50 The Olsen Formula

Thomas Olsen

The Olsen Formula

The Olsen formula was developed at the time when the Sanders-Retzlaff-Kraff (SRK) method was popular. Although the SRK formula was working all right in the normal range, errors were frequent in the extreme range and the lack of a flexible, optical model was frustrating. So, the ambition was to develop a thick-lens formula based on paraxial ray tracing as assumption-free as possible allowing for the use of real physical dimensions—including the physical position of the IOL— to be used in the formula.

The first step for the author was to realize that the K-reading of the keratometer using the standard index of 1.3375 was wrong (see "Keratometry" chapter). To avoid confusion, the author has always preferred to input the radius of the K-reading rather than the diopter value. The conversion to corneal power is then done internally by the formula. From the beginning, a fictitious index of 1.3315 based on the Gullstrand ratio of 0.883 was found to give a more realistic value for effective corneal power. This value has later been used by other authors, i.e., Haigis and Barrett, and there seems to be growing consensus among newer formulas that the lower value is a better choice for IOL power calculation.

The paraxial approach allows for thick-lens calculations whereby the cornea and the IOL can be represented as the two-surface optical lenses they are. The advantage is that different optic configurations can be dealt with, and the refractive effect of a, say 1:1 biconvex, 1:2 biconvex, or a meniscus concave-convex IOL, can be calculated independently from the IOL position. All it requires is a knowledge of the shape of the IOL, which must be provided by the IOL manufacturer.

One disadvantage of the paraxial approach is that higher-order aberrations are not taken into account. The most significant aberration is spherical aberration, which plays a role in normal eyes, but can be excessive in abnormal corneas like post-LASIK cases and keratoconus. Hence, from 2012 the Olsen formula was modified to allow exact ray tracing on aspheric surfaces in order to include the effect of spherical aberration in the calculated effective refraction. This meant a change in Gullstrand ratio to 0.83 (which is the value also demonstrated in many Scheimpflug reports) but now in addition using the Q-value of the front and back surface of the cornea for a more detailed calculation of the corneal power. If no Q-values are stated, the program will assume the default normal values. In this way, it was possible to include the effect of the wavefront-corrected spherical aberration of an aspheric IOL.

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A realistic corneal power is required to predict the refractive effect of the IOL using the physical position of the IOL. Once it was found that the position of the IOL could be predicted, the next step was to improve the ELP prediction. Over the years, a number of ELP predictors have been studied by the author: 1) K-reading, ACD and lens thickness (Olsen 1986) [1], 2) K-reading, ACD and axial length, K-reading, ACD, lens thickness, axial length, corneal diameter distance, and refraction [2], and finally 3) ACD and lens thickness measured by laser biometry to arrive at the novel concept called the C-constant approach (Olsen & Hoffmann 2014) [3]. The latter method represented a "heureka" moment in its simple form that proved to be effective and robust without the indirect predictors such as the K-reading, axial length, corneal diameter, refraction, and age with previous methods. The advantage of this approach is that it should work equally effectively in abnormal corneas such as post-LASIK cases, keratoconus, megalocornea, scleral buckling procedure, and horses, if you may.

PhacoOptics® Software

A stand-alone PC software for Microsoft Windows (www.phacooptics.com) was released by the author in 2009. Using paraxial and exact ray tracing, the software package offers a comprehensive system for IOL power calculation and data management.

Because of the ray tracing, the physical data of the IOL need to be stated in more detail than in most formulas. The IOL constants are:

1. Refractive index
2. Anterior and posterior radius of curvature of an average-powered IOL
3. Thickness of an average-powered IOL
4. Wavefront Z(4,0) correction for spherical aberration
5. ACD constant (average value in representative population)

When the physical parameters 1–4 have been entered, it is possible to have item 5, the ACD constant calculated from the SRK/T A-constant, as a first go. However, it is recommended to keep track of the outcome and adjust the ACD constant as more data become available.

Data Entry

Data entry can be made manually or by importing from biometers via a data bridge (xml files or similar). The following biometers are supported for data bridge import:

1. Haag-Streit Lenstar LS900
2. Oculus Pentacam (full cornea analysis)
3. Zeiss IOLMaster 700
4. Topcon Aladdin
5. Tomey OA-2000
6. Ziemer Galilei G6 (full cornea analysis)

The K-readings can be expanded (double-click on the field) to allow entry of posterior curvatures and Q-values if these are available. If no data are input for the posterior surface, the program will assume a default value. In this way, corneal astigmatism can be calculated based on the default posterior cylinder or based on exact measurements. This allows for a full-thickness analysis of the corneal power from tomography data, i.e., captured with the Oculus Pentacam or the Ziemer Galilei G6. This is particularly useful when dealing with post-LASIK cases or other abnormal corneas.

The Olsen formula has also been implemented as a dynamic library into the software of the Haag-Streit Lenstar, the Topcon Aladdin, the Tomey OA-2000, and the Oculus Pentacam.

The IOL power calculation algorithm follows the principles described in this chapter. The prediction of the ELP (rather: the physical IOL position) has been given the flexibility of a 2-factor version and a 4-factor version (selectable by the user). Both versions use the C-constant, which is based on the ACD and the lens thickness, but the 4-factor version uses an additional corrective term based on the K-reading and the axial length. The 4-factor version may have a little more accuracy than the 2-factor version as shown by Cooke and Cooke [4, 5], but is only applicable to normal, virgin eyes. The 2-factor version is independent of the K-reading and the axial length and is therefore more robust in post-LASIK cases and other abnormal cases.

Data Quality Is the Key

All calculations depend on the quality of the input data. Garbage in means garbage out, as everybody knows. To help filter out typing errors or other mistakes, the program will evaluate the plausibility of all data input when in manual entering mode. This plausibility check is performed at three different levels:

1. The out-of-range plausibility of the individual variable
2. The intra-eye plausibility of the input compared to other variables of the same eye (e.g., a flat cornea in a short eye)
3. The inter-eye plausibility of the input compared to existing data of the contralateral eye

The threshold of the plausibility levels can be set in the program settings.

As is the case with any IOL formula, it is important that the K-readings and the axial length are accurate. In addition, the Olsen formula is particularly sensitive to measurement errors of the anterior chamber depth and the lens thickness. This is because the C-constant is entirely dependent on these two variables. It is good clinical practice to check the consistency of the readings, especially for the lens thickness, which may be hard for the biometer software to pick up with good spikes of the anterior and the posterior surface.

Finally, the pupil size should be mentioned. Unlike most other formulas, PhacoOptics does take the pupil size into account as it will play a role when the spherical aberration is high. Care should be taken, however, to check the pupil size if you are importing data from an external biometer, and the patient was dilated at the examination. A safe procedure is to leave the pupil blank, which is the equivalent of a standard pupil size of 3 mm assumed by the program.

Figure 50.1 shows a PhacoOptics screenshot of the preoperative data of a post-LASIK case of the right eye and untouched left eye for comparison. A full-thickness analysis of the right cornea was done by importing the values from the Oculus Pentacam (highlighted fields). The detailed information can be viewed (and edited) by right- or double-clicking the K-reading fields (insert lower right). In this case, the Gullstrand ratio was 0.779 on the post-LASIK right eye and 0.883 (default) on the virgin left eye. An abnormal Q-value for the front surface of the right eye due to the LASIK procedure is noted.

Figure 50.2 shows the IOL power calculation screen of the same post-LASIK case. The IOL type has been selected from a drop-down menu. Both the power, the cylinder, and the axis can be changed by scrolling up and down, and the resulting sphere cylinder and axis are displayed below. By default, the optimum placement axis of the toric has been calculated based on the complete corneal data. The axis can be confirmed by pressing the small button marked? “Cyl axis.” Here, a small cylinder was chosen to minimize the astigmatism of the postoperative refraction. The surgically induced astigmatism (SIA) can also be added in a detail window (not shown).

For the post-LASIK case, the ELP prediction was done using a 2-factor algorithm (identical to the C-constant) because the post-LASIK K-reading is unsuited for this purpose. The selection was done after double-clicking the ACD field. Note the nearly identical values for the right and left eye despite the post-LASIK state of the right eye.

Formula Validation

The aim of the Olsen formula was to “divide and conquer” the unknowns of IOL power calculation. On the one side, we have the measurements of corneal power, axial length, and optical properties of the IOL. All measurements must be representative of the physical reality. Also, the physical properties of the IOL must be known so that we can calculate the refractive effect for a given IOL location. On the other side, we have an issue with the prediction of the IOL position for which empirical studies are needed.

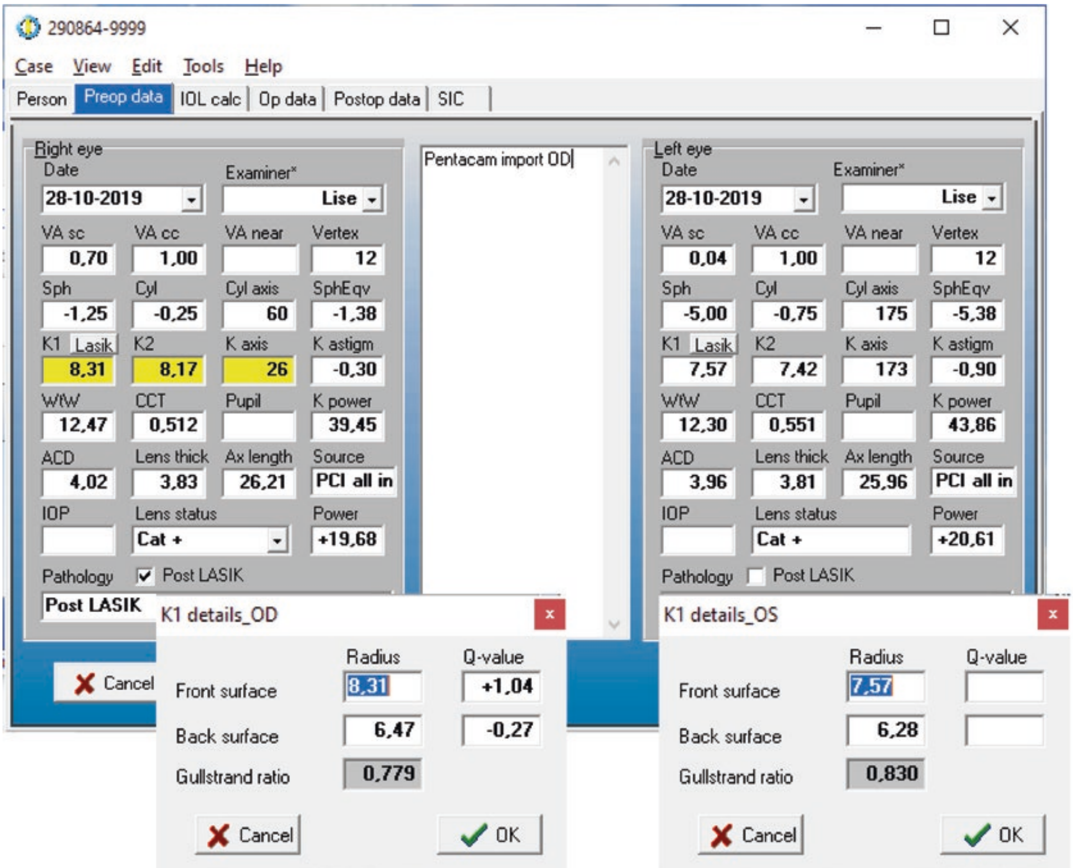


Fig. 50.1 Preoperative data screen of a post-LASIK case on the right eye with untouched left eye. You may note the right-left difference in K-readings. The K-readings of the right eye are highlighted in yellow after Pentacam import, because a full-thickness analysis of the corneal power is wanted. The two inserts at the bottom show the detailed information of the K1-reading (double-click in the K1 field) with complete data on the right eye and default data on the left eye

A critical question is as follows: What if the exact IOL position was known, and would the formula be able to predict the refractive outcome accurately? The question can be answered by recording the actual IOL position after surgery and using this value in the "predictions." This was done by Olsen and Hoffmann [3] in a subset of cases, demonstrating a drop in MAE from 0.39 to 0.36 for a public university series and from 0.30 D to 0.26 D in a private series, respectively, when the actual, measured postoperative IOL position was substituted for the predicted value in retrospect.

For this book chapter, the study concept was repeated with a larger database collected some years ago. The database contained 1622 cases of 1269 university clinic patients with an implanted power ranging from −3.0 to +39.0 D. Ninety percent of the IOLs were of the Alcon Acrysof family (SA60AT, SN60AT, and torics and MA60MA for the low IOL power), and 10% were of the Abbott Tecnis types. The pseudophakic ACD was recorded after surgery with Lenstar laser biometry.

The refractive prediction mean error was found to be −0.13 D ± 0.469 D (SD) with the standard Olsen procedure and −0.019 D ± 0.436 D (SD) when the postoperative, actual ACD was used in the "predictions." The mean error with the postoperative ACD was not significantly

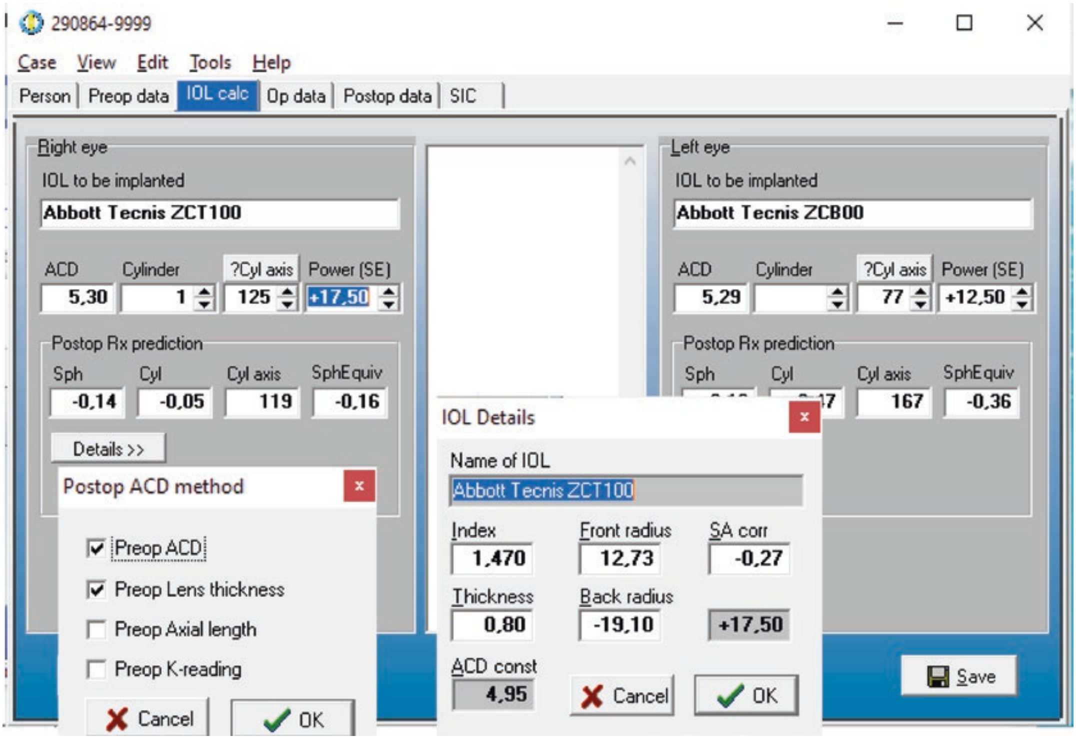


Fig. 50.2 IOL power calculation screen of the right eye post-LASIK case. The ELP prediction was done using a 2-factor algorithm (identical to the C-constant) because the post-LASIK K-reading is unsuited for this purpose. The selection was done after double-clicking the ACD field. An aspheric IOL with a small cylinder has been selected. The IOL details (insert) were called by double-clicking the IOL power field. The program calculates the exact curvatures of the front and back surfaces of the IOL to be used for ray tracing

different from zero. The standard deviation of ±0.436 D corresponded to a mean absolute error (MAE) of 0.35 D, which was significantly lower than that of the normal predictions ($p < 0.01$) (Fig. 50.3). In conclusion, when the IOL position was known, the formula was able to predict the refraction with no bias or offset error (!) and a corresponding improvement in accuracy. This finding means that if the ELP prediction would improve as a result of newer biometry techniques, the Olsen formula can utilize this information and improve the accuracy accordingly.

Another method of verification is to reverse the calculations: From the known postoperative refraction and the IOL position, it is possible to back-solve for the IOL power using ray tracing. This was originally done by Olsen and Funding (2012) [6] who studied 767 eyes with an implanted IOL power of the old Alcon Acrysof type ranging from −2.00 D to +36.0 D. The actual position of the IOL after surgery was recorded using Haag-Streit Lenstar laser interferometry. Based on the postoperative refraction and the biometric measurements, a ray tracing analysis was performed back-solving for the power of the IOL in situ. The results showed the calculated IOL power to be in good agreement with the labeled power over the entire power range with no offset or bias. This finding was another “heureka” moment for the author showing that the optics of the pseudophakic eye can be described by ray tracing and modern biometry techniques.

For the present book chapter, the study was repeated on the same database as mentioned above. Figure 50.4 shows the correlation between the calculated IOL power in situ and the labeled power for the 1622 cases. The correlation coefficient was 0.99, and the slope of the linear regression equation was not significant from unity. This

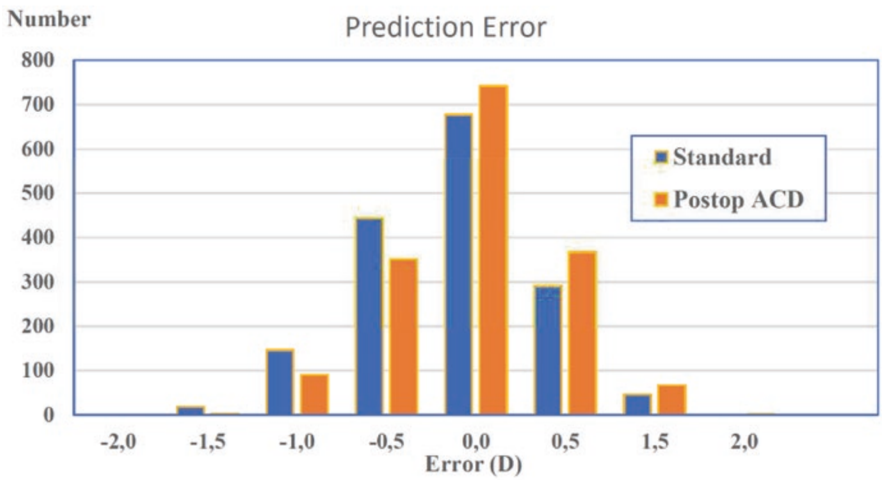
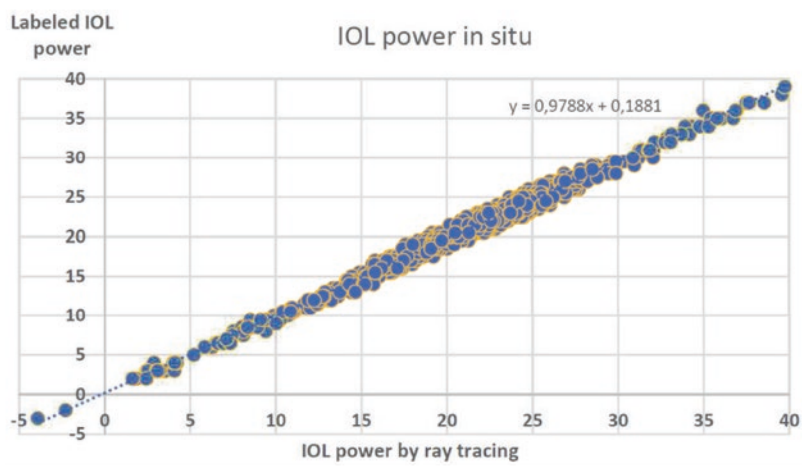


Fig. 50.3 Prediction accuracy of the Olsen formula with and without the usage of the postop ACD in the "predictions"

Fig. 50.4 IOL power in situ calculated by exact ray tracing compared to the labeled value



finding can be regarded as a verification of the optical algorithms used in the Olsen formula.

Own History of Calculation Accuracy

The author has over 30 years of experience with IOL power calculation. Looking back, it is amazing how the accuracy has been ever-increasing over time. One reason for the improvement in accuracy has been the unsurpassed accuracy of optical biometry, but other factors such as standardization of surgery and improvement in formula (ELP prediction) have combined to produce a highly standardized and controlled environment for IOL power calculation.

In Fig. 50.5, the accuracy observed by the author has been tabulated for a period of 30+ years, covering both ultrasound and later optical biometry. The number of cases within 0.5 D accuracy has been computed from the standard deviation of the prediction error observed in each series. Except for the last column (year 2020), all columns have been constructed from the papers published by the author and associates [3, 7–17]. The last column showing 90% of cases within ±0.5 D was the result of an independent study of 469 refractive lens exchange cases using

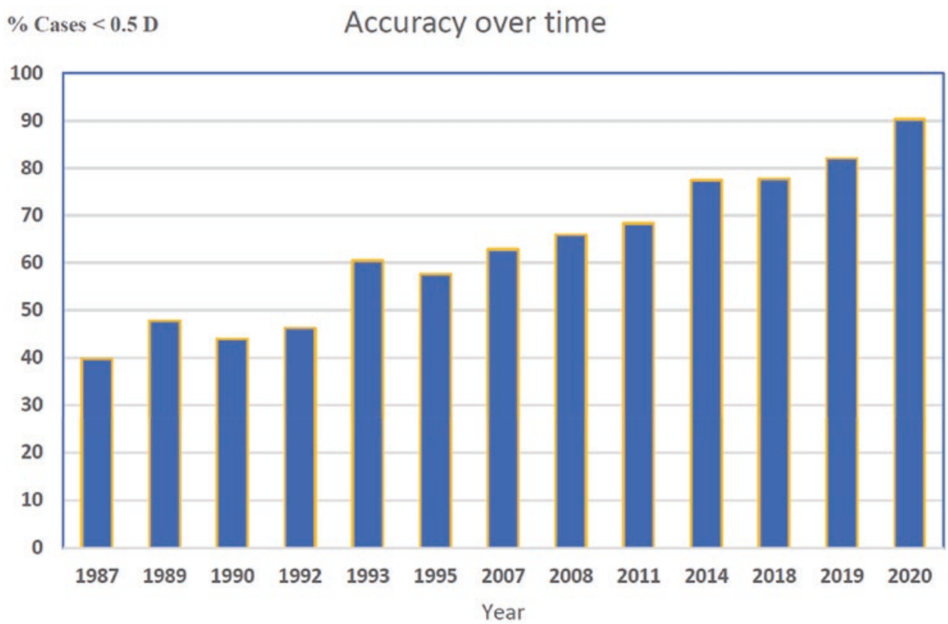


Fig. 50.5 History of IOL calculation accuracy (author's own series)

IOLMaster 700 and the Olsen formula (unpublished).

Recent Clinical Studies

There is a plethora of publications dealing with IOL power calculation, and many new IOL formulas have evolved. The interest comes from the fact that modern lens surgery with a perfect IOL power calculation holds the promise to free the spectacle dependence of the patient. As discussed in the section "The History of IOL Power Calculation Accuracy," the accuracy is approaching 90% of cases within 0.5 D of the target.

As the Olsen formula requires good measurements of the anterior chamber depth and of the lens thickness for the prediction of the IOL position, it is not possible to evaluate the performance of the Olsen formula using the traditional PCI optical biometry (IOLMaster 500) that does not measure the lens thickness. However, more and more studies have emerged using OLCR or swept-source OCT (SS-OCT) that does offer measurements of all intraocular distances by the laser.

One of the largest comparative studies ever was the study by Melles et al. (2018) [15] who investigated the accuracy of seven different formulas in a total of 18,501 cases of AcrySof SN60WF (13,301 cases) and SA60AT (5200 cases) implants using Haag-Streit Lenstar biometry. The lowest prediction error was found with the Barrett Universal II, followed by Olsen, Haigis, Holladay 2, Holladay 1, SRK/T, and Hoffer Q.

The Melles 2018 study was later repeated with updated versions of the Olsen formula (4-factor version rather than the 2-factor version studied in the first paper), the Hill RBF formula (newest version 2), the Holladay 2 (newest version, axial length adjusted for the hyperopic error in long eyes), and 2 newer formulas: the Kane formula and the EVO formula. The most accurate formulas were the Kane, the Olsen, and the Barret formula all achieving more than 80% of the predictions within ±0.50 D of the target, followed by the EVO, the Hill RBF, the Holladay 2, the Haigis, the Holladay 1, the SRK/T, and the Hoffer Q formulas in that order, respectively.

The 2-factor version of the Olsen formula was the version that was originally implemented on the Lenstar biometer. The 2-factor version only takes the anterior chamber depth and lens thickness as parameters and uses the unmodified C-constant concept for the prediction of the IOL position. However, as found by Cooke and Cooke [29, 30] there seems to be a marginal higher accuracy using the 4-factor version that also takes the axial length and the corneal curvature as additional parameters in the prediction of effective lens position. The 4-factor version is the default version of the stand-alone PC software available on the website www.phacooptics.com.

The author has had the opportunity to review the large database of the Melles study and check the prediction accuracy. The database consists of outcome data for many surgeons from many clinics, and therefore, some variation can be found in data quality. Some cases were noted to have recorded highly unlikely values for the lens thickness: for example, a lens thickness of 2.5 in a 76 years old, which is virtually impossible and must be due to a measurement mistake of the Lenstar biometer. Therefore, all cases with lens thickness <3 mm were excluded from the present review. None were excluded because of a high prediction error per se.

Thus, after the exclusion of 92 cases with unlikely lens thickness, the Melles database consisted of 13,209 cases of SA60WF implants suitable for analysis. The standard deviation of the prediction error was found to be ±0.38 D, and the mean absolute error (MAE) was 0.30 D with 81.8% of the cases within ±0.5 D. The material was analyzed for possible bias with the axial length. As shown in Fig. 50.6, no correlation was found between the numerical error and the axial length. This finding is noteworthy as a hyperopic error has been reported for some formulas in the long eyes, giving rise to the Wang-Koch adjustment of the Holladay 1 and the SRK/T formula.

The absolute error showed a trend toward higher error in the short eyes and lower error in the long eyes (Fig. 50.7). The short eyes remain the group of eyes with the highest error, first of all because all measurement errors have a relatively higher impact on a short eye and also because the error of the ELP estimation has a much higher impact on the short eyes (see Fig. 50.8).

When analyzing for bias with the K-reading, no correlation was found between the prediction error and the K-reading (Fig. 50.8). Hence, whether the eye is long, short, or has a steep or flat cornea did not appear to have a significant bias on the formula performance.

Finally, a note on the gender bias would be appropriate since some formulas use gender as a co-predictor. For example, gender was taken as a parameter by the Hoffer H formula [18] and is also included as a parameter in the newer Kane formula [19]. The rationale behind this is that female eyes tend to be a little shorter, have a

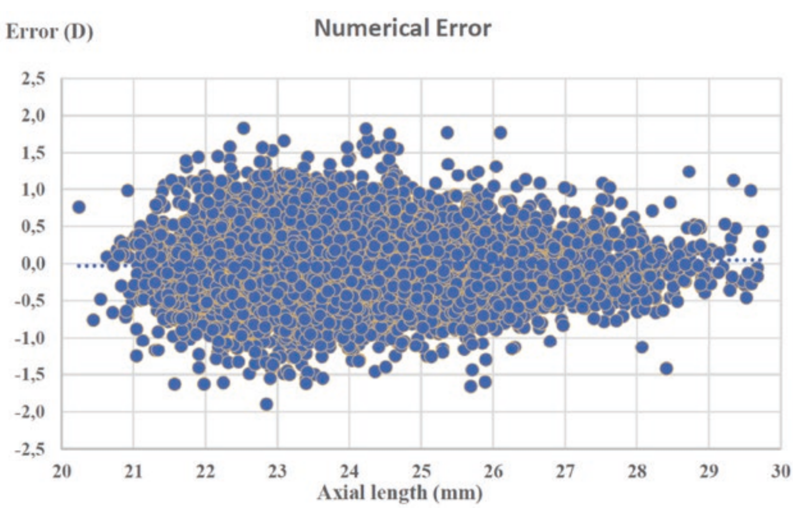


Fig. 50.6 Numerical error vs axial length in 13,209 cases

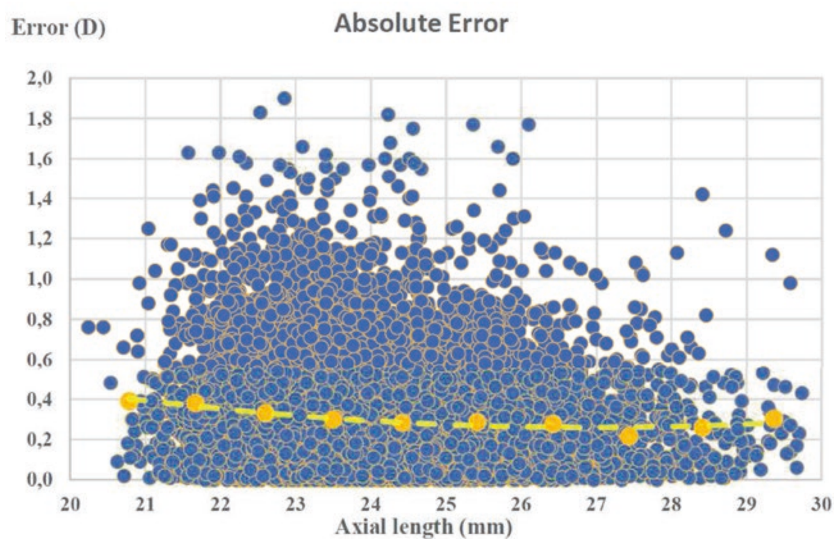


Fig. 50.7 Absolute error vs axial length in 13,209 cases

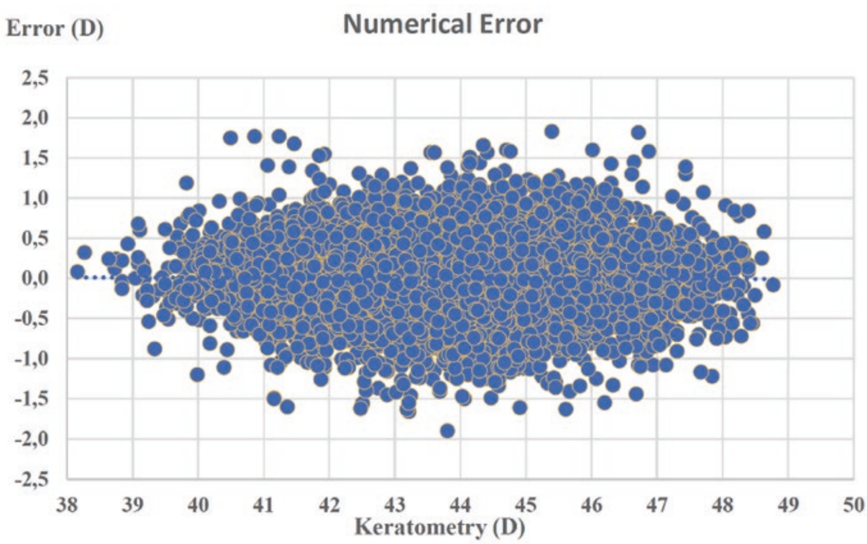


Fig. 50.8 Numerical error vs keratometry reading in 13,209 cases

steeper K-reading, and have a shallower anterior chamber than men. Therefore, one might suspect different behavior with respect to IOL constants and possibly introducing a bias in the IOL power prediction.

Table 50.1 shows the accuracy of the Olsen formula according to gender. The mean numerical error (± SD) was found to be +0.034 D (± 0.387) in males and − 0.029 D (± 0.392) in females. The mean difference was 0.06 D between males and females. Although statistically significant ($p < 0.01$), the difference is not clinically relevant. The lack of systematic bias may be due to the use of the C-constant, which is based on the position and thickness of the crystalline lens and works independently of the K-reading, the axial length, and anterior chamber depth.

Table 50.1 Influence of gender on the prediction accuracy of the Olsen formula

Gender	Error (± SD)	MAE	Range
Males (*n* = 5409)	+0.034 (± 0.387)	0.307	−1.66 to +1.82
Females (*n* = 7800)	−0.029 (± 0.392)	0.311	−1.93 to +1.80

References

1. Olsen T. Prediction of intraocular lens position after cataract extraction. J Cataract Refract Surg. 1986;12:376–9.
2. Olsen T. Prediction of the effective postoperative (intraocular lens) anterior chamber depth. J Cataract Refract Surg. 2006;22:419–24.
3. Olsen T, Hoffmann P. C constant: New concept for ray tracing–assisted. intraocular lens power calculation. J Cataract Refract Surg. 2014;40:764–773.
4. Cooke DL, Cooke TL. Prediction accuracy of pre-installed formulas on 2 optical biometers. J Cataract Refract Surg. 2016;42:358–62.
5. Cooke DL, Cooke TL. Comparison of 9 intraocular lens power calculation formulas. J Cataract Refract Surg. 2016;42:1157–64.
6. Olsen T, Funding M. Ray-tracing analysis of intraocular lens power in situ. J Cataract Refract Surg. 2012;38:641–7.
7. Olsen T. Theoretical, computer-assisted prediction versus SRK prediction of postoperative refraction after intraocular lens implantation. J Cataract Refract Surg. 1987;13:146–50.
8. Olsen T, et al. Computerised intraocular lens calculation: clinical results and predictability. Br J Ophthalmol. 1989;73:220–4.
9. Olsen T, et al. Theoretical versus SRK I and SRK II calculation of intraocular lens power. J Cataract Refract Surg. 1990;16:217–25.
10. Olsen T, Gimbel H. Phacoemulsification, capsulorhexis, and intraocular lens power prediction accuracy. J Cataract Refract Surg. 1993;19:695–9.
11. Olsen T, et al. Intraocular lens power calculation with an improved anterior chamber depth prediction algorithm. J Cataract Refract Surg. 1995;21:313–9.
12. Olsen T. Improved accuracy of intraocular lens power calculation with the Zeiss IOLMaster. Acta Ophthalmol Scand. 2007;85:84–7.
13. Preussner P-R, Olsen T, et al. Intraocular lens calculation accuracy limits in normal eyes. J Cataract Refract Surg. 2008;34:802–8.
14. Olsen T. Use of fellow eye data in the calculation of intraocular lens power for the second eye. Ophthalmology. 2011;118:1710–5.
15. Melles RB, Holladay JT, Chang WJ. Accuracy of intraocular lens calculation formulas. Ophthalmology. 2018;125:169–78.
16. Melles, et al. Update on IOL calculation. Ophthalmology. 2019;126:1334–6.
17. Olsen T et al. IOL prediction accuracy with the IOL Master 700. 2020; (data on file).
18. Hoffer KJ, Savini G. Clinical results of the Hoffer H-5 formula in 2707 eyes: first 5th-generation formula based on gender and race. Int Ophthalmol Clin. 2017;57(4):213–9.
19. Darcy K, Gunn D, Tavassoli S, et al. Assessment of the accuracy of new and updated intraocular lens power calculation formulas in 10 930 eyes from the UK National Health Service. J Cataract Refract Surg. 2020;46:2–7.