as opposed to a value altered by the cataract [4]. The addition of CCT as a variable has an impact in changing the calculated corneal power but also the predicted pseudophakic lens position since EVO uses corneal power in its prediction. The use of all five parameters then gives the formula multidimensional capability in predicting the pseudophakic lens position, which is derived through a combination of regression and iterative techniques.

Performance

Version 1.0 of the EVO formula was first compared in a large study of 13,301 eyes by Melles et al. in 2019, which showed that it outperformed Hill-RBF 2.0, Holladay 2, Haigis, Holladay 1, Hoffer Q and SKR/T [5]. Savini et al. then showed in their subsequent study of 150 eyes, using a swept-source optical coherence tomography (OCT) biometer and comparing 15 formulas, the EVO v1.0 formula achieved the lowest mean absolute error (MAE) and standard deviation of error, and the highest percentage of eyes within 0.50 D [6].

Further independent studies later revealed the performance of the updated EVO v2.0 formula. Cheng et al. in 2020 compared 12 formulas and concluded that the most accurate prediction of post-operative refraction can be achieved with the Barrett, EVO v2.0, Kane and Olsen formulas, with an improvement of the EVO v2.0 over its earlier version [7]. A paper by Hipolito-Fernandes et al. in 2020 looked at 13 formulas in 828 eyes and noted that the most accurate formulas were EVO v2.0, Kane and VRF-G overall and for all axial length subgroups, indicating that the EVO v2.0 did not have any bias against axial length [8]. For short eyes, another paper by Kane in 2020 looked at extremely short eyes with an IOL power of 30 or more diopters and reported that Kane and EVO v2.0 were the most accurate [9]. As for long eyes, Zhang et al. [10] and Tan et al. [11] both showed in separate papers that EVO v2.0 had the lowest MAE and median absolute error (MedAE), and highest percentages of eyes within 0.50 D in this group of eyes. In addition, Hipolito-Fernandes et al. in another paper reported that EVO v2.0 was reliable and stable in eyes with extreme ACD and LT combinations [4]. This was in contrast to the Haigis and Hill-RBF 2.0 formulas which had a bias against LT. Finally, an interesting paper that looked at eyes that underwent combined silicone oil removal and cataract surgery showed EVO v2.0 as having the highest prediction accuracy in this special population [12]. Therefore, there is good evidence that EVO v2.0 performs well for all axial length subgroups and in eyes with different ACD and LT combinations.

Toric Prediction

The EVO toric formula utilizes the EVO formula as its core, to predict its pseudophakic lens position. It is therefore an ELP-based toric formula rather than a fixed ratio toric formula. This means that it does not assume a fixed position of the IOL in all eyes but predicts the IOL position depending on the parameters of the eye and considers this in its calculation of a toric IOL. The EVO toric formula also predicts posterior corneal astigmatism and models different toric IOL designs in its calculations. The toric models on the formula website are ‘Anterior’, ‘Posterior’ or ‘Bitoric’, representing the location of the toric surface on the IOL. I believe that the principal planes of a toric IOL differ from that of a non-toric IOL of the same power, and also change depending on the location of the toric surface. All the above are taken into consideration in the calculations for a toric IOL within the formula. In addition, on the formula website, the different toric steps of different companies are also taken into account, with the calculations adjusted depending on the model of toric IOL selected. For example, the toric steps for SN6AT (Alcon, Texas, USA) are completely different from MX60T (Bausch and Lomb, Quebec, Canada).

The performance of the EVO toric formula was first presented at ASCRS in 2019, and the study looked at 117 eyes implanted with SN6AT IOLs [13]. The EVO toric formula performed similarly to the Barrett toric formula, and was statistically better than the Abulafia-Koch regression formula, the Johnson & Johnson online toric calculator and the Holladay 1 toric formula. Pantanelli et al. in 2020 further reported that the EVO toric formula outperformed the legacy enVista toric calculator (Bausch and Lomb, Quebec, Canada) with regard to eyes with low astigmatism [14]. Furthermore, Kane et al. in 2020 reported the EVO toric formula performed similarly to the Barrett toric formula and Abulafia-Koch regression formula and had better performance than the Naeser-Savini and Holladay 2 toric formulas [15].

Post-Myopic Laser Vision Correction

Version 2.0 of the EVO formula included the ability to predict post-myopic laser vision correction eyes such as photorefractive keratectomy (PRK), laser-assisted in situ keratomileusis (LASIK) and SMILE (small incision lenticule extraction). This can be used for both toric and non-toric IOL predictions. The calculations can be performed with or without clinical history, and the clinical history required are the refractions before and after laser vision correction. In addition, with the introduction of the new parameter called 'Total Keratometry' (TK) on the IOLMaster 700 (Zeiss, Jena, Germany) optical biometer, the formula is also able to predict post-myopic LVC eyes using the PK (posterior K) value from the machine. Prediction using PK is based on a novel 'reverse double-K method' as published in 2020 [16]. [1] PK is first converted to the posterior corneal radius [2]. Assuming the posterior corneal radius was not significantly altered by previous LVC, the pre-refractive surgery anterior corneal radius can then be calculated by dividing the measured posterior radius with the Gullstrand ratio of 0.883. This presumed pre-refractive surgery anterior radius is used to generate the pseudophakic lens position of the formula [3]. The measured TK value is used to generate the actual corneal power in the formula. EVO using TK was shown in a study of 64 eyes with previous LVC to have the lowest MAE, MedAE and standard deviation of the error, and the highest percentage of eyes within 0.50 D when compared to the Barrett True-K, Barrett True-K with TK, Haigis-L, Haigis with TK and Shammas-PL formulas [16].

Conclusion

The EVO v2.0 formula is one of the new modern IOL formulas available today. It has been shown to be of high accuracy in a wide range of biometric measurements (axial length, K, ACD and LT). There is also good evidence showing its good performance for both toric predictions and in eyes with previous myopic laser refractive surgery. However, it is understood that the quest for accuracy never ends, and as its name implies, the EVO formula will continue to be updated and evolve, to achieve higher accuracy and attain further capabilities.

References

1. Emmetropia Verifying Optical Formula v2.0. https://www.evoiolcalculator.com.
2. Yeo TK. EVO: A new intraocular lens formula. European Society of Cataract and Refractive Surgeons Meeting 2017, Lisbon, Portugal.
3. Cooke DL, Cooke TL. Approximating sum-of-segments axial length from a traditional optical low-coherence reflectometry measurement. J Cataract Refract Surg. 2019;45(3):351–4.
4. Hipólito-Fernandes D, Luís ME, Serras-Pereira R, Gil P, Maduro V, Feijão J, Alves N. Anterior chamber depth, lens thickness and intraocular lens calculation formula accuracy: nine formulas comparison. Br J Ophthalmol. 2020;106(3):349–55.

5. Melles RB, Kane JX, Olsen T, Chang WJ. Update on intraocular lens calculation formulas. Ophthalmology. 2019;126(9):1334–5.
6. Savini G, Hoffer KJ, Balducci N, Barboni P, Schiano-Lomoriello D. Comparison of formula accuracy for intraocular lens power calculation based on measurements by a swept-source optical coherence tomography optical biometer. J Cataract Refract Surg. 2020;46(1):27–33.
7. Cheng H, Kane JX, Liu L, Li J, Cheng B, Wu M. Refractive predictability using the IOLMaster 700 and artificial intelligence-based IOL power formulas compared to standard formulas. J Refract Surg. 2020;36(7):466–72.
8. Hipólito-Fernandes D, Elisa Luís M, Gil P, Maduro V, Feijão J, Yeo TK, Voytsekhivskyy O, Alves N. VRF-G, a new intraocular lens power calculation formula: a 13-formulas comparison study. Clin Ophthalmol. 2020;14:4395–402.
9. Kane JX, Melles RB. Intraocular lens formula comparison in axial hyperopia with a high-power intraocular lens of 30 or more diopters. J Cataract Refract Surg. 2020;46(9):1236–9.
10. Zhang J, Tan X, Wang W, Yang G, Xu J, Ruan X, Gu X, Luo L. Effect of axial length adjustment methods on intraocular lens power calculation in highly myopic eyes. Am J Ophthalmol. 2020;214:110–8.
11. Tan X, Zhang J, Zhu Y, Xu J, Qiu X, Yang G, Liu Z, Luo L, Liu Y. Accuracy of new generation intraocular lens calculation formulas in Vitrectomized eyes. Am J Ophthalmol. 2020;217:81–90.
12. Zhang J, Wang W, Liu Z, Yang G, Qiu X, Xu J, Jin G, Li Y, Zhang S, Tan X, Luo L, Liu Y. Accuracy of new generation intraocular lens calculation formulas in eyes undergoing combined silicone oil removal and cataract surgery. J Cataract Refract Surg. 2020;47(5):593–8.
13. Yeo TK, Barrett GD. A comparison of new and existing toric formulas. San Diego, USA: American Society of Cataract and Refractive Surgeons Meeting; 2019.
14. Pantanelli SM, Kansara N, Smits G. Predictability of residual postoperative astigmatism after implantation of a Toric intraocular lens using two different calculators. Clin Ophthalmol. 2020;14:3627–34.
15. Kane JX, Connell B. A comparison of the accuracy of 6 modern Toric intraocular lens formulas. Ophthalmology. 2020;127(11):1472–86.
16. Yeo TK, Heng WJ, Pek D, Wong J, Fam HB. Accuracy of intraocular lens formulas using total keratometry in eyes with previous myopic laser refractive surgery. Eye (Lond). 2020;35(6):1705–11.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.