Accuracy of seven intraocular lens power calculation formulas: according to corneal power

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Article

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Abstract

OBJECTIVES: To investigate the influence of corneal power on the accuracy of seven intraocular lens power calculation formulas in cataract surgery.

METHODS: Retrospective case series study. A total of 336 eyes were enrolled from 336 patients undergoing uncomplicated cataract surgery. The Barrett Universal II, Emmetropia Verifying Optical V.2.0 (EVO2.0), Haigis, Kane, K6, PearlDGS, and SRK/T formulas were analyzed. The mean prediction error, absolute prediction error, mean absolute prediction error, median absolute error (MedAE), and the percentage of eyes with a prediction error (PE) within ±0.25 D, ±0.50 D, ±0.75 D, ±1.00 D and ±2.00 D were calculated.

RESULTS: Across the entire cohort, the K6 formula had the lowest MedAE (0.23 D) and the highest percentage of eyes within ±0.50 D (80.06%). In the flat corneal power group (mean of the keratometry reading ≤ 43.0 D), the EVO2.0 (optional) and Kane (all) formulas had the highest percentage of eyes with a PE within ±0.50 D (86.15%). In the steep corneal power group (mean of the keratometry reading ≥ 46.0 D), the K6, EVO2.0 (all), and EVO2.0 (optional) formulas had the highest percentage of eyes with a PE within ±0.50 D (all were 83.33%).

CONCLUSIONS: Overall, the new-generation formulas performed better in eyes with extreme corneal power, particularly the EVO2.0 (optional) formula with flat corneal power and the K6 formula with steep corneal power. Both the old and new formulas displayed similar accuracy in eyes with medium corneal power.

Introduction

When ocular biometric measurements are obtained accurately and appropriate intraocular lens (IOL) power calculation formulas are used, the prediction error (PE) after cataract surgery can be reduced. Despite this, the PE would be exacerbated by extreme ocular parameters, including axial length (AL), anterior chamber depth (ACD, as measured from the corneal epithelium to the lens), corneal power, and lens thickness (LT) [1].

There has been a development of new-generation formulas in recent years. They are based on more complex principles and use a greater number of ocular parameters for calculation, including the Emmetropia Verifying Optical Version 2.0 (EVO 2.0), Hill-RBF, Kane, K6, PEARL-DGS and VRF-G formulas [2–5]. Currently, the third- and fourth-generation IOL power calculation formulas, including Barrett Universal II (BUII), Hoffer Q, Haigis, and SRK/T, are the most commonly used [6–9]. These formulas have previously been observed to perform well in eyes with normal ocular parameters [1, 10–12]. In comparison with earlier formulas, the new-generation formulas demonstrated greater accuracy, even in eyes with an extreme AL [13, 14], ACD [13] and other parameter combinations [15].

Corneal power plays an important role in the IOL power calculation as one of the essential ocular biometric parameters. Previous evidence from a large-sample study showed that extreme corneal power can impact the accuracy of IOL power calculation formulas [16–20]. Nevertheless, most of the studies conducted in the past compared the accuracy of the third- and fourth-generation formulas in the case of eyes with extreme corneal power. The Hoffer Q, SRK/T, Haigis, and BUII formulas did not display a high accuracy in eyes with steep corneal power [16–18]. Taking into account both AL and corneal power, the Haigis formula provided accurate results [19]. Only a few studies used the new-generation formulas, such as the Hill RBF and Olsen C formulas. There is a significant improvement in the accuracy of the new-generation formulas over the old ones [16, 20]. It is unclear whether the new generation of formulas will have better prediction accuracy in different corneal curvature ranges.
This study aims to examine the effect of corneal power on the prediction accuracy of different IOL calculation formulas. In comparing the accuracy of the new-generation IOL power calculation formulas (EVO2.0, Kane, K6, Pearl-DGS) and some earlier formulas (BUIII, Haigis, SRK/T), we hope to provide helpful suggestions for IOL calculation formula selection.

Materials And Methods

Patients and measurements

This was a retrospective case series study. From January 2019 through to December 2021, consecutive patients underwent uncomplicated cataract surgery at the Eye Hospital of Wenzhou Medical University. Two experienced cataract surgeons (LJ and HF) performed the phacoemulsification with in-the-bag implantation of the same IOL model (SN6CWS, Alcon, Fort Worth, TX, USA). The criteria for selecting the subjects largely followed the IOL power calculations published by Kenneth et al in 2020 [21]. Each patient had only one eye included. In the case of sequential bilateral cataract surgery, the right eye was selected. Only eyes with a corrected distance visual acuity of at least 20/40 were enrolled after surgery. The patients who had a history of eye disease, previous ocular surgery, invalid biometry, intraoperative or postoperative complications, or an absence of postoperative manifest refraction were excluded.

Preoperative ocular parameters of all patients were determined using the Lenstar LS900 (Haag-Streit AG, Koeniz, Switzerland), including AL, ACD, flat keratometry reading (K1), steep keratometry reading (K2), central corneal thickness (CCT), white-to-white, and LT. The mean of the keratometry reading (Km) was the meridian of the flat and steep keratometry readings. The manifest refraction was assessed at least three weeks to three months after surgery when refractive outcomes had stabilized.

IOL power calculation

On the basis of the following formulas, spherical equivalent predictions were obtained: BUIII, EVO2.0, Haigis, Kane, K6, Pearl-DGS, and SRK/T formulas. The Kane (all) and EVO2.0 (all) formulas were calculated with all parameters, including the AL, K1, K2, ACD, LT, and CCT, whereas the Kane (optional) and EVO2.0 (optional) formulas were calculated without the LT and CCT. The keratometric index was 1.3375.

The refractive PE was calculated as the difference between the spherical equivalent of the postoperative manifest refraction and the predicted spherical equivalent of each formula. A positive PE value indicated a hyperopic shift, whereas a negative PE value indicated a myopic shift. The absolute error (AE) was the absolute value of the PE. The mean refractive prediction error (ME), mean absolute error (MAE), median absolute error (MedAE), and the percentage of eyes with a PE within ±0.25 D, ±0.5 D, ±0.75 D, ±1.00 D and ±2.00 D were calculated.

The built-in software of the Lenstar LS900 device was used to perform the spherical equivalent predictions of the BUIII, Haigis, and SRK/T formulas. The Kane conditions used for the EVO2.0 and Pearl-DGS formulas were calculated manually using their respective online calculators. The calculation was based on the optimized IOL constants available on the User Group for Laser Interference Biometry (ULIB) website. The mean PE of the SRK/T formula was close to zero with the optimized constant provided by the ULIB website but not the other formulas. To zero out the mean PE, the IOL constants of each formula were adjusted for the entire dataset of patients. The BUIII and Haigis formulas were optimized and calculated by Warren Hill MD. The EVO2.0, Kane, K6, and Pearl-DGS formulas were optimized and calculated by their respective authors (Jack Kane MD, Tun Kuan Yeo MD, David Cooke MD, Guillaume Debellemanière...
MD). It should be noted that the Pearl-DGS formula was optimized using the latest version, which was then not available online (accessed May 1st, 2022).

**Statistical analysis**

The data were analyzed with the SPSS software (version 25.0, IBM Corp.). The Kolmogorov-Smirnov test was used to detect normality. For each formula, a 1-sample t-test was performed to determine whether the mean PE differed significantly from zero. Non-normal distributions of the PE was tested using the nonparametric Wilcoxon test. A one-way analysis of variance with a post hoc test was performed to assess the difference in the PE between the formulas. The Friedman test was used to compare AE differences, followed by Wilcoxon signed-rank tests for post hoc analysis and Bonferroni correction for multiple comparisons. Comparing the percentage of eyes with a PE within different diopter ranges was performed using Cochran's Q test. A *P*-value < 0.05 was considered to be statistically significant.

**Results**

A total of 336 eyes from 336 patients were enrolled. The mean age of the participants was 70.29 years (range 33–87 years), including 114 men (33.9%) and 222 women (66.1%), and 216 right eyes (64.3%) and 120 left eyes (35.7%). Table 1 summarized the biometric ocular parameters of the patients before surgery. On the basis of the Km, all patients were divided into three subgroups: flat corneal power subgroup (Km < 43 D), medium corneal power subgroup (43 D ≤ Km < 46 D), and steep corneal power subgroup (Km ≥ 46 D). The subgroups with flat and steep corneal power represented approximately 20% of the patients, respectively.
Table 1
Preoperative patient biometric ocular parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean ± SD/ Median (IQR)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial length, mm*</td>
<td>23.33 (0.7)</td>
<td>21.21–31.98</td>
</tr>
<tr>
<td>Anterior chamber depth, mm</td>
<td>3.01 ± 0.44</td>
<td>1.69–4.28</td>
</tr>
<tr>
<td>Flat keratometry (K1), D</td>
<td>44.14 ± 1.71</td>
<td>39.77–49.36</td>
</tr>
<tr>
<td>Steep keratometry (K2), D</td>
<td>44.85 ± 1.71</td>
<td>40.65–50.76</td>
</tr>
<tr>
<td>Mean of keratometry (Km), D</td>
<td>44.49 ± 1.68</td>
<td>40.21–50.06</td>
</tr>
<tr>
<td>Corneal central thickness, µm</td>
<td>535.09 ± 34.13</td>
<td>439–649</td>
</tr>
<tr>
<td>White-To-White, mm</td>
<td>11.54 ± 0.46</td>
<td>9.89–13.07</td>
</tr>
<tr>
<td>Lens thickness, mm</td>
<td>4.47 ± 0.49</td>
<td>2.77–5.88</td>
</tr>
<tr>
<td>Axial length distribution, n (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AL 22.0mm</td>
<td>29</td>
<td>8.6%</td>
</tr>
<tr>
<td>22.0mm ≤ AL 26.0mm</td>
<td>289</td>
<td>86.0%</td>
</tr>
<tr>
<td>AL ≥ 26.0mm</td>
<td>18</td>
<td>5.4%</td>
</tr>
<tr>
<td>Keratometry subgroups, n (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Km 43.0D (Flat)</td>
<td>65</td>
<td>19.3%</td>
</tr>
<tr>
<td>43.0D ≤ Km 46.0D (Medium)</td>
<td>205</td>
<td>61.0%</td>
</tr>
<tr>
<td>Km ≥ 46.0D (Steep)</td>
<td>66</td>
<td>19.6%</td>
</tr>
</tbody>
</table>

*Data with a non-normal distribution was shown as the median and interquartile range (IQR).

SD, standard deviation; D, diopter; IOL, intraocular lens.

Formula accuracy in all patients

As shown in Table 2, the results of the ME, MAE, MedAE, and percentage of eyes with a PE within different diopter ranges were summarized. For any formula, the PE was not normally distributed, and the ME was not significantly different from zero. The K6 formula had the lowest MAE and MedAE (0.30 D, 0.23 D, respectively), while the Haigis formula had the highest (0.35 D, 0.27 D, respectively). As indicated by the Friedman test ($P < 0.001$), there was a statistical difference between the AEs of all formulas. Post hoc analysis using Wilcoxon signed-rank pairwise comparisons for nonparametric samples with Bonferroni correction did not show a statistical difference ($P = 0.266$). The results of the Cochran's Q test indicated no significant difference among all formulas in the percentage of eyes with a PE within ± 0.25 D or ± 0.50 D ($P = 0.232$, $P = 0.100$, respectively). The EVO2.0 (all) and EVO2.0 (optional) formulas significantly outperformed the Haigis formula in the percentage of eyes with a PE within ± 0.75 D ($P = 0.002$). Compared to the Haigis formula, the EVO2.0 (optional), Pearl-DGS, and BUII formulas had significantly higher percentages of eyes with a PE within ± 1.0 D ($P = 0.001$).
### Table 2
Predictive outcomes of IOL calculation formulas in all patients

<table>
<thead>
<tr>
<th></th>
<th>Kane (all)</th>
<th>Kane (optional)</th>
<th>EVO2.0 (all)</th>
<th>EVO2.0 (optional)</th>
<th>K6</th>
<th>Pearl-DGS</th>
<th>BUII</th>
<th>SRK/T</th>
<th>Haigis</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOL constant</td>
<td>119.17</td>
<td>119.06</td>
<td>119.17</td>
<td>119.17</td>
<td>119.28</td>
<td>119.33</td>
<td>1.97</td>
<td>119.00</td>
<td>-1.041, 0.241, 0.231</td>
</tr>
<tr>
<td>ME ± SD</td>
<td>0.00 ± 0.40</td>
<td>0.00 ± 0.41</td>
<td>0.00 ± 0.40</td>
<td>0.03 ± 0.40</td>
<td>0.00 ± 0.41</td>
<td>0.03 ± 0.43</td>
<td>0.00 ± 0.45</td>
<td>0.00 ± 0.45</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>-1.15, 1.30</td>
<td>-1.26, 1.41</td>
<td>-1.21, 1.44</td>
<td>-1.20, 1.43</td>
<td>-1.10, 1.49</td>
<td>-1.03, 1.45</td>
<td>-1.71, 1.30</td>
<td>-1.74, 1.57</td>
<td>-1.26, 1.47</td>
</tr>
<tr>
<td>MAE</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
<td>0.30</td>
<td>0.31</td>
<td>0.32</td>
<td>0.34</td>
<td>0.35</td>
</tr>
<tr>
<td>MedAE</td>
<td>0.24</td>
<td>0.25</td>
<td>0.24</td>
<td>0.24</td>
<td>0.23</td>
<td>0.24</td>
<td>0.23</td>
<td>0.25</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Percentage of Eyes within Diopter Range Indicated:

<table>
<thead>
<tr>
<th></th>
<th>± 0.25D</th>
<th>0.50D</th>
<th>±0.75D*</th>
<th>±1.00D*</th>
<th>±2.00D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>52.08</td>
<td>50.89</td>
<td>53.57</td>
<td>53.57</td>
<td>53.27</td>
</tr>
<tr>
<td></td>
<td>53.57</td>
<td>78.57</td>
<td>94.64</td>
<td>97.62</td>
<td>100.0</td>
</tr>
<tr>
<td></td>
<td>53.27</td>
<td>80.06</td>
<td>94.64</td>
<td>97.92</td>
<td>100.0</td>
</tr>
<tr>
<td></td>
<td>51.79</td>
<td>77.38</td>
<td>91.96</td>
<td>97.62</td>
<td>100.0</td>
</tr>
<tr>
<td></td>
<td>52.98</td>
<td>77.98</td>
<td>91.07</td>
<td>98.21</td>
<td>100.0</td>
</tr>
<tr>
<td></td>
<td>51.49</td>
<td>75.00</td>
<td>91.07</td>
<td>98.21</td>
<td>100.0</td>
</tr>
<tr>
<td></td>
<td>47.32</td>
<td>75.89</td>
<td>89.88</td>
<td>96.13</td>
<td>100.0</td>
</tr>
<tr>
<td></td>
<td>70.00</td>
<td>75.89</td>
<td>89.88</td>
<td>96.13</td>
<td>100.0</td>
</tr>
</tbody>
</table>

EVO2.0, Emmetropia Verifying Optical Formula Version 2.0; BUII, Barrett Universal II; ME, mean prediction error; MAE, mean absolute error; MedAE, median absolute error. Kane (all) and EVO2.0 (all) formulas were calculated with all parameters, including AL, ACD, K1, K2, LT, and CCT. Kane (optional) and EVO2.0 (optional) formulas were calculated without the LT or CCT.

IOL constant: A constant for Kane, EVO2.0, K6, Pearl-DGS, and SRK/T; lens factor for BUII; a1, a2, and a3 for Haigis.

*Co<sub>or</sub>ran's Q test, P < 0.05.

### Formula accuracy according to corneal power

Table 3 and Fig. 1 showed the outcomes of each formula in the different corneal power subgroups.
Table 3
Predictive outcomes of IOL calculation formulas according to corneal power

<table>
<thead>
<tr>
<th></th>
<th>Kane (all)</th>
<th>Kane (optional)</th>
<th>EVO2.0 (all)</th>
<th>EVO2.0 (optional)</th>
<th>K6</th>
<th>Pearl-DGS</th>
<th>BUII</th>
<th>SRK/T</th>
<th>Haigis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Km 43.0D (N = 65)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ME ± SD</td>
<td>-0.05 ± 0.38</td>
<td>-0.01 ± 0.42</td>
<td>0.01 ± 0.38</td>
<td>0.02 ± 0.38</td>
<td>0.00 ± 0.39</td>
<td>-0.06 ± 0.39</td>
<td>0.07 ± 0.47</td>
<td>0.18 ± 0.46</td>
<td>-0.22 ± 0.44</td>
</tr>
<tr>
<td>MAE</td>
<td>0.30</td>
<td>0.32</td>
<td>0.29</td>
<td>0.39</td>
<td>0.28</td>
<td>0.34</td>
<td>0.37</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>MedAE</td>
<td>0.29</td>
<td>0.28</td>
<td>0.27</td>
<td>0.26</td>
<td>0.26</td>
<td>0.27</td>
<td>0.25</td>
<td>0.31</td>
<td></td>
</tr>
</tbody>
</table>

Percentage of Eyes within Diopter Range Indicated

|                |           |               |              |                   |    |            |      |       |        |
| ± 0.25D        | 44.62     | 46.15         | 47.69        | 46.15             | 49.23 | 50.77     | 49.23 | 55.38  | 33.85  |
| ±0.50D*        | 86.15     | 78.46         | 84.62        | 86.15             | 83.08 | 80.00     | 78.46 | 70.77  | 64.62  |
| ± 0.75D        | 95.38     | 92.31         | 96.92        | 96.92             | 96.92 | 90.77     | 89.23 | 90.77  |        |
| ± 1.00D        | 98.46     | 98.46         | 98.46        | 98.46             | 96.92 | 95.38     | 93.85 | 95.38  |        |

43.0D ≤ Km 46D (N = 205)

|                |           |               |              |                   |    |            |      |       |        |
| ME ± SD        | 0.01 ± 0.42 | 0.01 ± 0.42    | 0.01 ± 0.42  | 0.01 ± 0.42       | 0.04 ± 0.41 | -0.01 ± 0.42 | 0.02 ± 0.41 | 0.05 ± 0.44 | 0.00 ± 0.43 |
| MAE            | 0.32        | 0.32           | 0.32         | 0.31              | 0.32 | 0.31       | 0.34  | 0.33   |        |
| MedAE          | 0.23        | 0.24           | 0.23         | 0.23              | 0.24 | 0.25       | 0.27  | 0.24   |        |

Percentage of Eyes within Diopter Range Indicated

|                |           |               |              |                   |    |            |      |       |        |
| ± 0.25D        | 53.17     | 51.71         | 55.12        | 56.10             | 53.66 | 51.22     | 54.63 | 51.71  | 50.73  |
| ±0.50D         | 76.59     | 79.02         | 75.12        | 75.12             | 78.05 | 76.10     | 78.05 | 75.61  | 79.02  |
| ± 0.75D        | 92.20     | 90.73         | 93.17        | 93.17             | 92.20 | 91.71     | 92.68 | 90.73  | 91.22  |
| ± 1.00D        | 97.07     | 97.07         | 97.56        | 98.05             | 98.05 | 98.54     | 96.10 | 97.07  |        |

Km ≥ 46D (N = 66)

|                |           |               |              |                   |    |            |      |       |        |
| ME ± SD        | 0.02 ± 0.39 | -0.02 ± 0.37   | -0.04 ± 0.38 | -0.04 ± 0.38      | 0.05 ± 0.38 | 0.08 ± 0.40 | 0.02 ± 0.43 | -0.24 ± 0.37 | 0.23 ± 0.42 |
| MAE            | 0.29        | 0.29           | 0.29         | 0.30              | 0.29 | 0.30       | 0.32  | 0.33   | 0.36   |
| MedAE          | 0.23        | 0.25           | 0.23         | 0.25              | 0.20 | 0.19       | 0.25  | 0.26   | 0.25   |

Percentage of Eyes within Diopter Range Indicated

<p>| | | | | | | | | | |
|                |           |               |              |                   |    |            |      |       |        |
| ± 0.25D        | 56.06     | 53.03         | 54.55        | 53.03             | 56.06 | 54.55     | 51.52 | 48.48  | 50.00  |
| ±0.50D         | 78.79     | 81.82         | 83.33        | 83.33             | 83.33 | 78.79     | 77.27 | 77.27  | 77.27  |
| ± 0.75D*       | 92.42     | 96.97         | 96.97        | 96.97             | 92.42 | 87.88     | 86.36 | 93.94  | 84.85  |
| ± 1.00D        | 98.48     | 98.48         | 98.48        | 98.48             | 96.97 | 98.48     | 100.0 | 98.48  | 93.94  |</p>
<table>
<thead>
<tr>
<th>Kane (all)</th>
<th>Kane (optional)</th>
<th>EVO2.0 (all)</th>
<th>EVO2.0 (optional)</th>
<th>K6</th>
<th>Pearl-DGS</th>
<th>BUII</th>
<th>SRK/T</th>
<th>Haigis</th>
</tr>
</thead>
</table>

EVO2.0.0, Emmetropia Verifying Optical Formula Version 2.0; BUII, Barrett Universal II; ME, mean prediction error; MAE, mean absolute error; MedAE, median absolute error. Kane (all) and EVO2.0 (all) formulas were calculated with all parameters, including AL, ACD, K1, K2, LT, and CCT. Kane (optional) and EVO2.0 (optional) formulas were calculated without LT or CCT.

*Cochran's Q test, P < 0.05.

For flat corneal power subgroups (Km < 43 D), the K6 and Pearl-DGS formulas both had the lowest MAE (0.28 D) and the second lowest MedAE (0.26 D), the SRK/T formula had the lowest MedAE (0.25 D), and the Haigis formula had the highest MAE and MedAE (0.40 D, 0.31 D, respectively). The Friedman test revealed a significant difference in the AE for all the formulas (P < 0.001). However, the Wilcoxon signed-rank pairwise comparisons for nonparametric samples with Bonferroni correction revealed no statistical significance (P = 0.207). The Kane (all) and EVO2.0 (optional) formulas had the highest percentage of eyes with a PE within ± 0.50 D, while the Haigis had the lowest (64.62%). When comparing with the Kane (all), EVO2 (all), EVO2.0 (optional), and K6 formulas, respectively, the percentage of eyes with a PE within ± 0.50 D of the Haigis formula was significantly lower (P < 0.01). In terms of the percentage of eyes with a PE within ± 0.25 D, ± 0.75 D, and ± 1.0 D, there was no significant difference.

For the medium corneal power subgroup (43 D ≤ Km < 46 D), both the EVO2.0 (optional) and BUII formulas had the lowest MAE and MedAE (0.31 D, 0.23 D, respectively), whereas these were the highest for the SRK/T formula (0.34 D, 0.27 D, respectively). Overall, more than 75% of the eyes had a PE within ± 0.50 D with all formulas. A statistical analysis of the AEs and the percentage of eyes within different diopter ranges did not reveal any significant differences among all formulas.

For the steep corneal power subgroup (K ≥ 46 D), the Kane (all), Kane (optional), EVO2.0 (all), and K6 formulas all had the lowest MAE (0.29 D). The Pearl-DGS formula had the lowest MedAE (0.19 D). The MAE of Haigis and the MedAE of the SRK/T were the highest (0.36 D, 0.26 D, respectively). The Friedman test did not show a significant difference between the AEs (P = 0.213). The EVO2.0 (all), EVO2.0 (optional), and K6 formulas had the highest percentage of eyes with a PE within ± 0.50 D (83.33%), whereas the BUII, SRK/T, and Haigis formulas had the lowest (77.27%). The EVO2.0 (all), EVO2.0 (optional), and Kane (optional) formulas significantly outperformed the Haigis formula in terms of the percentage of eyes with a PE within ± 0.75 D (P = 0.013) according to the Cochran's Q test. No significant difference was found between any of the formulas for the percentage of eyes with a PE within ± 0.25 D, ± 0.50 D, or ± 1.0 D.

**Discussion**

This study aimed to assess the prediction accuracy of seven intraocular lens calculation formulas based on the corneal power range. On the basis of our data, both newer and older formulas can provide good refractive outcomes across the entire cohort. The K6 formula was considered one of the best formulas, achieving the lowest MAE and MedAE (0.30 D, 0.23 D, respectively) and the highest percentage of eyes with a PE within ± 0.50 D (80.06%). Although there have not been many studies assessing the K6 formula, it performed well in eyes with short and long ALs, and it was comparable to the Kane and EVO2.0 formulas [3, 14, 22].

The Kane and EVO2.0 formulas also performed well. No matter whether the LT and CCT were used in the calculation, the refractive outcomes of these formulas were extremely close, and there was no statistical difference between them. This finding was consistent with that of Connell and Kane [2], who calculated the Kane formula with three
parameters (AL, K, ACD), and this formula proved more accurate than the BUII, Olsen, and Hill-RBF 2.0 formulas among others. However, this study did not compare the calculation modes with the LT and CCT simultaneously. In the case of the EVO2.0 formula, previous research has shown that refractive outcomes are better without using the ACD [23]. With our findings, it appeared that the LT and CCT had little impact on the Kane and EVO2.0 formulas. There may thus be advantages to using these formulas when only partial parameters are available for the IOL calculation.

The Pearl-DGS formula is a thick intraocular calculation formula that was reported within the last few years [24]. It has been shown in several studies that this formula was not better than the other new formulas [14, 23, 24]. In agreement with our findings, the Pearl-DGS formula did not outperform the Kane, EVO2.0, K6, or BUII formulas, but was slightly better than the SRK/T and Haigis formulas.

As a result of grouping according to the Km, the results of the medium corneal power subgroup (43 D ≤ Km < 46 D) did not demonstrate any significant difference between the formulas. Previous studies indicated that the accuracy of the third- and fourth-generation formulas were similar, but there have been few comparisons of the new formulas [19, 20]. Our study showed that the accuracy of the new and old formulas was quite similar when they were used to predict the eyes with a normal corneal power range.

In the flat corneal power group (Km < 43.0 D), the K6 and Pearl-DGS formulas were slightly accurate. The EVO2.0, Kane, and BUII formulas followed closely. The K6 and Pearl-DGS formulas were slightly better than the BUII formula, which had an extremely high accuracy in a previous study [16]. Surprisingly, the SRK/T formula showed more contradictory results, with the lowest MedAE and the highest percentage of eyes with a PE within ± 0.25 D, but the lowest percentage within ± 0.75 D and ± 1.0D. It was shown in a previous study that the accuracy of the SRK/T formula is affected by extreme ACD values (ACD < 3.0 mm and ACD ≥ 3.5 mm) [15]. Taking the ACD into account, we found that the proportion of extreme ACD values was 79.3% in patients with a PE greater than ± 0.25 D, and this may be the cause of the decrease in accuracy of the SRK/T formula. In previous studies, the SRK/T formula performed relatively well in eyes of an average AL and flat keratometry [19, 20], but was not outperformed by the new-generation formulas, such as the Hill-RBF [16] or Olsen C [20]. With the long AL subgroup, the SRK/T formula was less accurate in the flat corneal power subgroup [19]. On the basis of the above results, the performance of the SRK/T was varied in flat corneal power eyes, and the AL and ACD should be considered when using this formula. In comparison to other formulas, the Haigis formula performed the poorest. As in some previous studies [16, 19, 20], this formula was the least accurate for eyes with flat corneal power and of medium AL. It is possible that such results can be explained in that this formula does not calculate with corneal power. However, it should be noted that the Haigis formula performed well in the eyes with flat corneal power and a long AL [19, 25].

In the steep corneal power group (K ≥ 46 D), the K6 formula performed slightly better than the other formulas. It was closely followed by the Pearl-DGS, EVO2.0, and Kane formulas. Consistent with previous results [16, 20], the newer formulas showed a higher percentage of eyes with a PE within ± 0.50 D in eyes with steep corneal power, such as the EVO2.0 (all), EVO2.0 (optional), and K6 formulas (all were 83.33%). When excluding the AL, the Hill-RBF formula had the highest ± 0.50 D proportion, which was 82.98% [16]. With the Olsen C formula, 81.65% of the eyes with a PE within ± 0.50 D were in the medium AL group, which was the higher than the SRK/T and Haigis formulas [20]. In our study, the AL of the steep corneal power subgroup ranged over 21.21–27.06 mm, which was almost within the normal range. In this case, some new-generation formulas performed well. However, in the long AL and steep corneal power subgroups, the accuracy of most third- and fourth-generation formulas was significantly reduced [18, 26]. Even for the best-performing formulas, such as the BUII [21] and Olsen [11,21], the percentage of eyes with a PE within ± 0.50 D was only approximately 70%. It has been shown in previous studies that some new-generation formulas had higher accuracy in long AL subgroups, such as the Kane [13, 27] and EVO2.0 [13] formulas. Whether these formulas have
higher accuracy in eyes with a long AL and steep corneal power requires further study. The percentage of eyes with a
PE within ± 0.50 D was similar for the BUII, SRK/T, and Haigis formulas (all were 77.27%) in our findings, which was
slightly higher than the proportion in eyes with steep corneal power reported previously [16, 20]. In the case of
extreme corneal power, optimizing the formula by corneal power could improve the accuracy of prediction. It was
possible to increase the percentage of eyes with a PE within ± 0.50 D of the SRK/T formula from 65.38–80.77% after
optimizing average keratometry values [16].

Some limitations have been identified in this study. Firstly, this was a retrospective study with a relatively small
sample size. In addition, it did not include many extreme eye parameters, with most eyes having a normal AL (22.0
mm ≤ AL < 26.0 mm). A sample of eyes with a long or short AL could not be subdivided based on the corneal
power for further analysis. Moreover, all surgeries were performed by two skillful surgeons, which may have had a
mild impact on the postoperative refraction.

In summary, the new-generation formulas performed better in eyes with extreme corneal power, particularly the
EVO2.0 (optional) formula with flat corneal power and the K6 formula with steep corneal power. Both the old and new
formulas showed similar accuracy in eyes with medium corneal power. The LT and CCT had little effect on the
calculation of the Kane and EVO2.0 formulas.

Summary

What as known before

In comparison with earlier formulas, the new-generation formulas demonstrated greater accuracy, even in eyes with
an extreme AL, ACD and other parameter combinations. Corneal power plays an important role in the IOL power
calculation as one of the essential ocular biometric parameters. It is unclear whether the new generation of formulas
will have better prediction accuracy in different corneal curvature ranges.

What this study adds

The new-generation formulas performed better in eyes with extreme corneal power, particularly the EVO2.0 (optional)
formula with flat corneal power and the K6 formula with steep corneal power. Both the old and new formulas
displayed similar accuracy in eyes with medium corneal power. The LT and CCT had little effect on the calculation of
the Kane and EVO2.0 formulas.

Declarations

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Competing interests None declared.

Ethical approval All included patients provided informed written consent. The Declaration of Helsinki tenets were followed in this study. Ethical approval was obtained from the Institution Review Board of the Eye Hospital of Wenzhou Medical University (Ethics approval number: 2022-042-K-27).

Patient consent for publication Not required.

References


Other Cited Material


C. K6 Formula IOL Calculator. Available at: https://cookeformula.com/Calculator. Accessed March 5, 2022;

Figures

Figure 1

Stacked histogram of the percentage of eyes with a PE within ±0.25 D, ±0.5 D, ±0.75 D, ±1.00 D, and ±2.0 D in all patients and different groups of keratometry. EVO2.0 = Emmetropia Verifying Optical Formula Version 2.0, BUII = Barrett Universal II, ME= mean prediction error, MAE= mean absolute error, MedAE= median absolute error. Kane (all) and EVO2.0 (all) formulas were calculated with all parameters, including AL, ACD, K1, K2, LT, and CCT. Kane (optional) and EVO2.0 (optional) formulas were calculated without LT or CCT.