INTRODUCTION

With improvement in the instruments and techniques used for cataract surgery, the most challenging subject in patient satisfaction is post-surgical refractive outcomes. Although new optical biometry systems have improved intraocular lens (IOL) power calculation results by accurate and reliable axial length (AL) and keratometry measurements,[1] the effective lens position (ELP) is still a matter of debate. Different generations of IOL power calculation formulas utilize different parameters for the prediction of the IOL position within the eye. Third-generation formulas are the most popular theoretical formulas, which predict the IOL position by the AL and keratometry. The Haigis, Olsen and Holladay 2 formulas utilize 2, 5 and 7 parameters for the prediction of the IOL position, respectively.[2-4] As the amount of keratometry is one of two cardinal factors in the calculation of the IOL power, and as most IOL power calculation formulas consider keratometry magnitudes...
for the prediction of ELP, we conducted this study to elucidate which formula is most accurate in eyes with steep keratometry. The superiority of different formulas for different amounts of AL has been shown in many studies,[5–7] but the accuracy of IOL power calculation formulas in steep keratometry has not been evaluated according to our best knowledge. Therefore, the purpose of the current study was to compare the accuracy of four common IOL power calculation formulas in steep corneas.

METHODS

The present study was a prospective comparative study, which included 45 eyes from 45 patients with senile cataracts and a mean keratometry greater than 46D who were candidates of phacoemulsification with IOL implantation from February 2014 to July 2015. The exclusion criteria were as follows: patients with a history of previous intraocular and/or corneal surgery, pre-existing ocular diseases including keratoconus or corneal scar, corneal astigmatism more than 0.75D, complicated cataract surgery including anterior or posterior capsular tear, combined surgical procedures, postoperative best-corrected visual acuity (BCVA) less than 20/40, and patients with follow-ups of less than 1 month. Topography was performed to rule out suspected keratoconus and keratoconus in all cases. Data collection included preoperative and postoperative examinations and refractive data. Additionally, age, sex, laterality, axial length, anterior chamber depth, and average corneal power were recorded. IOL power was calculated by the Lenstar 900 (Haag-Streit AG, Koeniz, Switzerland) using the Haigis, Holladay 1, Hoffer Q and SRK/T formulas with optimized IOL constants for the Haag-StreitLenstar 900 from the User Group for Laser Interference Biometry (ULIB). All patients underwent uneventful phacoemulsification cataract surgery by one experienced surgeon (AF) with a standard stop & chop technique with a sutureless 2.8 mm temporal incision under topical anesthesia. At the end of surgery, an AcrySof IOL (SA60AT, Alcon, Fort Worth, TX) was implanted in the capsular bag in all cases. The power of IOL measured by each formula that yielded a postoperative refraction nearest to emmetropia, erring on the side of myopia, was selected. The mean of four measurements was considered for IOL power selection.

Patients were examined one day, 1 week and 1 month after surgery. Postoperative refraction at least one month after the surgery was measured using an autorefractometer (RMA 7000, Tokyo, Japan) and converted to the spherical equivalent. For each patient, the prediction error was calculated, which is the difference in diopter between the achieved and predicted refractive outcomes in a particular patient. The mean numerical error (MNE) and the mean absolute error (MAE) were defined as the arithmetic mean of the prediction errors and the mean of the magnitude of the prediction errors, respectively. The MNE, MAE and the percentage of the eyes within ±0.5D, ±1.0D and ±2.0D of the SE were calculated for each formula.

Statistical Analysis

To assess the normal distribution of data, we used the Kolmogorov–Smirnov test and Q–Q plot. To describe the data, we used frequency (percent), mean, standard deviation, range and 95% confidence interval (95% CI) for each of the 4 formulas. To compare the MAE and the MNE values among the 4 formulas, we used a repeated measure ANOVA. The Bonferroni method was used to adjust for the multiple comparisons. P values less than 0.05 were considered statistically significant. All statistical analyses were conducted using SPSS software (IBM Corp. Released 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp.).

RESULTS

A total of 45 eyes from 45 patients with a mean keratometry greater than 46D who underwent phacoemulsification and IOL implantation were included in the present study. Table 1 summarizes the demographic and preoperative biometric ocular parameters of the patients.

The overall performances of the 4 formulas are presented in the Table 2. The MAE ranged from 0.39D to 0.5D, which was the smallest in the SRK/T formula (0.39D ± 0.35), followed by those of the Holladay 1 (0.44D ± 0.32), Haigis (0.45D ± 0.35) and Hoffer Q (0.5D ± 0.38) formulas. This study found no statistically significant differences between the MAE among different IOL calculation formulas compared to the Haigis

| Table 1. Demographic and biometric parameters |
| Parameter      | Statistics | Value   |
|----------------|------------|---------|
| Age            | Mean±SD    | 62±17   |
|                | Median (range) | 66 (13-90) |
| Mean K (D)     | Mean±SD    | 47.11±0.93 |
|                | Median (range) | 46.94 (46.25-49.73) |
| Post.Op.SE (D) | Mean±SD    | -0.18±0.58 |
|                | Median (range) | -0.25 (-1.5-1.5) |
| ACD (mm)       | Mean±SD    | 3.18±0.39 |
|                | Median (range) | 3.19 (2.37-4.12) |
| AL (mm)        | Mean±SD    | 22.58±0.77 |
|                | Median (range) | 22.54 (21.33-24.24) |
| Sex            | Male       | 34 (37.8%) |
| Eye            | OD         | 58 (64.4%) |
|                | OS         | 32 (35.6%) |

K, keratometry; ACD, anterior chamber depth; AL, axial length; D, diopter; Op, operative; SE, spherical equivalent; OD, oculus dexter; OS, oculus sinister; SD, standard deviation; mm, millimeter
Table 2. MAE & MNE and the percentages of the eyes within ±0.5D, ±1D and ±2D of the target refraction by 4 different formulas in all eyes

|         | Haigis | Holladay 1 | Hoffer Q | SRK/T |
|---------|--------|------------|----------|--------|
| MAE (D) | Mean±SD | Mean±SD | Mean±SD | Mean±SD |
|         | N      | P         | N       | P       |
| ±0.5 D  | 0.45±0.35 | 0.44±0.32 | 0.5±0.38 | 0.39±0.35 |
|         | (64.4%) | (90.0%) | (57.8%) | (77.8%) |
| ±1 D    | 0.16±0.55 | 0.21±0.51* | 0.36±0.51 <0.001* | -0.06±0.52* <0.001* |
|         | (95.6%) | (100.0%) | (91.1%) | (88.9%) |
| ±2 D    | 0.21±0.51* | 0.177* | -0.06±0.52* <0.001* | -0.06±0.52* <0.001* |
|         | (100.0%) | (100.0%) | (100.0%) | (100.0%) |

The MAE is the mean of the differences between the achieved and predicted SE, with consideration for the direction (negative or positive). Based on the MAE, a low hyperopic outcome was found with all formulas except the SRK/T. However, the differences were not statistically significant between the SRK/T and Haigis formulas.

The third-generation formulas, including the SRK/T, Hoffer Q and Holladay 1, utilize two biometric parameters (AL, keratometry) for the prediction of the ELP and one constant for the optimization of the results. In contrast, the Haigis formula, which is a fourth-generation formula, utilizes AL and preoperative ACD to predict the ELP and has 3 constants \([a_0 + (a_1 \times ACD) + (a_2 \times AL)]\) for the optimization of results. Therefore, rather than using a single number, the Haigis formula recommends the IOL power optimization based on three variables.

According to the keratometry by reflection-based systems, the anterior corneal curvature is extrapolated from the corneal radius and translated into the corneal power using a keratometric index that is based on the presumed fixed correlation between the anterior and posterior corneal radii. All third-generation IOL power formulas (SRK/T, Holladay 1, Hoffer Q) required corneal power to predict the ELP. When using the true corneal power, the corneal radii and keratometric index are required, and in cases when we do not have access to the posterior corneal radius, using a variable keratometric index that is dependent on the radius of the anterior corneal surface has been proposed.\[^9,10\] The Haigis formula utilizes the corneal radius to prevent problems related to the keratometric index.

DISCUSSION

In the current study, we compared the accuracy of four widely used IOL power calculation formulas, namely Haigis, Holladay 1, Hoffer Q, and SRK/T formulas, in eyes with steep corneas. According to this study, there were no statistically significant differences between the accuracy of the aforementioned formulas; however, the percentage of the eyes within ±0.5D of the target refraction was higher in IOL power selection based on the SRK/T formula.

The MNE is often used as an indicator for the IOL formula prediction accuracy, although it does not show a resulting direction (myopic or hyperopic). In the present study, the small standard deviation of the MNE for all formulas highlights that the accuracy of the prediction was very good for all included eyes. None of the formulas showed significant differences in the MNE compared with that of the Haigis formula. The SRK/T formula predicted the greatest percentage of the eyes that fell within ±0.5D of the target refraction (78%), which was the same as the results of the study by Shread et al (78.7%).\[^9\]
According to Bang et al, the Haigis formula was found to be the most accurate in predicting postoperative refractive error in long eyes, the SRK/T formula was the second most accurate.\(^{[13]}\) Eom et al found that the Haigis formula was significantly more accurate than the Hoffer Q formula in short eyes with an ACD less than 2.40 mm. They concluded that the predicted ELP by the Hoffer Q formula was deeper than the actual ELP, and the predicted refractions based on the ACD (the Haigis formula) were more accurate than fixed predicted refractions without considering the ACD (the Hoffer Q formula) in eyes with a short AL and shallow ACD.\(^{[14]}\) However, the superiority of the Haigis formula in eyes with steep corneas has not been established in the current study, and only a trend toward better results with the SRK/T was observed in this series. Unexpectedly, in the eyes with the shallow anterior chamber, we did not find higher accuracy of the Haigis formulas compared with third-generation formulas. In the eyes where the ACD was less than 3 mm, the number of the eyes within +/- 0.5D of the target refraction was highest in the SRK/T and Holladay 1 formulas (71.4% and 64.3%, respectively). This result may be due to the inaccuracy of the constants of the Haigis formula for the eyes with steep corneas. Adjustment of the constants of the Haigis formula may improve the results of this formula. However, the personalization of these constants requires input of at least 200 eyes.

In conclusion, the IOL power calculation using Lenstar showed relatively good postoperative IOL power.
prediction in steep corneas with Haigis, Holladay 1, Hoffer Q and SRK/T formulas. However, the SRK/T formula showed the best results.

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Conflicts of Interest
There are no conflicts of interest.

REFERENCES
1. Sahin A, Hamrah P. Clinically relevant biometry. Curr Opin Ophthalmol 2012;23:47-53.
2. Lee AC, Qazi MA, Pepose JS. Biometry and intraocular lens power calculation. Curr Opin Ophthalmol 2008;19:13-17.
3. Olsen T. Prediction of the effective postoperative (intraocular lens) anterior chamber depth. J Cataract Refract Surg 2006;32:419-424.
4. Haigis W. Challenges and approaches in modern biometry and IOL calculation. Saudi J Ophthalmol 2012;26:7-12.
5. MacLaren RE, Natkunarajah M, Riaz Y, Bourne RR, Restori M, Allan BD. Biometry and formula accuracy with intraocular lenses used for cataract surgery in extreme hyperopia. Am J Ophthalmol 2007;143:920-931.
6. Wang JK, Hu CY, Chang SW. Intraocular lens power calculation using the IOLMaster and various formulas in eyes with long axial length. J Cataract Refract Surg 2008;34:262-267.
7. Abulafia A, Barrett GD, Rotenberg M, Levy A, Koch DD, Wang L, 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;41:548-556.
8. Sheard RM, Smith GT, Cooke DL. Improving the prediction accuracy of the SRK/T formula: TheT2 formula. J Cataract Refract Surg 2010;36:1829-1834.
9. Piñero DP, Camps VJ, Mateo V, Ruiz-Fortes P. Clinical validation of an algorithm to correct the error in the keratometric estimation of corneal power in normal eyes. J Cataract Refract Surg 2012;38:1333-1338.
10. Camps VJ, Piñero DP, de Fez D, Mateo V. Minimizing the IOL Power Error Induced by Keratometric Power. Optom Vis Sci 2013;90:639-649.
11. Moschos MM, Chatziralli IP, Koutsandrea C. Intraocular lens power calculation in eyes with short axial length. Indian J Ophthalmol 2014;62:692-694.
12. Roh YR, Lee SM, Han YK, Kim MK, Wee R, Lee JH. Intraocular lens power calculation using IOLMaster and various formulas in short eyes. Korean J Ophthalmol 2011;25:151-155.
13. 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;118:503-506.
14. Eom Y, Kang SY, Song JS, Kim YY, Kim HM. Comparison of Hoffer Q and Haigis formulae for intraocular lens power calculation according to the anterior chamber depth in short eyes. Am J Ophthalmol 2014;157:819-824.