T2 formula in a highly myopic population, comparison with other methods and description of an improved approach for estimating corneal height

Carlos Alberto Idrobo -caidrobo22@gmail.com
Hospital de Especialidades Eugenio Espejo
Corresponding Author
ORCiD: 0000-0001-8692-2898

Gisella Santaella
Clínica Barraquer

Ángela María Gutiérrez
Clínica Barraquer

DOI: 10.21203/rs.2.9499/v2

SUBJECT AREAS Internal Medicine

KEYWORDS T2 formula, high myopia, corneal height estimation, cataract surgery, intraocular lens calculation.
Abstract

ABSTRACT Background: To determine the accuracy of the T2 formula as applied to highly myopic eyes, to compare the T2 formula to the SRK/T and Holladay 1 formulas, and to describe possible ways to improve the estimation of corneal height and prediction error in two settings, the Hadassah Hospital, Ophthalmology Department, Jerusalem, Israel and Clínica Barraquer, Bogotá, Colombia. Methods: In this retrospective case series, optical biometer measurements were taken for 63 highly myopic patients (> 25 mm) undergoing uneventful crystalline lens phacoemulsification and insertion of an acrylic intraocular lens. Prediction errors were obtained, with estimations of ± 0.50 D, ± 1.00 D, and greater than ± 2.00 D. A method to improve the corneal height calculation is described. Results: The SRK/T formula (mean absolute error $\text{MAE} = 0.418$; median absolute error $\text{MedAE} = 0.352$) was the most accurate, followed by the T2 ($\text{MAE} = 0.435$; $\text{MedAE} = 0.381$) and Holladay 1 ($\text{MAE} = 0.455$; $\text{MedAE} = 0.389$) formulas. Both the SRK/T and T2 formulas overestimated corneal height, but values were higher with the T2 formula. Corneal height was more precisely estimated using an alternative method that, when combined with axial length optimization, resulted in lower MAE (0.425) and MedAE (0.365) values than when applying the T2 formula alone. Conclusions: The T2 formula seems to be less accurate than the SRK/T formula in highly myopic eyes. An improved corneal height estimation method is described for the the T2 formula. Key words: T2 formula, high myopia, corneal height estimation, cataract surgery, intraocular lens calculation.

BACKGROUND
Highly myopic eyes have a long axial length (L); (> 25 mm), a deep anterior chamber depth (ACD), and a floppy capsular bag, therefore, calculating the intraocular lens (IOL) power of these eyes is challenging and often results in a postoperative hyperopic surprise. The use of partial coherence interferometry\(^1\) together with specific formulas (e.g. Barrett Universal II\(^2\) and Haigis\(^3\)) are strategies to improve the IOL estimation in these cases.

The SRK/T formula is a well-known method with evidence reporting its accuracy in cases of high myopia.\(^2\) The size of the postoperative anterior chamber and the position of the IOL are predicted by the SRK/T using the following concepts: 1) The corneal height (H), is a model in which the cornea is regarded as a section of a sphere, the base of which forms a plane at the level of the anterior iris, therefore H can be defined as the distance from the anterior surface of the iris to the central cornea, in the SRK/T paper measures dealing with this value included the corneal thickness\(^5\). 2) Corrected Axial Length (LCOR): The SRK/T assumes that the vitreous chamber size undergoes a greater elongation than the anterior segment, As a result, this formula applies a correction factor in eyes longer than 24.2 mm of axial length which allows for a more accurate estimation of ACD in the long eye, this adjustment is used as part of the corneal height (H) estimation\(^5\). 3) Offset: Below the iris, and with the IOL in position, the offset is the distance from the iris plane to the optical plane of the IOL.

In spite of the advantages of the SRK/T, authors like Haigis\(^6\) observed that it was not as effective in certain situations. For instance, in the calculation of the ACD, when the corneal width is two times greater than the corneal radius, the formula attempts to calculate the square root of a negative number, a phenomenon termed
imaginary ACD.” This event is controlled by changing the described negative value to zero, an adjustment that only represents a partial solution, and that induces a non-physiological behavior, called the “SRK/T cusp.”

The T2 formula was developed as a method which would tackle the pitfalls of the SRK/T, its authors describe two sources of error for the original formula: (1) LCOR reversal, where LCOR progressively decreases as AL values exceed 36.2 mm; and (2) the SRK/T cusp, corrected by replacing steps 2 to 4 in the original SRK/T formula with a regression formula for corneal height (from now on called H2). The T2 formula corrects estimation errors of H but its benefits are not as evident as expected in long eyes.

An important feature of the design of the T2 equation is that it uses L without any correction (avoiding the LCOR step from the SRK/T), and the keratometry. Interestingly, a second formula for the corneal height was developed in the original report on the T2 formula, which does include LCOR (termed H2.2 herein) and which will be of special interest in this paper. Appendix 2 presents all aforementioned equations.

The Holladay 1 formula has also been successfully used in normal and myopic eyes, and it has been included in the present study for comparison purposes, due to its similar design to the SRK/T.

The present investigation compared the outcomes of the SRK/T, T2, and Holladay 1 formulas in highly myopic eyes. In addition, it analyzed the SRK/T and T2 formulas in order to find options to improve the prediction of H in very long eyes.

METHODS
An observational retrospective chart review was performed. This review included 63 highly myopic patients (> 25.00 mm), who underwent uneventful crystalline lens phacoemulsification and IOL insertion at one of two clinics: the Hadassah Ein Keren Ophthalmology Clinic, Jerusalem, Israel (39 cases from June 2012 to January 2014) and the Clínica Barraquer, Bogotá, Colombia (24 cases from February 2013 to November 2015). Institutional review board approval was obtained, and all methods adhered to the Helsinki Declaration. Inclusion criteria were as follows: highly myopic eyes (L > 25 mm; ), Alcon Acrisof® SN60WF acrylic IOL in-the-bag implants, and postoperative visual acuity ≥ 20/40. Exclusion criteria were as follows: absent or inadequate optic biometry and/or conditions affecting best corrected visual acuity (e.g. choroidal neovascularization, optic atrophy, etc.). Myopic retinal degeneration and glaucoma were reasons for exclusion only if severely impairing.

The measured variables were as follows: L and keratometry (measured with Carl Zeiss IOL Master® Optical Biometer); preoperative and postoperative best corrected visual acuity (measured with ETDRS chart and converted to LogMAR notation using an online tool [http://www.myvisiontest.com/logmar.php]; postoperative refraction (measured at minimum one month post-operation). The Holladay 1, SRK/T, and T2 formulas were included for assessments. The applied A-constant and Surgeon Factor were respectively 119.0 and 1.84 (based on recommendations from the User Group for Laser Interference Biometry).10

The IOL powers for predicted refraction and emmetropia were estimated. Prediction error was defined as the difference between the refractive error calculated by the formula and the stable postoperative refraction. Calculations were performed using verified formulas developed by Dr. Richard Sheard (Microsoft Excel Functions Add-In
The estimation of errors was as follows: Mean Error (ME) was made equal to zero by changing the lens factor individually for each formula, this was achieved using the Excel software’s Data/What If Analysis/Goal Seek function, after this procedure, constants obtained were: A constant for SRK/T: 119, 21; A constant for T2: 119.23; A Constant for T2 formula including H2.2 and Wang’s AL optimization (described below): 118.63; Surgeon Factor for Holladay 1: 2.27.

After the mean errors were zeroed out, all negative values were converted to positive and the mean absolute error (MAE) was reported for each formula. Then, Median Absolute Error (MedAE) was calculated. Standard, minimum and maximum errors were estimated, together with the percentage of eyes with prediction errors ≤±0.50 diopter (D), ≤±1.00 D, and ≤±2.00 D.

The overall sample was analyzed to avoid subgroup bias. H was calculated using steps 2 to 4 of the SRK/T formula\(^5\) (termed hereafter as HSRK/T), and two equations described by Sheard et al.\(^7\) (H2 and H2.2). Correlative analyses were performed using commercially available software (Excel 2013, SPSS v.17.0).

Eyes with previous corneal surgery or corneal diseases, and preoperative pathologic changes affecting central vision were excluded. Foveal and perifoveal integrity together with confirmation of stability of any condition were required before inclusion in the sample for analysis.

RESULTS

Sample Description

The demographics of each sample group (i.e. 39 cases from Hadassah Ein Keren Hospital and 24 from Barraquer Clinic) are detailed in Table 1.
### Table 1. Demographics of the two studied groups

| Group                                           | Ethnicity                  | Mean Age       | Gender     | Laterality | N  |
|-------------------------------------------------|----------------------------|----------------|------------|------------|----|
| Hadassah Ein Keren Hospital, Jerusalem, Israel  | Jewish; Arabic             | 68.67 yo, SD ± 10,25 | Male: 43.85% | Right: 58.97% | 39 |
|                                                 |                            | Min: 43, Max: 85 | Female: 56.41% | Left: 41.02% |    |
| Clínica Barraquer, Bogotá-Colombia             | Latin American - Hispanic  | 60.41 yo, SD ± 12,14 | Male: 41.66% | Right: 66.6 % | 24 |
|                                                 |                            | Min: 37, Max: 81 | Female: 58.33% | Left: 33.3 % |    |
|                                                 |                            |                |            |            |    |
|                                                 |                            |                |            |            | Total = 63 |

yo: years old; SD: Standard Deviation; Min: Minimum; Max: Maximum, n: Number of eyes studied.

The pre and post-operative statuses of the assessed variables are summarized in Table 2.

### Table 2. Variables included in the present study
| Variable               | Mean   | Standard Deviation | Minimum | Maximum |
|------------------------|--------|--------------------|---------|---------|
| PreOp VA (Logmar)      | 0.494  | 0.346              | 0.041   | 1.477   |
| PostOp VA (Logmar)     | 0.101  | 0.1043             | 0       | 0.301   |
| Flat K                 | 42.99 D| 1.61906832 D       | 39.38 D | 46.81 D |
| Steep K                | 44.09 D| 1.76891495 D       | 40.23 D | 48.5    |
| Mean K                 | 43.54 D| 1.62941283 D       | 40.08 D | 47.2    |
| L                      | 26.94 mm| 1.107 mm           | 25.22 mm| 30.08 mm|

PreOp: Preoperative; PostOp: Postoperative; VA: Visual acuity; K: Keratometry; L: Axial length; n = 63.

The target preoperative refraction had a mean of -1.171 (Min -5 Max: 0.68, SD 1.330). Whereas the postoperative refraction had a mean Sphere of -0.783 (Min -4.25 ; Max:1.5 ; SD 1.382) and a mean Cylinder of -0.900 (Min -4 Max: 0 , SD 0.745).

Preoperative pathology was found in eight out of 63 eyes (12.69%): one case of uveitis (1.59%), one case of temporary diplopia (1.59%), one case of pseudo exfoliation syndrome (1.59%), one case with peripheral lesions requiring laser treatment (1.59%), and one case of extrafoveal choroidal neovascularization.
(1.59%). Three patients presented with atrophic macular changes outside the fovea (4.76%). Any pathology found was confirmed to be stable and not affecting visual acuity before cataract surgery took place, these cases were allowed in the analysis group provided that none of the changes was found to affect visual acuity.

**Ranking of Formulas**

Of the tested equations, the most accurate was the SRK/T formula (MedAE = 0.352), followed by T2 (MedAE = 0.381) and Holladay 1 (MedAE = 0.389) formulas (Table 3, Graph 1). Lin’s correlation factor was used to analyze the MedAE of the three methods (Table 4).

**Table 3.0 Summary of the prediction error in the present study**

| Formula    | MAE  | Standard Deviation | Minimum | Maximum | MedAE | ≤±0.50 D | ≤±1.0 D | Sum of errors ≤±0.50 D + ≤±1.0 D | >2.00 D |
|------------|------|--------------------|---------|---------|-------|----------|---------|---------------------------------|---------|
| SRK/T      | 0.41 | 0.327              | 0.003   | 1.359   | 0.35  | 71.42%   | 20.63%  | 92.05%                          | 7.93%   |
| Holladay 1 | 0.45 | 0.314              | 0.037   | 1.404   | 0.38  | 61.90%   | 31.74%  | 93.64%                          | 6.35%   |
| T2         | 0.43 | 0.328              | 0.014   | 1.389   | 0.38  | 69.84%   | 22.22%  | 92.06%                          | 7.94%   |

MAE: Mean absolute error, MedAE: Median absolute error, T2: T2 formula, n = 63

Table 4.0 Lin’s correlation coefficient of the median absolute error of the methods used in the present study.
$\rho_c$: Lin’s concordance correlation coefficient, 95% CI: 95% confidence interval. n = 63

A substantial correlation was found between the T2 and SRK/T formulas.

Correlations between the SRK/T and Holladay 1 formulas and between the Holladay 1 and T2 formulas were also substantial, but with only moderate lower limits of the confidence intervals.

### Analysis of Calculation Methods

Since the main difference between the T2 and SRK/T formulas is the estimation of $H$, the behaviors of $L$ and keratometry were analyzed respect to Corneal Height.

$L$ is used without any modification in $H_2$, while an adjusted $L$ (LCOR) is required by the HSRK/T formula. A correlative analysis was performed between both $H$-calculation methods and $L$, with the results being a very low correlation between HSRK/T and $L$ (Table 5) but a strong positive correlation between $H_2$ and $L$ ($r = 0.808; p < 0.05$).

Table 5.0 Correlation between different methods of Corneal Height estimation and associated variables.
|                  | Axial Length | Mean Keratometry |
|------------------|--------------|------------------|
| HSRKT            |              |                  |
|                  | $r = 0.224$  | $r = 0.805$      |
|                  | $p = 0.078$  | $p < 0.01$       |
| H2               |              |                  |
|                  | $r = 0.808$  | $r = 0.265$      |
|                  | $p < 0.01$   | $p < 0.05$       |
| H2.2             |              |                  |
|                  | $r = 0.425$  | $r = 0.695$      |
|                  | $p < 0.01$   | $p < 0.01$       |

HSRK/T: Corneal height estimation using SRK/T, H2: Corneal height estimation using T2, H2.2: Corneal height estimation using the alternative T2 formula.

This finding is important for the following reasons: (1) it suggests that L has a strong effect on the estimation of H calculated with the method included in the T2 formula; (2) it might explain the higher MedAE seen in highly myopic eyes with the T2 formula; and (3) it indicates that LCOR may be why L has less impact when H is estimated with the SRK/T approach.

In summary, modifying the calculation of H in the T2 formula improves its accuracy, resulting in a lower MedAE in eyes with normal L. However, the benefit of this adjustment seems to be lost in longer eyes, probably due to the effect of L on the estimation of H. On the other hand, the SRK/T formula seems to be less affected by an extreme L, which could be associated with the inclusion of LCOR in its design.

The second variable needed to calculate H is the keratometry. The average keratometry was found to have a strong positive relationship with HSRK/T ($r = 0.805$, $p < 0.05$), but a negligible correlation with H2 ($r = 0.265$, $p < 0.05$).
**Improvement Options**

Corneal Height (H) The performed analyses suggested that the presence of LCOR reduces the impact of extreme AL values in the estimation of H. Therefore, including the corrected AL in the T2 formula might improve its behavior in long eyes. Therefore, a formula which might both, solve the SRK/T cusp problem and include LCOR was needed. The easiest way to complete this task was using the second regression formula described by Sheard et al. in the original paper on the T2 formula. This second regression formula was excluded from the final T2 method because of its slightly lower correlation.\(^7\) In the present study, this formula is named H2.2 and is calculated as follows:

\[
H2.2 = -11.980 + 0.38626 \times \text{LCOR} + 0.14177 \times K
\]

Estimations of H using the H2.2 formulas were compared with results obtained using the HSRK/T and H2 formulas (Graph No. 2, Table 6). The H2.2 method reduced the mean H value and the reported range of values.

Table 6.0 Corneal Height estimation using three methods

|       | Minimum | Maximum | Mean  | Standard Deviation |
|-------|---------|---------|-------|--------------------|
| HSRKT | 3.5101  | 6.6086  | 4.2713| ±0.5490            |
| H2    | 3.7947  | 5.4057  | 4.3567| ±0.3503            |
| H2.2  | 3.6395  | 4.7624  | 4.0631| ±0.23624           |

HSRK/T: Corneal height estimation using SRK/T, H2: Corneal height estimation using T2, H2.2: Corneal height estimation using the alternative T2 formula, n = 63.

Statistically significant differences were found between the H2.2 and H2 formulas (p < 0.005), as well as between the H2.2 and HSRK/T formulas (p < 0.005). A moderate
correlation was found between H2.2 and average keratometry (r = 0.695, p < 0.05), and a low correlation was found between L and H2.2 (r = 0.425, p < 0.05).

These results suggest that the H2.2 formula might improve H estimations, reducing the mean H, the range of extreme values, and the influence of very high keratometry and L values. When H2.2 was used to estimate IOL, the MAE and MedAE were respectively 0.433 and 0.3815 (Table 7).

Table 7. Prediction error applying T2 with the alternative corneal height estimation method and optimization of axial length

| Formula                      | MAE    | Standard Deviation | Minimum | Maximum | MedAE | ≤±0.50 D | ≤±1.0 D | Sum of errors | >2.0 D |
|------------------------------|--------|--------------------|---------|---------|-------|----------|---------|---------------|--------|
| T2 using H2.2 alone         | 0.433  | ±0.0117            | 0.003   | 1.3856  | 0.381 | 69.84%   | 22.22%  | 92.06         | 7.93%  |
| T2 using H2.2 and optimized L | 0.425  | ±0.3318            | 0.002   | 1.382   | 0.364 | 68.25%   | 23.81%  | 92.06         | 0%     |

H2.2 = Corneal height estimation according to the alternative T2 formula, Optimized L: Adjustment of L according to Wang L et al. \(^{13}\) n=63.

While these results are only slightly better than T2 formula, a better estimation of H in highly myopic patients is obtained.

Optimized Axial Length An additional approach to improve results of the T2 formula...
in highly myopic eyes is to optimize axial length. Since H2.2 includes LCOR, the method described by Wang L et al.\textsuperscript{13} for the SRK/T formula can be used directly. When this approach was tested, the MedAE and MAE were even lower than obtained with H2.2 alone (Table 7).

DISCUSSION

The accuracy of the SRK/T formula in highly myopic patients has long been established,\textsuperscript{2,4,8} in spite of this, flaws estimating H have been described.\textsuperscript{6,7} The T2 formula, developed by Sheard et al.,\textsuperscript{7} improves H prediction and significantly reduces the prediction error in normal eyes. It could, therefore, be assumed that the T2 formula would perform better than the SRK/T formula among highly myopic patients, but the present investigation found that SRK/T formula could still be a better choice.

The SRK/T approach for estimating H utilizes keratometry and L, The axial length estimation is corrected using LCOR when it is higher than 24.2 mm.\textsuperscript{5} The resulting H value in highly myopic patients includes errors such as the H cusp and LCOR reversal,\textsuperscript{7} both of which result in a far greater H estimation than what could be considered normal, even for myopic patients. This is evident when studies of corneal height measurement in vivo are considered. For instance, Dong Hyun Kim et al.\textsuperscript{14} reported a mean H value of 3.71 ± 0.23 mm, measured by optical coherence tomography, in patients with a mean L of 28.00 mm. Another study comparing the eyes of anisometric patients reported that ACD did not differ greatly between the shorter and longer eye, even when very highly myopic patients were included. Therefore, ACD and H values in highly myopic patients do not differ extremely from
the values for normal eyes. The increased L in highly myopic eyes depends mostly on the vitreous cavity and not on an extremely deep anterior chamber.\textsuperscript{15}

The T2 formula solves the H cusp problem\textsuperscript{7}, but the equation used in the original report did not include LCOR. According to the findings of the present study, LCOR might be an important factor related to the higher precision of the SRK/T formula in highly myopic eyes. In addition, the H2 equation, included in the T2 formula, resulted in a higher mean H than the method used by the SRK/T formula. This could partially explain the higher MedAE and MAE values when applying the T2 formula to highly myopic eyes.

In this regard, the solution to improve the T2 prediction error proposed in the present study includes two parts. First, since LCOR helps improve the H estimate in the SRK/T formula, this step was included in the T2 estimation of H, specifically using the second regression formula described in the report on the T2 formula.\textsuperscript{7} The result of this change was a more precise H estimation than that obtained using either HSRK/T or the regular H2 method. The second step was to improve L estimation. This goal was accomplished by using a published L optimization equation for SRK/T,\textsuperscript{7} which resulted in lower MAE and MedAE values than those observed using T2 alone.

An issue of including LCOR in the T2 formula might be that in very long eyes (i.e. L > 36.2 mm) the LCOR reversal phenomenon appears, therefore a formula that uses the SRK/T platform together with additional solutions should assess this concern to best fit the requirements of long eyes. Methods to optimize L could be applied directly to the T2 formula or the described H2.2 method.

Other studies have tested the T2 formula in different settings (Table 8), and no
definitive consensus exists regarding the accuracy of the T2 vs SRK/T formulas in long eyes. One study found better results using SRK/T\textsuperscript{8}, while another described better accuracy using T2\textsuperscript{9}. The results of the present study are similar to previous analyses of the SRK/T and Holladay 1 formulas\textsuperscript{2,8}, but new information is provided in relation to calculating H. Suggestions for improving IOL calculations in highly myopic patients are provided. Despite these contributions, an important limitation of the present study is the relatively small sample size. This limitation is due to the relative infrequency of highly myopic eyes, even among very large sample pools. The inclusion of more highly myopic cases may be needed to clarify the presented observations and to develop necessary optimization formulas.

Table 8. Comparison of studies that include the T2 formula
|                                      | Kane, et al (2016) | Cooke & Cooke (2016) | Sheard et al (2010) | Present study |
|--------------------------------------|--------------------|----------------------|---------------------|---------------|
| **Total studied eyes (no. of long-eyes)** | 3241 (77)          | 1454 (54)            | 11189 (not target of study) | 63 (63) |
| **Long eye definition**              | >26.0 mm           | PCI (25.97–29.44 mm) | OCLR (26.02–29.51 mm) | Not target of study | >25.0 mm |
| **Formulas: MAE/MedAE**              | T2: 0.498/0.440    | PCI group T2: 0.319/0.269 | SRK/T: 0.399/0.368 | Holladay 1: 0.495/0.473 |
|                                      | SRK/T: 0.484/0.419 |                     |                     | OCLR group T2: 0.293/0.251 |
|                                      | Holladay 1: 0.586/0.441 |                   |                     | SRK/T: 0.392/0.344 |
|                                      |                     |                     |                     | Holladay 1: 0.505/0.479 |

*Only results concerning the studied formulas are shown. PCI = Partial coherence interferometry  OCLR = Optical low coherence reflectometry

Calculating the IOL in highly myopic eyes is still a complicated issue, and even with modern formulas, errors still exist. This reality underscores the importance of continued investigation and improvement in this subject. The SRK/T formula is one of the most accurate for long-eyed patients with the advantage of being readily available in different settings. Therefore, improving this method remains a relevant aim, even in the presence of new generation formulas.

Additionally, a more accurate estimation of H might benefit eyes with steep
irregular corneas, such as those observed after refractive surgery or in the presence of keratoconus, where the use of a value closer to normal may lower prediction errors. The fact that the most important source of error in third generation formulas is the ACD estimation\textsuperscript{16} makes the findings of this study relevant and points to ways for physicians to improve their calculations in highly myopic patients.

CONCLUSIONS

The T2 formula is recognized as the most precise option compared to the SRK/T and Holladay 1 formulas for the overall population (i.e. normal eyes). Nevertheless, evidence is contradictory regarding its accuracy in the highly myopic.

This paper provides evidence showing that T2 is less precise than SRK/T in the highly myopic eyes and describes a method to improve the corneal height estimation and the accuracy of the T2 formula.

A future study with more patients would be important in order to verify the findings in this paper. The addition of very long eyes, optimized constants, different intraocular lens designs and more formulas (like Olsen and Haigis) would allow for better comparison and confirmation of the effects found here.

ABBREVIATIONS

95% CI: 95% confidence interval.

A = constant used for $\text{SRK/T}^5$

ACD: Anterior Chamber Depth

ACD\text{const} = constant used for anterior chamber depth in $\text{SRK/T}$ formula for specific IOL/surgeon; can be computed from A-constant\textsuperscript{5}
Cw = corneal width computed from L and K (mm)\textsuperscript{5}

D: Diopters

ETDRS: Early Treatment Diabetic Retinopathy Study visual acuity test

H: Corneal Height – theoretical estimation of the distance from a plane which lies above the anterior surface of the iris and the top of the central cornea at its endothelial surface, this model regards the cornea as a dome which base lies at the anterior iris. The corneal width and the corneal curvature are employed to estimate this value.

H2.2: Corneal Height Calculated with formula number 2, described by Sheard et al.\textsuperscript{7}

H2: Corneal Height Calculated with formula number 1, described by Sheard et al.\textsuperscript{7}

HSRK/T: Corneal Height Calculated with steps 2 to 4 of the SRK/T formula.\textsuperscript{5,7}

IOL: Intraocular Lens

K: Keratometry. In appendix 1 it refers exclusively to the averaged Keratometry where the abbreviation was kept in order to preserve the original description of the SRK/T\textsuperscript{5}.

L = axial length measured using ultrasound in the original SRK/T paper\textsuperscript{5} and the IOL Master Biometer ® (mm) in this paper

LCOR: axial length with long eye correction; used in height formula\textsuperscript{5}

LogMar: Logarithm of the Minimum Angle of Resolution

MAE: Mean Absolute Error

Max: Maximum,

MedAE: Median Absolute Error

Min: Minimum;
mm: millimeters

n: Number of eyes studied.

offset = difference between corneal height of the average eye and the ACD-constant of a given IOL\(^5\)

OLCR = Optical low coherence reflectometry

PCI = Partial coherence interferometry

PostOp: Postoperative;

PreOp: Preoperative;

r = averaged corneal radius of curvature (mm)\(^5\)

SD: Standard Deviation;

SN60W: Biconvex, Aspheric Intraocular lens model by Alcon \(^®\), made of an Acrylate/Methacrylate Copolymer

SRK/T: Third generation formula for intraocular lens calculation developed by Sanders, Retzlaff , and Kraff

T2.2 OPTAL: calculation of introaocular lens using two improvement methods for the SRK/T formula: the H2.2 formula for corneal height\(^7\) and the optimized axial length by Wang et al\(^{13}\).

T2: formula developed by Sheard et al. for intraocular lens calculation based on the SRK/T\(^7\)

VA: Visual acuity

X: Mathematical estimation used as part of the calculation of the Corneal Height in the SRK/T formula

yo: years old;

\(\rho_c\): Lin’s concordance correlation coefficient,
Declarations

**Ethics Approval and Consent to Participate:** Ethics approval was sought and obtained from “Comité de Ética de la Clínica Barraquer”, in Bogotá Colombia. All methods adhered to the Helsinki Declaration. The Institutional Review Board waived the need for written informed consent of the participants.

**Consent for publication:** Not applicable in this study.

**Availability of data and material:** The datasets generated and/or analysed during the current study are available in the Mendeley repository, https://data.mendeley.com/datasets/nhgcnrjs9k/1, **DOI:** 10.17632/nhgcnrjs9k.1

**Competing Interests:** The authors declare that they have no competing interests.

**Funding:** No funding body participated in the present work. Authors were in charge of all costs related to study design, collection, analysis and interpretation of data as well as writing the manuscript.

**Authors’ contributions**

CI: Contributed with the study design, collection, analysis and interpretation of the data and writing of the manuscript.
GS: Contributed with the collection, interpretation of the data and writing of the manuscript.
AMG: Contributed with the collection and interpretation of the data and writing of the manuscript.

All authors have read and approved the manuscript.

**Acknowledgements:**

We would like to thank :

Edward Averbukh MD. Ophthalmologist, Retina and Vitreous Specialist at Hadassah Ein Keren Hospital (Jerusalem, Israel), for his advice during the design of this study and providing the cases from the Hadassah Hospital sample group.

We sincerely thank Dr. Kenneth J. Hoffer, MD and Clinical Professor of Ophthalmology at UCLA, for his advice in the design of the present study.

We want to acknowledge Dr. Richard M. Sheard, MD at the Royal Hallamshire Hospital, for providing the IOL calculation tool used in the present study.

We want to thank Clara López de Mesa, Epidemiologist at Clínica Barraquer, and the Research Department of Clínica Barraquer (Bogotá, Colombia) for the advice and aid regarding research.
methodology and statistics. Also Mireya Mora, Research Coordinator. We would like to acknowledge Eduardo Fuentes, PhD and Ashley VanCott for aiding in the composition of this article.

**Authors' information**

Carlos Idrobo MD is an Ophthalmologist and retina and vitreous specialist at the Eugenio Espejo Hospital, Quito - Ecuador. Former Retina and Vitreous Fellow in the Hadassah Ein Keren Hospital, Jerusalem – Israel and former Ophthalmology Resident in the Clínica Barraquer, Bogotá Colombia.

Guisella Santaella MD, is a Cataract and Refractive Surgery specialist in the Clínica Barraquer, Cornea & External Disease & Refractive Surgery fellow at the University of Toronto.

Angela María Gutiérrez MD, is a Cornea, Cataract and Refractive Surgery specialist at the Clínica Barraquer, Dean of the Instituto Barraquer de América and former President of The Sociedad Colombiana de Oftalmología.

**References**

1. Rajan MS, Keilhorn I, Bell JA. Partial coherence laser interferometry vs conventional ultrasound biometry in intraocular lens power calculations. Eye. 2002;16(5):552.

2. Abulafia A, Barrett GD, Rotenberg M, et al. Intraocular lens power calculation for eyes with an axial length greater than 26.0 mm: Comparison of formulas and methods. J Cataract Refract Surg. 2015;41(3):548-556.

3. Bang S, Edell E, Yu Q, Pratzer K, Stark W. Accuracy of Intraocular Lens Calculations Using the IOLMaster in Eyes with Long Axial Length and a Comparison of Various Formulas. Ophthalmology. 2011;118(3):503-506.

4. Chong EW, Mehta JS. High myopia and cataract surgery: Curr Opin Ophthalmol.
5. Retzlaff JA, Sanders DR, Kraff MC. Development of the SRK/T intraocular lens implant power calculation formula. J Cataract Refract Surg. 1990;16(3):333-340.

6. Haigis W. Occurrence of erroneous anterior chamber depth in the SRK/T formula. J Cataract Refract Surg. 1993; 19(3):442-446.

7. Sheard RM, Smith GT, Cooke DL. Improving the prediction accuracy of the SRK/T formula: The T2 formula. J Cataract Refract Surg. 2010;36(11):1829-1834.

8. Kane JX, Van Heerden A, Atik A, Petsoglou C. Intraocular lens power formula accuracy: Comparison of 7 formulas. J Cataract Refract Surg. 2016;42(10):1490-1500.

9. Cooke DL, Cooke TL. Comparison of 9 intraocular lens power calculation formulas. J Cataract Refract Surg. 2016;42(8):1157-1164.

10. Optimized IOL constants for the ZEISS IOLMaster. http://ocusoft.de/ulib/c1.htm. Accessed July 4, 2016.

11. Hoffer KJ, Aramberri J, Haigis W, et al. Protocols for Studies of Intraocular Lens Formula Accuracy. Am J Ophthalmol. 2015;160(3):403-405.e1.

12. Nickerson CAE. A Note On “A Concordance Correlation Coefficient to Evaluate Reproducibility.” Biometrics. 1997;53(4):1503-1507.

13. Wang L, Shirayama M, Ma XJ, Kohnen T, Koch DD. Optimizing intraocular lens power calculations in eyes with axial lengths above 25.0 mm. J Cataract Refract Surg. 2011;37(11):2018-2027.

14. Kim DH, Kim MK, Wee WR. Estimation of Intraocular Lens Power Calculation after Myopic Corneal Refractive Surgery: Using Corneal Height in Anterior
Segment Optical Coherence Tomography. Korean J Ophthalmol. 2015;29(3):195.

15. Kim S-Y, Cho SY, Yang JW, Kim CS, Lee YC. The Correlation of Differences in the Ocular Component Values with the Degree of Myopic Anisometropia. Korean J Ophthalmol. 2013;27(1):44.

16. Jeong Jinho, Song Han, Lee Jimmy K, Chuck Roy S, Kwon Ji-Won, The effect of ocular biometric factors on the accuracy of various IOL power calculation formulas, BMC Ophthalmology (2017) 17:62.

Appendix 1

Steps for calculating corneal height using the SRK/T method:

1. Corneal radius of curvature, \( r = \frac{337.5}{K} \)

2. Corrected axial length, \( \text{LCOR} \):

   If \( L \leq 24.2 \) then \( \text{LCOR} = L \)

   If \( L \geq 24.2 \) then \( \text{LCOR} = -3.446 + 1.716L - 0.0237 \times L^2 \)

3. Computed corneal width \( (C_w) \):

   \( C_w = -5.40948 + 0.58412 \times \text{LCOR} + 0.098 \times K \)

4. Corneal height \( (H) \):

   \( X = r^2 - (C_w^2/4) \)

   If \( x < 0 \) then \( x = 0 \)

   \( H = r - \sqrt{X} \)

5. Offset for specific intraocular lens (IOL) to be implanted:

   \( \text{Offset} = ACD_{\text{const}} - 3.336 \)
Steps in the T2 formula for calculating corneal height (H2)

\[ H_2 = -10.326 + 0.32630 \times L + 0.13533 \times K \]

Alternative formula for estimating T2 (H2.2)

\[ H_{2.2} = -11.980 + 0.38626 \times \text{LCOR} + 0.14177 \times K \]

Figures

Figure 1

Graph No. 1. Median and Mean Absolute Error of the T2, SRK/T and Holladay 1 for
Figure 2

Box plot of Corneal Height estimations using SRK/T, T2 and the alternative Cornea: