**Purpose:** To analyze the accuracy of newer intraocular lens power formulas in long and short eyes measured using the sum-of-segments biometry.

**Setting:** Private practice, Lynwood, California.

**Design:** Retrospective observational study.

**Methods:** 595 patients scheduled for cataract surgery had their eyes measured using the sum-of-segments biometry. The expected residual refractions were calculated using Barrett Universal II (B II), Barrett True Axial Length (BTAL), Emmetropia Verifying Optical (EVO), Hill-RBF, Hoffer QST, Holladay 2, Holladay 2-NLR, K6, Kane, Olsen, PEARL-DGS, T2, and VRF formulas and compared with the traditional Haigis, Hoffer Q, Holladay 1, and SRK/T formulas.

**Results:** In the 102 long eyes, all new formulas had a mean absolute error (MAE) equal or lower than the traditional formulas, ranging from 0.29 to 0.32 diopter (D). In the 78 short eyes, BTAL, EVO, Hoffer QST, K6, Olsen, and PEARL-DGS formulas had the lowest MAE (0.33 D, 0.33 D, 0.31 D, 0.36 D, 0.32 D, and 0.32 D, respectively), whereas all traditional formulas exceeded 0.36 D.

**Conclusions:** All new formulas performed equal or better than the traditional formulas with the sum-of-segments biometry. The best overall results in the short and long eyes as well as in the very short and very long eyes were noted with the BTAL, EVO, Hoffer QST, K6, Olsen, and PEARL-DGS formulas, closely followed by the B II and Kane formulas.

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For over 20 years, optical biometry has been the standard of care for axial length (AL) measurement and intraocular lens (IOL) power calculation in cataract surgery. The IOLMaster 500 (Carl Zeiss Meditec AG) uses partial coherence interferometry (PCI) with a 780 nm laser diode infrared light to measure the entire eye’s optical path length (OPL).1 The OPL is then converted to a geometrical path length (GPL) using a single variable regression equation, thus allowing the PCI biometer’s AL output to match the same AL measured with immersion ultrasound.2 The Lenstar LS900 (Haag-Streit AG) uses optical low-coherence reflectometry (OLCR) with an 820 nm superluminescent diode to also measure the entire eye’s GPL; the OPL is then converted to a GPL using a single-group refractive function for the entire eye.3,4 By contrast, the Argos (Movu, Inc.) swept-source optical coherence tomograph (SS-OCT) uses a 1060 nm wavelength and a 20 nm bandwidth swept-source technology to collect 2-dimensional OCT data of the full eye.5,6 More importantly, it measures the OPL of each segment of the eye and uses a specific refractive index for each of these segments (cornea, aqueous depth, lens, and vitreous). As such, when there are variations in the relative lengths of these components, the AL calculation is appropriately adjusted. In 3 recent studies, the refractive accuracy of most commonly used formulas was higher in eyes measured with a specific refractive index for each segment of the eye than in eyes measured with a single-group refractive function for the entire eye; in all 3 studies, this increase in the formulas’ refractive accuracy was more evident in the short and long eyes when the sum-of-segments (S-O-S) measurement is used.4,7,8

Newer formulas, some of which are based on artificial intelligence or machine learning, are quickly gaining in popularity. These include the Barrett Universal II (B II) formula currently programmed in the SS-OCT biometer, the Barrett True Axial Length (BTAL), Emmetropia...
Verifying Optical (EVO), Hill-RBF, Hoffer QST, Holladay 2, Holladay 2-NLR, K6, Kane, Olsen, PEARL-DGS, T2, and VRF formulas.\textsuperscript{11–14} The refractive outcomes of these newer formulas using the S-O-S biometry measurements remain unknown, especially in the long and the short eyes. The purpose of this retrospective study is to analyze the accuracy of the newer IOL power formulas in the long and short eyes and to compare them with the commonly used traditional Haigis, Hoffer Q, Holladay 1, and SRK/T formulas.\textsuperscript{15–18}

**METHODS**

This study conformed to the ethics code based on the tenets of the Declaration of Helsinki. It is a comparative noninterventional study comprising a retrospective chart review of patients with a history of cataract surgery at 1 center. The study was approved by the Milkie-Shammas Surgery Center Institutional Review Board (Lynwood, California). A waiver of informed consent was granted to allow the use of deidentified patient data.

Eligible charts were those from patients who have had previous uneventful cataract surgery where the biometry was performed with the Argos SS-OCT device. To reduce variability related to the IOL implanted, only eyes receiving the AcrySoft SN60WF aspheric monofocal IOL (Alcon Laboratories, Inc.) were included. Eyes with clinically significant ocular pathology other than residual refractive error (eg, macular degeneration or advanced glaucoma) were excluded. Eyes with suboptimal surgical outcomes that were not related to the treatment plan (eg, capsular tear, cystoid macular edema, and wound leaks necessitating corneal suturing) were also excluded. In addition, the corrected distance visual acuity in the eye had to be 20/40 or better to reduce the likelihood of variability in the postoperative refraction. If both eyes of a patient were eligible to be included in the study, only the first operated eye was included.

Both manual and electronic data records were used to identify a consecutive series of eyes that fit the inclusion and exclusion criteria above. Deidentified data from the preoperative examination and the 6- to 8-week postoperative examination were collected, including age, sex, postoperative refraction, and corrected distance visual acuity. The biometric data retrieved from the Argos OCT biomter included the displayed AL, the central corneal thickness, the aqueous depth, the anterior chamber depth, the lens thickness, the corneal diameter, and the keratometric readings in the flattest and steepest meridians. The displayed AL on the Argos biomter uses the following indices of refraction: 1.375 for the cornea, 1.336 for the aqueous depth and for the vitreous, and 1.41 for the lens.\textsuperscript{7} The K readings are not the result of a direct measurement of that power; instead, the integrated keratometer measures the anterior corneal radius in millimeters and converted to power values (K in diopters) according to the laws of Gaussian optics using the following formula: $K = 1000 \times (n - 1)/r$, where $n$ is the standard refractive index of 1.3375. The surgical treatment data, IOL power calculations, and power of the IOL implanted were also recorded.

With all biometry measurements kept the same for each eye, the expected residual refractions based on the newer IOL formulas were calculated in each eye. These formulas included:

- The B II formula: The expected residual refractive errors using the B II formula available on the biometer were noted.\textsuperscript{9}
- The BTAL formula: This is an updated version of the B II formula, designed for those measurements that use the sum-of-segment methodology.\textsuperscript{7} The formula will soon be available on the Asia-Pacific Association of Cataract and Refractive Surgeons website (G. Barrett, personal communication, July 17, 2021). Constant optimization and data analysis were performed by Graham Barrett, MD.
- The EVO formula, v. 2.0, available at: www.evovialciculator.com (accessed on May 17, 2021): It stands for Emmetropia Verifying Optical formula that generates an emmetropia factor for each eye. In this study, we used the Hill version of the formula available at its own website, flagging the specific icon. Constant optimization and data analysis were performed by one of the authors (L.T.).
- The Hill-RBF formula, v. 3.0, available at: https://rbrcalcutor.com/ (accessed on August 4, 2021): The formula is based on radial basis function using pattern recognition and sophisticated data interpolation. Eleven eyes (4 long and 7 short) were out of bounds of the pattern recognition grid and were not included in the calculations. Constant optimization and data analysis were performed by Warren Hill, MD.
- The Hoffer Q/Savini/Taroni formula (Hoffer QST) is an updated Hoffer Q formula by means of new algorithms and machine learning process.\textsuperscript{18} It is available at www.hofferqst.com (accessed on May 18, 2021). Constant optimization and data analysis were performed by one of the authors (L.T.).
- The Holladay 2 formula was used with the Holladay IOL Consultant (v. 2014.0607, Holladay consulting. Accessed on August 8, 2021): Constant optimization and data analysis were performed by David Cooke, MD.
- The Holladay 2 formula with NLR (Holladay 2-NLR) (accessed on December 18, 2021): This newer version of the software modifies the AL using a nonlinear regression (NLR) equation that affects eyes exceeding 24.0 mm. Constant optimization and data analysis were performed by David Cooke, MD.
- The K6 formula, available at: www.CookeFormula.com (accessed on August 8, 2021): The formula transforms the optical biometer’s AL to be the distance from the anterior cornea to the retinal pigment epithelium. It also uses a proprietary estimated lens position calculation based on postoperative measurement of 245 eyes. Constant optimization and data analysis were performed by David Cooke, MD.
- The Kane formula, available at: www.iolformula.com (accessed on May 18, 2021): The formula uses regression equations and artificial intelligence components to improve predictions.\textsuperscript{19} Constant optimization and data analysis were performed by one of the authors (L.T.).
- The Olsen formula, available at: www.phacoOptics.net (accessed on August 8, 2021): The formula is based on exact ray tracing, and it uses the C-constant concept to predict the IOL position inside the eye.\textsuperscript{20} Constant optimization and data analysis were performed by David Cooke, MD.
- The PEARL-DGS formula, available at: www.iolsolver.com (accessed on August 8, 2021): It stands for Postoperative spherical Equivalent prediction using ARTificial intelligence and Linear algorithms, developed by Debellemanière, Gatinel, and Saad.\textsuperscript{12} This formula is a thick lens version of the Haigis formula, trained using a perfect back-calculated lens position with artificial intelligence and a linear algorithms formula. The Cooke-modified AL (CMAL) function needed to correct the AL from a traditional one to a sum-of-segments one was replaced by the S-O-S measurement obtained by the SS-OCT biometer. Constant optimization and data analysis were performed by Guillaume Debellemanière, MD.
- The T2 formula, using the T2 formula calculator: The formula is an improvement on the SRK/T formula by replacing the steps in the data formula used to estimate corneal height with a regression equation derived from a large collection of patient data.\textsuperscript{13,15} Constant optimization and data analysis were performed by David Cooke, MD.
- The VRF formula: The formula uses a special algorithm to determine the postoperative position of the IOL.\textsuperscript{14} Constant optimization and data analysis were performed by David Cooke, MD.

Postoperative refractive evaluation was performed at 6 to 8 weeks from surgery. The operated eye is first checked objectively using an Auto Refractometer/keratometer (model ARK-1 from Nidek Co., Ltd.) followed by a subjective refraction performed by a licensed optometrist and checking the vision at 20 feet. To calculate the refractive prediction error (PE), the predicted refraction (based on the IOL power implanted) was subtracted from the postoperative refraction according to each formula. Therefore, a negative PE value reveals that the result achieved was more myopic than the predicted refraction, whereas a positive PE value reveals that the result achieved was more hyperopic than the predicted refraction
represents a more hyperopic result. The mean PE and its SD, the median absolute error (MedAE), the mean absolute error (MAE), and the percentage of eyes with a PE within ±0.25 diopter (D), ±0.50 D, ±0.75 D, and ±1.00 D were calculated for each formula. Lens constant optimization for each formula was achieved by bringing each mean PE to zero in the entire series. We analyzed the results of all these formulas in 78 short eyes (AL <22.50 mm) and 102 long eyes (AL >24.50 mm).19 We further analyzed the results in 42 very short eyes (AL of 22.0 mm and shorter) and 53 very long eyes (AL of 25.0 mm and longer).19

Statistical Analysis

For patients who had undergone surgery in both eyes, only the first eye was considered for analysis. Statistical calculations were conducted using R (v. 4.0.0) and RStudio (v. 1.2.5042) software. Because of the non-normal distribution of data, the variances of PEs were compared using the heteroscedastic method proposed by Holladay et al.20,21

Sample size calculations suggested a minimum of 388 eyes to be included in the dataset. A post hoc analysis (G*Power 3.1) of the whole dataset with N = 595, highest SD = 0.396, and lowest SD = 0.358 and 2 tails yields a power of 0.700 for an alpha level of 0.05.

RESULTS

In this study, we enrolled 595 eyes of 595 patients. The demographic and biometric data are noted in Table 1.

Patients with short eyes tended to be slightly older at the time of surgery than patients with long eyes (72 ± 10 years vs 68 ± 10 years), with a higher percentage of females (81% vs 46%). Compared with the long eyes, the short eyes had a shallower phakic anterior chamber depth (2.95 ± 0.34 mm vs 3.21 ± 0.37 mm, respectively). Aqueous depth was also shallower in the short eyes (2.42 ± 0.33 mm vs 2.68 ± 0.37 mm, respectively). The differences in phakic ACD and corneal diameter were also significant.

To further explore these differences, we compared the results of all these formulas in 78 short eyes (AL <22.50 mm) and 102 long eyes (AL >24.50 mm).19 We further analyzed the results in 42 very short eyes (AL of 22.0 mm and shorter) and 53 very long eyes (AL of 25.0 mm and longer).19

### Table 2. Optimized constants and refractive outcomes of the study population (N = 595)

| Formula | Optimized constant | MPE ± SD (D) | MedAE (D) | MAE (D) | MaxAE (D) | PE (%) | 0.25 D | 0.50 D | 0.75 D | 1.00 D |
|---------|--------------------|--------------|-----------|---------|-----------|--------|--------|--------|--------|--------|
| New formulas | | | | | | | | | | |
| B II | 2.00 | 0.00 ± 0.378 | 0.27 | 0.31 | 1.10 | 45.9 | 80.5 | 96.5 | 99.5 |
| BTAL | 1.97 | -0.01 ± 0.370 | 0.26 | 0.30 | 1.00 | 48.4 | 80.3 | 97.0 | 100.0 |
| EVO | 119.12 | 0.00 ± 0.364 | 0.27 | 0.30 | 0.98 | 47.4 | 81.5 | 97.3 | 100.0 |
| Hill-RBFa | 119.22 | 0.00 ± 0.380 | 0.28 | 0.31 | 1.18 | 44.4 | 81.5 | 97.0 | 99.5 |
| Hoffer QST | 5.72 | 0.00 ± 0.371 | 0.28 | 0.31 | 1.12 | 46.4 | 80.7 | 97.3 | 99.8 |
| HOL2 | 5.65 | 0.00 ± 0.396 | 0.29 | 0.32 | 1.09 | 44.7 | 76.6 | 95.3 | 99.5 |
| HOL2-NLR | 5.64 | 0.00 ± 0.390 | 0.28 | 0.32 | 1.15 | 44.7 | 77.8 | 95.3 | 99.5 |
| K6 | 119.22 | 0.00 ± 0.364 | 0.26 | 0.29 | 1.31 | 48.2 | 81.3 | 97.7 | 99.5 |
| Kane | 119.19 | 0.00 ± 0.373 | 0.27 | 0.30 | 1.38 | 47.2 | 80.5 | 97.1 | 99.7 |
| Olsen | 4.74 | -0.01 ± 0.377 | 0.26 | 0.30 | 1.64 | 47.7 | 80.5 | 96.1 | 99.5 |
| P-DGS | 118.60 | 0.00 ± 0.358 | 0.26 | 0.29 | 1.23 | 48.4 | 81.7 | 98.0 | 99.8 |
| T2 | 119.24 | 0.00 ± 0.386 | 0.29 | 0.32 | 0.98 | 44.4 | 78.8 | 90.0 | 100.0 |
| VRF | 5.67 | 0.00 ± 0.388 | 0.28 | 0.32 | 1.40 | 46.1 | 77.8 | 96.8 | 99.5 |
| Traditional formulas | | | | | | | | | | |
| Haigis b | 0.00 ± 0.397 | 0.29 | 0.32 | 1.10 | 45.8 | 77.4 | 94.2 | 99.8 |
| Hoffer Q | 5.75 | 0.00 ± 0.410 | 0.29 | 0.33 | 1.11 | 45.8 | 74.8 | 93.1 | 99.3 |
| Holladay 1 | 1.98 | 0.00 ± 0.388 | 0.28 | 0.32 | 1.10 | 45.8 | 77.4 | 94.2 | 99.8 |
| SRK/T | 119.25 | 0.00 ± 0.408 | 0.30 | 0.34 | 1.03 | 42.5 | 75.0 | 94.6 | 99.6 |

ACD = anterior chamber depth; K = keratometry
Data are presented as n (%) or mean ± SD (range)

### Table 1. Demographic and biometric data

| Parameter | Entire series (N = 595) | Short eyes (n = 78) | Long eyes (n = 102) |
|-----------|------------------------|---------------------|---------------------|
| Age (y)   | 71 ± 9 (23, 92)        | 72 ± 10 (23, 91)    | 68 ± 10 (27, 84)    |
| Sex (M/F) | 250 (42)/345 (58)      | 15 (19)/63 (81)     | 42 (54)/36 (46)     |
| Eye involved (R/L) | 297 (50)/298 (50) | 42 (55)/51 (46) | 51 (50)/51 (50) |
| Axial length (mm) | 23.58 ± 1.07 (20.75, 29.65) | 22.00 ± 0.38 (20.75, 22.49) | 25.27 ± 0.76 (24.51, 29.65) |
| Corneal thickness (mm) | 0.53 ± 0.03 (0.43, 0.64) | 0.53 ± 0.03 (0.45, 0.60) | 0.53 ± 0.03 (0.46, 0.63) |
| Aqueous depth (mm) | 2.68 ± 0.37 (1.75, 4.06) | 2.42 ± 0.33 (1.81, 3.38) | 2.95 ± 0.34 (2.31, 3.92) |
| Phakic ACD (mm) | 3.21 ± 0.37 (2.28, 4.60) | 3.16 ± 0.46 (2.31, 3.92) | 3.45 ± 0.36 (2.61, 4.60) |
| Corneal diameter (mm) | 12.16 ± 0.57 (10.47, 13.90) | 11.61 ± 0.46 (10.50, 12.81) | 12.69 ± 0.50 (11.33, 13.90) |
| Flat K (D) | 43.36 ± 1.66 (37.50, 49.88) | 45.23 ± 1.68 (41.65, 49.88) | 42.16 ± 1.61 (37.50, 47.22) |
| Steep K (D) | 44.28 ± 1.70 (38.92, 51.68) | 46.15 ± 1.62 (42.84, 50.90) | 43.23 ± 1.79 (38.92, 48.57) |
| Average K (D) | 43.82 ± 1.65 (38.56, 50.87) | 45.69 ± 1.62 (42.39, 50.39) | 42.69 ± 1.65 (38.56, 47.8) |

ACD = anterior chamber depth; K = keratometry
Data are presented as n (%) or mean ± SD (range)

1115 NEW FORMULAS WITH THE SUM-OF-SEGMENTS BIOMETRY

Volume 48 Issue 10 October 2022
vs 3.45 ± 0.36 mm), a smaller corneal diameter (11.61 ± 0.46 mm vs 12.69 ± 0.50 mm), and steeper Ks (average of 45.69 ± 1.62 D vs 42.69 ± 1.65 D).

Table 2 shows the refractive outcomes in the entire series, and the results were used to determine the optimized constants in our cohort by bringing each MPE closest to 0. All new formulas had a MAE equal or lower than the traditional formulas, with over 76% of the eyes achieving a refraction within ±0.50 D from the predicted one, with the B II, BTAL, EVO, Hill-RBF, Hoffer QST, K6, Kane, Olsen, and PEARL-DGS formulas exceeding 80%.

Table 3 shows the refractive outcomes in the 78 short eyes, keeping the same optimized constants. BTAL, EVO, Hoffer QST, Kane, and PEARL-DGS formulas had the lowest MAE of 0.29 D; the percentage of eyes achieving a refraction within ±0.50 D from the predicted one with these formulas was 82.4%, 78.0%, 80.4%, 79.4%, and 80.4%, respectively. In the very long eyes, all 5 of the previously mentioned formulas had a low MAE (0.26 D, 0.28 D, 0.27 D, 0.27 D, and 0.27 D, respectively), and the percentage of eyes achieving a refraction within ±0.50 D from the predicted one was 90.6%, 81.1%, 86.8%, 84.9%, and 83.0%, respectively (Table 4). Equally good results were noted with the B II, Hill-RBF, Holladay 2-NLR, K6, Olsen, and T2 formulas, with the percentage of eyes achieving a refraction within ±0.50 D from the predicted one was 91.2%, 86.8%, 88.7%, 88.7%, 84.9%, and 90.6%, respectively.

Supplemental Tables A, B, C, D, and E represent the matrices of SDs of PEs in the entire series, short eyes, very short eyes, long eyes, and very long eyes, respectively; the P values were computed using the heteroscedastic method.

**DISCUSSION**

The S-O-S methodology used in the Argos SS-OCT biometer measures each segment of the eye at its correct velocity just like A-scan biometry. Wang et al. calculated the segmented AL of 4992 eyes measured by an OLCR biometer by adding all geometrical ocular segments converted from the respective OPL in each medium.1 On

### Table 3. Refractive outcomes in the short eyes (n = 78)

| Formula          | Optimized constant | MPE ± SD (D) | MedAE (D) | MAE (D) | MaxAE (D) | PE (%) | 0.25 D | 0.50 D | 0.75 D | 1.00 D |
|------------------|--------------------|--------------|-----------|---------|-----------|--------|--------|--------|--------|--------|
| New formulas     |                    |              |           |         |           |        |        |        |        |        |
| B II             | 2.00               | 0.09 ± 0.418 | 0.31      | 0.35    | 1.01      | 38.5   | 70.5   | 93.6   | 98.7   |
| BTAL             | 1.97               | −0.07 ± 0.396| 0.30      | 0.33    | 0.86      | 42.3   | 71.8   | 97.4   | 100.0  |
| EVO              | 119.12             | −0.11 ± 0.383| 0.28      | 0.33    | 0.87      | 41.0   | 76.9   | 97.4   | 100.0  |
| Hill-RBF         | 119.22             | 0.18 ± 0.418 | 0.32      | 0.38    | 1.14      | 34.6   | 71.8   | 92.3   | 97.4   |
| Hoffer QST       | 5.72               | −0.00 ± 0.411| 0.34      | 0.36    | 0.95      | 41.0   | 74.4   | 96.2   | 100.0  |
| HOLL2            | 5.65               | −0.15 ± 0.437| 0.36      | 0.38    | 1.09      | 34.6   | 68.0   | 92.3   | 97.4   |
| HOLL2-NLR        | 5.64               | −0.11 ± 0.437| 0.35      | 0.38    | 1.13      | 30.8   | 70.5   | 94.9   | 97.4   |
| K6               | 119.22             | 0.09 ± 0.376 | 0.26      | 0.31    | 1.02      | 47.4   | 79.5   | 96.2   | 98.7   |
| Kane             | 119.19             | 0.02 ± 0.422 | 0.35      | 0.36    | 1.03      | 37.2   | 69.2   | 96.2   | 98.7   |
| Olsen            | 4.74               | 0.04 ± 0.383 | 0.28      | 0.32    | 0.88      | 42.3   | 79.5   | 94.9   | 100.0  |
| P-DGS            | 118.60             | −0.04 ± 0.377| 0.27      | 0.32    | 0.86      | 47.4   | 80.8   | 97.4   | 100.0  |
| T2               | 119.24             | −0.02 ± 0.428| 0.34      | 0.36    | 0.92      | 35.9   | 71.8   | 93.6   | 100.0  |
| VRF              | 5.70               | −0.06 ± 0.428| 0.33      | 0.36    | 1.04      | 37.2   | 73.1   | 94.9   | 98.7   |
| Traditional formulas |            |              |           |         |           |        |        |        |        |        |
| Haigis b         | 0.05 ± 0.462       | 0.36        | 0.38      | 1.10    | 38.5      | 66.7   | 91.0   | 98.7   |
| Hoffer Q         | 0.08 ± 0.461       | 0.37        | 0.38      | 0.94    | 38.5      | 66.7   | 85.9   | 100.0  |
| Holladay 1       | 0.02 ± 0.434       | 0.33        | 0.37      | 0.93    | 35.9      | 71.7   | 94.9   | 100.0  |
| SRK/T            | 0.02 ± 0.453       | 0.31        | 0.37      | 1.07    | 39.7      | 70.5   | 88.5   | 98.7   |

**B II = Barrett Universal II; BTAL = Barrett True Axial Length; EVO = Emmetropia Verifying Optical; HOLL2 = Holladay 2; HOLL2-NLR = Holladay 2 with the nonlinear regression; MAE = mean absolute error; MaxAE = maximal absolute error; MedAE = median absolute error; MPE = mean prediction error; P-DGS = PEARL-DGS; PE = prediction error**

*a Only 71 eyes were measured, with 7 eyes out of bounds of the pattern recognition grid*

*b Haigis constants (a0 = 0.623, a1 = 0.323, and a2 = 0.149)
average, the segmented ALs were longer in short eyes and shorter in long eyes compared with the displayed ALs calculated with a single-group refractive index for the entire eye. Furthermore, the refractive accuracy with segmented ALs was improved in short eyes with the Hoffer Q and Holladay 1 formulas and in long eyes with the B II, Haigis,

Table 4. Refractive outcomes in the very short eyes, 22.0 mm and shorter (n = 42)

| Formula    | Optimized constant | MPE ± SD (D) | MedAE (D) | MAE (D) | MaxAE (D) | PE (%) |
|------------|--------------------|--------------|-----------|---------|-----------|--------|
| **New formulas** |                    |              |           |         |           |        |
| B II       | 2.00               | 0.08 ± 0.443 | 0.35      | 0.38    | 1.02      | 39.5   |
| BTAL       | 1.97               | −0.09 ± 0.419| 0.32      | 0.36    | 0.86      | 38.1   |
| EVO        | 119.12             | −0.13 ± 0.400| 0.33      | 0.35    | 0.87      | 38.1   |
| Hill-RBF²  | 119.22             | 0.24 ± 0.430 | 0.32      | 0.40    | 1.14      | 33.3   |
| Hoffer QST  | 5.72               | −0.02 ± 0.420| 0.36      | 0.36    | 0.96      | 33.3   |
| HOL2       | 5.65               | −0.13 ± 0.452| 0.37      | 0.41    | 1.09      | 30.9   |
| HOL2-NLR   | 5.64               | −0.10 ± 0.452| 0.36      | 0.40    | 1.13      | 23.8   |
| K6         | 119.22             | 0.13 ± 0.401 | 0.26      | 0.33    | 1.02      | 47.6   |
| Kane       | 119.19             | 0.04 ± 0.429 | 0.36      | 0.36    | 1.03      | 35.7   |
| Olsen      | 4.74               | 0.04 ± 0.422 | 0.34      | 0.35    | 0.88      | 40.5   |
| P-DGS      | 118.60             | −0.04 ± 0.331| 0.27      | 0.33    | 0.86      | 45.2   |
| T2         | 119.24             | 0.03 ± 0.439 | 0.35      | 0.36    | 0.92      | 33.3   |
| VRF        | 5.70               | −0.04 ± 0.434| 0.35      | 0.37    | 1.04      | 28.6   |
| **Traditional formulas** |                |              |           |         |           |        |
| Haigis     |                     | 0.06 ± 0.479 | 0.38      | 0.40    | 1.10      | 34.9   |
| Hoffer Q   | 5.75               | −0.07 ± 0.474| 0.42      | 0.40    | 0.81      | 25.6   |
| Holladay 1 | 1.98               | 0.06 ± 0.444 | 0.39      | 0.38    | 0.93      | 27.9   |
| SRK/T      | 119.25             | −0.03 ± 0.443| 0.26      | 0.36    | 0.98      | 46.5   |

B II = Barrett Universal II; BTAL = Barrett True Axial Length; EVO = Emmetropia Verifying Optical; HOL2 = Holladay 2; HOL2-NLR = Holladay 2 with the nonlinear regression; MAE = mean absolute error; MedAE = median absolute error; MPE = mean prediction error; P-DGS = PEARL-DGS; PE = prediction error

²Only 71 eyes were measured, with 7 eyes out of bounds of the pattern recognition grid
³Haigis constants (a0 = 0.623, a1 = 0.323, and a2 = 0.149)

Table 5. Refractive outcomes in the long eyes, over 24.5 mm (n = 102)

| Formula    | Optimized constant | MPE ± SD (D) | MedAE (D) | MAE (D) | MaxAE (D) | PE (%) |
|------------|--------------------|--------------|-----------|---------|-----------|--------|
| **New formulas** |                    |              |           |         |           |        |
| B II       | 2.00               | −0.08 ± 0.372| 0.25      | 0.30    | 1.10      | 49.0   |
| BTAL       | 1.97               | −0.06 ± 0.357| 0.23      | 0.29    | 0.86      | 52.0   |
| EVO        | 119.12             | 0.06 ± 0.360 | 0.24      | 0.29    | 0.85      | 52.9   |
| Hill-RBF²  | 119.22             | −0.15 ± 0.368| 0.29      | 0.32    | 1.48      | 45.1   |
| Hoffer QST  | 5.72               | −0.03 ± 0.361| 0.25      | 0.29    | 1.12      | 50.0   |
| HOL2       | 5.65               | 0.13 ± 0.375 | 0.28      | 0.32    | 0.79      | 46.1   |
| HOL2-NLR   | 5.64               | 0.00 ± 0.374 | 0.24      | 0.30    | 1.15      | 52.0   |
| K6         | 119.22             | −0.13 ± 0.361| 0.25      | 0.30    | 1.31      | 50.0   |
| Kane       | 119.19             | −0.03 ± 0.376| 0.25      | 0.29    | 1.38      | 50.0   |
| Olsen      | 4.74               | −0.11 ± 0.376| 0.27      | 0.31    | 1.22      | 49.0   |
| P-DGS      | 118.60             | 0.00 ± 0.362 | 0.25      | 0.29    | 0.96      | 51.0   |
| T2         | 119.24             | −0.04 ± 0.375| 0.27      | 0.31    | 0.89      | 45.1   |
| VRF        | 5.70               | 0.02 ± 0.392 | 0.21      | 0.30    | 1.40      | 52.9   |
| **Traditional formulas** |                |              |           |         |           |        |
| Haigis     |                     | −0.02 ± 0.394| 0.25      | 0.32    | 0.88      | 50.0   |
| Hoffer Q   | 5.75               | 0.06 ± 0.423 | 0.27      | 0.34    | 1.01      | 47.1   |
| Holladay 1 | 1.98               | −0.01 ± 0.391| 0.27      | 0.32    | 1.09      | 49.0   |
| SRK/T      | 119.25             | 0.02 ± 0.412 | 0.27      | 0.33    | 0.93      | 46.1   |

B II = Barrett Universal II; BTAL = Barrett True Axial Length; EVO = Emmetropia Verifying Optical; HOL2 = Holladay 2; HOL2-NLR = Holladay 2 with the nonlinear regression; MAE = mean absolute error; MedAE = median absolute error; MPE = mean prediction error; P-DGS = PEARL-DGS; PE = prediction error

²Only 98 eyes were measured, with 4 long eyes out of bounds of the pattern recognition grid
³Haigis constants (a0 = 0.623, a1 = 0.323, and a2 = 0.149)
Hoffer, Holladay 1, and SRK/T formulas. Cooke and Cooke reviewed 215 eyes measured with an OLCR biometer and developed the CMAL that closely approximates the S-O-S AL. Reviewing the clinical results in 1442-eye validation set, the CMAL produced more accurate predictions in the Hoffer Q, Holladay 1, SRK/T, and Holladay 2 IOL formulas; the improvement was mainly noted in the short and long eyes. Shammas et al. compared the AL as measured by the Argos SS-OCT biometer using the S-O-S methodology to a measurement that simulates an AL measured with a single refractive index in 595 eligible eyes. On average, the simulated measurements were shorter than the Argos measurements in the short eyes and longer in the long eyes, with a higher MAE with the B II, Holladay 1, SRK/T, and P-DGS formulas exceeding 80% (476/595).

The BTAL, EVO, and PEARL-DGS formulas adjust for measurements made with the S-O-S biometry. All other formulas were the original ones with no modifications. The Hill-RBF, v. 3.0, is the only formula that does not require an estimated lens position or a vergence formula; instead, it uses artificial intelligence for pattern recognition using only data collected from the Lenstar OLCR biometer. The formula performed extremely well with 81.5% (585/595) within ±0.50 D in the entire study population and 82.4% (84/102) in the long eyes. However, the measurement differences between the traditional method of the Lenstar and the S-O-S method of the Argos appear to mainly affect the IOL prediction in the short eyes, with only 71.8% (84/116) achieving a refraction within ±0.50 D from the predicted one, with the B II, BTAL, EVO, Hill-RBF, Hoffer QST, K6, Kane, Olsen, and PEARL-DGS formulas exceeding 80% (476/595). The selected new formulas are currently among the most studied and available options for IOL power calculation. In our cohort of 595 eyes, all new formulas had a MAE equal or lower than the traditional formulas, with over 76% (452/595) of the eyes achieving a refraction within ±0.50 D from the predicted one, with the B II, BTAL, EVO, Hill-RBF, Hoffer QST, K6, Kane, Olsen, and PEARL-DGS formulas exceeding 80% (476/595).

The following table shows the refractive outcomes in the very long eyes, 25.0 mm and longer (n = 53):

| Formula            | Optimized constant | MPE ± SD (D) | MedAE (D) | MAE (D) | MaxAE (D) | PE (%) < 0.25 D | PE (%) < 0.50 D | PE (%) < 0.75 D | PE (%) < 1.00 D |
|--------------------|--------------------|--------------|-----------|---------|-----------|-----------------|-----------------|-----------------|-----------------|
| **New formulas**   |                    |              |           |         |           |                 |                 |                 |                 |
| B II               | 2.00               | −0.09 ± 0.332| 0.23      | 0.27    | 1.09      | 56.1            | 91.2            | 96.5            | 98.2            |
| BTAL               | 1.97               | −0.05 ± 0.327| 0.24      | 0.26    | 0.86      | 50.9            | 90.6            | 96.2            | 100.0           |
| EVO                | 119.12             | 0.08 ± 0.343 | 0.22      | 0.28    | 0.85      | 56.6            | 81.1            | 98.1            | 100.0           |
| Hill-RBFA         | 119.22             | −0.18 ± 0.348| 0.28      | 0.29    | 1.48      | 49.1            | 96.6            | 94.3            | 98.1            |
| Hoffer QST         | 5.72               | −0.06 ± 0.339| 0.19      | 0.27    | 1.12      | 54.7            | 86.8            | 98.1            | 98.1            |
| HOL2               | 5.65               | 0.17 ± 0.347 | 0.27      | 0.31    | 0.79      | 49.1            | 75.5            | 94.3            | 100.0           |
| HOL2-NLR          | 5.64               | −0.01 ± 0.351| 0.24      | 0.28    | 1.15      | 54.7            | 88.7            | 96.2            | 98.1            |
| K6                 | 119.22             | −0.14 ± 0.343| 0.18      | 0.27    | 1.31      | 56.6            | 88.7            | 94.3            | 98.1            |
| Kane               | 119.19             | −0.03 ± 0.369| 0.22      | 0.27    | 1.38      | 54.7            | 84.9            | 94.3            | 98.1            |
| Olsen              | 4.74               | −0.10 ± 0.365| 0.23      | 0.29    | 1.22      | 50.9            | 84.9            | 96.2            | 98.1            |
| P-DGS              | 118.60             | 0.03 ± 0.342 | 0.25      | 0.27    | 0.96      | 49.1            | 83.0            | 98.1            | 100.0           |
| T2                 | 119.24             | −0.06 ± 0.341| 0.27      | 0.28    | 0.89      | 43.4            | 90.6            | 96.2            | 100.0           |
| VRF                | 5.70               | 0.05 ± 0.392 | 0.19      | 0.29    | 1.09      | 60.4            | 77.4            | 96.2            | 98.1            |
| **Traditional formulas** |          |              |           |         |           |                 |                 |                 |                 |
| Haigis             | b                  | 0.03 ± 0.372 | 0.20      | 0.29    | 0.83      | 56.1            | 78.9            | 94.7            | 100.0           |
| Hoffer Q           | 5.75               | 0.11 ± 0.409 | 0.25      | 0.33    | 1.01      | 50.9            | 71.9            | 89.5            | 98.2            |
| Holladay 1         | 1.98               | −0.09 ± 0.332| 0.23      | 0.27    | 1.09      | 56.1            | 91.2            | 96.5            | 98.2            |
| SRK/T              | 119.25             | 0.01 ± 0.376 | 0.19      | 0.29    | 0.93      | 52.6            | 80.7            | 96.5            | 100.0           |

B II = Barrett Universal II; BTAL = Barrett True Axial Length; EVO = Emmetropia Verifying Optical; HOL2 = Holladay 2; HOL2-NLR = Holladay 2 with the nonlinear regression; MAE = mean absolute error; MedAE = median absolute error; MPE = mean prediction error; P-DGS = PEARL-DGS; PE = prediction error

*Only 98 eyes were measured, with 4 long eyes out of bounds of the pattern recognition grid

*Haigis constants (a0 = 0.623, a1 = 0.323, and a2 = 0.149)
In conclusion, all new formulas performed equal or better than the traditional formulas with the sum-of-segments biometry. The best overall results in the short and long eyes and in the very short and very long eyes were noted with the BTAL, EVO, Hoffer QST, K6, Olsen, and PEARL-DGS formulas, closely followed by the B II and Kane formulas.

WHAT WAS KNOWN
- Biometers using the sum-of-segments technology measure the optical path length of each segment of the eye and use a specific refractive index for each of these segments (cornea, aqueous depth, lens, and vitreous). As such, when there are variations in the relative lengths of these components, the axial length calculation is appropriately adjusted.
- The Haigis, Hoffer Q, Holladay 1, and SRK/T formulas are considered to be the traditional ones and are commonly used for IOL power calculation.
- Newer formulas, some of which are based on artificial intelligence or machine learning, are quickly gaining in popularity. These include the Barrett Universal II (B II), Barrett True Axial Length (BTAL), Emmetropia Verifying Optical (EVO), Hill-RBF, Hoffer QST, K6, Kane, Olsen, PEARL-DGS, T2, and VRF formulas.

WHAT THIS PAPER ADDS
- All new formulas performed relatively well with the sum-of-segments biometry.
- The best overall results in the short and long eyes and in the very short and very long eyes were noted with the BTAL, EVO, Hoffer QST, K6, Olsen, and PEARL-DGS formulas, closely followed by the B II and Kane formulas.

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