Metaanalysis of intraocular lens power calculation after laser refractive surgery in myopic eyes
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To evaluate the accuracy of intraocular lens (IOL) power calculation methods after laser refractive surgery in myopic eyes, a comprehensive literature search was carried out for retrospective case series studies with data on post-myopic laser surgery IOL power calculations published from January 2000 to May 2014. A metaanalysis of the 9 identified studies was performed using odds ratios in percentage of prediction error within ±0.5 or 1.0 diopter (D) of the target refraction. Compared with the Haigis-L method, the clinical history method, corneal bypass method, and Feiz-Mannis method were associated with lower odds of predication; the Masket method showed higher odds. The subgroup data showed significantly better performance of the Shammas no-history method with the Shammas post-LASIK formula than the Haigis-L method in predication error. The Masket method and the Shammas no-history method with the Shammas post-LASIK formula without historical data had more prediction accuracy than the Haigis-L method. The clinical history method, Feiz-Mannis method, and corneal bypass method, which required historical data, were less accurate in their predictions.

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The number of patients having laser refractive surgery is increasing worldwide. Acquiring a predictable and accurate cataract surgery intraocular lens (IOL) power calculation is more challenging in these patients than in those who have not had refractive surgery. The surgeon may face problems from patients' high visual expectations and the low power prediction of the standard formulas.

The 3 primary sources of prediction error in IOL power calculation after refractive surgery are the corneal radius measurement error, the keratometer index error, and the IOL power calculation method error. More than 30 methods have been developed to compensate for sources of error in post-refractive-surgery IOL power calculations. The popular methods include the Haigis-L method, the American Society of Cataract and Refractive Surgery (ASCRS) average method, and the clinical history method. All calculator methods can be divided into 3 groups according to whether the refractive surgery data are known, partly known, or not known. The data-known or data partly known methods, better known as historical methods, rely on pre-refractive corneal power and surgery data or a verified change in spherical equivalent refraction. The data-unknown methods use only the keratometric data at the initial cataract consultation or measure both anterior and posterior corneal powers directly using specialized equipment such as the slit...
Scheimpflug camera or optical coherence tomography (OCT). However, no standard resolution has been agreed on by surgeons worldwide.

The purpose of this review was to compare the accuracy of several IOL power calculation methods, to understand the strengths and weaknesses of each method, and to provide useful guidelines for selecting the most available method for IOL calculations. The review was confined to studies of eyes with previous myopic corneal refractive surgery.

**MATERIALS AND METHODS**

**Study Inclusion and Exclusion Criteria**

The aim of this study was to evaluate various methods of IOL power calculation after myopic laser refractive surgery based on a comparison with the Haigis-L formula. The following inclusion criteria were used to identify studies for this metaanalysis: (1) study design: retrospective case series; (2) population and intervention: patients who had uneventful laser in situ keratomileusis (LASIK) or photorefractive keratectomy (PRK) for myopia and subsequent cataract surgery; (3) IOL power calculation method: Haigis-L, clinical history, Feiz-Mannis, conical bypass, Masket, modified Masket, Wang-Koch-Maloney, Shammas no-history, Latkany, Geggel, Geggel consensus 3/6, and ASCRS average; (4) outcome measurement: mean arithmetic error in refractive prediction and percentage of prediction error within ±0.5 or 1.0 diopter (D) of the target refraction.

Exclusion criteria included (1) patients who had hyperopic laser surgery or radial keratotomy surgery, (2) the calculation method was based on scanning-slit tomography (Orbscan II, Bausch & Lomb), rotating-slit Scheimpflug camera (Pentacam, Oculus Optikgeräte GmbH), or dual-Scheimpflug systems (Galilei, Ziemer Ophthalmic Systems AG). Optical coherence tomography was also excluded from the metaanalysis due to its limited use in clinical work. It will be discussed in a future study.

The study methods adhered to the tenets of the Declaration of Helsinki for the use of human participants in biomedical research. Ethical approval was provided by the Zhongshan Hospital Ethics Committee.

**Search Strategy**

A literature search between January 2000 and May 2014 was conducted in PubMed, Embase, and Web-of-Science databases using the terms *intraocular lens calculation* and *refractive surgery*. After duplicate studies were removed, 386 articles were retrieved, of which 273 were excluded after a first-pass review of titles and abstracts. No previous metaanalysis on this topic was found. Most studies were eliminated after a full-text review based on the inclusion and exclusion criteria. Since its introduction in 2008, the Haigis-L method has been the easiest and most popular method. It is included in IOLMaster software (version 4.x and onward) and also available in the ASCRS average method, the Geggel consensus 3/6 technique, and the new biometry device, Lenstar (Haag-Streit). Unlike other methods that often use different formula combinations, the Haigis-L method is calculated with the Haigis formula only. This simple algorithm combination was therefore selected as the control method to simplify the metaanalysis. After searching the studies for references to comparison with the Haigis-L method, 9 studies were identified.

**Quality Assessment of Retrieved Articles**

Two reviewers (X.C., L.W.) independently reviewed the eligible studies. Each study’s first author, year of publication, number of patients, IOL power calculation methods, and outcome variables were recorded on a custom data extraction sheet. The study quality was assessed using the 9-star Newcastle-Ottawa Scale for assessing the quality of nonrandomized studies in metaanalyses. Any disagreement about study inclusion, quality assessment, selection of outcome parameters, and data extraction was resolved by discussion between the 3 authors.

**Outcome Measures**

In total, 12 methods were analyzed in the metaanalysis, including the Haigis-L, clinical history, corneal bypass, Feiz-Mannis, Masket, modified Masket, Wang-Koch-Maloney, Shammas no-history, Latkany, Geggel, Geggel consensus 3/6, and ASCRS average. The details of these IOL power calculation methods are described in Appendix e1 (available at http://jcrsjournal.org). Third-generation formulas (Hoffer Q, Holladay, and SRK/T) were used to calculate the IOL powers with the different methods, whereas the Haigis-L method used only the fourth-generation Haigis formula. In some research, the effective lens position (ELP) was optimized with the Aramberri double-K method, in which an original pre-refractive surgery cornea curvature (pre-K) is used to obtain the effective IOL position and the post-refractive surgery cornea curvature (post-K) for the vergence formula. If pre-LASIK/PRK corneal power was not available, 43.86 D was used.

The primary outcome parameters included the percentage of prediction refractive error within ±0.5 or 1.0 D of the target. A high percentage of refractive error within ±0.5 or 1.0 D means the calculation method has a high degree of accuracy.

**Statistical Analysis**

The statistical analysis was carried out using Review Manager software (Revman, version 5). Heterogeneity between studies was tested using chi-square statistics with I² more than 50% and a P value of less than 0.1 of statistical significance. When significant evidence of statistical heterogeneity was not found, a fixed-effects model was used, whereas a random-effects model was applied as the expected heterogeneity. Odds ratios (ORs) were calculated for the proportions of the prediction error in each method. Odds ratio less than 1 represented a lower rate of the method’s outcome. A P value less than 0.05 was considered statistically significant in the test for an overall effect.

**LITERATURE ANALYSIS**

**Characteristics of the Eligible Studies for Metaanalysis**

The characteristics of the 9 studies (12 calculation methods) included in the final analysis are summarized in Table 1. Along with the Haigis-L method,
the 3 most popular methods were the Shammas no-history, the clinical history, and the Masket. A total of 777 eyes were calculated by the Haigis-L method in the 9 studies; other methods involved sample sizes of 16 to 737 eyes.

Main Outcomes

Percentage of Intraocular Lens Prediction Error Within \( \pm 0.5 \) D  Table 2 summarizes the pooled OR estimates of the comparison of refractive error within \( \pm 0.5 \) D of the target refraction between the studied methods and the Haigis-L method. In the metaanalysis, the clinical history method, corneal bypass method, and Feiz-Mannis method were associated with lower odds than the Haigis-L method. Pooling the data from studies using the clinical history method showed significantly lower percentages of prediction results within \( \pm 0.5 \) D than pooling the data from studies using the Haigis-L method (OR, 0.72; confidence interval [CI], 0.60-0.88; \( P = .00 \)). A significant difference was also noted in the pooled OR of the corneal bypass method and the Feiz-Mannis method versus the Haigis-L method for the percentage of IOL prediction error within \( \pm 0.5 \) D (OR, 0.42; CI, 0.31-0.56; \( P = .00 \) and OR, 0.53; CI, 0.40-0.70; \( P = .00 \)).

The Masket method was associated with higher odds of prediction results than the Haigis-L method (OR, 1.69; CI, 1.30-2.21; \( P = .00 \)). No statistically significant associations were observed between other methods and the Haigis-L method.

Percentage of Intraocular Lens Prediction Error Within \( \pm 1.0 \) D  Table 3 compares percentages of IOL prediction error within \( \pm 1.0 \) D between the studied methods and the Haigis-L method. As in the results in the study of percentages of \( \pm 0.5 \) D, 4 methods (clinical history, corneal bypass, Feiz-Mannis, and Masket) achieved similar results in the study of percentages within \( \pm 1.0 \) D. In addition, the Geggel method showed lower odds (OR, 0.43; CI, 0.20-0.96; \( P = .04 \)), whereas the Latkany method (OR, 1.53; CI, 1.09-2.15; \( P = .01 \)) had higher odds than the Haigis-L method in percentages of IOL prediction error within \( \pm 1.0 \) D.

Different Methods and Their Subgroup Outcomes

Clinical History Method  The metaanalysis results of the clinical history method versus the Haigis-L method are summarized in Appendix e2 (available at http://jcrsjournal.org). The results of each subgroup in the studies are presented in a forest plot. In all 8 calculation combinations, only the SRK/T formula with the double-K and the Holladay formula with the double-K correction combinations were consistently significantly different than the Haigis-L method in all studies, whereas the clinical history method using the Hoffer Q, Holladay, and SRK/T formulas consistently showed no significant difference.

Masket Method  Data synthesis of various formula calculations showed that the Masket method had a significantly higher OR than the Haigis-L method within \( \pm 0.5 \) D and \( \pm 1.0 \) D, which did not favor the Haigis-L method. The Masket method with SRK/T combination was consistently significantly different than the Haigis-L method in both the studies (Appendix e3, available at http://jcrsjournal.org).

Shammas No-History Method  There was no significant difference between the Shammas method and the Haigis-L method. Furthermore, in the subgroup of the Shammas no-history method with the Shammas post-LASIK formula, data synthesis showed a significantly better performance in only the percentage of IOL prediction errors within \( \pm 1.0 \) D (OR, 1.39; CI, 1.02-1.88; \( P = .03 \)). The Shammas no-history method with the Shammas post-LASIK formula was mentioned in 6 of the 9 studies. It was the most popular algorithm, except the Haigis-L method, in our metaanalysis (Appendix e4, available at http://jcrsjournal.org).

Latkany Method  Although there were no significant differences in percentages in the \( \pm 0.5 \) D group, the Latkany method showed significantly higher accuracy percentages than the Haigis-L method in percentages within \( \pm 1.0 \) D. However, no subgroup showed a significant difference (Appendix e5, available at http://jcrsjournal.org).

Corneal Bypass Method, Feiz-Mannis Method, and Other Methods  Most of the formula combination data showed consistently significantly lower accuracy in the corneal bypass group and the Feiz-Mannis group in all the studies, whereas most formula combination data showed no significant difference between any of the 6 methods (modified Masket method, Wang-Koch-Maloney method, Shammas method, Geggel consensus 3, Geggel consensus 6, ASCRS average method) and the Haigis-L method (Appendices e6 to e13, available at http://jcrsjournal.org).

DISCUSSION

To our knowledge, this is the first metaanalysis to look at the accuracy of the IOL power prediction methods after refractive surgery. Almost 400 papers on this topic have been published, starting with Holladay in 1989. The various methods integrate with the various third- or fourth-generation IOL power calculation formulas, leading to too many calculation combinations, making it difficult to evaluate the methods between studies. This review was designed to investigate the
data from 9 retrospective case series studies, including 12 common methods and more than 30 formula calculation combinations compared with the Haigis-L method. The Haigis-L method is not only the most popular method for IOL power calculation after refractive surgery, it is also the only one with a fixed combination that uses only 1 formula, the Haigis. Therefore, we chose it as the control method to compare with other calculation combinations. However, because of the limited number of studies included, further efforts should be made to confirm our findings.

Many criteria are used to evaluate the accuracy of the IOL power calculation methods, such as the percentage of eyes within ±0.5 D, ±1.0 D, ±1.5 D, and ±2.0 D of the target refraction; mean arithmetic IOL prediction error; mean absolute IOL prediction error; and a variance of the IOL prediction error. Unfortunately, only with the publication of the recent study by Hoffer et al.24 has there been established methodology standards. Hoffer et al. suggest the mean numeric error of the study group for each formula should be made to equal zero by changing the IOL factor (constant) individually for each formula before comparing the results of the formulas. However, all the published studies, including our research, are wrong without the mean numeric error being zeroed out. As for the absolute error, it is not a normal Gaussian distribution. Using median absolute errors instead of mean absolute errors is recommended when comparing the accuracy of the calculation. Unfortunately, compared with the many studies published with the erroneous mean absolute error methodology, there are few studies using the median absolute error as the assessment criterion, including only 2 of the 9 studies in this metaanalysis. Based on these reasons, we excluded the mean arithmetic IOL prediction error, mean absolute IOL prediction error, and the median absolute error analysis in our metaanalysis.

Findings from our metaanalysis suggest that the Masket method is more predictably accurate than the popular Haigis-L method; the methods using historical K data (including the clinical history method, corneal bypass method, and Feiz-Mannis method) produced results associated with less accuracy in their predictions. Other methods, except the Latkany method, showed no significantly different results from the Haigis-L method in both studies; the Latkany method performed better in the prediction error within ±1.0 D study.

The data analysis demonstrated that the accuracy of IOL power prediction of the clinical history method was significantly lower than that of the Haigis-L method. The clinical history method has been well known since its introduction by Holladay5 in 1989 and Hoffer6 in 1995. Although it had been considered a gold standard for some years, more and more studies have indicated it is less accurate than new methods.11,18,29 In our metaanalysis of the clinical history method, there were 33.90% of eyes (422 of 1245 eyes) in the clinical history method group compared with 42.18% of eyes (302 of 716 eyes) in the Haigis-L group in the percentage of eyes within ±0.5 D of the target refraction. The prediction error of the clinical history method may be due to its not accounting for corneal changes resulting from the initial laser procedure. The same reason explained our metaanalysis results for the corneal bypass method and the Feiz-Mannis method. Furthermore, the methods that rely on clinical historical data are not always applicable because historical K data from the time of the laser procedure are often missing or incomplete.

We found that the algorithm using only the changes in refractive data seemed to perform better than the 3
methods that use previous keratometry and manifest refraction change. The Masket method showed lower prediction error than the Haigis-L method. It is now available in the Lenstar software and recommended for post-laser refractive patients with known histories of refractive change induced by the laser surgical procedure.

As mentioned above, all the methods with historical data have a limitation. When the refractive surgical data (pre-LASIK K readings, amount of myopia corrected, or both) are not available, these IOL power calculation methods cannot be used. Surgeons developed many clinically derived methods, including the Wang-Koch-Maloney method, Shammas method, Geggel method, and Haigis-L method. Except for the Geggel method, all methods are based on correcting the K reading of the post-LASIK cornea according to the regression method. The corrected corneal power is then put into the various formulas to calculate the IOL power. The Geggel method assumes that the ratio of the original central to superior corneal pachymetry remains constant for any given patient, while the superior corneal pachymetry does not change after LASIK or PRK surgery. According to the estimated ablation depth, Geggel uses the linear regression formula to determine the adjustment value to be added to the IOL power to achieve the desired result. These 3 methods did not differ from the Haigis-L method in our review except in the percentage of prediction error within ±1.0 D in the Geggel method.

<table>
<thead>
<tr>
<th>Method</th>
<th>No. of Formula Combination*</th>
<th>No. of Studies</th>
<th>Effect Measure</th>
<th>Analysis Model</th>
<th>Events/Total</th>
<th>OR</th>
<th>CI</th>
<th>I-Sqr(Q)</th>
<th>P(Q)</th>
<th>P(Z)</th>
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<tbody>
<tr>
<td>Clinical history</td>
<td>8</td>
<td>2</td>
<td>OR, Fixed</td>
<td>422/1245</td>
<td>302/716</td>
<td>0.72</td>
<td>0.60-0.88</td>
<td>0.29</td>
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<td>Corneal bypass</td>
<td>4</td>
<td>2</td>
<td>OR, Fixed</td>
<td>136/575</td>
<td>154/348</td>
<td>0.42</td>
<td>0.31-0.56</td>
<td>0.89</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>Feiz-Mannis</td>
<td>4</td>
<td>3</td>
<td>OR, Fixed</td>
<td>164/581</td>
<td>160/373</td>
<td>0.53</td>
<td>0.40-0.70</td>
<td>0.63</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Masket</td>
<td>4</td>
<td>3</td>
<td>OR, Fixed</td>
<td>332/592</td>
<td>160/373</td>
<td>1.69</td>
<td>1.30-2.21</td>
<td>0.36</td>
<td>8.94</td>
<td>0.00</td>
</tr>
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<td>Modified Masket</td>
<td>1</td>
<td>2</td>
<td>OR, Fixed</td>
<td>50/82</td>
<td>49/97</td>
<td>1.32</td>
<td>0.87-1.44</td>
<td>0.90</td>
<td>0.00</td>
<td>0.39</td>
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<td>Wang-Koch-Maloney</td>
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<td>2</td>
<td>OR, Fixed</td>
<td>73/134</td>
<td>68/134</td>
<td>1.16</td>
<td>0.72-1.89</td>
<td>0.37</td>
<td>0.00</td>
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<tr>
<td>Shammas c.d. (no-history)</td>
<td>2</td>
<td>7</td>
<td>OR, Fixed</td>
<td>352/693</td>
<td>292/609</td>
<td>1.13</td>
<td>0.91-1.42</td>
<td>0.64</td>
<td>0.00</td>
<td>0.27</td>
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<td>Geggel</td>
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<td>77/132</td>
<td>88/132</td>
<td>0.70</td>
<td>0.42-1.15</td>
<td>0.46</td>
<td>0.00</td>
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<td>2</td>
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<td>409/574</td>
<td>248/342</td>
<td>1.10</td>
<td>0.60-2.02</td>
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<td>46/66</td>
<td>44/66</td>
<td>1.15</td>
<td>0.55-2.39</td>
<td>1.00</td>
<td>0.00</td>
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<td>Consensus 6</td>
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<td>0.72-3.58</td>
<td>0.37</td>
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<td>ASCRS average</td>
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<td>80/134</td>
<td>1.47</td>
<td>0.89-2.41</td>
<td>0.48</td>
<td>0.00</td>
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</table>

CI = confidence interval; I-Sqr(Q) = I² statistics which have been used to test for the presence of heterogeneity; OR = odds ratio; P(Q) = P value of the chi-square test for heterogeneity; P(Z) = P value of test for overall effect; lower OR (<1) favors Haigis-L method, while higher OR (>1) favors the investigated method.

*Number of calculation pairs; 1 calculation method with the different formulas 9 such as Holladay formula, Hoffer Q formula.
We wanted to know whether the predictive power could be improved by the application of third-generation formulas, but according to our research, there was no consistent statistical difference when more linear regression formulas were used, even in the same calculation mode. The disadvantage of third-generation formulas is calculating the ELP through an estimation based on corneal power, as with the SRK/T, Hoffer Q, and Holladay formulas. After refractive surgery, using these formulas will lead to an error in corneal power correction, leading to an error in IOL power and the postoperative refractive surprise. Unlike most formulas that use both axial length and corneal power values to estimate the ELP, the Shammas post-LASIK and Haigis formulas determine the ELP without the central corneal power data, while the classic double-K correction of Aramberri is also applied as an ELP. When the Shammas no-history method with the Shammas post-LASIK formula was compared with the Haigis-L method, it was similar, even better, according to our metaanalysis. The magnitude of these calculation errors decreases when only the post-LASIK K value correction for IOL calculation in post-refractive eyes is needed, without any post-LASIK calculation artifacts due to prediction of the ELP. Therefore, this method has been added to the Lenstar optical biometer.

After the ASCRS provided the online calculator, which produced 1 average IOL power, the combined method became a good choice for surgeons, especially those who cannot choose the proper calculation method or judge which method is best. The various combined methods select the type and the amount of method procedures that had been used for the calculation; the reason for the formula choice was not clear. The Geggel consensus uses 3 or 6 formulas to produce an average IOL power, the ASCRS average method uses 11 formulas, and the ocular MD calculator uses 20 methods. These combined methods share the Shammas and Haigis-L formulas. Based on our review, we suggest the more accurate solution should include the following methods: Masket method, Shammas no-history method with Shammas post-LASIK formula, and Haigis-L method. More clinical studies are needed to investigate the best of the combined formulas.

This study has limitations: (1) Only a small number of trials were enrolled in the metaanalysis and some method and formula combinations are available in only 1 study. (2) We evaluated only the differences between the Haigis-L method and the others but did not directly point out which method was the most accurate method for predicting the IOL diopter after myopic laser surgery.

In summary, findings in the present metaanalysis indicate that the Masket method and many no-history data methods were not less predictably accurate than the Haigis-L method. The results of the clinical history method, Feiz-Mannis method, and corneal bypass method—methods that require pre-PRK/LASIK data—were associated with less accurate predictability. We also suggest that the ASCRS should emphasize the assessment criteria regarding IOL power calculation approaches for further larger controlled studies.
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