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Evaluation of Wang-Koch optimisation of axial length for intraocular lens power calculation in myopic eyes

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Background: Refractive outcome has become more relevant in myopic patients. Refractive surprises are mainly caused by errors in axial length (AL) measurement.

Aim: This study aimed to evaluate the accuracy of intraocular lens (IOL) power calculation in myopic eyes using the AL measured by optical biometry versus an optimised AL calculated by the Wang-Koch method.

Setting: Ophthalmology Department, Cairo University and Ophthalmic Diagnostic and Laser Unit, Cairo University Hospitals, both in Cairo, Egypt.

Methods: A prospective study of 30 eyes of 23 patients with ALs greater than 25.0 mm that underwent phacoemulsification with IOL implantation in the capsular bag. The LENSTAR was used for preoperative IOL power calculation using the Holladay 1 formula and the LENSTAR AL (group 1), and for back-calculation of the prediction error (PE) for the same 30 eyes using the Holladay 1 formula and the optimised AL (group 2). Postoperative PEs and mean absolute errors (MAEs) were calculated six weeks after surgery.

Results: The postoperative spherical equivalent was within ± 1.00 dioptre (D) of predicted in 86.7% and 90.0% of eyes, respectively, ($p = 0.69$). However, 66.7% of eyes had a hyperopic outcome in group 1, in comparison to 20.0% that would be left hyperopic using the optimised AL in group 2 ($p < 0.05$).

Conclusion: The Wang-Koch method of optimising the AL would have significantly reduced the percentage of eyes rendered hyperopic using the LENSTAR AL from 66.7% to 20.0%. This difference represents a clinically significant improvement in IOL power prediction in these eyes.

Keywords: IOL power calculation; phacoemulsification; optical biometry; myopia; Wang-Koch.

Introduction

Refractive surprises after cataract surgery can seriously compromise patient satisfaction and also give rise to potential problems of anisometropia or dominance switch in which the dominant eye ends up with the weaker uncorrected vision and, above all, give rise to a sense of failure in patients expecting good uncorrected visual acuity.[1] In 1992 prior to the advent of optical biometry, Olsen reported that 54% of refractive surprises were due to errors in axial length (AL) measurement.[2] The advent of optical biometry improved the accuracy and consistency of AL measurements to such a degree that a similar study by Norrby in 2008 showed that errors in AL measurement account only for 17% of refractive surprises.[3]

In myopic patients, refractive outcome has become more relevant, especially when clear lens exchange is used for refractive surgery.[4] It is well known that highly myopic eyes show a higher incidence of eyeball deformities.[5] Laser interference biometry (LIB) evaluates the AL along the visual axis, whereas ultrasound biometry (USB) measures along the optical axis. Laser interference biometry has a major advantage in patients where the globe shows deformities.[6]

In 2011, Wang et al. described how to adjust the AL for myopic eyes with AL more than 25 mm, when using optical biometry.[7]

Wang et al. suggested using the AL adjustment below, combined with the Holladay 1 formula and the manufacturer's lens constant for the intraocular lens (IOL) to be used: Optimised AL = (0.8814 × measured AL) + 2.8701.

The aim of this study is to evaluate the accuracy of this formula in predicting IOL power in myopic patients with an AL greater than 25 mm.

Material and methods

This study was conducted in accordance with the Declaration of Helsinki (1989) of the World Medical Association. It was approved by the Research Ethics Committee of Kasr El-Aini University School of Medicine. Study participants gave a signed informed consent before cataract extraction surgery, and the study was conducted in compliance with informed consent regulations.

This is a prospective observational study that included myopic patients with AL greater than 25 mm scheduled for phacoemulsification for cataract extraction or refractive lens exchange and capsular bag implantation of an IOL.

This study included 30 eyes of 23 patients attending the Ophthalmology outpatient clinic, Kasr Al-Ainy School of Medicine, Cairo University, Egypt, scheduled to undergo phacoemulsification.

This study included myopic patients with AL greater than 25 mm, aged 35 years or older (for a greater likelihood of AL stability) and scheduled for cataract extraction or refractive lens exchange.

Exclusion criteria included dense cataract preventing AL measurement by optical biometry, previous ocular surgery and concomitant ocular pathology such as myopic macular degeneration, retinal detachment and corneal opacities. Patients were also excluded if the IOL was not implanted in the bag.

All patients had a routine preoperative ophthalmological examination including measurement of uncorrected and best corrected visual acuity, manifest refraction if possible, slit lamp biomicroscopic examination of the anterior segment, Goldmann applanation tonometry, dilated fundus examination by biomicroscopy and indirect ophthalmoscopy and macular optical coherence tomography to exclude foveoschisis and occult choroidal neovascularisation.

Intraocular lens calculation was performed through a complete LENSTAR (LENSTAR LS900®, Haag-Streit AG, Koeniz, Switzerland) evaluation, including measurement of AL, anterior chamber depth, lens thickness, horizontal white-to-white diameter and keratometry. This was used for preoperative IOL power calculations with the Holladay 1 formula, without optimising the AL. In all cases, IOL power was selected aiming for a target refraction of −0.50 D. In addition, IOL power calculation was performed using an optimised AL according to the Wang-Koch formula[7]; this would be used postoperatively for back-calculation of the prediction error (PE). The optimised AL was calculated according to the following formula:optimised AL = (0.8814 × LENSTAR AL) + 2.8701.

All patients underwent phacoemulsification and insertion of an EYECRYL™ posterior chamber IOL into the capsular bag (EYECRYL™ is a hydrophilic, acrylic, single-piece, 360° square-edge IOL, manufactured by Biotech Vision Care, India). The overall length of this lens is 12.5 mm, the optic diameter is 6.0 mm and the estimated A constant is 118.2.

Six weeks after surgery, manifest refraction was performed to determine the postoperative spherical equivalent (SE) refractive error. For each patient, the PE (using the unmodified LENSTAR AL) was calculated by subtracting the predicted postoperative refractive power (using the implanted IOL power) from the actual postoperative refraction (POR). For example, the patient received an IOL of + 6.0 dioptre (D) power. According to the pre-operative IOL calculation with an unmodified AL, a + 6.0 D lens would lead to –0.45 D POR (predicted refraction, PR = –0.45 D). Postoperatively, the SE refraction was –0.25 D. Therefore the PE would be calculated by subtracting the predicted refraction from the actual POR: POR (–0.25 D) – PR (–0.45 D) = +0.20 D. A positive value of PE would indicate a hyperopic surprise, whereas a negative value would indicate a myopic surprise.

The power of the implanted lens was then checked against the IOL calculation performed using the optimised AL to determine the optimised predicted refraction, opt-PR (if we had used the optimised AL for IOL power calculation). The optimised prediction error (opt-PE) using the optimised AL was then calculated in a similar fashion, by subtracting the optimised predicted refraction from the actual POR measured after surgery. Using the same given example, a +6.0 D IOL would have given a predicted refraction of –0.25 D, if we had used the optimised AL. As the actual POR was –0.25 D, then the opt-PE would be calculated by subtracting the optimised predicted refraction from the actual POR: POR (–0.25 D) – opt-PR (–0.25 D) = 0.0 D. In this case, this indicates a higher accuracy of the optimisation method.

Therefore, we determined five values for each eye:

- Actual postoperative spherical equivalent refraction (POR)
- Predicted POR using an unmodified AL (PR)
- Prediction error using an unmodified AL (PE)
- Predicted POR using the optimised AL (opt-PR)
- Prediction error using the optimised AL (opt-PE)

For statistical and description purposes we used the following grouping system; group 1 included the 30 eyes with IOL power calculation using the Holladay 1 formula and the unmodified LENSTAR AL, and group 2 included the same 30 eyes with IOL power calculation using the Holladay 1 formula and the optimised AL.

Statistical methods

Statistical analysis was done using IBM Statistical Package for Social Sciences (SPSS) version 20.0 statistical software (IBM Corporation, United States [US]). Descriptive statistics were calculated and the data were summarised as range

(maximum to minimum), mean ± standard deviation (s.d.). Comparisons between the two groups were carried out using the Chi-square test. Correlation between variables was performed by Pearson's correlation coefficient. The results were considered statistically significant with a $p \leq 0.05$.

Results

This study included 30 eyes of 23 patients. The mean corneal power was 44.08 ± 1.84 D and the mean LENSTAR AL was 27.32 ± 1.89 mm (Table 1).

Following IOL power calculation using the LENSTAR AL (group 1) and using the optimised AL (group 2), 26 (86.7%) and 27 eyes (90.0%) showed a postoperative spherical equivalent, which was within ± 1.00 D from the predicted value, respectively. In 22 (73.3%) and 16 eyes (53.3%) the postoperative spherical equivalent was within ± 0.50 D whilst the error was beyond ± 1.00 D in four (13.3%) and three eyes (10.0%), respectively (Table 2).

Compared with the mean predicted postoperative SE of –0.52 ± 0.32 D (range: –1.66 D – 0.01 D) for group 1, and 0.12 ± 0.41 (range: –1.05 D – 0.66 D) for group 2, the mean actual postoperative refractive error was –0.29 ± 0.67 D (range: –2.13 D – 1.0 D).

The mean PE was 0.24 ± 0.54 D for group 1, and –0.41 ± 0.54 D for group 2 and the numerical values ranged from –0.70 to 1.35 D and from –1.46 to 0.99 D, respectively. The mean absolute error (MAE) was 0.46 ± 0.36 D (range 0.08 D – 1.35 D) for group 1 and 0.54 ± 0.39 D (range 0.01 D – 1.46 D) for group 2 (Table 3).

The percentage deviation of refractive outcomes from the predicted (target) refraction in both groups (in numerical values) is presented in Table 4 and Figures 1 and 2.

Although the refractive predictability of the two groups is quite similar, group 1 showed a significantly greater tendency towards hyperopia. A total of 20 eyes (66.7%) had a hyperopic outcome in group 1, in comparison to six eyes (20.0%) that would be left hyperopic in group 2 ($p < 0.05$).

Figures 3 and 4 show scatter plots of the predicted and actual POR (in spherical equivalent) in group 1 (Figure 3) and group 2 (Figure 4). The diagonal line represents the ideal correlation between the predicted and actual POR.

The analysis of the PE of group 1 with regard to the LENSTAR AL showed a trend towards positive PE values with higher ALs. However, the statistical analysis does not reveal any significance. No statistically significant correlation between AL and PE could be detected in either group (Figure 5 & 6).

Discussion

Using modern IOL formulas gives accurate outcomes when used for eyes with ALs ranging from 22.0 mm to 25.0 mm.[7]

TABLE 1: Preoperative data.

Parameter	Mean ± s.d.	Range
Mean keratometric reading (D)	44.08 ± 1.84	41.09–50.51
LENSTAR AL (mm)	27.32 ± 1.89	25.05–31.55
Optimised AL (mm)	26.94 ± 1.66	24.95–30.68
Anterior chamber depth (mm)	3.58 ± 0.32	3.02–4.33

AL, axial length; s.d., standard deviation.

TABLE 2: Deviation of refractive outcome from predicted (target) refraction (absolute values).

Prediction error	Group 1		Group 2		*p*
	n	%	*n*	%	
≤ 0.5 D	22	73.3	16	53.3	0.11
≤ 1.0 D	26	86.7	27	90.0	0.69
> 1.0 D	4	13.3	3	10.0	0.69

D, dioptre.

TABLE 3: Mean ± standard deviation and ranges of predicted refractive outcome, actual postoperative refraction, prediction error and mean absolute error.

Value	Group 1	Group 2
Predicted refraction (D)		
Mean ± s.d.	-0.52 ± 0.32	0.12 ± 0.41
Range	-1.66–0.01	-1.05–0.66
Actual postoperative refraction (D)		
Mean ± s.d.	-0.29 ± 0.67	-0.29 ± 0.67
Range	-2.13–1.0	-2.13–1.0
Prediction error (D)		
Mean ± s.d.	0.24 ± 0.54	-0.41 ± 0.54
Range	-0.70–1.35	-1.46–0.99
Mean absolute error (D)		
Mean ± s.d.	0.46 ± 0.36	0.54 ± 0.39
Range	0.08–1.35	0.01–1.46

s.d., standard deviation; D, dioptre.

TABLE 4: Deviation of refractive outcome from predicted (target) refraction (numerical values).

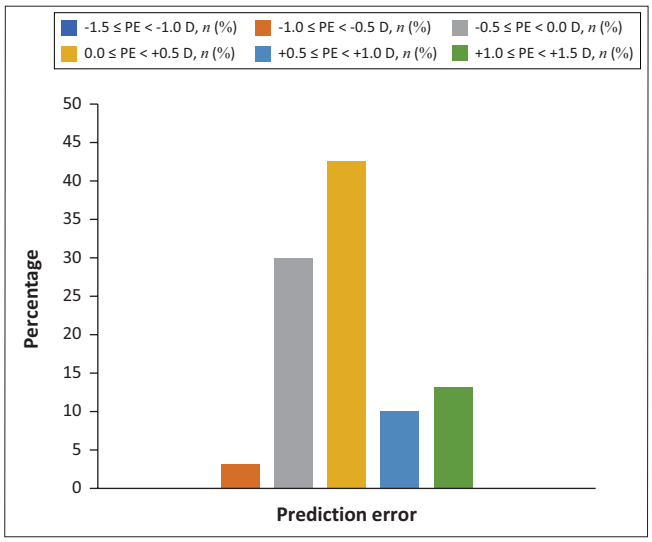
Prediction error	Group 1		Group 2		*p*
	n	%	*n*	%	
-1.5 ≤ PE < -1.0 D	0	0.0	3	10.0	0.08
-1.0 ≤ PE < -0.5 D	1	3.3	10	33.3	< 0.05
-0.5 ≤ PE < 0.0 D	9	30.0	11	36.7	0.58
0.0 ≤ PE < +0.5 D	13	43.3	5	16.7	< 0.05
+0.5 ≤ PE < +1.0 D	3	10.0	1	3.3	0.3
+1.0 ≤ PE < +1.5 D	4	13.3	0	0.0	< 0.05

PE, prediction error; D, dioptre.

However, in longer eyes using these formulas leads to postoperative hyperopia.[5]

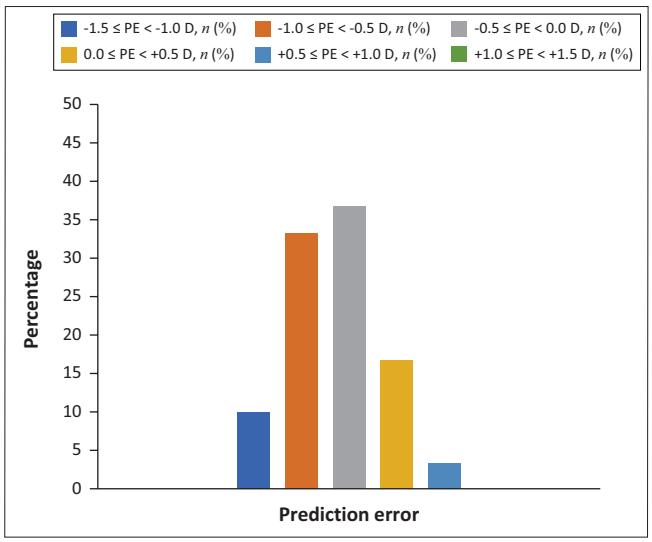
To reduce the chance of postoperative hyperopia, some surgeons target one or two dioptres of postoperative myopia on empiric basis.[7] The purpose of this study was to evaluate the accuracy of refractive prediction of the Holladay 1 formula in long eyes using the LENSTAR AL versus using the AL optimisation method proposed by Wang et al. in 2011.

Our results show that with the optical biometer ALs and manufacturer's lens constants, the majority of eyes would be left hyperopic postoperatively with the Holladay 1 formula, which is consistent with findings in previous studies.[8] The AL optimisation method would have improved the accuracy



PE, prediction error; D, dioptre.

FIGURE 1: Percentage deviation of refractive outcome from predicted refraction in group 1.



PE, prediction error; D, dioptre.

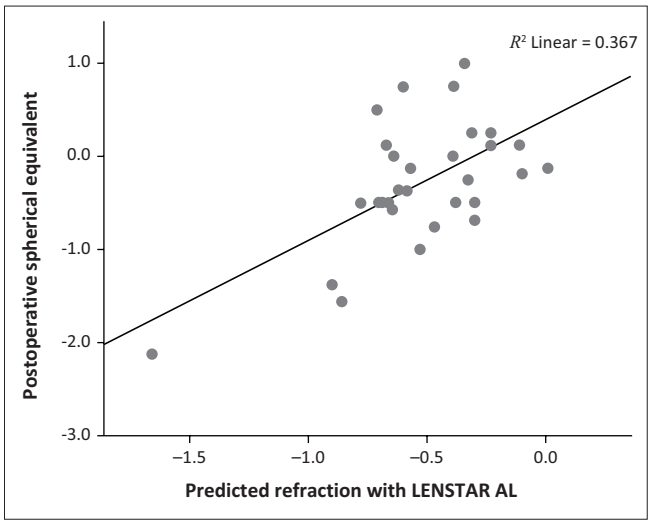
FIGURE 2: Percentage deviation of refractive outcome from predicted refraction in group 2.

of IOL power calculation and would have significantly reduced the hyperopic outcome.

Four potential sources of error in IOL power calculation have been identified. These are corneal power measurement, estimation of the effective lens position (ELP), AL measurement and IOL power calculation formulas.[3,7]

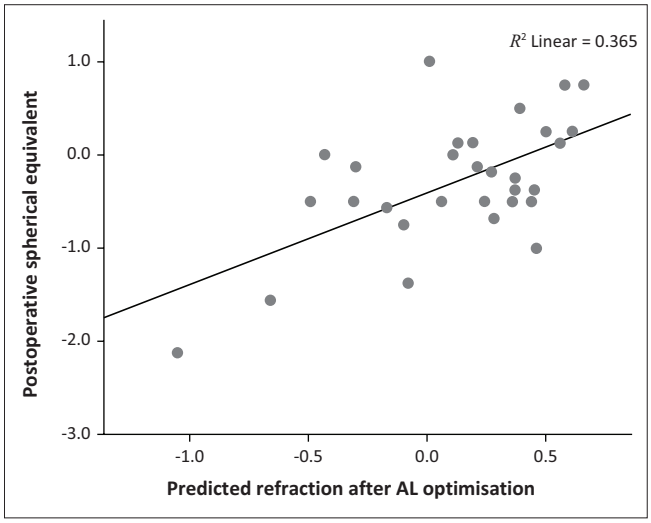
Accuracy of corneal power measurement is a less likely source of poor accuracy in refractive prediction in long eyes. Shirayama et al. have studied the problem in emmetropic eyes. They measured the total corneal power with a combined Placido and dual Scheimpflug device. Although different values for ELP were generated, accuracy of IOL power calculation did not improve.[9]

Studies of eyes with zero-dioptre IOL implantation consistently report postoperative hyperopic outcomes.[10] The



AL, axial length.

FIGURE 3: Target versus actual postoperative SE in group 1.



AL, axial length.

FIGURE 4: Target versus actual postoperative SE in group 2.

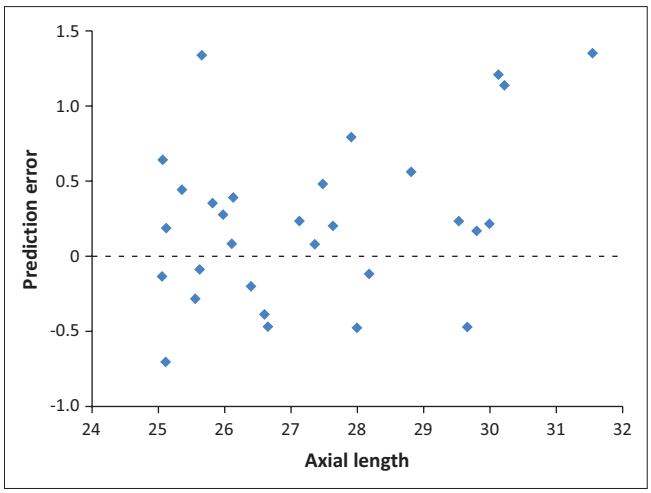


FIGURE 5: Axial length versus prediction error in group 1.

accuracy of ELP estimation is irrelevant in eyes with zero-dioptre IOLs, indicating that inaccurate estimation of the ELP is not the main source of the error.[7]

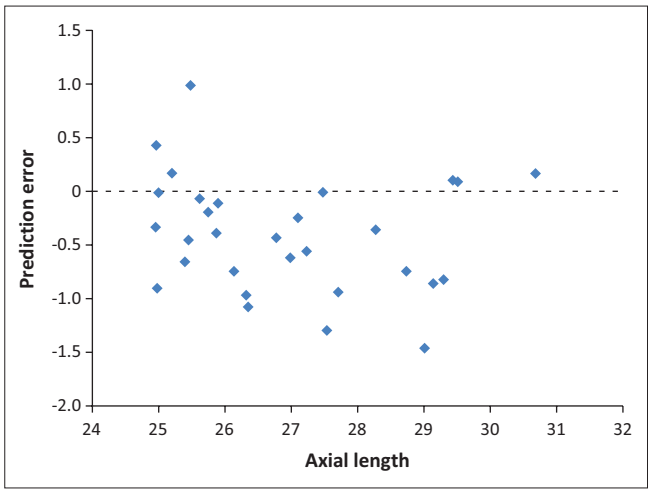


FIGURE 6: Axial length versus prediction error in group 2.

Also, the anterior chamber depth as a parameter for ELP seems to lose some of its relevance with increasing AL. It was shown by Haigis that the change in refraction per mm IOL deviation was three times higher in eyes shorter than 27 mm compared with longer eyes.[11]

Posterior staphylomas may cause errors in AL measurement with falsely longer ALs when USB is used. Theoretically, LIB accurately measures the AL in these eyes. However, results in this study and in the study by Wang et al.[7] show that optical coherence biometry still tends to produce postoperative hyperopia.

Although the formulas themselves could be the source of error, Wang et al.[7] suggest AL measurement is the primary source of error.

In this study, we studied the refractive outcome of the Holladay 1 formula using the LENSTAR AL (group 1) and using the AL optimisation method proposed by Wang et al. (group 2), in 30 eyes with ALs above 25.0 mm. The predictive capability of both groups is more or less satisfactory. The postoperative SE was within ± 1.0 D of predicted refraction in 86.7% of cases in group 1 and 90.0% of cases in group 2.

Findl et al. found that the Holladay 1 formula yielded a MAE of 0.44 D using partial coherence interferometry AL data.[12] This is comparable to our results; we found that the MAE after IOL power calculation using the Holladay 1 formula and the LENSTAR AL was 0.46 D.

The improved predictive capacity in our study group is probably related to the improved accuracy of AL measurements in these relatively shorter eyes.[5] The mean LENSTAR AL was 27.32 ± 1.89 mm.

When we performed IOL power calculation and PE back-calculation using the optimised AL, we found that, in most cases, using the optimised (shorter) AL could have reduced the hyperopic error. As the power calculations using the LENSTAR AL tended to suggest IOLs of lower power than the ideal IOLs, it is clear that by using shorter ALs, the results would improve. These results are consistent with those of the study conducted by Wang et al. in 2011.

A few other studies evaluated the use of Wang-Koch optimisation method with Holladay 1 formula. Liu et al. found that the Wang-Koch optimisation method significantly reduced the hyperopic outcome than other formulas including the Holladay 1 formula with unadjusted AL.[13] Popovic et al. concluded that the optimisation method along with Holladay 1 formula should only be used in eyes with AL longer than 27.0 mm.[14]

Inaccurate measurement of AL has been reported to be the main source of postoperative refractive error in highly myopic eyes.[15] The incidence of posterior staphyloma increases with increasing AL. Ultrasonic biometry can produce errors in the presence of a posterior staphyloma by giving a falsely longer AL. This results from eccentric measurements of the AL to the depth of the staphyloma rather than to the fovea.

Laser interference biometry more accurately measures the AL in these eyes because it depends on patient's fixation.[7]

However, consistent hyperopic errors were reported with using all three methods of biometry (A-scan, B-scan and optical) in a study by MacLaren et al.[16] They evaluated the accuracy of biometry using the Sanders, Retzlaff and Kraff theoretical formula (SRK/T) in eyes with negative-powered or zero-powered IOLs. This indicates that even eliminating or reducing the effect of posterior staphylomas on IOL calculations does not prevent hyperopic outcomes in highly myopic eyes.[7]

The optical-path-length data that were measured by the IOL Master device were calibrated to match immersion ultrasound by regression.[17] To achieve this, a single average refractive index for the whole eye was used.

However, this did not consider that the refractive index of the vitreous in myopic eyes may be different from that in emmetropic eyes.[7] Also the data set used in this study[17] included eyes with ALs up to 27.45 mm only. When this conversion method is used in eyes longer than 27.45 mm, extrapolation is used and errors may occur. Wang et al. assume that the hyperopic outcome in myopic eyes is the result of inaccurate measurement of the AL or in the way that formulas use this value.[7]

Conclusion

Our study showed that the method of optimising AL significantly reduces the percentage of eyes that would be left hyperopic. Our investigations imply that even though the Holladay 1 formula using the LENSTAR AL gives quite accurate results with regard to lens power calculation in our population of myopic patients in general, the investigation of a larger number of eyes with even higher AL values would be beneficial to identify the reasons for the hyperopic outcome in some of these cases. If larger patient groups

confirmed our trend of a hyperopic shift, modification of the formula and the LENSTAR AL measurement method would be useful.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

M.E. conceived of the presented idea, developed the methodology and supervised the project. A.A. collected the data, made the formal analysis and wrote the initial draft of the manuscript. M.E. and A.A. edited the final version of the manuscript. A.O. and M.K. contributed to the analysis of the results and to the writing of the manuscript.

Ethical considerations

This article followed all ethical standards for research involving human participants.

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Data availability

The data that support the findings of this study are available from the corresponding author, A.A., upon reasonable request.

Disclaimer

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of any affiliated agency of the authors.

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