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Research article

# IOL power calculation in long eyes: Selection of the best axial length adjustement factor using the most common formulas

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## ARTICLE INFO

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## ABSTRACT

*Purpose:* Comparing IOL power calculation formulas in long eyes ($AL \geq 26.00$ mm) to find the best axial length (AL) adjustment/IOL power calculation formula combination.

*Design:* Retrospective, comparative, case-series.

*Participants:* Patients with long eyes that underwent cataract surgery.

*Methods:* five-hundred-fifty-four eyes of 554 patients were examined before and after standard phacoemulsification without complications. Eyes were subdivided in 3 groups according to AL: $26.00 \leq AL < 28.00$ mm, $28.00 \leq AL < 30.00$ mm, $AL \geq 30.00$ mm. Eight formulas that do not require anterior chamber depth (ACD) were evaluated: Barrett Universal II (BUII), Emmetropia Verifying Optical (EVO) 2.0, Ladas Super Formula (LSF), Hoffer Q, Holladay 1, SRKT, T2 and T2.2. The lens constant of ULIB database and IOLCon database were used. Each formula was analyzed by using uncorrected AL (ALu) and following AL adjustments: Wang-Koch 1 (wk1), wk2, wk polinomial (wk-pol), estimated Cooke modified axial length (CMALe) and ALc correcting factor.

*Main outcome measures:* Mean absolute error (MAE), median absolute error (MedAE) and percentage of eyes within ±0.50 and ± 1.00 diopters (D) of prediction error.

*Results:* T2-ALu gave best outcome when $26.00 \text{ mm} \leq AL < 28.00$ mm. LSF-ALu, BUII-ALu, EVO 2.0-ALu, Holladay 1-wk-pol and T2.2-CMALe represented valid alternatives. EVO 2.0-ALc gave best outcomes when $28.00 \text{ mm} \leq AL < 30.00$ mm. Other thick-lens or hybrid artificial-intelligence-vergence based formulas (BUII-ALu, LSF-CMALe) and Holladay 1-wk2 demonstrated greater reliability compared to thin lens-based formulas. EVO 2.0-CMALe gave best outcomes when $AL \geq 30.00$ mm. Holladay 1-wk-pol e T2.2-wk1 represented valid alternatives (all $p < 0.050$). LSF could fail in 50 % of cases without ACD when $AL \geq 30.00$ mm.

*Conclusions:* Choosing the best AL adjustment/IOL power calculation formula combination for each AL subrange, can improve refractive outcomes in patients with long eyes that undergo cataract surgery.

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## 1. Introduction

According to the World Health Organization (WHO), cataract is the leading cause of reversible blindness in the world today [1], and myopia is the most common refractive defect in Europe [1]. Different classification systems were proposed to measure myopia severity, such those based on the amount of the refractive defect. However, axial length (AL) is not only the principal element determining the myopic defect, but also the main contributor to related complications (retinal detachment, macular schisis, staphyloma, myopic chorioretinopathy). For this reason, using AL as the parameter for quantifying the degree of myopia could be more correct. Therefore, “High myopia” is defined as the presence of myopic refractive defect associated with AL≥26.00 mm [2–8].

The increased risk to develop cataract in eyes with high myopia is well known: for example, a 30 % increased risk of developing a posterior subcapsular type of cataract in myopic patients has been reported [7,8].

For these patients, cataracts now represent a real “refractive procedure” that could potentially eliminate the refractive defect.

Several authors reported that patients with high myopia undergoing cataract surgery have an increased risk to have a residual hyperopic refractive error using both traditional and new generation formulas for Intraocular Lens (IOL) power calculation [4,8–10].

Indeed, Stopyra et al. [5] and Bernardes et al. [11] confirmed the excellence of the IOL power calculation in eyes with an average AL (22.00 mm–25.00 mm), with a refractive prediction error (PE) < ±0 50 diopters (D), but they reported that the hyperopic refractive error increases with increasing AL [5,11]; for example, when AL>26.00 mm the absolute PE increases by about 0.1D per 0.10 mm of AL, while with AL>33.00 mm the absolute PE increases by about 1.1D per 0.10 mm of AL [5].

For this reason, the ophthalmic surgeon is often suggested to choose an IOL with a myopic refractive residual as a postoperative target in order to avoid hyperopic surprise, similar to what happens in eyes that underwent myopic refractive surgery [12].

To reduce the percentage of eyes with hyperopic refractive outcome, in view of the great impact of AL on IOL power calculation in patients with high myopia, some authors proposed preoperative AL correction factors [13–19].

For these reasons, the purpose of the present study was to compare the efficacy and reliability of the different correction formulas, comparing the results obtained in different ranges of ALs in high myopic eyes.

## 2. Methods

In this retrospective, comparative study, eyes with AL≥26.00 mm that underwent uneventful phacoemulsification and subsequent capsular bag IOL implantation were analyzed. Five-hundred-fifty-four eyes of 554 patients were evaluated, partly derived from own database and partly from freely accessible databases in the literature. Specifically:

- 71 eyes from our database;
- 370 eyes from Cheng et al. study database [20].
- 63 eyes from Langenbucher et al. study database [21].
- 60 eyes from Idrobo-Robalino et al. study database [22].

Partial Coherence Interferometry (PCI) biometry (IOL Master 500) with our database, Cheng et al. [20] database, and Idrobo-Robalino et al. [22] database was obtained. A Swept-Source Optical Coherence Tomography (SS-OCT) biometry (IOL Master 700) for Langenbucher et al. [21] database was performed. For this reason, lens thickness (LT) measurement was available only for 63 eyes. In addition, anterior chamber depth (ACD) was not measured for our database and this data was not available also for Idrobo-Robalino et al. [22] database.

The research was carried out in accordance with the principles of the Declaration of Helsinki and a written informed consent was obtained from all our patients before cataract surgery.

In view of the multi-database nature of the study, the final evaluation of the postoperative data was carried out at the Ophthalmological Unit, Department of Medicine, Surgery and Dentistry, Scuola Medica Salernitana, University of Salerno, which served as the data collection center. Institutional Review Board (IRB) approval was then obtained from the reference institution of the data collection center (Cometico Campania).

Regarding the evaluation of patient data from literature, as performed in other studies [12], only eyes where biometric and refractive data were available were selected, applying the same inclusion and exclusion criteria of our eyes.

Similar to what has been done in other recent studies [3–6,8–11,20], different AL ranges were identified, and in particular, patients were divided into 3 AL Groups, according to the paper by Rong et al. [23].

- Group 1: 26.00≤ AL<28.00 mm with 269 eyes;
- Group 2: 28.00≤AL<30.00 mm with 144 eyes;
- Group 3: AL ≥ 30.00 mm with 141 eyes.

The study was then divided into 2 steps:

- Step One: selection of the best AL adjustment for each formula analyzed for each Group;
- Step Two: selection of the best IOL power calculation formula/AL adjustment combination for each Group.

### *2.1. Patients selection*

Only patients with AL≥26.00 mm with the following characteristics were included in the study:

- Uneventful phacoemulsification, with in the capsular bag IOL implantation;
- Optical biometry performed with an IOL Master biometer (model 500 or 700, Carl Zeiss Meditec, Jena, Germany);
- Availability of postoperative refraction, measured as spherical equivalent (SE) and performed at least one month after surgery, achieving a corrected distance visual acuity >20/40.

Consequently, all patients who did not fit the inclusion criteria were excluded from the study, specifically:

- Patients with dense cataracts that did not allow AL detection by optical biometry;
- Patients with corneal ectasia, irregular astigmatism, pterygium or any other condition that may alter the corneal surface;
- Patients with glaucoma, exudative maculopathy (wet-type age-related macular degeneration, diabetic macular oedema, retinal vascular occlusion) or any other ongoing ophthalmic pathology.
- Patients with a history of previous ophthalmic surgery.

### *2.2. IOL power calculation formulas and AL adjustments*

Eight formulas for calculating IOL power were analyzed, all of which have in common that they can work without the knowledge of the ACD[5,24–26].

- Barrett Universal II (BUII) [27].
- Emmetropia Verifying Optical (EVO) 2.0 [5].

**Table 1**
Analyzed IOL models and lens constants.

| Modello IOL | N° | BUII | EVO 2.0 | Hoffer Q | Holladay 1 | LSF | SRKT/T2/T2.2 |
|---|---|---|---|---|---|---|---|
| Alcon MA60MA+ | 8 | 118.9<br>Nominal | 118.9<br>Nominal | 15.94<br>IOLCon | 10.29<br>IOLCon | 118.9<br>Nominal | 126.6<br>IOLCon |
| Alcon MA60MA- | 5 | 118.9<br>Nominal | 118.9<br>Nominal | −5.52<br>IOLCon | −7.08<br>IOLCon | 118.9<br>Nominal | 103.6<br>IOLCon |
| Alcon SA60AT | 3 | 118.5<br>Barrett | 118.8<br>IOLCon | 5.44<br>IOLCon | 1.67<br>IOLCon | 118.8<br>IOLCon | 118.8<br>IOLCon |
| Alcon SN60WF | 129 | 119.0<br>IOLCon | 119.0<br>IOLCon | 5.64<br>IOLCon | 1.84<br>IOLCon | 119.0<br>IOLCon | 119.0<br>IOLCon |
| AMO SensarAR40e | 49 | 118.7<br>IOLCon | 118.7<br>IOLCon | 5.39<br>IOLCon | 1.62<br>IOLCon | 118.7<br>IOLCon | 118.7<br>IOLCon |
| AMO Tecnis PCB00 | 19 | 119.3<br>IOLCon | 119.3<br>IOLCon | 5.80<br>IOLCon | 2.02<br>IOLCon | 119.3<br>IOLCon | 119.3<br>IOLCon |
| AMO Tecnis ZA9003 | 35 | 119.1<br>IOLCon | 119.1<br>IOLCon | 5.61<br>IOLCon | 1.84<br>IOLCon | 119.1<br>IOLCon | 119.1<br>IOLCon |
| B&L Akreos Adapt-AO | 111 | 118.4<br>IOLCon | 118.4<br>IOLCon | 5.20<br>ULIB | 1.42<br>ULIB | 118.4<br>IOLCon | 118.4<br>IOLCon |
| Corneal ACR6D SE | 3 | A Constant = 120.0 from literature (Reference N°43) | | | | | |
| Hoya iSert 250/251 | 6 | 118.5<br>IOLCon | 118.5<br>IOLCon | 5.30<br>IOLCon | 1.52<br>IOLCoN | 118.5<br>IOLCon | 118.5<br>IOLCon |
| Hoya VA60BB | 18 | 118.7<br>ULIB | 118.7<br>ULIB | 5.52<br>ULIB | 1.71<br>ULIB | 118.7<br>ULIB | 118.7<br>ULIB |
| Rayner S. Asph 920H | 105 | 118.3<br>ULIB | 118.3<br>ULIB | 5.21<br>ULIB | 1.41<br>ULIB | 118.3<br>ULIB | 118.3<br>ULIB |
| Sensar 1-Piece AAB00 | 63 | 119.0<br>IOLCon | 119.0<br>IOLCon | 5.56<br>IOLCon | 1.78<br>IOLCon | 119.0<br>IOLCon | 119.0<br>IOLCon |

BUII=Barrett Universal II; EVO = Emmetropia Verifying Optical; LSF=Ladas Super Formula; T2.2 = T2 refinement by Idrobo-Robalino et al.; Nominal = Nominal Constant; IOLCon = Optimized Constant ULIB from the IOLCon database (https://iolcon.org); Barrett = Optimized Constant obtained from the APACRS website (https://calc.apacrs.org/barrett_universal2105/); ULIB=Optimized Constant from the User Group for Laser Interference Biometry database (http://ocusoft.de/ulib/c1.htm).

Note 1: For the BUII, EVO 2.0, and LSF formulas, as indicated on their respective websites, the nominal constant of the Alcon MA60MA ± IOL model was used. Since the websites of these formulas reported discordant values, the nominal value reported on the IOLCon database was used.

Note 2: Considering the disparity between the IOLCon and ULIB databases regarding lens constants for the Hoffer Q and Holladay 1 formulas, constants from the latter database were used for the B&L Akreos Adapt-AO model. Since the Hoya VA60BB and Rayner S. Asph 920H models are not present on IOLCon database, data from ULIB database were used.

Note 3: Since the Corneal ACR6D SE model is not reported in either the IOLCon or ULIB databases, an A-Constant value derived from the literature was used, obtaining the remaining constants using standard conversion formulas.

- Hoffer Q [2].
- Holladay 1 [28].
- Ladas Super Formula (LSF) [29].
- SRKT [30].
- T2 [31].
- T2.2, meaning the refinement of the T2 formula by Idrobo-Robalino et al. [22].

Each formula was evaluated by testing the effectiveness of different AL adjustments:

- Uncorrected AL (ALu), which is the measurement taken by the optical biometer without the application of any correction factor;
- ALc [18].
- estimated Cooke modified AL [17] (CMALe), where the LT parameter was calculated using the PANACEA IOL AND TORIC CALCULATOR program (version 22.12.20, "Age LT" calculation function);
- AL adjustments according to Wang-Koch (wk1) [13], available for the Holladay 1, Hoffer Q and SRKT formulas;
- AL adjustments according to Wang-Koch updated (wk2) [14], available for the Holladay 1 and SRKT formulas;
- AL adjustment according to Wang-Koch with a polynomial factor (wk-pol) [15], available only for the Holladay 1 formula.

Since T2 and T2.2 methods are based on the SRKT formula [22,31], the correction factors wk1 and wk2 for SRKT were also analyzed for these two formulas.

According to the most recent protocols on the accuracy of IOL power calculation [32], the constant optimization of the different analyzed IOL models was not carried through zeroing-out the mean error (ME). In fact, as this study analyses a specific subgroup of long eyes, using lens constants optimized for the entire population and not constants optimized for limited AL ranges is more appropriate [32]. Therefore, optimized constants from the IOLCon Database (https://www.iolcon.org) or, when this was not possible, from the User Group for Laser Interference Biometry database (http://ocusoft.de/ulib/c1.htm) were used. The data of the analyzed IOL models and the criteria for choosing the various lens constants [33] are shown in Table 1.

Patient data and refractive results were processed using Excel software (Microsoft Corporation, USA). Specifically:

1) Input into the Excel spreadsheet of: patient data, mean keratometry (Km) and AL values, model and power of the implanted IOL, SE.
2) The published and therefore reproducible Hoffer Q, Holladay 1, SRKT, T2 and T2.2 formulas algorithms were programmed into the spreadsheet to obtain the expected refractive results.
3) The algorithms of the BUII, EVO 2.0 and LSF methods are not published, so the only way to calculate the power of the IOL was through the respective calculators. Specifically, the following online calculators were consulted:
   - BUII: available at the Asia Pacific Association of Cataract & Refractive Surgeon (APACRS) website, https://www.apacrs.org;
   - EVO 2.0: available at https://www.evoiolcalculator.com;
   - LSF: available at https://www.iolcalc.com.

Refractive errors were then calculated through the respective calculators, using a specific computer programming language obtained with Python software (Python Software Foundation. Available at https://www.python.org).

4) PEs, consisting of the difference between the postoperative refraction and the predicted refraction, were calculated for each patient and each formula. The predicted refraction is the expected refraction with the implanted IOL for each method.

### *2.3. Descriptive and inferential statistics*

Descriptive and inferential statistics were performed with SPSS software (SPSS Inc. Version 26.0, Chicago, IL, USA). The normality of the data was checked with the exact Kolmogorov-Smirnov. One-sample T-test (in the case of a normal distribution of PEs) and one-sample Wilcoxon test (in the case of a non-normal distribution of PEs) were used to test whether the MEs obtained with the various formulas were significantly different from zero.

Regarding Step 1 of the study, Mean Absolute Error (MAE) and Median Absolute Error (MedAE) were chosen as primary parameters when comparing the different AL adjustments for each formula. The various IOL formula/AL adjustment combinations for each method were evaluated using the Friedman test. In doubtful cases, the mean value of the ranks acted as a discriminator in the choice of the best AL adjustment for each formula. If no statistically significant differences were found between two alternatives, the option with the best refractive trend (lowest MAE and MedAE) was selected.

For Step 2 of the study, the best IOL power calculation formula/AL adjustment combinations were compared.

MedAE, MAE and the percentages of eyes with PE $<\pm 0.5$ D and $<\pm 1.0$ D were chosen as evaluation parameters. Data were analyzed respectively with Friedman's test and Cochran's test, both with Bonferroni's post-hoc correction.

The definition of the required sample size, following the example of previous studies [12], was calculated using G*Power software (Version 3.1.9.7, Faul, Erdfelder, Lang, & Buchner, 2020. Available at https://www.gpower.hhu.de, access date March 18, 2023). Given Partial $\eta 2$ values of 0.204 and a nonsphericity correction $\varepsilon$ of 0.426, corrected by the Greenhouse-Geisser method, both calculated with SPSS software, and an effect size of 0.506 derived from the G*Power program, it was estimated that a sample size of 33 eyes would be required, considering a significance level of 5 % and a test power of 95 %.

## 3. Results

The PEs obtained with the Hoffer Q, Holladay 1, SRKT and T2 formulas showed a normal distribution (all $p > 0.050$), while the PEs obtained with the remaining formulas did not show normal distribution (all $p < 0.050$). All PEs analyzed in absolute value showed a non-normal distribution (all $p < 0.050$). All MEs were statistically significantly different from zero (all $p < 0.001$).

The mean age of analyzed patients was 61.06 ± 12.31 years, with a mean AL value of 28.68 ± 2.15 mm, median = 28.09 mm, and a Km value of 43.61 ± 1.74D, median = 43.66D.

### 3.1. *Choice of the best AL adjustment for each AL range*

#### 3.1.1. *Group 1*

The MAE and MedAE values obtained are shown in Table 2. The best AL adjustments for each formula are shown below:

- BUII, EVO 2.0: ALu ($p > 0.050$, ALu showed a better trend than the alternatives);
- LSF: ALu ($p = 0.003$);
- Hoffer Q, T2.2: CMALe ($p < 0.001$);
- Holladay 1: wk-pol ($p < 0.001$);
- SRKT: CMALe ($p > 0.050$, CMAL showed a better trend than the alternatives);
- T2: ALu ($p < 0.001$, ALu proved to be almost equivalent to wk2, ranks acted as discriminator).

#### 3.1.2. *Group 2*

The MAE and MedAE values are shown in Table 3. The best AL adjustments for each formula are shown below:

- BUII: ALu ($p > 0.050$, ALu showed a better trend than the alternatives);
- EVO 2.0: ALc ($p > 0.050$, ALc showed a better trend than the alternatives);
- LSF: CMALe ($p > 0.050$, only 133 eyes were analyzed; CMALe showed a better trend than the alternatives);
- Hoffer Q, T2.2: wk1 ($p < 0.001$);
- Holladay 1: wk2 ($p < 0.001$);
- SRKT: CMALe ($p = 0.005$);
- T2: CMALe ($p = 0.001$, CMAL proved to be almost equivalent to ALc, ranks acted as discriminant).

#### 3.1.3. *Group 3*

The MAE and MedAE values are shown in Table 4. The best AL adjustments for each formula are shown below:

- BUII: CMALe ($p = 0.030$);

**Table 2**

Step 1 - Mean Absolute Errors and Median Absolute Errors obtained by analyzing various axial length (AL) adjustments for each formula (Group 1: 26.00≤AL<28.00 mm–269 eyes).

| Formula | Parameter | AL Adjustments | | | | | |
|---|---|---|---|---|---|---|---|
| | | ALu | ALc | CMALe | wk1 | wk2 | wk-pol |
| BUII | MAE | 0.40D | 0.42D | 0.41D | – | – | – |
| | MedAE | 0.31D | 0.33D | 0.33D | – | – | – |
| EVO 2.0 | MAE | 0.40D | 0.42D | 0.41D | – | – | – |
| | MedAE | 0.31D | 0.33D | 0.33D | – | – | – |
| Hoffer Q | MAE | 0.50D | 0.43D | 0.43D[a] | 0.52D | – | – |
| | MedAE | 0.46D | 0.39D | 0.38D[a] | 0.49D | – | – |
| Holladay 1 | MAE | 0.60D | 0.47D | 0.46D | 0.45D | 0.43D | 0.41D[a] |
| | MedAE | 0.49D | 0.35D | 0.35D | 0.34D | 0.32D | 0.31D[a] |
| LSF | MAE | 0.39D[a] | 0.43D | 0.43D | – | – | – |
| | MedAE | 0.30D[a] | 0.34D | 0.34D | – | – | – |
| SRKT | MAE | 0.46D | 0.45D | 0.45D | 0.47D | 0.4D | – |
| | MedAE | 0.37D | 0.36D | 0.34D | 0.38D | 0.35D | – |
| T2 | MAE | 0.40D[a] | 0.44D | 0.43D | 0.48D | 0.41D[a] | – |
| | MedAE | 0.30D[a] | 0.35D | 0.34D | 0.40D | 0.38D[a] | – |
| T2.2 | MAE | 0.46D | 0.41D | 0.40D[a] | 0.40D | 0.42D | – |
| | MedAE | 0.37D | 0.32D | 0.30D[a] | 0.31D | 0.32D | – |

AL = Axial Length; ALu=Uncorrected AL, ALc = AL correction according to De Bernardo et al. CMALe = Cooke modified estimated AL; wk1 = AL correction according to Wang-Koch; wk2 = AL correction update according to Wang-Koch; wk-pol = Polynomial AL correction according to Wang-Koch; BUII=Barrett Universal II; EVO = Emmetropia Verifying Optical; LSF=Ladas Super Formula; T2.2 = Refinement of Formula T2 by Idrobo-Robalino et al.; MAE = Mean Absolute Error; MedAE = Median Absolute Error; - = AL correction factor not available.

[a] = P value < 0.050 according to Friedman's test with Bonferroni post-hoc correction.

**Table 3**
Step 1 - Mean Absolute Errors and Median Absolute Errors obtained by analyzing various axial length (AL) adjustment for each formula (Group 2: $28.00 \leq AL < 30.00$ mm–144 eyes).

| Formula | Parameter | AL Adjustments | | | | | |
|---|---|---|---|---|---|---|---|
| | | ALu | ALc | CMALe | wk1 | wk2 | wk-pol |
| BUII | MAE | 0.48D | 0.48D | 0.50D | – | – | – |
| | MedAE | 0.36D | 0.38D | 0.39D | – | – | – |
| EVO 2.0 | MAE | 0.50D | 0.48D | 0.50D | – | – | – |
| | MedAE | 0.37D | 0.36D | 0.43D | – | – | – |
| Hoffer Q | MAE | 0.86D | 0.72D | 0.65D | 0.58D[a] | – | – |
| | MedAE | 0.78D | 0.60D | 0.54D | 0.46D[a] | – | – |
| Holladay 1 | MAE | 1.06D | 0.87D | 0.78D | 0.52D | 0.52D[a] | 0.52D |
| | MedAE | 1.09D | 0.81D | 0.70D | 0.40D | 0.37D[a] | 0.39D |
| LSF[b] | MAE | 0.50D | 0.55D | 0.48D | – | – | – |
| | MedAE | 0.46D | 0.37D | 0.35D | – | – | – |
| SRKT | MAE | 0.63D | 0.56D | 0.54D[a] | 0.57D | 0.57D | – |
| | MedAE | 0.51D | 0.43D | 0.41D[a] | 0.43D | 0.44D | – |
| T2 | MAE | 0.57D | 0.52D[a] | 0.52D[a] | 0.58D | 0.59D | – |
| | MedAE | 0.45D | 0.37D[a] | 0.38D[a] | 0.50D | 0.50D | – |
| T2.2 | MAE | 0.72D | 0.59D | 0.54D | 0.50D[a] | 0.50D | – |
| | MedAE | 0.65D | 0.47D | 0.40D | 0.38D[a] | 0.39D | – |

AL = Axial Length; ALu=Uncorrected AL, ALc = AL correction according to De Bernardo et al. CMALe = Cooke modified estimated AL; wk1 = AL correction according to Wang-Koch; wk2 = AL correction update according to Wang-Koch; wk-pol = Polynomial AL correction according to Wang-Koch; BUII=Barrett Universal II; EVO = Emmetropia Verifying Optical; LSF=Ladas Super Formula; T2.2 = Refinement of Formula T2 by Idrobo-Robalino et al.; MAE = Mean Absolute Error; MedAE = Median Absolute Error; - = AL correction factor not available.

[a] = P value $< 0.050$ according to Friedman's test with Bonferroni post-hoc correction.

[b] 138 eyes analyzed.

**Table 4**
Step 1 - Mean Absolute Errors and Median Absolute Errors obtained by analyzing various axial length (AL) adjustment for each formula (Group 3: $AL \geq 30.00$ mm–141 eyes).

| Formula | Parameter | AL Adjustments | | | | | |
|---|---|---|---|---|---|---|---|
| | | ALu | ALc | CMALe | wk1 | wk2 | wk-pol |
| BUII | MAE | 0.64D | 0.59D | 0.59D[a] | – | – | – |
| | MedAE | 0.48D | 0.39D | 0.35D[a] | – | – | – |
| EVO 2.0 | MAE | 0.60D | 0.54D | 0.51D[a] | – | – | – |
| | MedAE | 0.45D | 0.36D | 0.33D[a] | – | – | – |
| Hoffer Q | MAE | 1.40D | 1.23D | 1.04D | 0.55D[a] | – | – |
| | MedAE | 1.39D | 1.23D | 1.06D | 0.41D[a] | – | – |
| Holladay 1 | MAE | 1.44D | 1.26D | 1.06D | 0.53D[a] | 0.56D | 0.53D[a] |
| | MedAE | 1.43D | 1.23D | 0.99D | 0.34D[a] | 0.34D | 0.35D[a] |
| LSF[b] | MAE | 0.76D | 0.59D[a] | 0.60D | – | – | – |
| | MedAE | 0.54D | 0.36D[a] | 0.36D | – | – | – |
| SRKT | MAE | 1.03D | 0.88D | 0.72D | 0.53D[a] | 0.55D | – |
| | MedAE | 0.98D | 0.79D | 0.63D | 0.33D[a] | 0.35D | – |
| T2 | MAE | 0.95D | 0.82D | 0.69D | 0.54D[a] | 0.57D | – |
| | MedAE | 0.95D | 0.76D | 0.57D | 0.40D[a] | 0.42D | – |
| T2.2 | MAE | 1.09D | 0.92D | 0.75D | 0.53D[a] | 0.53D[a] | – |
| | MedAE | 1.07D | 0.88D | 0.69D | 0.35D[a] | 0.33D[a] | – |

AL = Axial Length; ALu=Uncorrected AL, ALc = AL correction according to De Bernardo et al. CMALe = Cooke modified estimated AL; wk1 = AL correction according to Wang-Koch; wk2 = AL correction update according to Wang-Koch; wk-pol = Polynomial AL correction according to Wang-Koch; BUII=Barrett Universal II; EVO = Emmetropia Verifying Optical; LSF=Ladas Super Formula; T2.2 = Refinement of Formula T2 by Idrobo-Robalino et al.; MAE = Mean Absolute Error; MedAE = Median Absolute Error; - = AL correction factor not available.

[a] = P value $< 0.050$ according to Friedman's test with Bonferroni post-hoc correction.

[b] 68 eyes analyzed.

- EVO 2.0: CMALe ($p < 0.001$);
- LSF: ALc ($p < 0.001$, only 68 eyes analyzed);
- Hoffer Q, SRKT, T2: wk1 ($p < 0.001$);
- Holladay 1: wk-pol ($p < 0.001$, wk-pol proved to be almost equivalent to wk1, ranks acted as discriminator);
- T2.2: wk1 ($p < 0.001$, wk1 proved to be nearly equivalent to wk2, ranks acted as discriminant).

### *3.2. Choice of the best combination IOL power calculation formula/AL adjustment for each AL range*

#### *3.2.1. Group 1 (26.00≤A<28.00 mm - 269 eyes)*

The descriptive statistics of the various IOL calculation formula/AL adjustment combinations are shown in Table 5 and Fig. 1.

In this group, the T2-ALu combination was the best option, being superior to the SRKT-CMALe when evaluating the MedAE ($p = 0.043$). Furthermore, T2-ALu showed a higher percentage of eyes with PE <±0.5D compared to SRKT-CMALe ($p < 0.001$). BUII-ALu ($p < 0.001$), EVO 2.0-ALu ($p = 0.003$), Holladay 1-wk-pol ($p = 0.007$), LSF-ALu ($p < 0.001$) and T2.2-CMALe ($<0.001$) showed a higher percentage of eyes with PE <±0.5D than SRKT-CMALe. No statistically significant differences were found between the different formulas in the percentage of eyes with PE <±1.0D ($p > 0.050$).

#### *3.2.2. Group 2 (28.00≤AL<30.00 mm - 138 eyes)*

The descriptive statistics of the various IOL calculation formula/AL adjustment combinations are shown in Table 6 and Fig. 2.

In this group, data analysis was performed only on 138 eyes out of a total of 144 because the LSF formula, which consists of a combination of several vergence formulas, in some cases (e.g., in the calculation of negative power IOL) it requires the application of the Haigis formula, which necessitates the knowledge of ACD [29,34]. For this reason, 6 eyes were excluded from the study, corresponding to eyes where the calculation using the LSF formula cannot be performed.

The EVO 2.0-ALc combination was the best option, reporting superiority to the Hoffer Q-wk1 option when evaluating the MedAE ($p = 0.043$). Furthermore, EVO 2.0-ALc showed a higher percentage of eyes with PE <±0.5D compared to Hoffer Q-wk1 ($p = 0.011$). The combinations LSF-CMALe ($p = 0.011$), BUII-ALu and Holladay 1-wk2 (both $p = 0.001$) showed a higher percentage of eyes with PE <±0.5D compared to Hoffer Q-wk1. No statistically significant differences were found between the different formulas in the percentage of eyes with PE <±1.0D ($p > 0.050$).

#### *3.2.3. Group 3 (AL≥30.00 mm - 141 eyes)*

The descriptive statistics of the various IOL calculation formula/AL adjustment combinations are shown in Table 7 and Fig. 3.

Since the LSF method could only perform the calculation in 68 eyes out of the total 141 in this group, it was excluded from the analysis.

The EVO 2.0-CMALe combination was the best option, reporting a lower MedAE than Hoffer Q-wk1 ($p = 0.006$). In addition, EVO 2.0-CMALe ($p = 0.004$), Holladay 1-wk-pol ($p < 0.001$) and T2.2-wk1 ($p = 0.025$) options showed a higher percentage of eyes with PE <±0.5D compared to T2-wk1. No statistically significant differences were found between the various formulas in the percentage of eyes with PE <±1.0D ($p > 0.050$).

## 4. Discussion

The knowledge of the Km and AL parameters is mandatory for IOL power calculation in any condition. Most recent formulas may require a greater number of parameters, even up to 7,[5] to perform a correct IOL power calculation, that it is related to the correct

**Table 5**

Step 2– Analysis of refractive outcomes of the best IOL power calculation formula/axial length adjustment combinations for each formula (Group 1).

| Formula-AL | Group 1: 26.00≤AL<28.00 mm–269 eyes | | | | | |
|---|---|---|---|---|---|---|
| | MedAE(IQR) | MAE(SD) | CI95 % | Min/Max | <0.5D(%) | <1.0D(%) |
| BUII-ALu | 0.31D<br>(0.42D) | 0.40D<br>(0.35D) | 0.36D/<br>0.45D | 0.00D/<br>2.50D | 215<br>(79.9 %)[b] | 257<br>(95.5 %) |
| EVO 2.0-ALu | 0.31D<br>(0.41D) | 0.40D<br>(0.35D) | 0.36D/<br>0.44D | 0.00D/<br>2.47D | 212<br>(78.8 %)[b] | 256<br>(95.2 %) |
| Hoffer Q-CMALe | 0.34D<br>(0.43D) | 0.43D<br>(0.42D) | 0.38D/<br>0.48D | 0.00D/<br>3.29D | 208<br>(77.3 %) | 254<br>(94.4 %) |
| Holladay 1-wk-pol | 0.31D<br>(0.42D) | 0.41D<br>(0.39D) | 0.36D/<br>0.46D | 0.00D/<br>3.11D | 211<br>(78.4 %)[b] | 256<br>(94.4 %) |
| LSF-ALu | 0.30D<br>(0.41D) | 0.39D<br>(0.36D) | 0.35D/<br>0.44D | 0.00D/<br>2.49D | 216<br>(80.3 %)[b] | 257<br>(95.5 %) |
| SRKT-CMALe | 0.34D<br>(0.50D) | 0.45D<br>(0.39D) | 0.40D/<br>0.50D | 0.00D/<br>2.26D | 195<br>(72.5 %) | 253<br>(94.1 %) |
| T2-ALu | 0.30D[a]<br>(0.42D) | 0.40D<br>(0.37D) | 0.36D/<br>0.44D | 0.00D/<br>2.49D | 215<br>(79.9 %)[b] | 256<br>(95.2 %) |
| T2.2-CMALe | 0.30D<br>(0.44D) | 0.40D<br>(0.36D) | 0.36D/<br>0.45D | 0.00D/<br>2.45D | 214<br>(79.6 %)[b] | 257<br>(95.5 %) |

AL = Axial Length; Formula-AL = Combination of formula-axial length correction factor; BUII=Barrett Universal II; EVO = Emmetropia Verifying Optical; LSF=Ladas Super Formula; T2.2 = Refinement of Formula T2 by Idrobo-Robalino et al.; ALu=Uncorrected AL; CMALe = Cooke modified estimated AL; wk-pol = Polynomial AL correction according to Wang-Koch; MedAE = Median Absolute Error; IQR=Interquartile Range; MAE = Mean Absolute Error; SD=Standard Deviation; CI95 % = 95 % Confidence Interval around the mean; Min/Max = minimum error/maximum error; <0.5D (%)/<1.0D(%) = number and percentage of eyes with refractive error <0.5D and <1.0D.

[a] = P value < 0.050 according to Friedman's test with Bonferroni post-hoc correction.

[b] = P value < 0.050 according to Cochran's test with Bonferroni post-hoc correction.

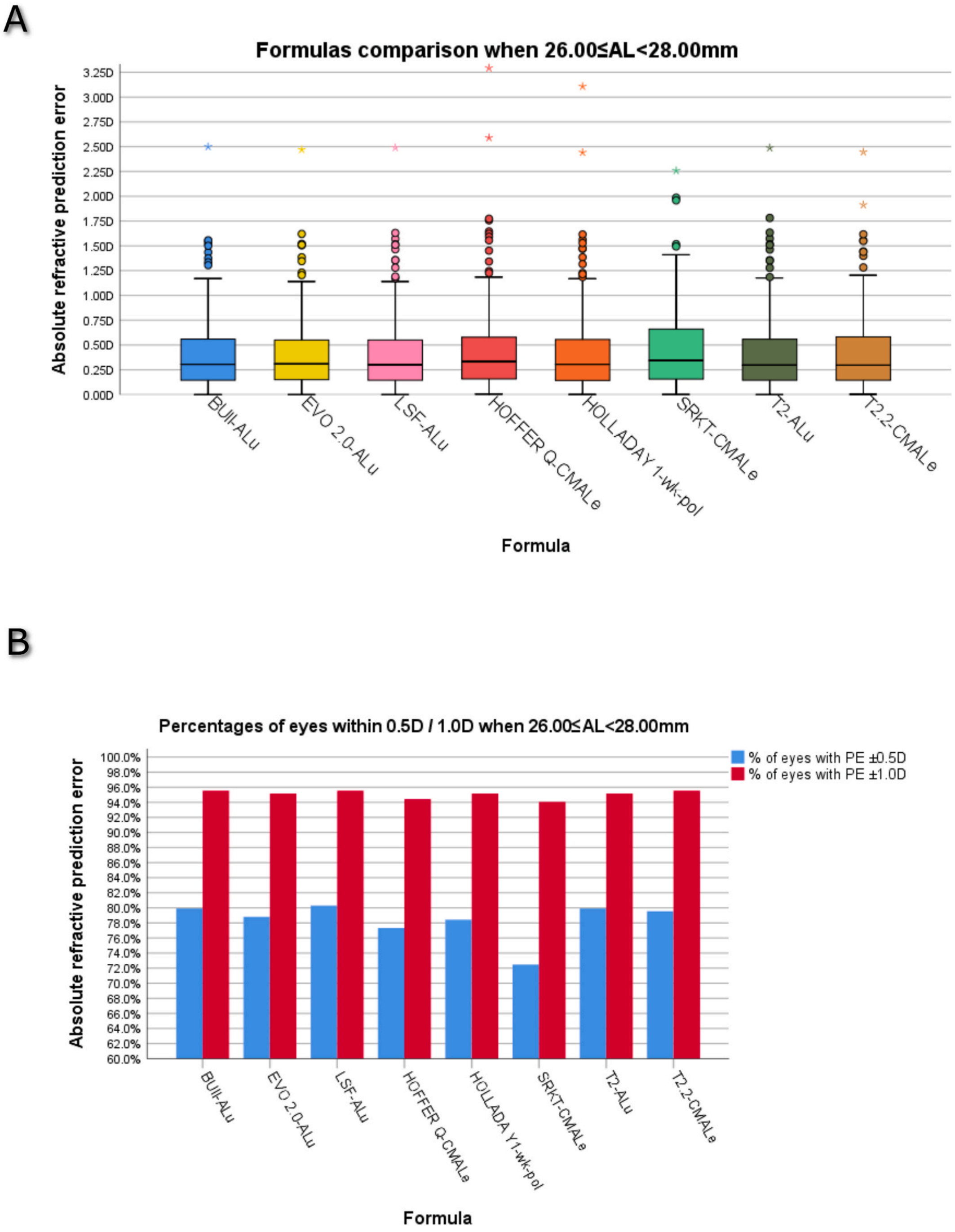

**Fig. 1.** Fig. 1a: Box-Plot diagram with the comparison of refractive outcomes obtained from different Intraocular Lens (IOL) Power Calculation Formula/Axial Length (AL) combinations in Group 1 (26.00≤AL<28.00 mm–269 eyes). Fig. 1b: Bar Chart with the comparison of the percentage of eyes with refractive error <0.5D/1.0D among different IOL Power Calculation Formula/AL adjustment combinations in Group 1.

**Footnotes** Box: Interquartile range (IQR); Thick line: Median; Whiskers: range of non-anomalous values; Dots: mild outlier values (values greater than 1.5 x IQR below Q1 or above Q3); Asterisks: extreme outlier values (values greater than 1.5 x IQR below Q1 or above Q3); BUII=Barrett Universal II; EVO = Emmetropia Verifying Optical; LSF=Ladas Super Formula; T2.2 = Refinement of Formula T2 by Idrobo-Robalino et al.; ALu=Uncorrected AL, CMALe = Cooke modified estimated AL; wk-pol = Polynomial AL correction according to Wang-Koch; PE= Predicted refractive error.

**Table 6**

Step 2– Analysis of refractive outcomes of the best IOL power calculation formula/axial length adjustment combinations for each formula (Group 2).

| Formula-AL | Group 2: 28.00≤AL<30.00 mm–138 eyes[a] | | | | | |
|---|---|---|---|---|---|---|
| | MedAE(IQR) | MAE(SD) | CI95 % | Min/Max | <0.5D(%) | <1.0D(%) |
| BUII-ALu | 0.35D (0.43D) | 0.46D (0.43D) | 0.39D/ 0.53D | 0.00D/ 2.25D | 106 (76.8 %)[c] | 126 (91.3 %) |
| EVO 2.0-ALc | 0.36D (0.46D) | 0.47D[b] (0.42D) | 0.40D/ 0.54D | 0.00D/ 2.15D | 103 (74.6 %)[c] | 126 (91.3 %) |
| Hoffer Q-wk1 | 0.46D (0.61D) | 0.57D (0.53D) | 0.48D 0.66D | 0.00D/ 3.75D | 87 (63.0 %) | 125 (90.6 %) |
| Holladay 1-wk2 | 0.37D (0.42D) | 0.51D (0.50D) | 0.42D/ 0.59D | 0.00D/ 3.40D | 106 (76.8 %)[c] | 124 (89.9 %) |
| LSF-CMALe | 0.35D (0.45D) | 0.48D (0.43D) | 0.41D/ 0.55D | 0.00D/ 2.30D | 103 (74.6 %)[c] | 127 (92.0 %) |
| SRKT-CMALe | 0.40D (0.45D) | 0.53D (0.47D) | 0.45D/ 0.61D | 0.01D/ 2.59D | 98 (71.0 %) | 123 (89.1 %) |
| T2-CMALe | 0.36D (0.46D) | 0.50D (0.45D) | 0.42D/ 0.57D | 0.03D/ 2.19D | 101 (73.2 %) | 125 (90.6 %) |
| T2.2-wk1 | 0.37D (0.49D) | 0.49D (0.45D) | 0.42D/ 0.57D | 0.00D/ 2.32D | 100 (72.5 %) | 124 (89.9 %) |

AL = Axial Length; Formula-AL = Combination of formula-axial length correction factor; BUII=Barrett Universal II; EVO = Emmetropia Verifying Optical; LSF=Ladas Super Formula; T2.2 = Refinement of Formula T2 by Idrobo-Robalino et al.; ALu=Uncorrected AL, ALc = AL correction according to De Bernardo et al. CMALe = Cooke modified estimated AL; wk1 = AL correction according to Wang-Koch; wk2 = AL correction update according to Wang-Koch; MedAE = Median Absolute Error; IQR=Interquartile Range; MAE = Mean Absolute Error; SD=Standard Deviation; CI95 % = 95 % Confidence Interval around the mean; Min/Max = minimum error/maximum error; <0.5D(%)/<1.0D(%) = number and percentage of eyes with refractive error <0.5D and <1.0D.

[a] 6 eyes excluded due to limitations of the Ladas Super Formula.

[b] = P value < 0.050 according to Friedman's test with Bonferroni post-hoc correction.

[c] = P value < 0.050 according to Cochran's test with Bonferroni post-hoc correction.

estimation of the effective lens position (ELP), the latter being influenced by the choice of lens constant [35]. Various sources of error can lead to an inaccurate IOL power calculation, ranging from an inaccurate choice of lens constant to an incorrect estimate of Km, for example in refractive surgery [12]. In long eyes, however, it is the inaccurate measurement of AL that has been reported as the main source of error [6,7], leading to a hyperopic postoperative refractive error [4,9]. Several factors can contribute to the inaccurate measurement of AL in the high myopes patient. These can be identified:

- Patient-related factors: poor fixation, posterior staphyloma [5,6,36]: in fact, it is well known that the high myopic eye is often affected by profound changes to the sclera but also to the choroid [37,38].
- Measurement Mode Related Factors: The use of group refractive index (GRI)-based biometers, due to the higher contribution of the vitreous chamber to the total AL, tends to measure longer AL values than biometers that uses sum-of-segments [18,39]. In addition, in case of cataract patients, lens opacity may further alter the reliability of GRI-based biometers [18,19].
- Factors related to the IOL power calculation formula: lower predictability of some methods for extreme AL values was reported [46].

Wang et al. first proposed an AL correction factors to reduce the percentage of eyes with hyperopic refractive outcome [13]. These AL adjustments were later updated by the same and authors [14–16].

The so called Cooke modified AL (CMAL) was proposed by Cooke who demonstrated that CMAL can simulate a sum-of-segments AL by using a biometer that works with GRI [17].

In addition, De Bernardo et al. noting the influence of lens opacity and GRI on the reliability of the AL measurement, proposed a correction factor to be applied to the preoperative AL, called ALc, in order to eliminate any systematic error in IOL power calculation, without changing the lens constant [18,19].

Recently, several studies have compared different methods of IOL power calculation in eyes with high myopia [3,4,6,9–11,16,20,23,36,40], but only few of them have focused on AL correction in this type of eyes [6,10,11,16,20]. These studies have only applied the Wang and Koch factors [6,11,20] and CMAL [16] to thin-lens based formulas. Only in a very few cases AL adjustment in long eyes has also been evaluated with the most recently introduced formulas, with CMAL in particular being analyzed [10], but no study has ever analyzed the impact of ALc in eyes with AL≥26.00 mm.

Considering the crucial role of AL reliability on IOL power calculation, the present study was therefore developed in 2 steps: in the first step which AL adjustment could give the best refractive results for each formula, in specific AL ranges was determined (Tables 2–4); in the second step, the best IOL power calculation formula/AL adjustment combination for each AL range was identified. (Tables 5–7, Figs. 1–3). In this way it was possible to minimize the impact of postoperative error and the influence of AL inaccuracy.

Both steps of the study were performed without taking the ACD parameter into account. In fact, the measurement of ACD, measured from the corneal epithelium to the anterior surface of the lens, is also an important source of error that reflects in an incorrect estimate of the ELP [41,42]. Several reasons led to the exclusion of this parameter from the study:

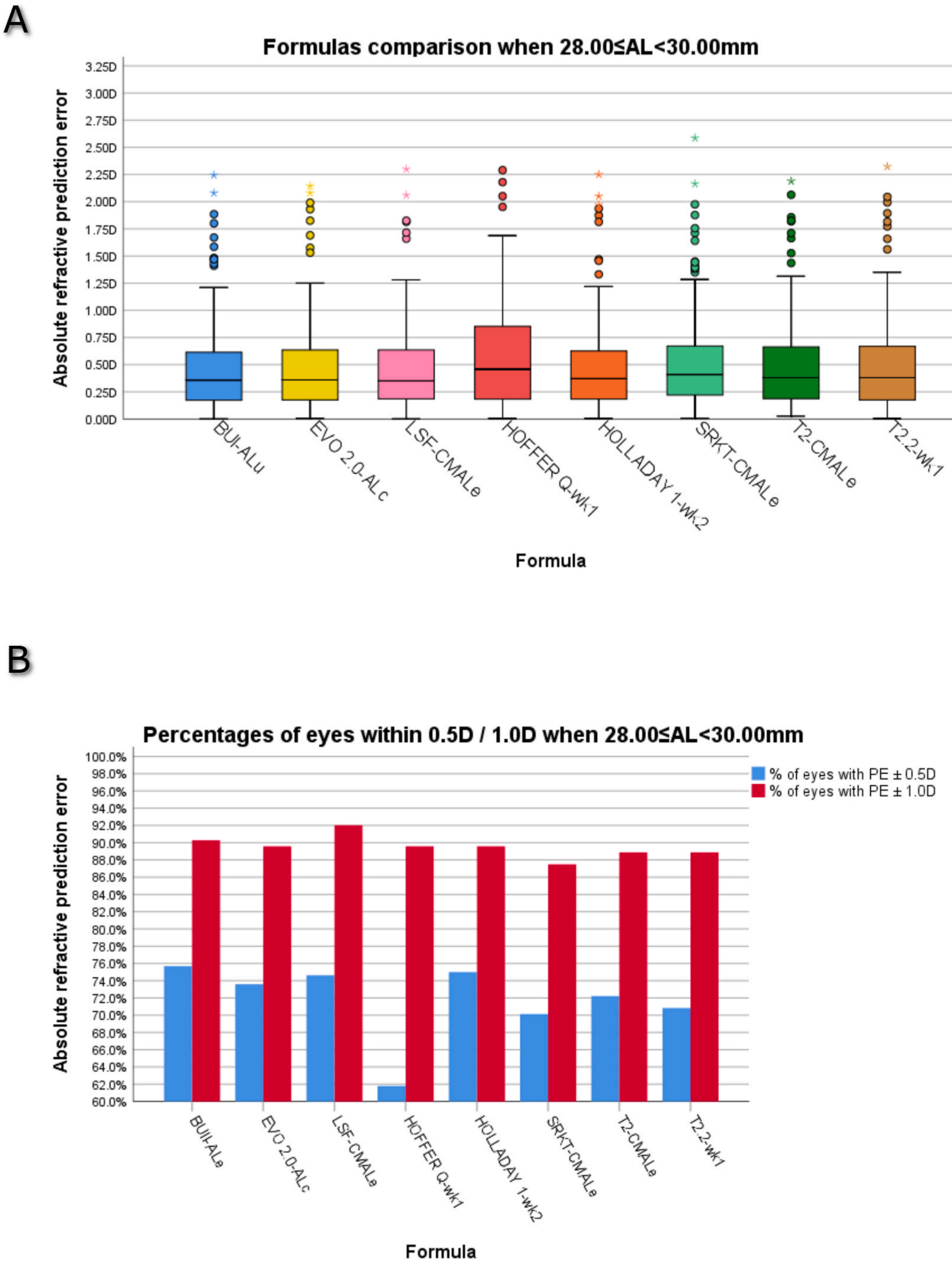

**Fig. 2.** Fig. 2a: Box-Plot diagram with the comparison of refractive outcomes obtained from different Intraocular Lens (IOL) Power Calculation Formula/Axial Length (AL) combinations in Group 2 (28.00≤AL<30.00 mm–138 eyes) Fig. 2b: Bar Chart with the comparison of the percentage of eyes with refractive error <0.5D/1.0D among different IOL Power Calculation Formula/AL adjustment combinations in Group 2.

**Footnotes** Box: Interquartile range (IQR); Thick line: Median; Whiskers: range of non-anomalous values; Dots: mild outlier values (values greater than 1.5 x IQR below Q1 or above Q3); Asterisks: extreme outlier values (values greater than 1.5 x IQR below Q1 or above Q3); BUII=Barrett Universal II; EVO = Emmetropia Verifying Optical; LSF=Ladas Super Formula; T2.2 = Refinement of Formula T2 by Idrobo-Robalino et al.; ALu=Uncorrected AL, ALc = AL correction according to De Bernardo et al. CMALe = Cooke modified estimated AL; wk1 = AL correction according to Wang-Koch; wk2 = AL correction update according to Wang-Koch. PE= Predicted refractive error.

**Table 7**

Step 2– Analysis of refractive outcomes of the best IOL power calculation formula/axial length adjustment combinations for each formula (Group 3).

| Formula-AL | Group 3: $AL \geq 30.00$ mm–141 eyes | | | | | |
|---|---|---|---|---|---|---|
| | MedAE(IQR) | MAE(SD) | CI95 % | Min/Max | <0.5D(%) | <1.0D(%) |
| BUII-CMALe | 0.35D (0.45D) | 0.59D (0.82D) | 0.45D/ 0.72D | 0.00D/ 4.75D | 106 (75.2 %) | 125 (88.7 %) |
| EVO 2.0-CMALe | 0.33D[a] (0.42D) | 0.51D (0.74D) | 0.39D/ 0.63D | 0.00D/ 5.75D | 112 (79.4 %)[b] | 128 (90.8 %) |
| Hoffer Q-wk1 | 0.41D (0.46D) | 0.55D (0.58D) | 0.45D/ 0.65D | 0.00D/ 3.93D | 104 (73.8 %) | 127 (90.1 %) |
| Holladay 1-wk-pol | 0.35D (0.46D) | 0.53D (0.75D) | 0.40D/ 0.65D | 0.02D/ 6.07D | 115 (81.6 %)[b] | 126 (89.4 %) |
| SRKT-wk1 | 0.33D (0.46D) | 0.53D (0.69D) | 0.42D/ 0.65D | 0.00D/ 6.21D | 103 (73.0 %) | 126 (89.4 %) |
| T2-wk1 | 0.40D (0.55D) | 0.54D (0.59D) | 0.45D/ 0.64D | 0.01D/ 4.65D | 96 (68.1 %) | 127 (90.1 %) |
| T2.2-wk1 | 0.35D (0.39D) | 0.53D (0.69D) | 0.42D/ 0.65D | 0.00D 5.62D | 110 (78.0 %)[b] | 127 (90.1 %) |

AL = Axial Length; Formula-AL = Combination of formula-axial length correction factor; BUII=Barrett Universal II; LSF=Ladas Super Formula; T2.2 = Refinement of Formula T2 by Idrobo-Robalino et al.; CMALe = Cooke modified estimated AL; wk1 = AL correction according to Wang-Koch; wk2 = AL correction update according to Wang-Koch; wk-pol = Polynomial AL correction according to Wang-Koch; MedAE = Median Absolute Error; IQR=Interquartile Range; MAE = Mean Absolute Error; SD=Standard Deviation; CI95 % = 95 % Confidence Interval around the mean; Min/Max = minimum error/maximum error; <0.5D(%)/<1.0D(%) = number and percentage of eyes with refractive error <0.5D and <1.0D.

[a] = P value $< 0.050$ according to Friedman's test with Bonferroni post-hoc correction.

[b] = P value $< 0.050$ according to Cochran's test with Bonferroni post-hoc correction.

- Significant contribution of the ACD in the error in IOL power calculation (22–38 %) [41,43].
- Preponderance of the role of the inaccurate AL measurement in the error of IOL power calculation in long eyes [6,7].
- Significant variation in ACD measurement between optical and ultrasonic biometry [44], between different optical biometry technologies [45–47] and between different optical biometers using the same technology [39].
- ACD variation following instillation of mydriatic or miotic eye drops [48,49], This is not the case with AL measurement [48–50].
- ACD variation following numerous surgical procedures, such as refractive surgery [40], phaco-vitrectomy [51] or even cataract surgery itself, where the reduction in ACD caused by the different thickness between the natural lens and IOL is well known [52]. Furthermore, several studies have reported how comparable or even better refractive results can be achieved when this ACD is excluded from the formula [5,12,18,24–26].

Based on the obtained results, the following study showed that formulas based on a thick vergence-lens model (BUII, EVO 2.0) or on a hybrid artificial-intelligence-vergence (LSF) method do not need AL correction when $26.00 \leq AL < 28.00$ mm, benefiting of AL adjustment only in case of very high myopia ($AL \geq 28.00$ mm). Furthermore, in case of formulas based on a thin-lens model (Hoffer Q, Holladay 1, SRKT), ALc always improves refractive results compared to no AL correction. In general, any formula improves refractive outcomes with an AL correction factor for extreme myopia ($AL \geq 30.0$ mm).

In addition, in the case of extreme AL ($AL \geq 30.0$ mm), wk1 [13] proves to be better than the most recent and updated wk2 [14]. This could be explained by the fact that wk2, according to the authors, is applied when $AL > 27.00$ mm [14]; thus, the better results of wk2 found by Wang et al. could result from the analysis of long eyes, but with non-extreme AL. This is in agreement with the results of the present study: in fact, wk2 turns out to be the best option for Holladay 1 in Group 2, while wk-pol proves to be by far the best of Holladay 1 correction factors in extreme ALs ($AL \geq 30.0$ mm) and in medium-high ALs ($AL < 28.00$ mm). In Group 2, on the other hand, the correction factor wk2 proves to be better.

Interestingly, the T2 formula shows better refractive results with a different AL correction factor for each group analyzed. LSF, in the absence of ACD, may fail when $AL \geq 28.00$ mm, resulting in a failure of calculation in about 50 % of cases when $AL \geq 30.00$ mm.

Although the role of AL is preponderant in the reliability of IOL calculation in eyes with high myopia, recent studies have shown that the Km value can also guide the clinician in choosing the most appropriate formula [4,9]. Further studies based on a combined analysis of different ranges of Km and AL, in order to find the best formula based on the combination of these parameters, are needed in order to develop a multiformula approach, as already exists for refractive surgery [12].

In addition, CMALe used in this work was determined from an estimation of LT using the PANACEA IOL AND TORIC CALCULATOR software. This methods was developed by David Flickier, it is available online (www.panaceaiolandtoriccalculator.com, accessed on January 05th, 2024), and it is known as the only formula enabling surgeons to enter the corneal asphericity (Q-value) and the ratio between the anterior and posterior corneal curvature [53]. LT estimation with a validate tool such as the PANACEA IOL AND TORIC CALCULATOR software, made our findings repeatable and reproducible.

Cooke et AL used the LT value measured by optical biometry in the development of CMAL. However, it should be mentioned that not all biometers have this function: for example, the IOL Master 500 cannot detect this parameter. Furthermore, LT may not be detected even in the case of significant opacity of the crystalline lens [54]. The small number of eyes with the LT measurement did not allow to compare the original CMAL (without LT estimation) to CMALe, this could represent a limitation of our study. Further studies

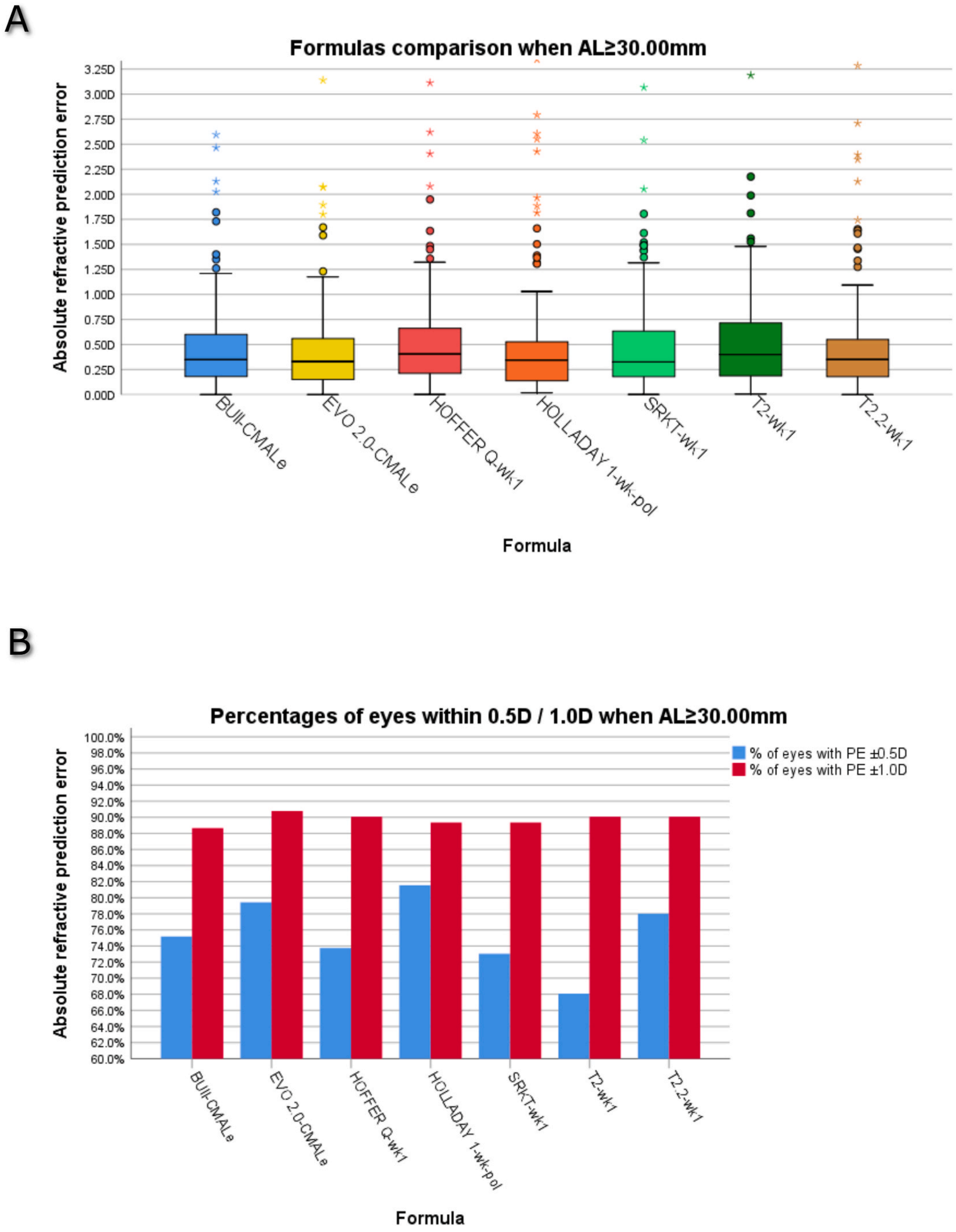

**Fig. 3.** Fig. 3a: Box-Plot diagram with the comparison of refractive outcomes obtained from different Intraocular Lens (IOL) Power Calculation Formula/Axial Length (AL) combinations in Group 3 (AL≥30.00 mm–141 eyes). Fig. 3b: Bar Chart with the comparison of the percentage of eyes with refractive error <0.5D/1.0D among different IOL Power Calculation Formula/AL adjustment combinations in Group 3.

**Footnotes** Box: Interquartile range (IQR); Thick line: Median; Whiskers: range of non-anomalous values; Dots: mild outlier values (values greater than 1.5 x IQR below Q1 or above Q3); Asterisks: extreme outlier values (values greater than 1.5 x IQR below Q1 or above Q3); BUII=Barrett Universal II; EVO = Emmetropia Verifying Optical; LSF=Ladas Super Formula; T2.2 = Refinement of Formula T2 by Idrobo-Robalino et al.; CMALe = Cooke modified estimated AL; wk1 = AL correction according to Wang-Koch; wk2 = AL correction update according to Wang-Koch; wk-pol = Polynomial AL correction according to Wang-Koch; PE= Predicted refractive error.

evaluating non estimated CMAL will be necessary to make such comparison. CMALe has nevertheless proven to improve the refractive results of many of the analyzed formulas, even using an estimated LT value, and CMALe could be considered a valid alternative in case of lacking LT (e.g. biometry with IOL Master 500 or dense cataract [54]).

In addition, it should be mentioned that the EVO 2.0 formula has a special function to select AL detection by means of the Argos biometer (Alcon Laboratories, Fort Worth, USA), which uses swept source optical coherence tomography (SS-OCT) technology and measures the AL value by segment summation. However, as the AL values obtained in this study were obtained from biometers using GRI, the EVO 2.0 formula was used using the various AL correction factors, without the Argos option being selected.

It should be noted that in the first step of this study, if no statistically significant differences were found between two alternatives, the option with the best refractive trend was chosen. Theoretically, in these cases (for example with BUII and EVO methods when $26.00 \leq AL < 28.00$ mm) the best choice may vary in other databases. To overcome this problem, a point of strength of this study is the large database that minimizes the variability related to the analyzed sample. In addition, all the results obtained in the second step of this paper showed robust statistical significance, making the final conclusions of our paper very solid.

Finally, it should be pointed out that although the reported data were obtained using two different devices employing two different technologies (PCI for IOL Master 500, SS-OCT for IOL Master 700), both devices are GRI-based and the high correlation and minimal, clinically irrelevant differences in AL measurement between IOL Master 500 and IOL Master 700 are known [18,55]. It should be underlined that part of database was taken from literature [20–22], meaning that a possible error in database transcription can generate a bias in data analysis of our study, because this data can't be verified by the authors. On the other hand, only validated databases that are published on prestigious peer-reviewed scientific journals were recruited for evaluation, following the example of other recent studies [12]. The inclusion of more IOL models could seem a limitation of the study, but Hoffer et al. reported in their protocols that when more IOL models were analyzed simultaneously, it can be acceptable to use (for each IOL) optimized constants from large databases [32]. By using IOLCon database constants, this study was carried out in accordance with most updated protocols in IOL power calculation accuracy studies [32]. In addition, the choice of multiple IOL models inclusion is acceptable when limited data is available, as in case of very long eyes, following the example of other similar studies that analyzed long eyes [36,56,57]. In conclusion, selecting the most appropriate AL adjustment improves the refractive outcomes of most IOL power calculation formulas in eyes with $AL \geq 26.00$ mm, without the need to know the ACD parameter.

- The T2-ALu combination represents the best option when $26.00 \text{ mm} \leq AL < 28.00$ mm. LSF-ALu, BUII-ALu, EVO-ALu, Holladay 1-wk-pol and T2.2-CMALe represent acceptable alternatives.
- The EVO 2.0-ALc combination represents the best option when $28.00 \text{ mm} \leq AL < 30.00$ mm. The other formulas based on thick-lens (BUII-ALu) hybrid artificial intelligence-vergence (LSF-CMALe), and Holladay 1-wk2 have shown higher reliability than formulas based on thin vergence-lens. LSF may not work in all eyes in this range in the absence of ACD.
- The EVO 2.0-CMALe combination is the best option when $AL \geq 30.00$ mm. Holladay 1-wk-pol and T2.2-wk1 represent a viable alternative. LSF may fail in 50 % of cases in the absence of ACD.

The selection of the best combination IOL power calculation formula/AL adjustment for each AL range can improve refractive outcomes in patients with long eyes that undergo cataract surgery.

## Ethics and consent section

The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Cometico Campania Sud, Italy (protocol code no. 16544). Detailed information about written informed consent were subjected to the patients.

## Data availability statement

Data will be made available on request.

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## CRediT authorship contribution statement

**Ferdinando Cione:** Writing – original draft, Methodology, Data curation, Conceptualization. **Maddalena De Bernardo:** Writing – review & editing, Visualization, Supervision, Project administration, Investigation. **Ilenia Di Paola:** Writing – original draft, Investigation, Formal analysis, Data curation. **Alessandro Caputo:** Software, Methodology, Investigation. **Mario Graziano:** Writing – original draft, Investigation. **Nicola Rosa:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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