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New method to assess the accuracy of intraocular lens power calculation formulas according to ocular biometric parameters

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Purpose: To develop a new method that makes it easy to detect accuracy deficiencies of any intraocular lens power calculation formulas and to test it on 9 different formulas.

Setting: IOA, Madrid, Spain.

Design: Retrospective observational case series.

Methods: This study's first stage included 3519 eyes from 3519 candidates to cataract surgery for which frequency distributions for the following biometric eye parameters were computed: axial length (AXL), anterior chamber depth (ACD), lens thickness (LT), white-to-white (WTW), and mean corneal radius (Rm). The resulting data for each parameter were fifth, 25th, 75th and 95th percentile, which allowed us to define the corresponding normality range. In a second stage, the new graphic-representation method was tested for 9 different formulas in a sample of 70 eyes undergoing cataract surgery with multifocal intraocular lens (MIOL) implantation.

Results: Normality ranges (defined as the 25th-to-75th-percentile interval) were 22.84 to 24.42 mm for AXL, 2.86 to 3.39 mm for ACD, 4.36 to 4.88 mm for LT, 11.64 to 12.19 mm for WTW, and 7.52 to 7.87 mm for Rm, with lower sizes in women. No significant differences were found along the 9 formulas for percentage of eyes in ± 0.50 D ($P = .82$) or ± 1.00 D ($P = .97$). The new graphical method showed less accuracy in ± 0.50 D for ACDs from 2.46 to 2.85 mm (5th to 25th percentile) for several formulas ($P < .05$).

Conclusions: Nine formulas showed nonsignificant differences in the general predictability for a sample of eyes candidates to MIOL implantation. Predictability in this sample decreased for short ACDs.

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Accuracy in intraocular lens (IOL) power calculation has become a topic arousing great interest, because nowadays crystalline-lens replacement can be considered not only for the surgical treatment of an ocular disease but also for a refractive surgery procedure.¹ New formulas and updates to existing ones have been proposed in the last years, but refractive-status prediction errors greater than ± 0.50 diopters (D) still occur in a rather high percentage of cases—which ranges between 8% and 50% of the eyes, depending on the specific study or sample stratification,^{2–9}—with the best accuracy obtained for multifocal IOL implantation procedures, and the vast majority of surgeons being clustered around 78%.^{5,10}

The major part of the methods for IOL power calculation is based on the vergence formula, and the main difference lies in the estimation of the effective lens position including from 2 up to 7 variables, some of them corresponding to eye parameters.^{5,11} The wide range of the reported accuracy

values can therefore be partly explained by the bias in accuracy of formulas according to eye parameters.^{2,3,6–9} The most common eye parameter classification to evaluate the accuracy of different formulas is based on the axial length (AXL), and most of the publications follow the classification used by Hoffer (short, <22 mm; average, 22 to 24.49 mm; long, 24.5 to 26 mm, and very long >26 mm).¹² Although the criteria followed by the author to define these cut-off points were not clearly explained in his study, these ranges possibly resulted from the ultrasound biometry of 7500 cataractous eyes, which revealed that 74% of the eyes were between 22 and 24.50 mm of AXL.^{12,13}

There are authors that have explored the influence of other eye parameters, different from AXL. Jeong et al. reported significant correlations between the postoperative spherical equivalent relative to the intended target and the following 3 variables: AXL, anterior chamber depth (ACD), and postoperative change of ACD.¹⁴ Gökce et al. also found

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an influence of the ACD in the accuracy for eyes with AXL from 22 to 25 mm obtaining lower predictability for ACDs ≤ 3.00 and ≥ 3.5 mm.⁹ Melles et al., besides AXL and ACD, also included in their study the lens thickness (LT) and the average keratometric value.⁸ The main problems of these studies are that it is unclear which criteria they used to define the normality ranges for the eye parameters and that the statistical methods they used are not easy to be assimilated by the readers.¹⁵ The main aim of the current study is to introduce a new method, based on the frequency distribution of each biometric eye parameter (AXL, ACD, LT, white-to-white [WTW], and mean corneal radius [Rm]), that makes it possible to easily detect accuracy weaknesses of any current formulas according to each parameter. For this purpose, the frequency distribution of each biometric eye parameter was first calculated for a normal population of candidates to cataract surgery and, after that, the new method—which was developed based on this normal population—was tested in another patient sample that had been implanted with a multifocal intraocular lens for the following formulas: Barrett Universal II, EVO, Holladay II, Kane, Pearl-DGS, Haigis, Hill, Hoffer, and SRK/T.^{16,17}

METHODS

Subjects

Study design was divided into 2 stages: a first stage that involved the measurement of eye biometric parameters in a normal population and the design of the new graphical method. At this first stage, all patients were measured independently and they were or not later implanted with an IOL. In a second stage, the new graphical method was used to evaluate the accuracy of several formulas in a sample of consecutive patients from the previous population who were implanted with the same IOL. All patients were informed about the study and provided their informed consent to undergo the clinical examinations required by the study, in accordance with the tenets of the Declaration of Helsinki. The study received the approval of the local ethics committee.

First Stage: Frequency Distribution of Eye Parameters

A normal population of 3519 eyes from 3519 consecutive patients was evaluated at Miranza IOA from 2016 to 2018 during their preoperative screening for cataract surgery, using the IOL Master 700 platform (Carl Zeiss Meditec, Inc). More specifically, we measured those parameters that are used by several IOL-power-calculation formulas, including AXL, ACD, LT, WTW, and Rm. An evaluation of the measurements quality reported by the IOL Master 700 was conducted previously to the analysis including only those with “Successful” outcome. Right eyes were generally included except for those subjects for whom a non “Successful” outcome was obtained in the right eye; in that case the left eye was included instead of the right eye.

The only inclusion criterion was patient’s age ≥ 50 years, whereas the exclusion criteria were any corneal pathology that could have an impact on the reliability of the measurement, severe dry-eye syndrome, and a history of corneal surgery. Measurements were taken before instilling the mydriatic drops and before measuring intraocular pressure with a Goldmann tonometer. Artificial tears were administered before keratometry measurements to those patients with ocular dryness.¹⁸

Second Stage: Accuracy of the Formulas

The evaluation of the new method for assessing the accuracy of the IOL power calculation depending on the previously described eye

parameters was conducted in a sample of 70 subjects (70 right eyes) undergoing cataract surgery in 2018 with multifocal IOL implantation—namely, FineVision Trifocal IOLs (PhysIOL), models POD F and POD F GF—for which IOL power calculation relied on the Barrett Universal II formula. The lens factor used for calculating the IOL power with the previous formula was optimized for both lenses (1.89 for POD F and 2.15 for POD F GF).¹⁹ The expected intended target for the other formulas was computed postoperatively considering the preoperative biometric data, the IOL power implanted, and the equivalent constants to the previous ones.

Refraction was measured 1 month after surgery by the same optometrist for all patients. All patients were informed about the study and provided their informed consent to undergo the clinical examinations required by the study, in accordance with the tenets of the Declaration of Helsinki. The study received the approval of the local ethics committee.

New Graphical Method Description

The suggested graphical method represents an extension of the standard plot for reporting the predictability in which the percentage of cases in ± 0.50 D and ± 1.00 D are summarized.²⁰ In this new graphical method, eyes were categorized by a dichotomous variable, inside or outside ± 0.50 D or ± 1.00 D of postoperative refractive error relative to the intended target. Then, eyes were rearranged in 5 groups depending on the percentiles defined in the stage 1 of this research (0 to 5th, 5th to 25th, 25th to 75th, 75th to 95th, and 95th to 100th) for each of the measured variables (AXL, ACD, LT, WTW, and Rm). The proportion of eyes outside ± 0.50 D or ± 1.00 D along each of the 5 subgroups and for each of the measured variables was computed and represented in a bar chart clustered by percentiles and eye parameters. Despite the standard plot describes proportion of the eyes in ± 0.50 D or ± 1.00 D, we preferred to use the opposite proportion outside these ranges for avoiding many long bars in the plot which difficult the visibility of the findings.²⁰ A horizontal line corresponding to the general predictability of the formula for all the samples crossed the plot as a reference line. Therefore, a bar that crossed this line represented a predictability poorer for the variable and percentile corresponding to that bar.

Statistical Analysis

Only one eye per subject were included in both stages. Skewness and kurtosis were computed so as to detect any deviations from a normal distribution. Percentiles were used to define normality ranges. Correlations were evaluated with the Spearman rho test. The correlation matrix was computed using the *Plotmatrix* function included in MATLAB (R2018a; MathWorks). The Refractive Analysis toolbox for MATLAB was used to conduct the standard and new plots.²¹ In the second stage, only right eyes were included. The hypothesis testing of difference in proportion of eyes outside ± 0.50 D or ± 1.00 D between each range and the general predictability was conducted using the Binomial Test. Finally, as the predictability can vary depending on the sample size, the number of eyes at each subgroup was reported consecutively next to the variable abbreviation (n_{0-5} , n_{5-25} , n_{25-75} , n_{75-95} , and n_{95-100}). The SPSS software package, version 24 (SPSS, Inc), was also used for the statistical analysis. The significance level was set at $P < .05$.

RESULTS

First Stage: Cut-Off Points Definition

Mean age was 70.25 ± 8.93 years for men and 70.68 ± 8.65 years for women ($t = -1.4$, $P = .16$). Table 1 shows the population’s descriptive statistics considering all the sample or stratified by gender. Frequency distributions for all the variables were approximately normal except for AXL, T1

Table 1. Eyes classification according to the measured parameters.

Percentile range	AXL	ACD	LT	W2W	Rm
All sample (n = 3519)					
0 to 5	≤21.84	≤2.45	≤3.98	≤11.24	≤7.28
5 to 25	21.85 to 22.83	2.46 to 2.85	3.99 to 4.35	11.25-11.63	7.28 to 7.51
25 to 75	22.84 to 24.42	2.86 to 3.39	4.36 -4.88	11.64-12.19	7.52 to 7.87
75 to 95	24.43 to 26.63	3.40 to 3.78	4.89-5.28	12.20-12.58	7.88 to 8.15
95 to 100	≥26.64	≥3.79	≥5.29	≥12.59	≥8.16
Mean ± SD	23.78 ± 1.58	3.12 ± 0.41	4.63 ± 0.40	11.92 ± 0.41	7.70 ± 0.27
Median (IQR)	23.53 (1.59)	3.13 (0.55)	4.63 (0.53)	11.92 (0.56)	7.69 (0.35)
Skewness (SE)	1.68 (0.04)	-0.07 (0.04)	0.13 (0.04)	-0.01 (0.04)	0.57 (0.04)
Kurtosis (SE)	5.95 (0.08)	0.02 (0.08)	0.12 (0.08)	-0.02 (0.08)	3.36 (0.08)
Men (n = 1364)					
0 to 5	≤22.22	≤2.48	≤3.99	≤11.29	≤7.35
5 to 25	22.23 to 23.30	2.49 to 2.93	4.0 to 4.37	11.30 to 11.75	7.36 to 7.59
25 to 75	23.31 to 24.82	2.94 to 3.48	4.38 to 4.93	11.76 to 12.29	7.60 to 7.94
75 to 95	24.83 to 26.73	3.49 to 3.86	4.94 to 5.35	12.30 to 12.67	7.95 to 8.21
95 to 100	≥26.74	≥3.87	≥5.36	≥12.68	≥8.22
Mean ± SD	24.18 ± 1.44	3.20 ± 0.42	4.65 ± 0.42	12.01 ± 0.42	7.77 ± 0.26
Median (IQR)	24.00 (1.52)	3.23 (0.55)	4.66 (0.56)	12.01 (0.55)	7.76 (0.35)
Skewness (SE)	1.41 (0.07)	-0.20 (0.07)	0.13 (0.07)	-0.04 (0.07)	0.35 (0.07)
Kurtosis (SE)	4.83 (0.13)	-0.05 (0.13)	0.18 (0.01)	0.13 (0.13)	0.91 (0.13)
Women (n = 1364)					
0 to 5	≤21.71	≤2.43	≤3.97	≤11.22	≤7.25
5 to 25	21.72 to 22.64	2.44 to 2.81	3.98 to 4.34	11.23 to 11.57	7.26 to 7.48
25 to 75	22.65 to 24.00	2.82 to 3.32	4.35 to 4.85	11.58 to 12.13	7.49 to 7.82
75 to 95	24.01 to 26.37	3.33 to 3.70	4.86 to 5.24	12.14 to 12.50	7.83 to 8.08
95 to 100	≥26.38	≥3.71	≥5.25	≥12.51	≥8.09
Mean ± SD	23.53 ± 1.61	3.07 ± 0.39	4.61 ± 0.38	11.85 ± 0.39	7.66 ± 0.27
Median (IQR)	23.26 (1.36)	3.07 (0.51)	4.60 (0.52)	11.86 (0.55)	7.65 (0.34)
Skewness (SE)	2.04 (0.05)	-0.03 (0.05)	0.11 (0.05)	-0.05 (0.05)	0.77 (0.05)
Kurtosis (SE)	7.65 (0.11)	0.16 (0.11)	-0.01 (0.11)	-0.16 (0.11)	5.67 (0.11)

ACD = anterior chamber depth; AXL = axial length; LT = lens thickness; SE = standard of error

which was positively skewed (skewness >1), and Rm (skewness of 0.35 for men and 0.77 for women). Both variables showed a higher number of outliers (kurtosis >3) in women and only for AXL in men. Table 1 shows left-shifted distributions for all variables for women compared with men, due to women having generally smaller eyes. Women-to-men median values' ratios were 0.969 for AXL, 0.951 for ACD, 0.987 for LT, 0.988 for WTW, and 0.986 for Rm.

The following variables were significantly correlated ($P < .0005$) with age: AXL ($r = -0.16$), ACD ($r = -0.19$), LT ($r = 0.38$), Rm ($r = -0.14$), and WTW ($r = -0.12$). However, adjusted r -square values resulting from linear regression models were very low: 0.03 for AXL, 0.04 for ACD, 0.14 for LT, 0.02 for Rm, and 0.01 for WTW.

T2 Table 2 shows a linear correlation of AXL with the other variables but this correlation decreased outside the range's central portion and showed very low adjusted r -square values, the maximum corresponding to ACD when all the sample was considered (0.25). The break from the linear tendency is clearly seen in Figure 1, either for men (A) or women (B), especially for longer AXLs with an increase of the outliers. However, for the correlations between the other variables, not such positive skewed, tendencies also appeared between them (ie, ACD vs WTW and Rm vs WTW) but with less incidence of outliers.

Accuracy of the Formulas

Table 3 shows that despite Hoffer and Kane resulted in **T3** a slightly higher percentage of eyes in ± 0.50 D or Hoffer and Barrett II in ± 1.00 D, no statistically significant differences were found among formulas. Figures 2 and 3 show the percentage of eyes outside ± 0.50 D and ± 1.00 D, respectively, according to the classification of the parameters in the percentile ranges described in Table 1 for all the sample. An horizontal line crossed each plot marking the accuracy considering all the sample in such a way that bars above this line are of special interest. For instance, the most dependent formula from biometric eye parameters was the SRK/T (Figure 2), especially in the extremes of the distributions (from 0 to 5th and from 95th to 100 percentiles) of some variables. Up to 5 formulas showed a statistically significant decrease of accuracy for the ACD in the percentile range from 5th to 25th, according to Table 1 ranging from 2.46 to 2.85 mm (Figure 2). Figure 3 shows the same plots but for eyes outside ± 1.00 D with only significant differences from general accuracy for the Rm in the EVO formula at the range from 75th to 95th percentiles.

DISCUSSION

In the first stage of this study, we computed the frequency distribution for those variables involved in IOL power

Table 2. Correlation of AXL with other eye parameters for different ranges of axial length.

	ACD (rho, P Value, r^2)	LT (rho, P Value, r^2)	WTW (rho, P Value, r^2)	Rm (rho, P Value, r^2)
All sample				
Extreme-short (176)	0.14, .06, 0.02	0.01, .95, -0.004	0.11, .13, -0.002	0.04, .5, -0.005
Short (705)	0.26, <.0005*, 0.06	-0.10, .007*, 0.006	0.17, <.0005*, 0.03	0.13, .001*, 0.02
Normal (1759)	0.29, <.0005*, 0.09	-0.12, <.0005*, 0.02	0.23, <.0005, 0.05	0.30, <.0005*, 0.08
Long (703)	0.26, <.0005*, 0.06	-0.09, .02*, 0.009	0.11, .005*, 0.007	0.05, .20, -0.001
Extreme-long (176)	-0.17, .02*, 0.02	0.14, .06, 0.02	-0.12, .11, 0.01	-0.03, .70, -0.001
All eyes	0.57, <.0005*, 0.25	-0.24, <.0005*, 0.04	0.38, <.0005*, 0.1	0.39, <.0005*, 0.09
Men				
Extreme-short (68)	-0.15, .22, 0.04	0.19, .12, -0.03	-0.06, .61, -0.01	-0.22, .07, -0.04
Short (272)	0.22, .001*, 0.05	-0.1, .11, 0.0002	0.15, .01, 0.05	0.20, .001*, 0.007
Normal (686)	0.19, <.0005*, 0.08	-0.06, .13, 0.03	0.14, <.0005*, 0.05	0.22, <.0005*, 0.09
Long (270)	0.12, .05, 0.07	-0.02, .75, 0.006	-0.003, .97, 0.009	-0.12, .06, -0.001
Extreme-long (68)	-0.12, .36, -0.009	0.05, .68, -0.10	-0.24, .05, 0.0002	0.01, .93, -0.005
All eyes	0.52, <.0005*, 0.23	-0.26, <.0005*, 0.05	0.36, <.0005*, 0.11	0.38, <.0005*, 0.11
Women				
Extreme-short (110)	0.18, .06, 0.03	0.16, .09, -0.005	0.04, .70, -0.002	-0.12, .20, -0.005
Short (436)	0.17, <.0005*, 0.06	-0.01, .89, 0.005	0.13, .01*, 0.03	0.13, .01*, 0.02
Normal (1071)	0.26, <.0005*, 0.08	-0.12, <.0005*, 0.02	0.24, <.0005*, 0.04	0.32, <.0005*, 0.07
Long (430)	0.31, <.0005*, 0.06	-0.10, .03*, 0.02	0.04, .45, -0.001	-0.16, .001, -0.002
Extreme-long (108)	-0.10, .29, 0.02	0.19, .05, 0.03	-0.02, .81, -0.009	0.06, .56, -0.005
All eyes	0.57, <.0005*, 0.25	-0.27, <.0005*, 0.04	0.35, <.0005*, 0.07	0.36, <.0005*, 0.06

ACD = anterior chamber depth; AXL = axial length; LT = lens thickness; Rm = mean corneal radius; WTW = White-to-white

* $P < .05$.

calculation, for a population of candidates to cataract surgery. We then relied on the resulting percentiles to create a new graphical method that allows us to easily understand the impact of each of these eye parameters upon postoperative spherical equivalent.

With regard to the frequency distribution of the individual eye parameters, we obtained a mean AXL of 23.78 mm, which is close to the 23.44 mm reported by Fotedar et al. for a White population.²² A higher difference from our study which included a White population can be found in comparison to other studies with non-White population. Hashemi et al. reported mean AXL of 23.14 mm for an Iranian population, Huang et al. found 24.32 mm for a group of Chinese subjects, and Warriar et al. reported the lowest mean value of 22.76 mm for a Myanmar-based population.²³⁻²⁵ From these authors, Fotedar et al. found a mean reduction in AXL with age of 0.12 mm per decade in women but only 0.02 mm per decade in men.²² This result is not supported by Warriar et al. and in our study, despite finding a significant correlation between AXL and age, the corresponding r -square value was too low to draw conclusions and to be able to predict AXL changes with age.²⁵

As for ACD, our results (3.12 ± 0.41 mm) were again in good agreement with Fotedar's findings (3.10 mm), but higher differences were found in comparison to China (3.08 mm), Myanmar (2.82), and Iran (2.62 mm).²²⁻²⁵ Regarding LT, our study yielded a mean value of 4.63 mm, which is higher than Iran's (4.28 mm) and Myanmar's (4.51 mm).^{23,25} However, this LT increase is also related to smaller ACD values, which is something we found in our study but which was not reported by the other

authors. Regarding corneal parameters, authors usually calculate corneal power based on the keratometric index. However, we preferred to use corneal radius because this is the parameter that formulas for calculating the IOL power usually use with their own indices from 1.3315 to 1.336 for computing corneal power.⁴ We have converted the corneal power values reported by other authors into corneal radius values, obtaining a mean value of 7.77 mm for White, which is close to the 7.70 mm we found in our study but flatter than in Chinese population, which ranged between 7.63 mm and 7.65 mm.^{22,24,26} The corneal diameter or WTW was 11.92 mm closest again to the White population mean of 12.06 mm and bigger than Chinese people with a mean of 11.75 mm.^{20,27} For all the parameters under analysis and all the studies we compared our results with, mean values were higher for men than for women.^{22,23,25} Considering the bias reported for eye parameters between populations, it is important to note cut-off points of the new graphical method should be adapted according to the population for which the accuracy of IOL power calculation is going to be assessed. Therefore, the stage 1 of our study should be conducted with other populations in future studies.

Eye parameters were correlated with age: AXL decreased with age, as ACD, WTW, and Rm, while LT increased. Regarding AXL, this drop has been reported by other authors.^{22,25,28} The increase in LT with age can be attributed to the increase in protein fiber layers forming under the capsule.²³ If we consider the anterior segment length as the sum of ACD and LT, the increase in LT could be the main reason that compensates the decrease in ACD for maintaining that total anterior segment length stable

Figure 1. Frequency distributions are shown with scatterplots for inspecting the relationships among eye biometric parameters for (A) men and (B) women (ACD = anterior chamber depth; AXL = axial length; LT = lens thickness; Rm = mean corneal radius; WTW = white-to-white).

during aging, as Praveen hypothesized.²⁸ Based on this theory, it would be important to know how the anterior segment can vary its parameters. Interestingly, in our study, we found that ACD decreases with age, which is in line with Huang and Hashemi's findings, with a half the correlation of the LT ($r = -0.19$) vs for ACD ($r = 0.38$).^{23,24}

Regarding those studies focusing on the refractive outcomes obtained with different IOL calculation formulas, many of them have used Hoffer's classification (from 1993).¹² Part of the basis of this publication is on another publication by Hoffer where he evaluated 7500 eyes with cataracts, although, as he explained, that publication

Table 3. Predictability of 9 formulas.

Formulas	Eyes in ± 0.50 D; % (n)	Eyes in ± 1.00 D; % (n)
Barrett Universal II	77.1 (54)	97.1 (68)
EVO	78.6 (55)	95.7 (67)
Holladay II	81.4 (57)	94.3 (66)
Kane	84.3 (59)	92.9 (65)
Pearl-DGS	81.4 (57)	95.7 (67)
Haigis	82.9 (58)	95.7 (67)
Hill	74.3 (52)	95.7 (67)
Hoffer	84.3 (59)	97.1 (68)
SRK/T	77.1 (54)	95.7 (67)
χ^2	4.39, $P = .82$	2.32, $P = .97$

showed a bias for extremely long eyes (>26 mm) and very short eyes (<24 mm).^{12,13} In addition, the data of these publications were taken with ultrasonic biometers while most studies of the last decade are already measured by optical biometers.

Knox Cartwright et al. evaluated 22,458 unpaired eyes with optical biometry.²⁹ This study found that 50% of eyes, centered around the median of 23.25 mm, were between 22.60 and 23.98 mm. The population in our study had longer eyes centered over a median of 23.53 mm with 50% of cases between 22.84 and 24.42 mm. Considering the criteria followed by Hoffer of 75% of eyes centered over the median, our study would classify the average range defined by Hoffer between 22.34 and 25.28 mm instead of 22.00 and 24.49 mm.^{12,13} This point is important because this new data can be an indicator of how eye parameters and devices of measurement are evolving, changing the measurements considered as normal some years ago or between different populations.

It is important to highlight that the new method, based on the frequency distribution of each biometric eye parameter described in this article, shows the influence that different parameters have on the final results after cataract surgery. Comparing our results with those published by other authors,

Figure 2. New plots with percentage outside ± 0.50 D. For accuracy plots depending on eye parameters, the number of eyes along each percentile (n_{0-5} , n_{5-25} , n_{25-75} , n_{75-95} , n_{95-100}) are shown next to the following eye parameters: axial length (AXL), anterior chamber depth (ACD), lens thickness (LT), white-to-white (WTW), and mean corneal radius (Rm). A dotted horizontal line crossing the plot represents the percentage outside ± 0.50 or ± 1.00 D without eye parameter stratification. Asterisks were used to mark statistically significant differences between each percentile in comparison to the general accuracy.

Figure 3. New plots with percentage outside ± 1.00 D. For accuracy plots depending on eye parameters, the number of eyes along each percentile (n_{0-5} , n_{5-25} , n_{25-75} , n_{75-95} , n_{95-100}) are shown next to the following eye parameters: axial length (AXL), anterior chamber depth (ACD), lens thickness (LT), white-to-white (WTW), and mean corneal radius (Rm). A dotted horizontal line crossing the plot represents the percentage outside ± 0.50 or ± 1.00 D without eye parameter stratification. Asterisks were used to mark statistically significant differences between each percentile in comparison to the general accuracy.

Melles et al. evaluated the extent of bias that resulted in lower predictability within several formulas for several biometric factors.⁸ They evaluated the prediction error discretizing each variable to the most proximal value for specific steps. For instance, they obtained a higher prediction error that achieved a mean close to ± 0.25 D for some formulas in $AXL \leq 22$ mm and ≥ 26 mm values. The same happened for ACD: they obtained a higher error in prediction that achieved a mean close to ± 0.25 D (0.31 D) for some formulas for ACDs ≤ 2.50 and ≥ 3.75 mm values. Gökce et al. reported that ACD was an important factor for the accuracy of IOL calculation in eyes with normal AXL but shallow (< 3.0 mm) and deep (> 3.5 mm) ACDs.⁹ Yang et al., after splitting their cases into 4 groups based on AXL and 3 subgroups based on ACD, reported that in short eyes, irrespective of ACD, only around 62% of the patients obtained a postoperative outcome within ± 0.50 D.³⁰ Also in the study by Yang et al., the predictability was again of 60.8% for eyes with short ACD (< 2.5 mm) vs the 69.7% and 75.4% they reported for groups of longer ACDs.³⁰

Although the cut-off values vary among the previously mentioned studies, all generally agree that formulas can fail in short eyes and shallow ACDs, and there is less agreement about the predictability for longer eyes and deep ACDs.^{8,9,14,30} Our results are in partial agreement with the previous reported literature, being the ACD in the 5th to 25th percentile (2.46 to 2.85 mm) the variable which decreased significantly the predictability (± 0.50 D) with several formulas. Conversely, a decrease on predictability was not found for short/very short eyes or very short ACDs as it has been reported in previous literature, possibly due to the lower number of eyes in these extreme cases.^{8,9,30} This is one of the main limitations of our study, despite the method described provides useful information to detect the weakness in several formulas, the use of multifocal intraocular lens in our sample leads to a higher number of eyes in the normal range. Future studies should apply the method in samples with monofocal IOLs with less restricted inclusion criteria and then with a higher number of extreme eyes in the sample. Another limitation is that the

interaction between variables was not evaluated in this work but logistic regression models including all eye parameters and the classification inside each parameter can be implemented in future works with higher sample sizes.

Another parameter that we observed through our method that caused worse results of predictability (± 0.50 D) in the eyes with values farther from normal, the 0% to 5% percentile (≤ 3.98 mm), is the LT. In those cases, we found worse results for all formulas, whether third or fourth generation or based on artificial intelligence, although the differences were not statistically significant. Considering the lack of significance, the small sample in this range, and that this is the first study that has reported this finding, we consider it interesting to confirm this finding in the future with a higher sample of eyes. Finally, there was not a clear tendency for refractive surprises ($> \pm 1.00$ D) despite predictability for Rm in the 75th to 95th percentile was poorer than the general predictability for all the formulas suggesting that this refractive surprises might be due to a less reliable measurement of corneal radii in very few cases.

In conclusion, this new method based on the frequency distribution of each biometric eye parameter described in this article shows the influence that the different parameters have on the final results after cataract surgery. It allows to detect, in a more friendly way, the accuracy of current formulas according to each parameter. However, some considerations should be taken into account about this new graphical method or about the conclusions obtained for the formulas. As we have discussed, normal ranges can vary between populations; therefore, the method should be personalized with percentiles obtained from different populations or measurement devices. The study should be expanded in the future with the inclusion of more extreme cases through higher sample sizes to obtain more reliable conclusions about the comparison between formulas.

WHAT WAS KNOWN

- Eyes have been classified according to axial length measurement in short, average, long, and very long eyes based on the frequency distribution of ultrasound biometry.
- Previous studies have demonstrated that mean predictability of the formulas can vary mainly according to axial length and anterior chamber depth.

WHAT THIS PAPER ADDS

- A new classification in 5 levels has been conducted according to the frequency distribution of eye parameters measured with sweep source optical biometry.
- A new graphical method has been designed to assess the accuracy based on the percentage of eyes outside ± 0.50 D and ± 1.00 D according to the eye parameters measured with an optical biometer.

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000 New method to assess the accuracy of intraocular lens power calculation formulas according to ocular biometric parameters

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Develop a new method based on the frequency distribution of each biometric eye parameter. It makes easy to detect accuracy deficiencies of any intraocular lens power calculation formulas.