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Outcomes Review of Intraocular Lens Power Calculation Formulas

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Acronyms

AE	Absolute error
ME	Mean (numerical) prediction error
MAE	Mean absolute error
MedAE	Median absolute error
OLCR	Optical low-coherence reflectometry (Lenstar LS900, Haag-Streit AG, Kõniz, Switzerland)
Olsen2P	Device preinstalled Olsen (utilizing 2 parameters, ACD and LT to determine ELP
Olsen4P	Standalone Olsen from PhacoOptics (4 determinants, ACD, LT, AL, and K, of ELP)
P_{emme}	Emmetropic IOL power for the specific eye
PCI	Partial coherence interferometry
PI	Performance Index
PE	Prediction error (numerical)
SS-OCT	Swept-source optical coherence tomography
WK	Formula specific Wang-Koch adjustment for axial length for long eye

In Memory of Wolfgang Haigis

The late Wolfgang Haigis proposed a concept of quality metrics of measuring the performance IOL power calculation formulas. The final index is known as the IOL formula performance index, **PI**. This is a quantitative analysis. For a good and fair comparison, the constants should be optimized before analyzing their performances. This eliminates the bias of the lens constant that was chosen for the analysis. After optimizing the constants, the formulas are compared on their standard deviation, $\mathbf{SD_{ME}}$**,** of prediction (numerical) error; the median absolute error, **MedAE**; the dependency of prediction error on axial length, ***m*****,** and; finally, the reciprocal of the percentage of predicted refraction within ±1.00 D, ***n*****10**.

A good formula comparison is when, ME = 0:

1. $SD_{ME} \rightarrow 0$
2. $\text{MedAE} \rightarrow 0$
3. $|m| = \dfrac{\Delta PE}{\Delta AL} \rightarrow 0$
4. $\dfrac{1}{n_{10}} \rightarrow 0$

where ***ME*** *is the Mean (numerical) prediction error of the formula and should be zero when the constant is optimized. PE is the prediction error.* $\boldsymbol{SD_{ME}}$ *is the standard deviation of prediction (numerical) error;* ***MedAE*** *is the median absolute*

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error; **|*m*|** *is the absolute gradient of the relationship of prediction error with axial length; and finally,* ***n***10 *is the percentage of eyes within ±1.00 D of predicted spherical equivalent refraction target.*

Thereafter, $f = \mathrm{SD}_{\mathrm{ME}} + \mathrm{MedAE} + 10 * |m| + 10 * (n_{10})^{-1}$

Finally, the IOL formula performance index, PI

$$PI = \frac{1}{f} = \frac{1}{\mathrm{SD}_{\mathrm{ME}} + \mathrm{MedAE} + 10 * |m| + 10 * (n_{10})^{-1}}$$

The metrics **|*m*|** and ***n10*−1** were amplified by a factor of 10 because of their small values. Absolute values are used to prevent false reduction of outcomes. In any case, a good formula should be independent of axial length. Whether positive or negative gradient would denote dependency of formula on axial length.

Modification

Wolfgang Haigis first presented the above metric in an ESCRS Meeting and it is available to view on the ESCRS website. It was updated and published in JCRS in 20 [1] which is the only publication of it to date. Today [1], the newer formulas have become more accurate and therefore some updates to his original concept are due to allow for better resolution. There is an increasing emphasis on the importance of MAE, and rightly so, since this should be included as a metric. Besides n_{10}, n_5 is added also is. n_5 which is defined as the reciprocal of the percentage of correctly predicted refractions within ±0.50 D. This should provide a better resolution. n_{10} is kept as a safety metric. n_5 and n_{10} are normalized by multiply by 20.

Besides having a dependency on AL, some formulas also exhibit bias against K. For more detailed analysis, the relationship between prediction outcomes and K is also included as a metric in the modified Haigis index.

With the additional metrics to the equation, the PI becomes:

$$f = \mathrm{SD}_{\mathrm{ME}} + \mathrm{MAE} + \mathrm{MedAE} + 10 * |m| + 3 * |k| + 20 * (n_5)^{-1} + 20 * (n_{10})^{-1}$$

$$PI = \frac{1}{f} = \frac{1}{\mathrm{SD}_{\mathrm{ME}} + \mathrm{MAE} + \mathrm{MedAE} + 10 * |m| + 3 * |k| + 20 * (n_5)^{-1} + 20 * (n_{10})^{-1}}$$

where **|k|** is the gradient, $\left(\frac{\Delta PE}{\Delta k}\right)$ of prediction *error against keratometry.* ***MAE*** *is the mean absolute error.*

Application

It must be noted at the outset of evaluating these formulas, that the author of the Hoffer Q formula [2, 3] recommended it primarily for short eyes (<22.0 mm) and never for eyes with an AL greater than 24.5 mm and definitely not for very long eyes (>26.0 mm), yet most of these studies evaluated the Hoffer Q over the full range of ALs, thus insuring it's rating would be rather low.

In 2017, Fam presented a paper at the annual conference of the Asia-Pacific Association of Cataract and Refractive Surgeons (APACRS) [4]. The paper detailed the outcomes of a single IOL, ZCB00. A total of 291 eyes from 291 patients with preoperative biometry measured with partial coherent interferometry (PCI) (IOLMaster 500) and postoperative refractions carried out between 4 and 6 weeks. All the third-generation formulas are calculated using constants from a previous pool of patients. Barrett Universal II (BUII) [5, 6], EVO, and RBF are based on using an optimized A constant from the same pool of patients. BUII, EVO 1.0, and RBF 1.0 were more accurate than the third-generation theoretical formulas. The Haigis formula, both with personalized triple optimization and ULIB constants, did also very well (see Fig. 33.1, Table 33.1).

Using the modified Haigis' quality metrics on IOL power calculation formula, as described in Table 33.1, the following *f* values and performance indices are generated for the above data. These values are tabulated in Table 33.2 and featured in Fig. 33.2.

Unfortunately, the bias of the prediction errors against K and AL were not available in most studies in this review and therefore have to be omitted as metrics. Ideally, only optimized constants should be used when comparing formulas. In this review, not all studies were based on optimized constants, especially in subgroup analyses. In this review, ME would be omitted in the ranking of formulas in general studies across ALs. This is to avoid a systematic error. For subgroup analyses, PE would be included as a metric to capture bias against the subgroup.

For analysis of the general group, the following metrics would be included:

1. Standard deviation of prediction error $\mathrm{SD_{ME}}$ 0
2. Mean absolute error MAE 0
   Mean Absolute Error MedAE 0
3. Percentage of error within ±0.5D $n_5^{-1} = \frac{1}{n_5} 0$
4. Percentage of error within ±1.0D $n_{10}^{-1} = \frac{1}{n_{10}} 0$

f is the sum of all the above metrics:

$$f = \mathrm{SD_{ME}} + \mathrm{MAE} + \mathrm{MedAE} + 20 * (n_5)^{-1} + 20 * n_{10}^{-1}$$

and finally **PI,** the **performance index:**

$$\mathbf{PI} = \frac{1}{f} = \frac{1}{\mathrm{SD_{ME}} + \mathrm{MAE} + \mathrm{MedAE} + 20 * (n_5)^{-1} + 20 * (n_{10})^{-1}}$$

The following metrics will be used for analyzing subgroup studies:

1. Absolute mean numerical prediction error ⌈ME⌉ 0
2. Standard deviation of prediction error $\mathrm{SD_{ME}}$ 0
3. Mean absolute error MAE 0
4. Median absolute error MedAE 0
5. Percentage of error within ±0.50 D $n_5^{-1} = \frac{1}{n_5} 0$
6. Percentage of error within ±1.00 D $n_{10}^{-1} = \frac{1}{n_{10}} 0$

f is the sum of all the above metrics:

$$f = |\mathrm{ME}| + \mathrm{SD_{ME}} + \mathrm{MAE} + \mathrm{MedAE} + 20 * (n_5)^{-1} + 20 * n_{10}^{-1}$$

and finally $\mathbf{PI_{sub}}$, the **performance index (subgroup):**

$$\mathbf{PI_{sub}} = \frac{1}{f} = \frac{1}{|\mathrm{ME}| + \mathrm{SD_{ME}} + \mathrm{MAE} + \mathrm{MedAE} + 20 * (n_5)^{-1} + 20 * (n_{10})^{-1}}$$

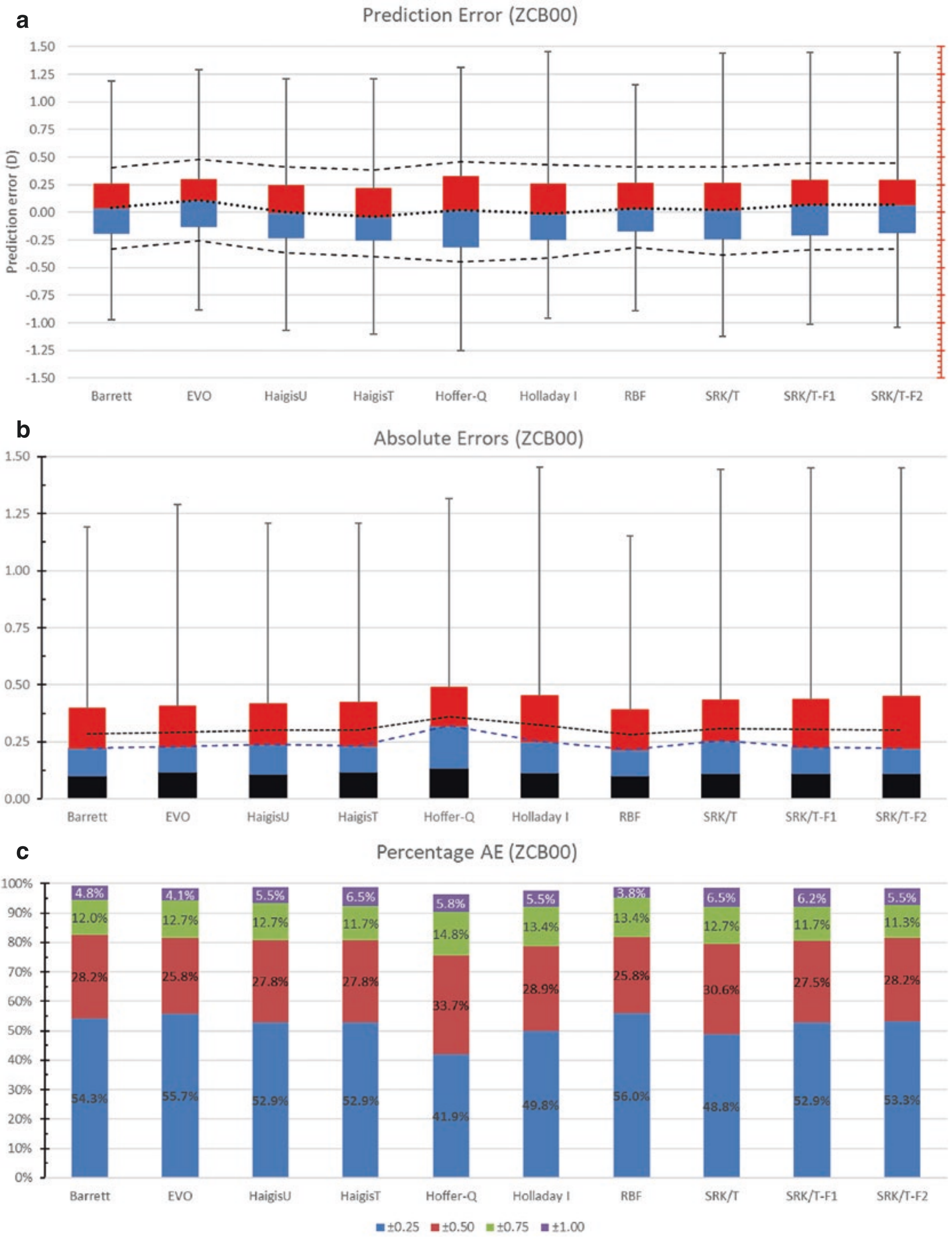

Fig. 33.1 This Figure and Table 33.1 depict the outcomes of the various formulas. (**a**) The spread of the prediction errors of the eyes of the different formulas. The bottom and top error plots represent the lower and upper quartiles while the blue and red boxes, the second and third quartiles. The dotted line is the mean prediction errors and the dashed lines, the lower and upper SDs. (**b**) is a graph showing the absolute errors of the formulas. The MAE and MedAE are represented by the dotted line and blue dashed lines, respectively. Chart (**c**) is a stacked histogram showing the percentage of eyes within a predicted spherical equivalent (SE) (EVO is EVO 1.0; HaigisT is Haigis with personalized triple optimization; HaigisU is Haigis with ULIB constants; RBF is RBF 1.0. SRK/T-F1 [10–12] and SRK/T-F2 are the Fam-adjusted SRK/T formulas [13] (Fam, The Formula1 of IOL Power Calculation [7])

Table 33.1 This table shows the results of the various formulas (EVO is EVO 1.0; HaigisT is Haigis with personalized triple optimization; HaigisU is Haigis with ULIB constants; RBF is RBF 1.0) [7]. The ±0.50 D is in bold and important clinically, as are ±1.00 D

Formula	*n*	MeanPE	SD E	MAE	MedAE	±0.25 D	±0.50 D	±0.75 D	±1.00 D
Barrett	291	0.04	0.37	*0.28*	*0.22*	*54.3%*	***82.5%***	*94.5%*	***99.3%***
EVO	291	0.11	0.37	*0.29*	*0.23*	*55.7%*	***81.4%***	*94.2%*	***98.3%***
HaigisT	291	−0.01	0.39	*0.30*	*0.23*	*52.9%*	***80.8%***	*92.4%*	***99.0%***
HaigisU	291	0.02	0.39	*0.30*	*0.24*	*52.9%*	***80.8%***	*93.5%*	***99.0%***
Hoffer Q	291	0.01	0.46	*0.36*	*0.32*	*41.9%*	***75.6%***	*90.4%*	***96.2%***
Holladay I [8, 9]	291	0.01	0.42	*0.32*	*0.25*	*49.8%*	***78.7%***	*92.1%*	***97.6%***
RBF	291	0.05	0.36	*0.28*	*0.22*	*56.0%*	***81.8%***	*95.2%*	***99.0%***
SRK/T	291	0.02	0.40	*0.31*	*0.26*	*48.8%*	***79.4%***	*92.1%*	***98.6%***
SRK/T-F1	291	0.05	0.39	*0.31*	*0.23*	*52.9%*	***80.4%***	*92.1%*	***98.3%***
SRK/T-F2	291	0.06	0.39	*0.30*	*0.22*	*53.3%*	***81.4%***	*92.8%*	***98.3%***

Table 33.2 This table shows the values of the Haigis quality metrics based on the data from the previous table

Formula	±0.50	±1.00	mAL	mK	*f*	PI
Barrett	0.012	0.010	0.046	−0.027	**1.757**	**0.569**
EVO	0.012	0.010	−0.004	−0.019	**1.334**	**0.750**
HaigisT	0.012	0.010	−0.011	0.093	**1.663**	**0.601**
HaigisU	0.012	0.010	0.007	0.082	**1.590**	**0.629**
Hoffer-Q	0.013	0.010	0.162	0.002	**3.134**	**0.319**
Holladay I	0.013	0.010	0.142	−0.045	**2.907**	**0.344**
Hill-RBF	0.012	0.010	0.042	−0.009	**1.654**	**0.604**
SRK/T	0.013	0.010	0.089	−0.105	**2.521**	**0.397**
SRK/T-F1	0.012	0.010	0.079	−0.091	**2.336**	**0.428**
SRK/T-F2	0.012	0.010	0.065	−0.088	**2.172**	**0.460**

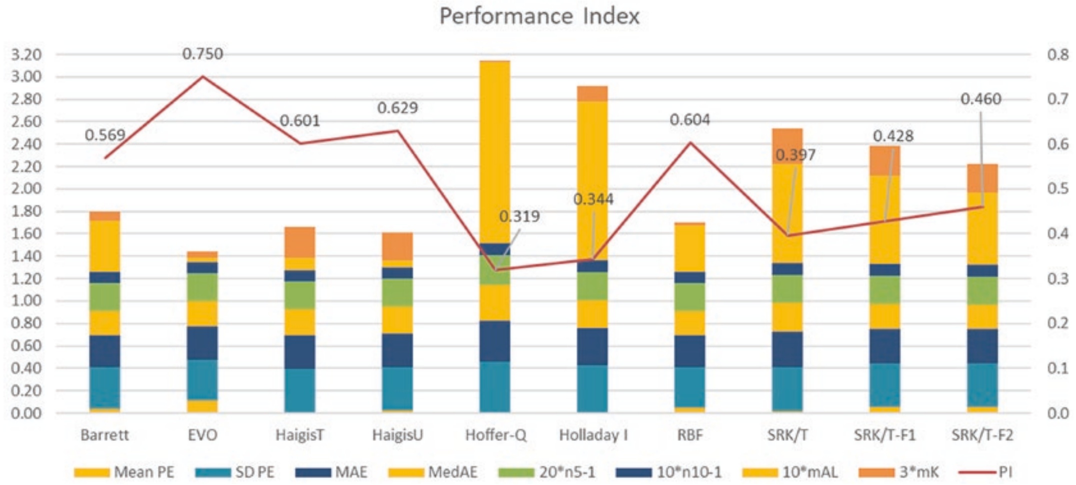

Fig. 33.2 The stacked histogram depicts the values of individual metrics, based on the previous table. The lower the individual component and overall height *f* of the stacked histogram the better. The scale for the stacked histogram *f* is on the left. The red line graph depicts the performance indices of the formulas. The performance index is the reciprocal of the total value of the stacked column. The higher, the better is the performance. The scale for the performance index is on the right. As illustrated, the best performing formula is EVO followed by the 2 Haigis, RBF 1.0, and BUII. These 4 formulas performed much better than the other formulas

Not all studies detailed all of the above metrics. For this review, we will only rank formulas in studies, in both general and subgroups, that have more than 3 of the above 6 metrics.

Further Review

There have been numerous studies published comparing the outcomes of the newer formulas, as well as against the established 3rd generation theoretical formulas. We will review some of these published articles and papers presented during recent conferences. A summary of the review is tabulated in Table 33.3.

Table 33.3 is a summary of outcomes in the literature as well as papers presented at conferences. The orders of the formula for each source are sorted in an order based on a modification of the Haigis performance index (PI) for comparing IOL power calculation formulas as explained above. The parameters used in this modified quality metrics are the SD, MAE, and MedAE, percentage of absolute error within ±0.50 D and ±1.00 D. The inverse of the percentage of absolute error are used and these are normalized by amplifying by 20 for ±0.50 D and ±1.00 D, respectively. All the parameters are added up quantitatively. All the 4 to 6 parameters are summed up. The lower the sum the better. The reciprocal of that sum is the PI. The order above was sorted in decreasing performance index. The outcome is quite similar to that employed by Cooke et al. The formulas are ranked within the same study and not between studies, as the available parameters and clinical situations may be different.

The stacked histogram (Fig. 33.3) shows how the formulas fare in 17 articles, of which sixteen are ranked. Each box indicates the frequency the formula is ranked first, second, third, and fourth based on their PI. These are denoted by blue for 1st; magenta for 2nd; turquoise for 3rd and yellow for 4th. The line graph represents the number of ranked studies the formula was being compared. BUII was the most quoted and had performed well with most studies ranking it as first. EVO and Kane had also done well, with Kane having a relatively high proportion as best performing formula while EVO 2.0 had the highest proportion of being featured as one of the top 4 ranked formulas.

Table 33.3 ME, SD, MAE, and MedAE refer to mean numerical prediction error, the standard deviation of prediction error, mean absolute error, and median absolute error, respectively. BUII-noACD and EVO 2.0-no ACD signify ACD values were omitted in the related formulas. Holladay 2 PreSurgRef and Holladay 2 NoRef refer to Holladay 2 formula with and without preoperative refractions, respectively. Holladay 2018 and Holladay 2019 pertains to the versions of the Holladay 2 formula. Holladay 2-ALadj is a non-linear AL adjustment available as an option in the Holladay 2 program for eyes that are longer than 24.0 mm. LSF stands for Ladas Super Formula. Olsen2P and Olsen4P are Olsen formula using 2 parameters and 4 parameters to determine ELPs, respectively. Olsen2P is preinstalled in biometers while Olsen4P is also known as Olsen standalone and is available in the program, PhacoOptics. SRK/T-F1 and SRK/T-F2 are SRK/T with Fam-adjustment to the ALs and Ks. When specified, ULIB implies using the constants from the ULIB website. _WK indicates Wang-Koch adjustment

Article	Formula	ME	SD	MAE	MedAE	± 0.50	± 1.00	PI	Rank
Cooke and Cooke [14] 1079 eyes/1079 LS-900 SN60WF	Olsen4P	0.000	0.361	0.284	0.225	83.7	99.1	***0.763***	**1**
	BUII	0.000	0.365	0.285	0.230	82.9	99.2	***0.756***	**2**
	Olsen2P	0.000	0.378	0.296	0.245	82.0	98.6	***0.732***	**3**
	T2	0.000	0.397	0.313	0.262	79.6	98.8	***0.701***	**4**
	Haigis	0.000	0.393	0.314	0.268	80.4	98.7	***0.701***	**5**
	Holladay 2 NoRef	0.000	0.404	0.318	0.261	79.0	98.1	***0.694***	**6**
	LSF	0.000	0.403	0.321	0.269	79.1	98.4	***0.690***	**7**
	Holladay 1	0.000	0.408	0.320	0.268	79.1	98.6	***0.689***	**8**
	Holladay 2 PreSurgRef	0.000	0.423	0.336	0.288	76.6	98.4	***0.662***	**9**
	Hoffer Q	0.000	0.428	0.340	0.285	77.8	97.4	***0.660***	**10**
	SRK/T	0.000	0.433	0.342	0.289	75.7	98.1	***0.653***	**11**

Article	Formula	ME	SD	MAE	MedAE	± 0.50	± 1.00	PI	Rank
Cooke and Cooke [14] 1079 eyes/1079 IOLMaster3.02 SN60WF	BUII	0.000	0.387	0.306	0.255	80.6	99.3	***0.716***	**1**
	T2	0.000	0.404	0.319	0.265	79.0	98.7	***0.693***	**2**
	Haigis	0.000	0.401	0.319	0.271	79.8	98.7	***0.692***	**3**
	LSF	−0.060	0.410	0.326	0.275	79.9	98.3	***0.683***	**4**
	Holladay 1	0.000	0.414	0.326	0.270	79.5	98.4	***0.683***	**5**
	Holladay 2 NoRef	0.000	0.417	0.331	0.287	79.3	97.7	***0.670***	**6**
	Hoffer Q	0.000	0.432	0.341	0.281	77.0	97.4	***0.658***	**7**
	Holladay 2 PreSurgRef	0.000	0.432	0.346	0.297	75.2	98.1	***0.647***	**8**
	SRK/T	0.000	0.440	0.346	0.290	75.1	98.1	***0.647***	**9**
	Olsen4P	0.010	0.446	0.348	0.285	75.1	97.1	***0.645***	**10**
Kane et al., Intraocular lens power formula accuracy: Comparison of 7 formulas [15] 3241 eyes/3241 IOLMaster 5.4 SN60WF	Barrett	−0.190		0.385	0.305	72.3	99.9	***0.857***	**1**
	Holladay 1	0.000		0.408	0.326	69.4	99.6	***0.818***	**2**
	T2	−0.030		0.407	0.330	70.0	99.7	***0.817***	**3**
	SRK/T	−0.010		0.413	0.335	69.6	99.7	***0.809***	**4**
	Haigis	0.010		0.420	0.337	68.3	99.6	***0.800***	**5**
	Holladay 2	0.000		0.420	0.341	67.4	99.7	***0.795***	**6**
	Hoffer Q	−0.010		0.427	0.347	67.2	99.6	***0.786***	**7**
Kane et al., Accuracy of 3 new methods for intraocular lens power selection [16] 3122 eyes/3122 IOLMaster 5.4 SN60WF	BUII	−0.020		0.381	0.300	72.8	94.8	***0.857***	**1**
	Holladay 1	−0.010		0.398	0.321	70.1	94.3	***0.822***	**2**
	T2	−0.030		0.398	0.330	70.8	94.4	***0.818***	**3**
	LSF	−0.040		0.402	0.325	69.8	94.3	***0.816***	**4**
	SRK/T	−0.010		0.402	0.330	70.4	94.4	***0.814***	**5**
	RBF 1.0	−0.130		0.407	0.330	69.6	94.3	***0.809***	**6**
	Haigis	0.000		0.409	0.334	69.2	93.6	***0.803***	**7**
	Holladay 2	−0.010		0.410	0.337	68.2	94.4	***0.799***	**8**
	Hoffer Q	−0.020		0.417	0.344	67.9	93.5	***0.788***	**9**
	FullMonte IOL	−0.110		0.428	0.351	66.6	93.0	***0.773***	**10**
Fam, 7 good habits of IOL power calculations [17] 291 eyes/291 IOLMaster 5.4 ZCB00	RBF 1.0	0.047	0.365	0.283	0.220	81.8	99.0	***0.760***	**1**
	BUII	0.040	0.368	0.284	0.220	82.5	99.3	***0.760***	**2**
	EVO	0.113	0.366	0.294	0.230	81.4	98.3	***0.747***	**3**
	SRK/T-F2	0.057	0.387	0.303	0.220	81.4	98.3	***0.736***	**4**
	Haigis	−0.008	0.392	0.303	0.230	80.8	99.0	***0.728***	**5**
	SRK/T-F1	0.053	0.391	0.306	0.230	80.4	98.3	***0.725***	**6**
	Haigis (ULIB)	0.022	0.388	0.301	0.240	80.8	99.0	***0.725***	**7**
	SRK/T	0.015	0.400	0.309	0.260	79.4	98.6	***0.702***	**8**
	Holladay 1	0.010	0.421	0.324	0.250	78.7	97.6	***0.688***	**9**
	Hoffer Q	0.008	0.455	0.360	0.320	75.6	96.2	***0.622***	**10**
Naeser [18] & Savini, Accuracy of thick-lens intraocular lens power calculation based on cutting-card or calculated data for lens architecture [19] 151 eyes/151 Aladdin optical biometer SN60WF	BUII	0.020	0.310	0.240	0.180	89.0	100.0	***0.866***	**1**
	Næser 1	0.010	0.320	0.240	0.180	89.0	99.0	***0.857***	**2**
	Næser 2	0.000	0.320	0.240	0.180	89.0	99.0	***0.857***	**2**
	Haigis	0.000	0.340	0.240	0.190	87.0	99.0	***0.832***	**4**
	SRK/T	−0.020	0.340	0.270	0.230	86.0	99.0	***0.785***	**5**
	Hoffer Q	−0.060	0.360	0.280	0.230	85.0	99.0	***0.765***	**6**

(continued)

Table 33.3 (continued)

Article	Formula	ME	SD	MAE	MedAE	± 0.50	± 1.00	PI	Rank
	Holladay 1	−0.060	0.360	0.290	0.250	85.0	100.0	***0.749***	**7**
Melles (Melles Ophth 2019) Melles et al. [20, 21] 18,501 eyes/18,501 LS900 SA60AT, SN60WF	Kane	0.000	0.384	0.295	0.236	83.0	98.3	***0.736***	**1**
	Olsen4P	0.000	0.394	0.302	0.244	81.7	98.0	***0.720***	**2**
	BUII	0.000	0.404	0.311	0.252	80.9	97.8	***0.705***	**3**
	EVO	0.000	0.409	0.315	0.255	80.2	97.9	***0.698***	**4**
	Olsen2P	0.000	0.424	0.325	0.258	78.7	97.4	***0.682***	**5**
	RBF 2.0	0.000	0.421	0.325	0.266	78.9	97.6	***0.680***	**6**
	Holladay 22019	0.000	0.429	0.332	0.269	78.0	97.4	***0.670***	**7**
	Haigis	0.000	0.437	0.338	0.275	77.0	97.3	***0.660***	**8**
	Holladay 1_WK	0.000	0.439	0.340	0.275	76.6	97.2	***0.658***	**9**
	Holladay 2018	0.000	0.450	0.350	0.285	75.4	97.0	***0.642***	**10**
	Holladay 1	0.000	0.453	0.351	0.287	75.0	96.8	***0.639***	**11**
	SRK/T	0.000	0.463	0.360	0.292	74.1	96.6	***0.628***	**12**
	Hoffer Q -WK	0.000	0.461	0.360	0.295	74.0	96.5	***0.628***	**13**
	SRK/T-WK	0.000	0.467	0.363	0.295	73.6	96.5	***0.623***	**14**
	Hoffer Q	0.000	0.473	0.369	0.303	73.0	96.2	***0.615***	**15**
	Haigis-WK	0.000	0.490	0.383	0.318	71.0	95.6	***0.595***	**16**
Darcy et al. [22] 10,930 eyes/10,930 SA60AT, 920H, 970C, AO	Kane	0.000		0.377	0.302	72.0	95.2	***0.857***	**1**
	RBF 1.0	0.000		0.387	0.310	71.2	94.9	***0.841***	**2**
	Olsen	0.000		0.388	0.309	70.6	94.9	***0.840***	**3**
	Holladay 2	0.000		0.390	0.312	71.0	94.9	***0.837***	**4**
	BUII	0.000		0.390	0.314	70.7	94.7	***0.835***	**5**
	Holladay 1	0.000		0.397	0.321	69.6	94.4	***0.822***	**6**
	SRK/T	0.000		0.403	0.323	69.1	93.9	***0.814***	**7**
	Haigis	0.000		0.405	0.327	69.0	94.3	***0.810***	**8**
	Hoffer Q	0.000		0.410	0.332	68.1	94.0	***0.801***	**9**
Savini et al. [23] 155 eyes/155 OA-2000 SN60WF	EVO	0.000	0.306	0.205	0.240	90.7	100.0	***0.854***	**1**
	BUII	0.005	0.323	0.202	0.253	88.0	100.0	***0.830***	**2**
	T2	0.001	0.328	0.200	0.257	88.7	100.0	***0.826***	**3**
	RBF 1.0	0.037	0.335	0.205	0.252	90.7	99.3	***0.824***	**4**
	Olsen4P	−0.010	0.326	0.209	0.256	89.3	100.0	***0.823***	**5**
	Kane	0.000	0.342	0.200	0.257	90.0	100.0	***0.819***	**6**
	Holladay 2-ALadj	−0.076	0.325	0.225	0.266	89.3	99.3	***0.806***	**7**
	VRF	0.000	0.340	0.210	0.262	86.0	99.3	***0.803***	**8**
	SRK/T	0.001	0.344	0.221	0.262	84.7	100.0	***0.792***	**9**
	Olsen2P	0.013	0.378	0.240	0.294	84.0	98.7	***0.739***	**10**
	Holladay 2	−0.020	0.417	0.228	0.279	86.7	98.0	***0.736***	**11**
	Hoffer Q	0.000	0.395	0.248	0.307	85.3	97.3	***0.719***	**12**
	Haigis	0.002	0.400	0.254	0.307	84.7	98.0	***0.714***	**13**
	Holladay 1	0.000	0.407	0.249	0.306	85.3	96.7	***0.713***	**14**
	Panacea	−0.006	0.413	0.248	0.314	80.0	96.7	***0.698***	**15**

Table 33.3 (continued)

Article	Formula	ME	SD	MAE	MedAE	± 0.50	± 1.00	PI	Rank
Cheng et al. [24] 410 eyes/410 IOLMaster700 MX60	Kane	0.000	0.451	0.348	0.286	77.1	100.0	***0.647***	**1**
	Olsen	0.000	0.456	0.349	0.283	75.9	100.0	***0.645***	**2**
	EVO 2.0	0.000	0.460	0.354	0.293	74.6	100.0	***0.635***	**3**
	BUII	0.000	0.470	0.362	0.283	75.2	100.0	***0.633***	**4**
	Holladay 2	0.000	0.482	0.378	0.325	72.6	100.0	***0.602***	**5**
	RBF 2.0	0.000	0.492	0.385	0.314	73.4	100.0	***0.601***	**6**
	T2	0.000	0.500	0.391	0.317	72.0	100.0	***0.593***	**7**
	PEARL-DGS	0.000	0.515	0.388	0.305	71.0	100.0	***0.592***	**8**
	Haigis	0.000	0.521	0.404	0.322	68.8	100.0	***0.575***	**9**
	SRK/T	0.000	0.548	0.426	0.371	66.4	100.0	***0.542***	**10**
	Hoffer Q	0.000	0.612	0.465	0.379	63.0	100.0	***0.507***	**11**
	Holladay 1	0.000	0.611	0.478	0.376	60.5	100.0	***0.501***	**12**
Fernandez et al. [25] 3519 eyes/3519 IOLMaster700 POD-F, POD-FGF	Hoffer Q					84.3	97.1		
	Haigis					82.9	95.7		
	Pearl-DGS					81.4	95.7		
	BUII					77.1	97.1		
	EVO					78.6	95.7		
	Kane					84.3	92.9		
	SRK/T					77.1	95.7		
	Holladay 2					81.4	94.3		
	RBF 1.0					74.3	95.7		
Turnbull et al. [26] 176 eyes/88 SN6ATT	BUII	0.000	0.235	0.268	0.200	86.9	98.9	***0.881***	**1**
	RBF 2.0	−0.080	0.232	0.286	0.228	84.1	98.9	***0.843***	**2**
	Haigis	0.000	0.263	0.308	0.240	77.3	97.7	***0.785***	**3**
	SRK/T	0.000	0.255	0.327	0.268	76.7	98.9	***0.762***	**4**
	Holladay 1	0.000	0.302	0.355	0.282	75.0	97.2	***0.709***	**5**
	Hoffer Q	0.000	0.303	0.368	0.297	69.9	96.0	***0.684***	**6**
Zhao et al. [27] 53 eyes/41 IOLMaster SBL-3	EVO	0.000	0.600	0.430	0.300	69.8	88.7	***0.543***	**1**
	BUII	0.000	0.610	0.440	0.310	67.9	88.7	***0.532***	**2**
	Kane	0.000	0.610	0.450	0.310	67.9	88.7	***0.529***	**3**
	Haigis	0.000	0.600	0.450	0.330	66.0	90.6	***0.525***	**4**
	RBF 2.0	0.000	0.610	0.460	0.360	62.3	90.6	***0.507***	**5**
	Holladay 1	0.000	0.620	0.460	0.380	67.9	90.6	***0.506***	**6**
	Hoffer Q	0.000	0.610	0.470	0.360	60.4	86.8	***0.500***	**7**
	SRK/T	0.000	0.620	0.460	0.400	64.2	90.6	***0.497***	**8**

(continued)

Table 33.3 (continued)

Article	Formula	ME	SD	MAE	MedAE	± 0.50	± 1.00	PI	Rank
Savini et al. [28] 205 eyes/205 AL-Scan SI255	BUII-noACD	−0.058	0.343	0.262	0.218	88.0	99.0	***0.799***	**1**
	Kane	−0.001	0.348	0.265	0.214	86.5	99.0	***0.794***	**2**
	T2	0.000	0.347	0.269	0.228	88.5	99.0	***0.786***	**3**
	EVO 2.0-(noACD	0.000	0.348	0.267	0.225	87.0	98.5	***0.786***	**4**
	BUII	−0.045	0.353	0.268	0.218	85.5	99.0	***0.784***	**5**
	RBF 2.0	−0.003	0.356	0.272	0.215	85.0	99.5	***0.782***	**6**
	Holladay 1	0.000	0.355	0.275	0.232	88.5	99.0	***0.775***	**7**
	EVO 2.0	0.000	0.357	0.276	0.233	83.5	99.0	***0.765***	**8**
	SRK/T	0.000	0.365	0.287	0.223	86.0	98.0	***0.762***	**9**
	VRF	0.000	0.372	0.280	0.235	84.5	99.5	***0.755***	**10**
	Pearl-DGS	0.000	0.366	0.286	0.238	84.5	98.5	***0.752***	**11**
	Hoffer Q	0.000	0.388	0.295	0.229	84.0	99.5	***0.740***	**12**
	Holladay 2-Aladj	0.000	0.387	0.297	0.228	83.0	98.5	***0.737***	**13**
	Haigis	−0.012	0.402	0.306	0.240	82.0	98.5	***0.717***	**14**
	Næser 2	0.027	0.409	0.313	0.256	80.0	99.0	***0.699***	**15**
Szalai et al. [29] 95 eyes/95 Anterion 690AB, AO, SA60AT, SN60WF, Clareon	Haigis	−0.013		0.273	0.200	78.0	98.0	***1.071***	**1**
	LSF	0.011		0.387	0.330	62.0	89.0	***0.791***	**2**
	Hoffer Q	0.175		0.424	0.290	63.0	84.0	***0.788***	**3**
	Holladay 1	0.125		0.424	0.310	59.0	88.0	***0.769***	**4**
	Kane	−0.070		0.346	0.500	79.0	86.0	***0.751***	**5**
	RBF 2.0	−0.065		0.400	0.410	61.0	89.0	***0.734***	**6**
	BUII	−0.037		0.449	0.370	60.0	88.0	***0.725***	**7**
	SRK/T	0.161		0.449	0.370	55.0	88.0	***0.709***	**8**
Reitblat et al. [30] 90 eyes/90 IOLMaster 5.21 SN60WF	BUII	0.030	0.590	0.440	0.330	72.2	92.2	***0.54***	**1**
	Kane	0.020	0.610	0.460	0.350	72.2	90.0	***0.52***	**2**
	SRK/T	−0.020	0.630	0.480	0.380	61.1	98.9	***0.50***	**3**
	Haigis	−0.010	0.630	0.490	0.370	65.6	86.7	***0.49***	**4**
	Holladay 1	−0.080	0.610	0.470	0.390	58.9	90.0	***0.49***	**5**
	Hoffer Q	−0.050	0.650	0.490	0.370	61.1	90.0	***0.49***	**6**
Hipolito-Fernandes et al. [31] 828 eyes/828 LS-900 SN60WF	Kane	0.000	0.418	0.324	0.274	79.3	97.7	***0.679***	**1**
	VRF-G	0.000	0.423	0.332	0.273	79.5	97.1	***0.673***	**2**
	EVO 2.0	0.000	0.419	0.329	0.282	78.5	97.6	***0.671***	**3**
	BUII	0.000	0.429	0.339	0.291	77.8	97.2	***0.657***	**4**
	RBF 2.0	0.000	0.433	0.342	0.291	76.7	97.6	***0.653***	**5**
	PEARL-DGS	0.000	0.436	0.344	0.290	76.9	97.2	***0.651***	**6**
	VRF	0.000	0.440	0.347	0.293	76.7	97.0	***0.646***	**7**
	T2	0.000	0.441	0.346	0.291	75.5	97.1	***0.646***	**8**
	SRK/T	0.000	0.454	0.356	0.303	75.1	97.2	***0.631***	**9**
	Næser 2	0.000	0.455	0.357	0.309	74.9	96.3	***0.627***	**10**
	Holladay 1	0.000	0.461	0.361	0.299	74.3	96.1	***0.626***	**11**
	Haigis	0.000	0.459	0.359	0.309	74.5	95.4	***0.623***	**12**
	Hoffer Q	0.000	0.489	0.383	0.317	69.9	95.7	***0.594***	**13**

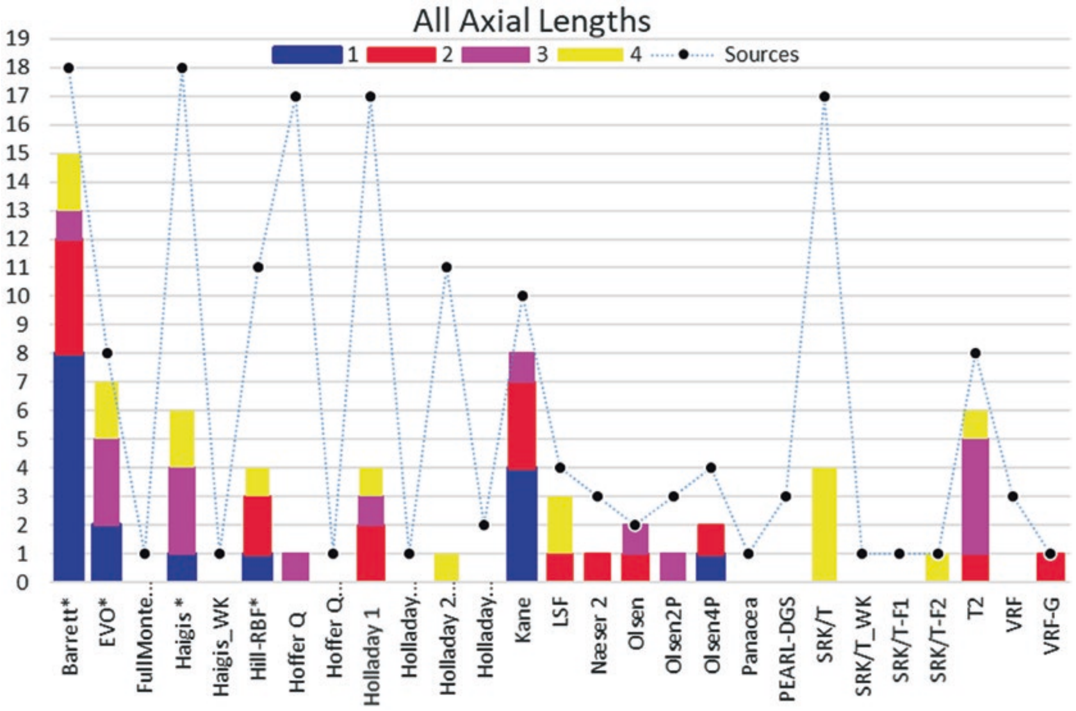

Fig. 33.3 Stacked histogram showing the performance indices of the various formulas in the literature

Subgroup Analyses

The third-generation theoretical formulas are good but are noted to have a bias against AL and K. In the past, different formulas were recommended for different ALs and Ks as first recommended and published by Hoffer in 1993. For normal, these older formulas function well. Against this backdrop, newer formulas must show improvement in longer and shorter axial lengths and extreme corneal curvatures.

The Long and Short of It

Short Eyes

A short eye is generally defined as an eye that is 22.0 mm in AL or shorter. IOL power calculation in short eyes is always a challenge. The biometric measurements have to be more precise. The IOL powers are of higher iopter and are consequently more sensitive to even small variations in ELP. Hence, the prediction errors are generally higher than in normal eyes.

The charts (Fig. 33.4) and Table 33.4 showed the accuracy of the different formulas in short eyes (≤22.0 mm). IOL constants for the third-generation formulas were from the greater pool of patients and IOLs. ULIB constants were used for Haigis as some IOLs did not have sufficient numbers for triple optimization. 8 different IOLs are used in this study. BUII, EVO, and RBF were calculated with the optimized A-constant. Fig. 33.4a shows the prediction errors of the formulas, while Fig. 33.4b, c show the absolute errors and percentage of absolute errors.

From Fig. 33.4 and Table 33.4, BUII, Haigis (ULIB), RBF 1.0 and EVO had better outcome metrics than the other formulas. BUII, Haigis, RBF 1.0, and EVO 1.0 had lower than 0.40 D and 0.30 D of MAE and MedAE, respectively, and more than 70% within ±0.5 D of expected refraction. All four formulas scored better than 0.60 on the performance index.

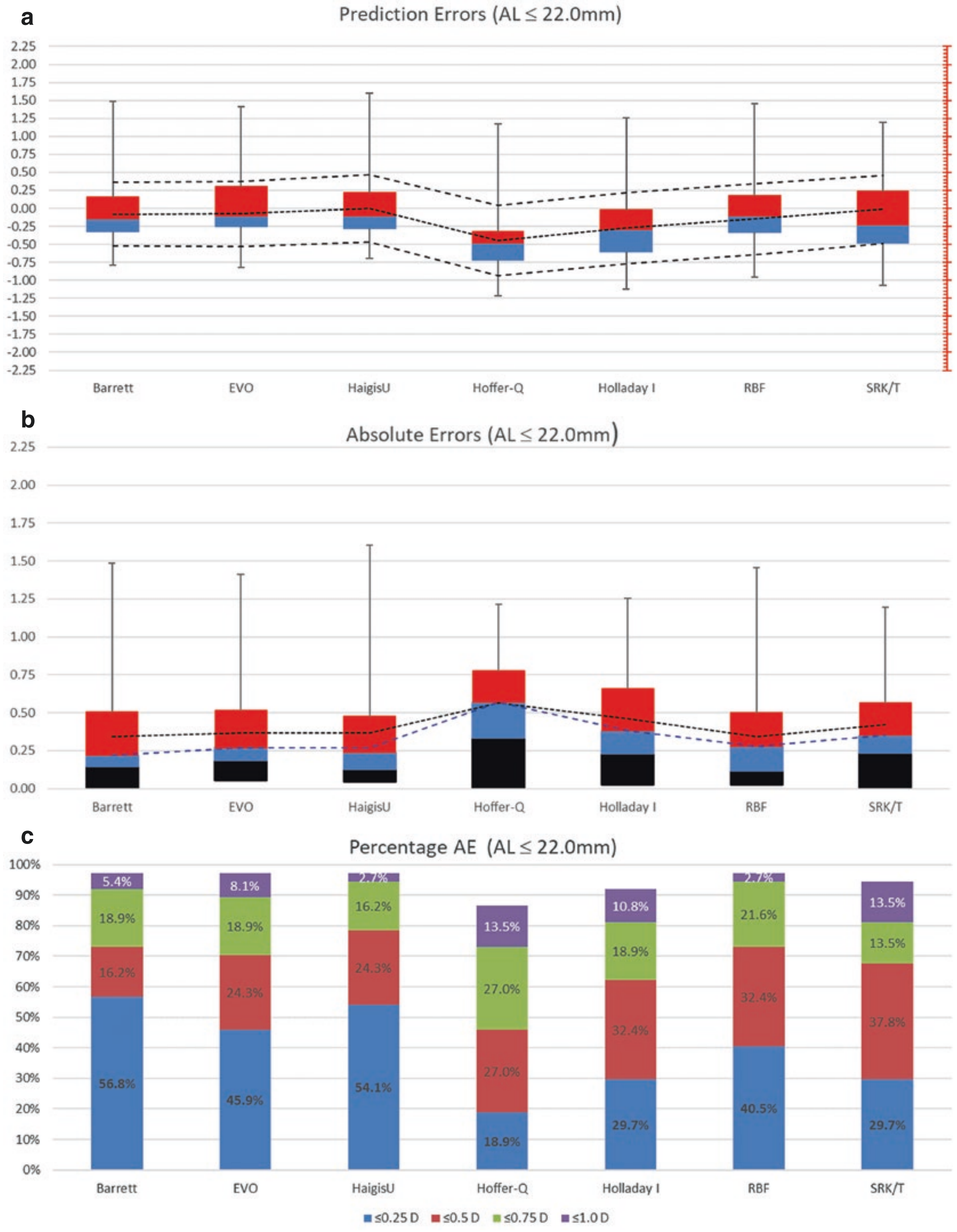

Fig. 33.4 Chart (**a**) displays the prediction error of the formulas. The dual colored boxes in chart (**a**) represent the 2nd and 3rd quartiles of the spread of prediction errors. The error plots are the 1st and 4th quartiles. The line graphs are the upper and lower SDs. Chart (**b**) shows the absolute error of the formulas. The tri-colored boxes are the 1st, 2nd, and 3rd quartiles while the error plot is the last quartile. The blue and black dashed lines are the MedAEs and MAEs. Chart (**c**) is a stacked histogram showing the percentage of eyes within ±0.25, ±0.50, ±0.75, and ±1.00 D of the refraction target

Table 33.4 This table shows the modified Haigis performance indices of the various formulas (EVO is EVO 1.0; RBF is RBF 1.0) [32]

Formula	*n*	ME	SD	MAE	MedAE	±0.50 D	±1.00 D	PI	Rank
BUII	37	−0.077	0.452	0.344	0.220	73.0	97.3	***0.668***	**1**
Haigis	37	0.002	0.466	0.342	0.240	78.4	97.3	***0.663***	**2**
RBF 1.0	37	−0.079	0.445	0.342	0.280	73.0	97.3	***0.646***	**3**
EVO	37	−0.015	0.471	0.369	0.270	70.3	97.3	***0.625***	**4**
SRK/T	37	−0.149	0.496	0.424	0.350	67.6	94.6	***0.563***	**5**
Holladay 1	37	−0.274	0.490	0.459	0.380	62.2	91.9	***0.535***	**6**
Hoffer Q	37	−0.444	0.490	0.565	0.570	45.9	86.5	***0.436***	**7**

Review (Short Axial Lengths)

Table 33.5 is a summary of outcomes in the literature as well as papers presented at conferences on short eyes. As with the above table, the order of the formulas for each source are sorted in order based on a modification of Haigis “Quality metrics for comparing IOL calculation formulas.”

The stacked histogram (Fig. 33.5) shows how the formulas fare in 8 ranked datasets of 11 articles. Each box indicates the number of times the formula is being ranked based on its PI. Blue is for 1st ranking; magenta for 2nd; turquoise for 3rd and yellow for 4th. The line graph represents the frequency of ranked studies the formula was being compared. Most of the new formulas performed reasonably well. PEARL-DGS was ranked 1st in both studies quoted. Holladay 1 and Barrett were the two most featured formulas. Both had performed reasonably well with most studies ranking it as among the top 4. Among the older theoretical formulas, Haigis and Holladay 1 stand out.

Wendelstein et al. did a study to look at the accuracy of 13 different concepts in extreme short eyes [4]. 150 eyes of 150 patients were recruited for this study and 2 IOL models (SA60AT and ZCB00) were used. The constants were optimized from a separate patient cohort. Biometry was measured with either LenStar LS 900 or IOLMaster 700 (Carl Zeiss Meditec AG, Jena, Germany). Postoperative refraction was done at 4 weeks. They concluded that PEARL-DGS, Okulix [43], Kane, and Castrop showed the lowest MAE.

From the graph (Fig. 33.6), Castrop had good accuracy for both groups. PEARL-DGS was the most accurate for the >28.5 D group and was also good for the ≤28.5D group. Okulix had also performed well with the subgroup performance index of above 0.60.

Medium Axial Length

Medium AL is the range of a AL where most eyes are found. It is generally taken to be between 22.0 mm to 24.5 mm, with minor variations. Most formulas perform well in these eyes.

Review (Medium Axial Lengths)

Table 33.6 is a summary of outcomes in the literature as well as papers presented at conferences on medium AL eyes. As with the earlier tables, the orders of the formula for each source are sorted in order based on a modification of Haigis “Quality metrics for comparing IOL calculation formulas.”

The stacked histogram (Fig. 33.7) shows how the formulas fare in 6 ranked datasets in 9 papers. Each box indicates the frequency the formula is being ranked based on PI. Blue for 1st; magenta for 2nd; turquoise for 3rd; and yellow for 4th. The dotted line joins the number of ranked studies the formula was being compared to. There were far fewer studies specifically focused on this range. This chart mirrored that of all ALs, as most of the eyes fall into this group. The performances in this range of ALs were quite spread out. This is not surprising as most formulas perform well in this “normal” range. BUIIt and Holladay 1 were the most quoted and had the highest number of top 4 rankings. RBF 2.0, Kane, and Olsen were next.

Table 33.5 ME, SD, MAE, and MedAE refer to mean numerical prediction error, the standard deviation of prediction error, mean absolute error, and median absolute error, respectively. Holladay 2 PreSurgRef and Holladay 2 NoRef refer to Holladay 2 formula with and without preoperative refractions, respectively. LSF stands for Ladas Super Formula [33]. Olsen2P and Olsen4P are Olsen [34–41] using 2 parameters and 4 parameters to determine ELPs, respectively. Olsen2P is preinstalled in biometers while Olsen4P is also known as Olsen standalone and is available in the program, PhacoOptics. When specified, ULIB implies using the constants from the ULIB website

Article	Formula	ME	SD	MAE	MedAE	±0.50	±1.00	PI	Rank
Cooke et al. [14] LS 900 SN60WF ≤22.0	Olsen4P	−0.070	0.402	0.322	0.225	75.6	100.0	***0.674***	**1**
	BUII	−0.150	0.417	0.338	0.260	78.0	95.1	***0.613***	**2**
	Haigis	0.000	0.460	0.390	0.308	65.9	100.0	***0.602***	**3**
	Olsen2P	0.080	0.453	0.380	0.325	70.7	97.6	***0.579***	**4**
	SRK/T	−0.150	0.494	0.407	0.327	68.3	95.1	***0.532***	**5**
	Holladay 1	−0.250	0.457	0.397	0.302	75.6	92.7	***0.530***	**6**
	T2	−0.230	0.474	0.407	0.341	70.7	95.1	***0.514***	**7**
	LSF	−0.290	0.472	0.426	0.320	75.6	92.7	***0.503***	**8**
	Holladay 2 PreSurgRef	−0.270	0.445	0.426	0.397	70.7	92.7	***0.491***	**9**
	Holladay 2 NoRef	−0.350	0.430	0.437	0.345	58.5	90.2	***0.470***	**10**
	Hoffer Q	−0.440	0.455	0.500	0.493	53.7	90.2	***0.403***	**11**
Cooke et al. [14] IOLMaster3.02 SN60WF ≤ 22.0	Haigis	−0.020	0.509	0.407	0.311	68.3	95.1	***0.571***	**1**
	BUII	−0.150	0.483	0.392	0.295	78.0	92.7	***0.558***	**2**
	Holladay 1	−0.210	0.486	0.389	0.269	80.5	92.7	***0.550***	**3**
	SRK/T	−0.110	0.508	0.402	0.301	68.3	95.1	***0.548***	**4**
	T2	−0.190	0.493	0.394	0.296	73.2	95.1	***0.539***	**5**
	LSF	−0.230	0.479	0.401	0.283	80.5	92.7	***0.538***	**6**
	Olsen4P	−0.020	0.565	0.458	0.370	61.0	95.1	***0.513***	**7**
	Holladay 2 PreSurgRef	−0.240	0.472	0.427	0.395	65.9	92.7	***0.487***	**8**
	Holladay 2 NoRef	−0.330	0.467	0.443	0.402	73.2	87.8	***0.467***	**9**
	Hoffer Q	−0.410	0.493	0.483	0.383	63.4	87.8	***0.432***	**10**
Fam (Fam, Approaching atypical eyes with confidence [32]) 59 eyes IOLMaster3.02 eyes/ IOLMaster5.4 8 IOLs ≤ 22.0	Haigis-ULIB	0.002	0.466	0.342	0.240	78.4	97.3	***0.662***	**1**
	BUII	−0.077	0.452	0.344	0.220	73.0	97.3	***0.636***	**2**
	EVO	−0.015	0.471	0.369	0.270	70.3	97.3	***0.619***	**3**
	RBF	−0.079	0.445	0.342	0.280	73.0	97.3	***0.615***	**4**
	SRK/T	−0.149	0.496	0.424	0.350	67.6	94.6	***0.519***	**5**
	Holladay 1	−0.274	0.490	0.459	0.380	62.2	91.9	***0.467***	**6**
	Hoffer Q	−0.444	0.490	0.565	0.570	45.9	86.5	***0.366***	**7**
Kane et al., Intraocular lens power formula accuracy: Comparison of 7 formulas [15] IOLMaster 5.4 SN60WF ≤ 22.0	Haigis	−0.090		0.473	0.334	62.8	100.0	***0.706***	**1**
	Holladay 1	−0.070		0.453	0.377	63.5	99.4	***0.706***	**2**
	SRK/T	−0.040		0.458	0.397	59.6	99.4	***0.698***	**3**
	Holladay 2	−0.070		0.466	0.383	61.5	100.0	***0.692***	**4**
	T2	−0.100		0.459	0.415	60.3	99.4	***0.664***	**5**
	BUII	−0.260		0.469	0.395	62.2	100.0	***0.608***	**6**
	Hoffer Q	−0.220		0.499	0.441	55.8	100.0	***0.582***	**7**
Accuracy of 3 new methods for IPC	Holladay 1	−0.090		0.417	0.360	66.4	95.6	***0.726***	**1**
Kane, JCRS 2017; 43:333–339	RBF	−0.150		0.423	0.360	66.4	95.6	***0.693***	**2**
	LSF	−0.140		0.433	0.370	63.5	94.9	***0.681***	**3**
IOLMaster 5.4	BUII	−0.280		0.451	0.400	63.5	94.2	***0.603***	**4**

Table 33.5 (continued)

Article	Formula	ME	SD	MAE	MedAE	±0.50	±1.00	PI	Rank
SN60WF	FullMonte IOL	−0.250		0.513	0.462	55.5	89.1	***0.553***	**5**
IPC in short eyes	RBF	0.050	0.470	0.360	0.310	70.9	96.5	***0.595***	**1**
Gökce, [42]	BUII	−0.040	0.490	0.390	0.320	68.6	95.3	***0.574***	**2**
86 eyes eyes/67	Holladay 1	−0.040	0.500	0.390	0.340	70.9	97.7	***0.569***	**3**
LS900	Holladay 2	−0.250	0.460	0.400	0.330	69.8	91.9	***0.514***	**4**
SN60WF, SN6AT, SA60AT, ZCB00, ZCT	Haigis	−0.090	0.540	0.420	0.390	68.6	90.7	***0.512***	**5**
	Hoffer Q	−0.220	0.490	0.440	0.390	64.0	94.2	***0.484***	**6**
	Olsen	0.270	0.510	0.460	0.410	59.3	91.9	***0.454***	**7**
Melles et al. [20, 21] LS900 SA60AT, SN60WF < 22.5 mm	Kane			0.345					
	Olsen4P			0.360					
	BUII			0.377					
	RBF			0.382					
	EVO			0.384					
	Holladay 1			0.400					
	Haigis			0.402					
	Holladay 2			0.416					
	SRK/T			0.417					
	Hoffer Q			0.448					
Darcy et al. [22] IOLMaster SA60AT, 920H, 970C, AO ≤ 22.5 mm	Kane				0.441				
	Holladay 2				0.458				
	Olsen				0.459				
	Hill-RBF 2.0				0.470				
	Holladay 1				0.493				
	BUII				0.461				
	Hoffer Q				0.478				
	Haigis				0.486				
	SRK/T				0.492				
Cheng et al. [24] IOLMaster700 MX60	PEARL-DGS			0.378	0.278	70.8	95.8	***0.872***	**1**
	Hoffer Q			0.409	0.273	70.8	91.7	***0.846***	**2**
	Holladay 1			0.420	0.352	70.8	91.7	***0.786***	**3**
	Kane			0.472	0.417	62.5	87.5	***0.696***	**4**
	RBF 2.0			0.608	0.579	41.7	83.3	***0.524***	**5**
Hipolito-Fernandes et al. [31] LS-900 SN60WF	VRF-G			0.345					
	EVO 2.0			0.347					
	Kane			0.348					
	VRF			0.365					
	BUII			0.367					
	RBF 2.0			0.368					
	PEARL-DGS			0.368					
	Næser 2			0.380					
	SRK/T			0.384					
	Haigis			0.397					
	T2			0.400					
	Holladay 1			0.409					
	Hoffer Q			0.478					

(continued)

Table 33.5 (continued)

Article	Formula	ME	SD	MAE	MedAE	±0.50	±1.00	PI	Rank
Wendelstein et al. [4] 150 eyes/150 LS-900, IOLMaster700 SA60AT, ZCB00 < 21.5 mm; Pemme>28.5D	Pearl-DGS	0.030	0.420	0.330	0.260	80.0	96.7	***0.668***	**1**
	Castrop	−0.040	0.420	0.330	0.270	74.7	99.3	***0.654***	**2**
	Okulix	−0.040	0.420	0.340	0.300	79.3	98.7	***0.643***	**3**
	Kane	−0.010	0.450	0.350	0.300	78.7	96.0	***0.636***	**4**
	Olsen2P	0.030	0.500	0.400	0.330	70.0	96.7	***0.571***	**5**
	Haigis	−0.060	0.490	0.390	0.320	68.0	95.3	***0.567***	**6**
	RBF 2.0	−0.100	0.490	0.380	0.320	73.3	95.3	***0.564***	**7**
	Holladay 1	0.030	0.530	0.410	0.340	66.7	94.0	***0.549***	**8**
	EVO 2.0	0.220	0.440	0.390	0.300	70.0	96.7	***0.543***	**9**
	Holladay 2	−0.260	0.490	0.430	0.380	66.0	92.0	***0.481***	**10**
	BUII	−0.200	0.640	0.490	0.330	62.7	84.7	***0.451***	**11**
	SRK/T	0.250	0.600	0.500	0.420	76.9	94.9	***0.446***	**12**

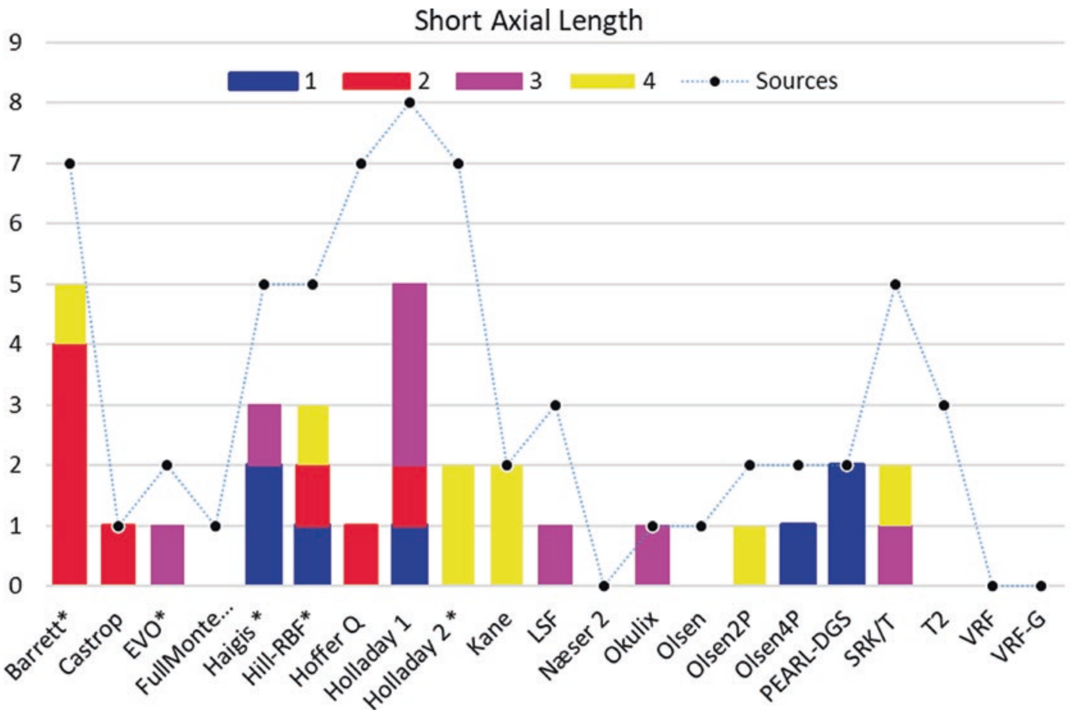

Fig. 33.5 Stacked histogram showing the performance indices of the various formulas for short axial length

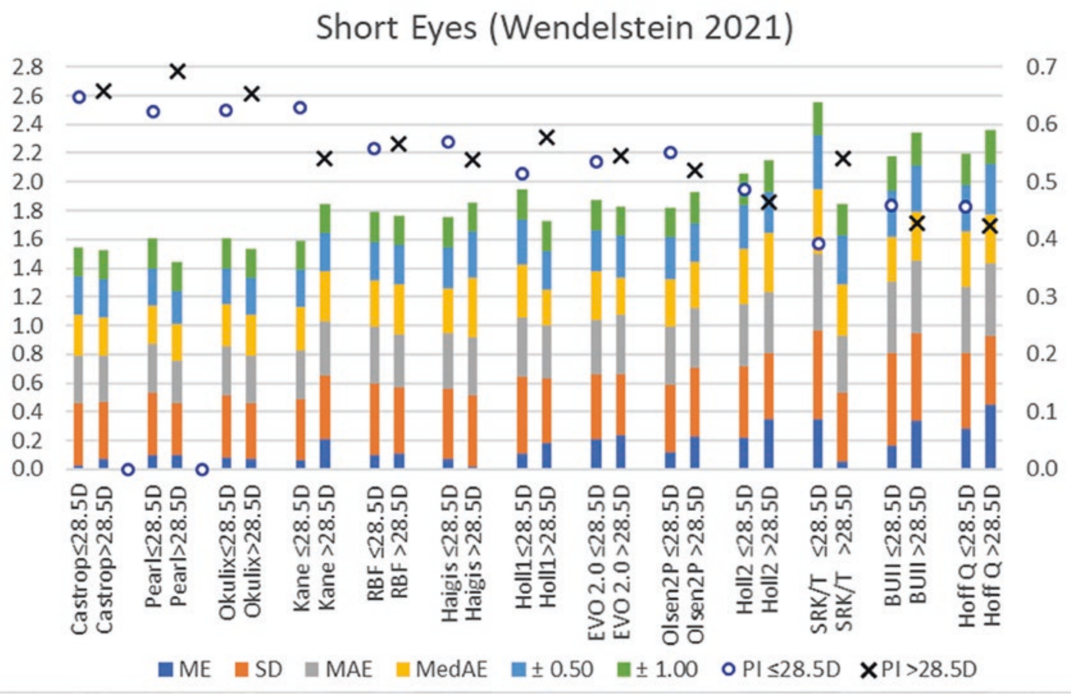

Fig. 33.6 The stacked histograms show the quality metrics *f* of the formulas in extremely short eyes [4]. Each formula is divided into 2 groups (1. Emmetropic IOL power ≤28.5D and 2. Emmetropic IOL power >28.5D). The scale for the stacked histogram *f* is on the left. The lower the stacked histogram, the better is the formula performance. The circles and triangles represent the PI. The scale for PI is on the right. The higher the PI score, the better. *BUII* = Barrett, *Hai* = Haigis, *HoffQ* = Hoffer Q, *Holl1* = Holladay 1, Holl2 = Holladay 2, *PEARL* = PEARL-DGS, *RBF* = RBF 2.0.

Very Long Axial Length (>26.0 mm)

The threshold for medium long AL is from 24.5 mm to 26.0 mm. Very long ALs are defined as >26.0 mm.

At the 2016 APACRS annual conference in Bali, Fam presented his findings on the performances of the various formulas for eyes with very long ALs [32]) (Fig. 33.8, Table 33.7).

In long eyes, the third-generation formulas underestimated the dioptric powers and the resultant refractions were hyperopic. The newer formulas such as BUII, EVO, and RBF 2.0 were more accurate in their calculations. EVO was the most accurate in both datasets. The Fam and Wang-Koch adjustment compensated well for the otherwise hyperopic outcomes of Holladay 1. The hyperopic errors and inconsistencies were more apparent and exacerbated in the low dioptric lens powers.

Review (Long Axial Lengths)

Table 33.8 is a summary of outcomes in the literature as well as papers presented at conferences on long eyes. As with the earlier tables, the orders of the formula for each source are sorted in order based on a modification of Haigis “Quality metrics for comparing IOL calculation formulas.”

The stacked histogram (Fig. 33.9) shows how the formulas fare in 16 articles, of which sixteen are ranked. Each box indicates the number of

Table 33.6 ME, SD, MAE, and MedAE refer to mean numerical prediction error, the standard deviation of prediction error, mean absolute error, and median absolute error, respectively. LSF stands for Ladas Super Formula. Olsen2P and Olsen4P are Olsen using 2 parameters and 4 parameters to determine ELPs, respectively. Olsen2P is preinstalled in biometers, while Olsen4P is also known as Olsen standalone and is available in the program, PhacoOptics. SRK/T-F1 and SRK/T-F2 are SRK/T with Fam-adjustment to the ALs and Ks. When specified, ULIB implies using the constants from the ULIB website

Article	Formula	ME	SD	MAE	MedAE	± 0.50	± 1.00	PI	Rank
Kane et al., Intraocular lens power formula accuracy: Comparison of 7 formulas [15] IOLMaster 5.4 SN60WF 22.0 < AL < 24.5 mm	Holladay 1	−0.010		0.404	0.323	69.8	99.7	***0.817***	**1**
	SRK/T	−0.020		0.408	0.329	70.8	99.8	***0.807***	**2**
	Haigis	−0.010		0.415	0.335	69.0	99.6	***0.800***	**3**
	T2	−0.030		0.405	0.330	69.5	99.7	***0.798***	**4**
	Holladay 2	−0.020		0.416	0.337	68.1	99.7	***0.789***	**5**
	Hoffer Q	−0.020		0.420	0.339	68.1	99.6	***0.785***	**6**
	BUII	−0.200		0.386	0.300	71.3	99.9	***0.732***	**7**
Kane et al., Intraocular lens power formula accuracy: Comparison of 7 formulas [15] IOLMaster 5.4 24.5 £ AL < 26.0 mm	BUII	−0.130		0.338	0.270	76.6	100.0	***0.834***	**1**
	T2	0.030		0.385	0.305	71.2	99.7	***0.832***	**2**
	Holladay 1	0.050		0.385	0.316	71.2	99.7	***0.811***	**3**
	Holladay 2	0.120		0.405	0.334	67.2	99.7	***0.737***	**4**
	SRK/T	0.120		0.414	0.341	66.7	99.7	***0.727***	**5**
	Haigis	0.130		0.409	0.347	68.5	99.5	***0.725***	**6**
	Hoffer Q	0.140		0.415	0.357	68.8	99.5	***0.712***	**7**
Kane et al., Accuracy of 3 new methods for intraocular lens power selection [16] IOLMaster 5.4 SN60WF 22.0 < AL < 24.5 mm	LSF	−0.010		0.400	0.320	70.5	94.2	***0.816***	**1**
	Holladay 1	−0.010		0.400	0.321	70.1	94.0	***0.814***	**2**
	BUII	−0.200		0.383	0.300	72.5	94.4	***0.730***	**3**
	RBF 2.0	−0.140		0.412	0.330	69.1	93.8	***0.722***	**4**
	FullMonte IOL	−0.120		0.426	0.347	67.2	92.8	***0.711***	**5**
Kane et al., Accuracy of 3 new methods for intraocular lens power selection [16] IOLMaster 5.4 SN60WF 24.5 ≤ AL < 26.0 mm	RBF 2.0	−0.010		0.370	0.305	75.0	96.8	***0.863***	**1**
	Holladay 1	0.030		0.374	0.313	72.4	95.6	***0.832***	**2**
	BUII	−0.140		0.333	0.270	77.9	97.9	***0.831***	**3**
	FullMonte IOL	−0.090		0.385	0.306	69.7	96.8	***0.785***	**4**
	LSF	−0.110		0.398	0.328	68.5	95.3	***0.747***	**5**
Melles et al. [20, 21] LS900 SA60AT, SN60WF 22.5 £ AL £ 25.5 mm	Kane			0.291					
	Olsen4P			0.297					
	BUII			0.304					
	EVO			0.305					
	RBF 22.0			0.319					
	Holladay 2			0.325					
	Haigis			0.332					
	Holladay 1			0.328					
	SRK/T			0.351					
	Hoffer Q			0.348					
Darcy et al. [22] IOLMaster SA60AT, 920H, 970C, AO 22.0 < AL < 26.0 mm	Kane				0.375				
	Holladay 2				0.387				
	Olsen				0.384				
	RBF 2.0				0.382				
	Holladay 1				0.385				
	BUII				0.387				
	Hoffer Q				0.401				
	Haigis				0.402				
	SRK/T				0.399				

Table 33.6 (continued)

Article	Formula	ME	SD	MAE	MedAE	± 0.50	± 1.00	PI	Rank
Cheng et al. [24] IOLMaster700 MX60 22.0 < AL < 24.5 mm	Olsen			0.347	0.255	76.5	95.7	***0.932***	**1**
	Kane			0.351	0.271	76.9	95.7	***0.917***	**2**
	EVO 2.0			0.353	0.280	75.2	95.3	***0.902***	**3**
	BUII			0.361	0.281	75.6	96.2	***0.897***	**4**
	PEARL-DGS			0.356	0.292	74.4	95.7	***0.888***	**5**
Cheng et al. [24] IOLMaster700 MX60 24.5 ≥ AL < 26.0 mm	Kane			0.350	0.338	78.5	98.5	***0.873***	**1**
	BUII			0.357	0.308	72.3	96.9	***0.871***	**2**
	Olsen			0.353	0.337	75.4	96.9	***0.861***	**3**
	RBF 2.0			0.368	0.334	76.9	96.9	***0.856***	**4**
	EVO 2.0			0.358	0.355	72.3	96.9	***0.836***	**5**
Hipolito-Fernandes et al. [31] LS-900 SN60WF 22.0 < AL <26.0 mm	Kane			0.323					
	EVO 2.0			0.329					
	VRF-G			0.333					
	BUII			0.338					
	RBF 2.0			0.339					
	PEARL-DGS			0.339					
	VRF			0.346					
	Næser 2			0.357					
	Haigis			0.357					
	Holladay 1			0.339					
	Hoffer Q			0.357					

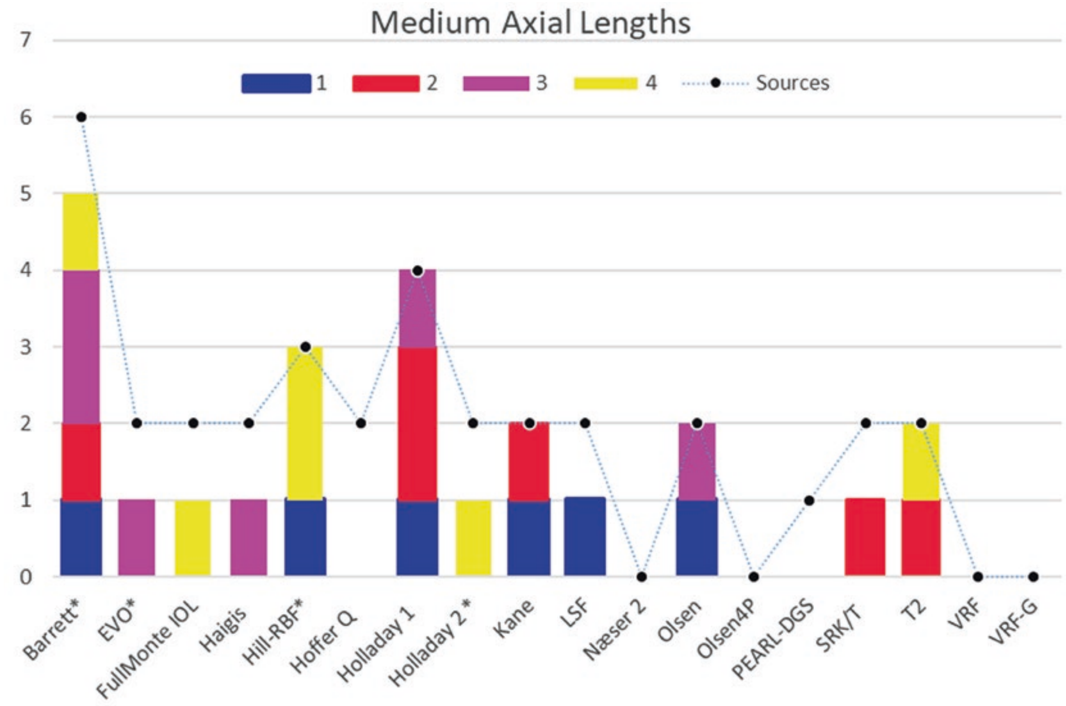

Fig. 33.7 Stacked histogram comparing the performance indices of the various formulas for medium ALs

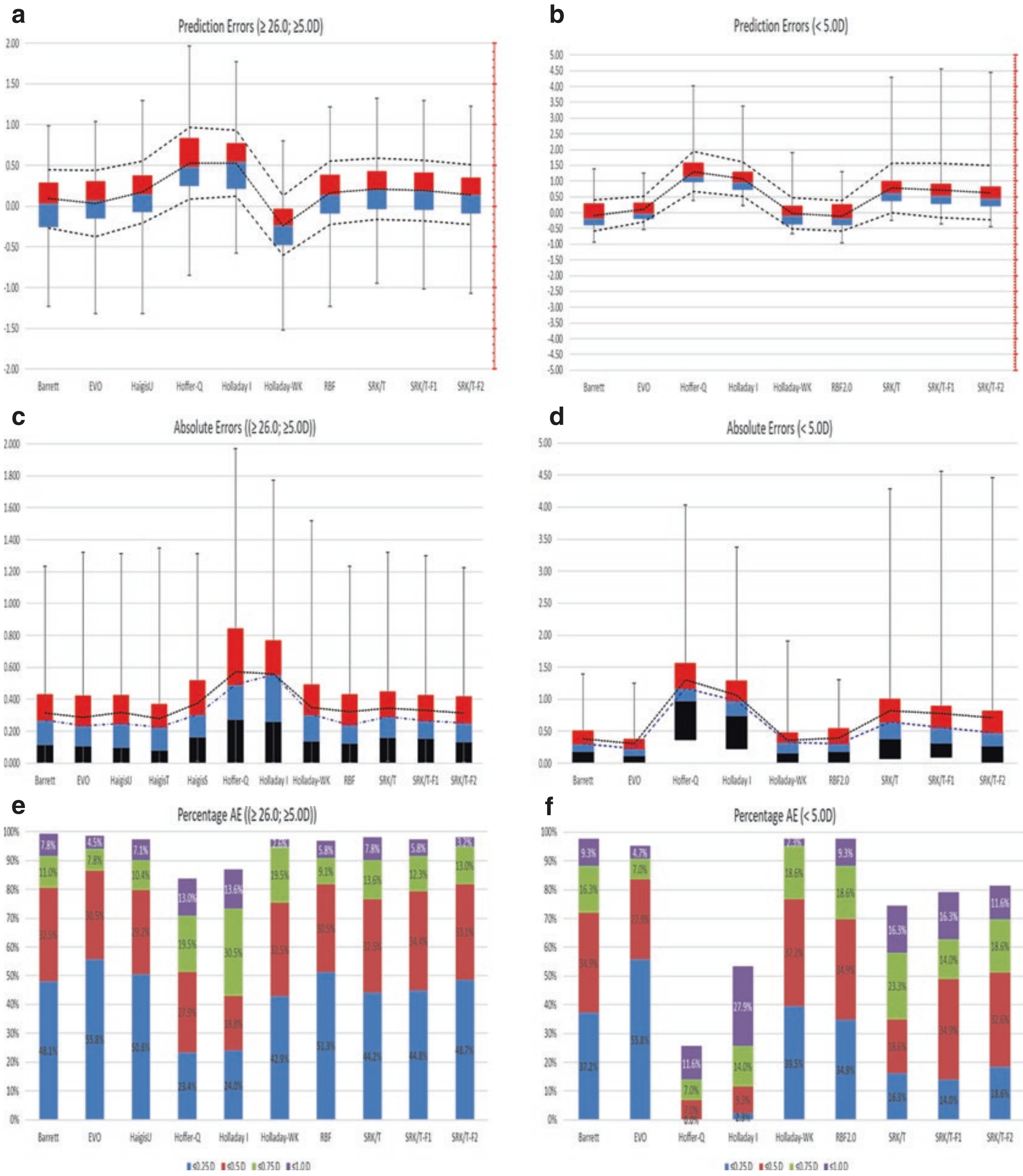

Fig. 33.8 The charts and Table 33.7 depict the outcomes for very long eyes (≥26.0 mm). Charts on the left column were for eyes 26.0 mm and longer and implanted with IOL ≥ 5.0D. 11 different IOLs were used in this study. IOL constants for the third-generation formulas were from the greater pool of patients and IOLs. ULIB constants were used for Haigis as some IOLs did not have sufficient numbers for triple optimization. BUII, EVO, and RBF 2.0 were calculated with the optimized A-constant of SRK/T. The charts on the right column show outcomes for eyes 26.0 mm and longer, and implanted with IOL <5.0D. 7 different IOLs were included in the study; most of these were special very low or negative-diopter IOLs. Figure (**a**, **b**) display the numerical prediction errors of the formulas, while Figs. (**c**, **d**) depict the absolute errors; and (**e**, **f**) the percentage of absolute errors. Most of these eyes were out of the domain for RBF 1.0. RBF in the original presentation was updated to RBF 2.0 in these charts. The formulas in Table 33.7 are arranged in order of their subgroup PI ranking. *n* is for the number of eyes. ME and SD are the means and standard deviations of numerical prediction errors, respectively. MAE and MedAE are the mean and median absolute errors. ±0.50 D and ±1.00 D are the percentage of eyes within those ranges of target refractions, respectively

Table 33.7 This table shows the modified Haigis performance indices of the various formulas (EVO is EVO 1.0; RBF is updated to RBF 2.0) [32]

>26.0 mm	***n***	**ME**	**SD E**	**MAE**	**MedAE**	**±0.50**	**±1.00**	**PI**	**Rank**
EVO	154	0.092	0.361	0.288	0.230	86.4	98.7	***0.761***	**1**
SRK/T-F2	154	0.144	0.369	0.313	0.250	81.8	98.1	***0.724***	**2**
RBF 2.0	154	0.168	0.388	0.324	0.240	81.8	96.8	***0.713***	**3**
Haigis	154	0.174	0.381	0.317	0.250	79.9	97.4	***0.712***	**4**
SRK/T-F1	154	0.193	0.371	0.333	0.260	79.2	97.4	***0.703***	**5**
BUII	154	0.030	0.406	0.316	0.270	80.5	99.4	***0.694***	**6**
SRK/T	154	0.212	0.376	0.346	0.290	76.6	98.1	***0.677***	**7**
Holladay1WK	154	−0.237	0.365	0.348	0.310	75.3	97.4	***0.670***	**8**
Hoffer Q	154	0.530	0.440	0.571	0.500	51.3	83.8	***0.467***	**9**
Holladay 1	154	0.526	0.404	0.560	0.560	42.9	87.0	***0.450***	**10**
>26.0 mm;<5.0D	***n***	**ME**	**SD E**	**MAE**	**MedAE**	**± 0.50**	**± 1.00**	**PI**	**Rank**
EVO	43	0.110	0.402	0.303	0.230	83.7	95.4	***0.723***	**1**
Holladay1WK	43	−0.025	0.490	0.365	0.330	76.7	97.7	***0.606***	**2**
BUII	43	−0.088	0.484	0.388	0.310	72.1	97.7	***0.601***	**3**
RBF 2.0	43	−0.107	0.482	0.396	0.310	69.8	97.7	***0.596***	**4**
Haigis	43	0.575	0.509	0.596	0.510	48.8	83.7	***0.442***	**5**
SRK/T-F2	43	0.636	0.852	0.716	0.480	51.2	81.4	***0.372***	**6**
SRK/T-F1	43	0.714	0.859	0.778	0.560	48.8	79.1	***0.350***	**7**
SRK/T	43	0.788	0.780	0.821	0.650	34.9	74.4	***0.323***	**8**
Holladay 1	43	1.068	0.553	1.068	0.980	11.6	53.5	***0.213***	**9**
Hoffer Q	43	1.308	0.634	1.308	1.170	7.0	25.6	***0.148***	**10**

times the formula is being ranked according to the color: blue for 1st; magenta for the 2nd; turquoise for 3rd and yellow for 4th. The dotted line joins the number of ranked studies the formula was being compared to. BUII was the most quoted and had performed well. EVO 2,0 was quoted in 6 articles but had a proportionately higher number of first ranking. RBF 2.0 and Haigis had also done well.

We will look deeper into the accuracy of the formulas in long axial length but between low-diopter and even lower-diopter eyes.

The 2 charts (Fig. 33.10) illustrate the difference in formula precision as the ALs approach low diopter or negative diopter territory. Chart A is by Abulafia [44] and Chart B by Fam [32]. Abulafia used 6 D while Fam used 5 D as thresholds. The newer formulas such as EVO 2.0, BUII, and RBF 2.0 showed good precisions throughout both groups, as demonstrated by the high subgroup PIs. Wang-Koch adjustments also showed good results, especially with the Holladay 1.

Table 33.8 ME, SD, MAE, and MedAE refer to mean numerical prediction error, the standard deviation of prediction error, mean absolute error, and median absolute error, respectively. Barrett-noACD and EVO 2.0-no ACD signify ACD values were omitted in the related formulas. Holladay 2 PreSurgRef and Holladay 2 NoRef refer to Holladay 2 formula with and without preoperative refractions, respectively. Holladay 2018 and Holladay 2019 pertain to the versions of the Holladay 2 formula. Holladay 2-ALadj is a nonlinear AL adjustment available as an option in Holladay 2 program for eyes that are longer than 24.0 mm. LSF stands for Ladas Super Formula. Olsen2P and Olsen4P are Olsen using 2 parameters and 4 parameters to determine ELPs, respectively. Olsen2P is preinstalled in biometers, while Olsen4P is also known as Olsen standalone and is available in the program, PhacoOptics. SRK/T-F1 and SRK/T-F2 are SRK/T with Fam-adjustment to the axial lengths and corneal powers. -AL1, AL2, and nonlinear AL indicate the first and second linear versions and the non-linear version of Wang-Koch axial length adjustments, respectively. CMAL pertains to the Cook-modified AL. When specified, ULIB implies the constants from the ULIB website are being used in the calculations. _WK indicates ALs with Wang–Koch adjustments

Article	Formula	ME	SD	MAE	MedAE	± 0.50	± 1.00	PI	Rank
Abulafia et al. [44] 106 eyes/68 IOLMaster5.4 MA60MA, SA60AT, SN60TT, SN60WF, SN6AD1, SN6ATT >26.0 mm; ≥6.0D	Haigis (ULIB)	−0.030	0.320	0.270		89.5	100.0	***0.958***	**1**
	Olsen	0.060	0.320	0.260		88.6	100.0	***0.938***	**2**
	SRK/T (ULIB)	−0.040	0.350	0.280		86.8	100.0	***0.909***	**3**
	SRK/T	−0.050	0.350	0.280		86.8	100.0	***0.901***	**4**
	BUII	−0.100	0.320	0.280		89.5	100.0	***0.890***	**5**
	Haigis	−0.170	0.350	0.310		78.9	100.0	***0.779***	**6**
	Holladay 2	0.220	0.380	0.340		83.0	95.7	***0.719***	**7**
	Holladay 1_WK	−0.270	0.320	0.360		69.7	100.0	***0.696***	**8**
	Hoffer Q (ULIB)	0.270	0.370	0.360		71.1	98.7	***0.674***	**9**
	Hoffer Q	0.290	0.370	0.370		71.1	97.4	***0.659***	**10**
	SRK/T-WK	−0.310	0.360	0.410		65.8	100.0	***0.631***	**11**
	Holladay 1 (ULIB)	0.330	0.360	0.380		64.5	97.4	***0.631***	**12**
	Hoffer Q-WK	−0.350	0.350	0.420		67.1	98.7	***0.617***	**13**
	Holladay 1	0.350	0.360	0.400		63.2	97.4	***0.613***	**14**
	Haigis-WK	−0.720	0.330	0.730		23.7	77.6	***0.347***	**15**
Abulafia et al. [44] 106 eyes/68 IOLMaster5.4 MA60MA, SA60AT, SN60TT, SN60WF, SN6AD1, SN6ATT >26.0 mm; <6.0D	Haigis-WK	−0.030	0.400	0.320		86.7	96.7	***0.842***	**1**
	BUII	0.100	0.390	0.300		83.3	96.7	***0.808***	**2**
	Holladay 1-WK	0.070	0.420	0.320		80.0	96.7	***0.789***	**3**
	SRK/T-WK	0.020	0.490	0.390		66.7	96.7	***0.711***	**4**
	Hoffer Q-WK	0.170	0.480	0.390		63.3	96.7	***0.640***	**5**
	Haigis (ULIB)	0.120	0.580	0.480		60.0	86.7	***0.573***	**6**
	Olsen	0.460	0.400	0.490		57.1	90.5	***0.520***	**7**
	SRK/T (ULIB)	0.140	0.670	0.550		53.3	86.7	***0.509***	**8**
	Holladay 1 (ULIB)	0.180	0.840	0.720		40.0	76.7	***0.400***	**9**
	Haigis	0.670	0.410	0.690		40.0	76.7	***0.395***	**10**
	SRK/T	0.820	0.530	0.840		30.0	70.0	***0.318***	**11**
	Hoffer Q (ULIB)	0.230	1.000	0.880		26.7	53.3	***0.309***	**12**
	Holladay 2	1.130	0.470	1.130		3.3	50.0	***0.109***	**13**
	Holladay 1	1.210	0.410	1.210		3.3	33.3	***0.105***	**14**
	Hoffer Q	1.420	0.490	0.370		3.3	16.7	***0.105***	**15**

Table 33.8 (continued)

Article	Formula	ME	SD	MAE	MedAE	± 0.50	± 1.00	PI	Rank
Cooke et al. [14] LS 900 SN60WF ≥26.0	Olsen4P	−0.020	0.325	0.250	0.190	85.2	100.0	***0.820***	**1**
	Olsen2P	−0.050	0.312	0.249	0.183	85.2	100.0	***0.814***	**2**
	Haigis	0.000	0.351	0.259	0.208	83.3	98.1	***0.792***	**3**
	BUII	0.050	0.355	0.274	0.218	83.3	100.0	***0.748***	**4**
	T2	0.030	0.388	0.293	0.251	83.3	96.3	***0.709***	**5**
	LSF	−0.220	0.388	0.335	0.278	72.2	96.3	***0.586***	**6**
	Holladay 1-WK	−0.220	0.388	0.335	0.278	72.2	96.3	***0.586***	**6**
	Holladay 2 NoRef	0.270	0.382	0.382	0.325	74.1	98.1	***0.546***	**8**
	SRK/T	0.200	0.444	0.392	0.344	77.8	94.4	***0.541***	**9**
	Holladay 2 PreSurgRef	0.260	0.400	0.394	0.352	72.2	98.1	***0.530***	**10**
	Hoffer Q	0.320	0.436	0.435	0.405	61.1	96.3	***0.469***	**11**
	Holladay 1	0.430	0.431	0.505	0.479	53.7	94.4	***0.412***	**12**
Cooke et al. [14] IOLMaster3.02 SN60WF ≥26.0	Haigis	−0.010	0.366	0.280	0.168	81.5	98.1	***0.785***	**1**
	Olsen4P	−0.140	0.352	0.290	0.198	83.3	98.1	***0.702***	**2**
	BUII	0.030	0.379	0.303	0.255	75.9	98.1	***0.697***	**3**
	T2	0.000	0.401	0.319	0.269	81.5	98.1	***0.695***	**4**
	LSF	−0.250	0.404	0.348	0.291	75.9	96.3	***0.567***	**5**
	Holladay 1-WK	−0.250	0.404	0.348	0.291	75.9	96.3	***0.567***	**5**
	SRK/T	0.170	0.454	0.399	0.368	75.9	98.1	***0.538***	**7**
	Holladay 2 NoRef	0.230	0.407	0.390	0.353	68.5	98.1	***0.533***	**8**
	Holladay 2 PreSurgRef	0.220	0.426	0.407	0.377	68.5	98.1	***0.519***	**9**
	Hoffer Q	0.300	0.445	0.430	0.388	63.0	96.3	***0.479***	**10**
	Holladay 1	0.400	0.446	0.495	0.473	55.6	92.6	***0.418***	**11**
Fam (Fam, Approaching atypical eyes with confidence [32]) 154 eyes eyes/146 IOLMaster3.02 eyes/ IOLMaster5.4 11 IOLs ≥26.0 mm; ≥ 5.0D	EVO	0.092	0.361	0.288	0.230	86.4	98.7	***0.712***	**1**
	BUII	0.030	0.406	0.316	0.270	80.5	99.4	***0.679***	**2**
	SRK/T-F2	0.144	0.369	0.313	0.250	81.8	98.1	***0.656***	**3**
	RBF	0.168	0.388	0.324	0.240	81.8	96.8	***0.637***	**4**
	Haigis (ULIB)	0.174	0.381	0.317	0.250	79.9	97.4	***0.634***	**5**
	SRK/T-F1	0.193	0.371	0.333	0.260	79.2	97.4	***0.619***	**6**
	SRK/T	0.212	0.376	0.346	0.290	76.6	98.1	***0.592***	**7**
	Holladay 1-WK	−0.237	0.365	0.348	0.310	75.3	97.4	***0.578***	**8**
	Hoffer Q	0.530	0.440	0.571	0.500	51.3	83.8	***0.375***	**9**
	Holladay 1	0.526	0.404	0.560	0.560	42.9	87.0	***0.364***	**10**

(continued)

Table 33.8 (continued)

Article	Formula	ME	SD	MAE	MedAE	± 0.50	± 1.00	PI	Rank
Fam (Fam, Approaching atypical eyes with confidence [32]) 43 eyes/40 7 type of IOLs ≥26.0 mm; < 5.0D	EVO	0.110	0.402	0.303	0.230	83.7	95.4	***0.669***	**1**
	Holladay-WK	−0.025	0.490	0.365	0.330	76.7	97.7	***0.597***	**2**
	Barrett	−0.088	0.484	0.388	0.310	72.1	97.7	***0.571***	**3**
	RBF 2.0	−0.107	0.482	0.396	0.310	69.8	97.7	***0.560***	**4**
	Haigis	0.575	0.509	0.596	0.510	48.8	83.7	***0.352***	**5**
	SRK/T-F2	0.636	0.852	0.716	0.480	51.2	81.4	***0.301***	**6**
	SRK/T-F1	0.714	0.859	0.778	0.560	48.8	79.1	***0.280***	**7**
	SRK/T	0.788	0.780	0.821	0.650	34.9	74.4	***0.258***	**8**
	Holladay 1	1.068	0.553	1.068	0.980	11.6	53.5	***0.174***	**9**
	Hoffer Q	1.308	0.634	1.308	1.170	7.0	25.6	***0.124***	**10**
Kane et al., Intraocular lens power formula accuracy: Comparison of 7 formulas [15] SN60WF IOLMaster 5.4 ≥26.0 Accuracy of 3 new methods for IPC Kane, JCRS 2017; 43:333–339 SN60WF IOLMaster 5.4 ≥26.0	SRK/T	0.060		0.484	0.419	62.7	97.3	***0.672***	**1**
	T2	−0.050		0.498	0.440	64.0	100.0	***0.666***	**2**
	BUII	−0.200		0.435	0.370	62.7	100.0	***0.656***	**3**
	Haigis	0.210		0.526	0.392	57.3	98.7	***0.595***	**4**
	Holladay 2	0.220		0.544	0.404	57.3	97.3	***0.581***	**5**
	Holladay 1	0.380		0.586	0.441	57.3	97.3	***0.510***	**6**
	Hoffer Q	0.340		0.589	0.467	53.3	98.7	***0.507***	**7**
	RBF	−0.070		0.373	0.310	68.1	95.7	***0.796***	**1**
	SRK/T	−0.080		0.365	0.358	66.0	97.9	***0.763***	**2**
	BUII	−0.290		0.375	0.325	76.6	95.7	***0.685***	**3**
	LSF	−0.410		0.503	0.435	55.3	93.6	***0.520***	**4**
	FullMonte IOL	0.470		0.576	0.511	46.8	87.2	***0.452***	**5**
Melles et al. [20, 21] SA60AT, SN60WF LS900 25.5 > AL ≥ 28.5 mm	Kane			0.283					
	Olsen			0.289					
	BUII			0.298					
	Holladay 2			0.307					
	RBF			0.314					
	EVO			0.319					
	Haigis			0.320					
	SRK/T			0.365					
	Hoffer Q			0.428					
Melles et al. [20, 21] SA60AT, SN60WF LS900 >28.5 mm	Holladay 1			0.438					
	Kane			0.284					
	Olsen4P			0.288					
	Holladay 2			0.317					
	BUII			0.340					
	RBF			0.340					
	EVO			0.380					
	Haigis			0.420					
	SRK/T			0.502					
	Hoffer Q			0.828					

Table 33.8 (continued)

Article	Formula	ME	SD	MAE	MedAE	± 0.50	± 1.00	PI	Rank
Accuracy and precision of IOL Calculation	Holladay 1			0.978					
Wan, Am J Ophthalmol 2019; 205:66–73									
127 eyes/127	BUII		0.390		0.210	86.6	98.4	***0.967***	**1**
ZCB00, AR40E, SN60WF, SA60WF, SA60AT, MA60MA, MX60	RBF 2		0.400		0.200	86.6	96.9	***0.964***	**2**
IOLMaster500	Haigis		0.440		0.280	83.5	97.6	***0.859***	**3**
≥26.0 mm	Holladay 1-WK		0.410		0.310	71.7	96.1	***0.828***	**4**
	SRK/T		0.490		0.270	82.7	95.3	***0.825***	**5**
	Holladay 1		0.500		0.300	70.9	94.5	***0.773***	**6**
	SRK/T-WK		0.450		0.370	70.1	95.3	***0.760***	**7**
	Hoffer Q		0.540		0.330	73.2	94.5	***0.738***	**8**
	Hoffer Q-WK		0.440		0.490	51.2	92.9	***0.651***	**9**
	Haigis-WK		0.440		0.770	22.8	70.1	***0.422***	**10**
Darcy et al. [22] SA60AT, 920H, 970C, AO IOLMaster ≥26.0 mm	Kane				0.329				
	Holladay 1				0.338				
	Holladay 2				0.352				
	Olsen				0.352				
	RBF 2.0				0.352				
	Haigis				0.359				
	SRK/T				0.363				
	Hoffer Q				0.454				
Savini et al. [45] SN60WF OA-2000 > 26.0 mm	BUII				0.475				
	EVO 2.0	0.042	0.306	0.168	0.211	89.5	100.0	***0.869***	**1**
	Kane	−0.075	0.310	0.200	0.220	94.7	100.0	***0.822***	**2**
	BBUII	−0.011	0.323	0.202	0.253	84.2	94.7	***0.808***	**3**
	RBF 2.0	0.068	0.301	0.230	0.244	94.7	100.0	***0.797***	**4**
	Olsen4P	−0.076	0.308	0.209	0.256	89.5	100.0	***0.786***	**5**
	Haigis	−0.017	0.382	0.253	0.298	84.2	100.0	***0.721***	**6**
	T2	−0.049	0.378	0.270	0.311	89.5	100.0	***0.699***	**7**
	Holladay 2-ALadj	−0.142	0.345	0.265	0.296	84.2	100.0	***0.673***	**8**
	SRK/T	0.173	0.371	0.313	0.312	84.2	100.0	***0.622***	**9**
	VRF	−0.240	0.387	0.196	0.344	68.4	94.7	***0.599***	**10**
	Olsen2P	0.194	0.509	0.205	0.338	84.2	94.7	***0.590***	**11**
	Hoffer Q	0.346	0.439	0.248	0.397	73.7	89.5	***0.519***	**12**
	Panacea	−0.331	LT ≤ 4.19 mm	0.345	0.415	63.2	94.7	***0.499***	**13**

(continued)

Table 33.8 (continued)

Article	Formula	ME	SD	MAE	MedAE	± 0.50	± 1.00	PI	Rank
Cheng et al. [24] 87 eyes/87 IOLMaster700 MX60 ≥26.0 mm	Holladay 2	0.428	0.672	0.260	0.483	73.7	79.0	***0.422***	**14**
	Holladay 1	0.567	0.454	0.436	0.582	57.9	79.0	***0.379***	**15**
	Kane			0.306	0.248	80.5	98.9	***0.995***	**1**
	EVO 2.0			0.315	0.250	78.2	97.7	***0.975***	**2**
	BUII			0.341	0.247	77.0	96.6	***0.948***	**3**
Zhang et al. [46] 164 eyes/164 IOLMaster700 MX60 ≥26.0 mm	RBF 2.0			0.345	0.251	74.7	97.7	***0.936***	**4**
	PEARL-DGS			0.475	0.325	60.9	86.2	***0.735***	**5**
	EVO 2.0	0.000	0.460	0.350	0.270	79.3	96.3	***0.649***	**1**
	Holladay 1-AL1	0.000	0.480	0.350	0.270	74.4	95.7	***0.634***	**2**
	EVO-CMAL	0.000	0.470	0.360	0.280	76.2	95.7	***0.632***	**3**
	Holladay 1-nonlinear AL	0.000	0.470	0.360	0.280	75.0	95.7	***0.631***	**4**
	BUII	0.000	0.490	0.380	0.280	73.2	93.9	***0.611***	**5**
	SRK/T-AL1	0.000	0.500	0.380	0.290	76.2	94.5	***0.608***	**6**
	BUII-CMAL	0.000	0.500	0.380	0.300	70.1	93.9	***0.596***	**7**
	LSF-CMAL	0.000	0.540	0.400	0.290	72.0	93.3	***0.581***	**8**
	Holladay 1-AL2	0.000	0.510	0.400	0.330	68.9	95.1	***0.575***	**9**
	SRK/T-CMAL	0.000	0.540	0.400	0.310	72.6	92.7	***0.574***	**10**
	SRK/T-AL2	0.000	0.530	0.420	0.360	69.5	93.9	***0.552***	**11**
	Holladay 1-CMAL	0.000	0.550	0.420	0.350	68.9	94.5	***0.549***	**12**
Hipolito-Fernandes et al. [31] 828/828 LS-900 SN60WF 4 weeks Optimized ≥26.0 mm	LSF	0.000	0.570	0.430	0.320	68.3	91.5	***0.546***	**13**
	SRK/T	0.000	0.580	0.430	0.350	66.5	93.3	***0.533***	**14**
	Holladay 1	0.000	0.620	0.480	0.400	63.4	92.1	***0.492***	**15**
	Kane			0.301					
	EVO 2.0			0.308					
	VRF-G			0.309					
	BBUII			0.319					
	Næser 2			0.319					
	RBF 2.0			0.325					
	VRF			0.329					
	T2			0.339					
	Haigis			0.352					
	SRK/T			0.364					

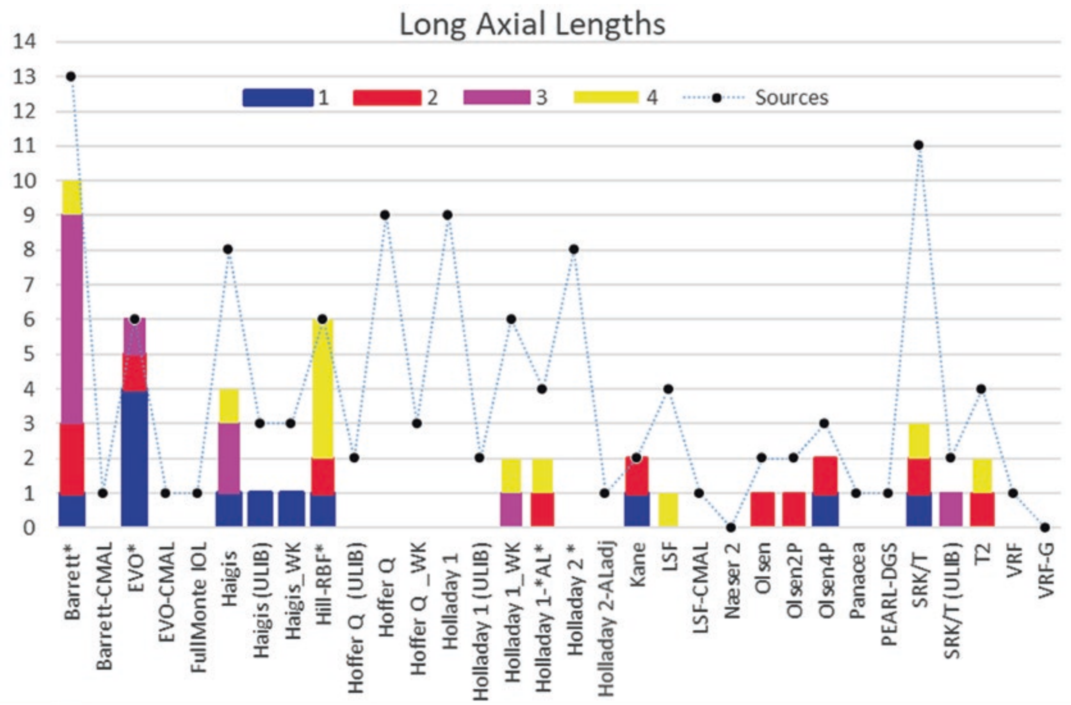

Fig. 33.9 Stacked histogram comparing the performance indices of the various formulas for long axial lengths (≥26 mm)

Other Parameters

Flat Cornea (<42.0D) & Steep Cornea (>48.0D)

The charts (Figs. 33.11 and 33.12) and Table 33.9 depict the extremes of cornea curvatures. These were virgin eyes without any history of corneal refractive surgery. Charts on the left column were for a flat cornea (<42.0D) and on the right column for a steep cornea (>48.0D). 7 different IOLs were used for flat eyes and 8 different IOLs for steep eyes. IOL constants for the third-generation formulas were from the larger pool of patients. ULIB constants were used for Haigis as some IOLs did not have enough numbers for triple optimization. BUII, EVO 2.0, and RBF 2.0 were calculated with the optimized A-constant. Fig. 33.11a, b shows the prediction errors of the formulas while Fig. 33.11

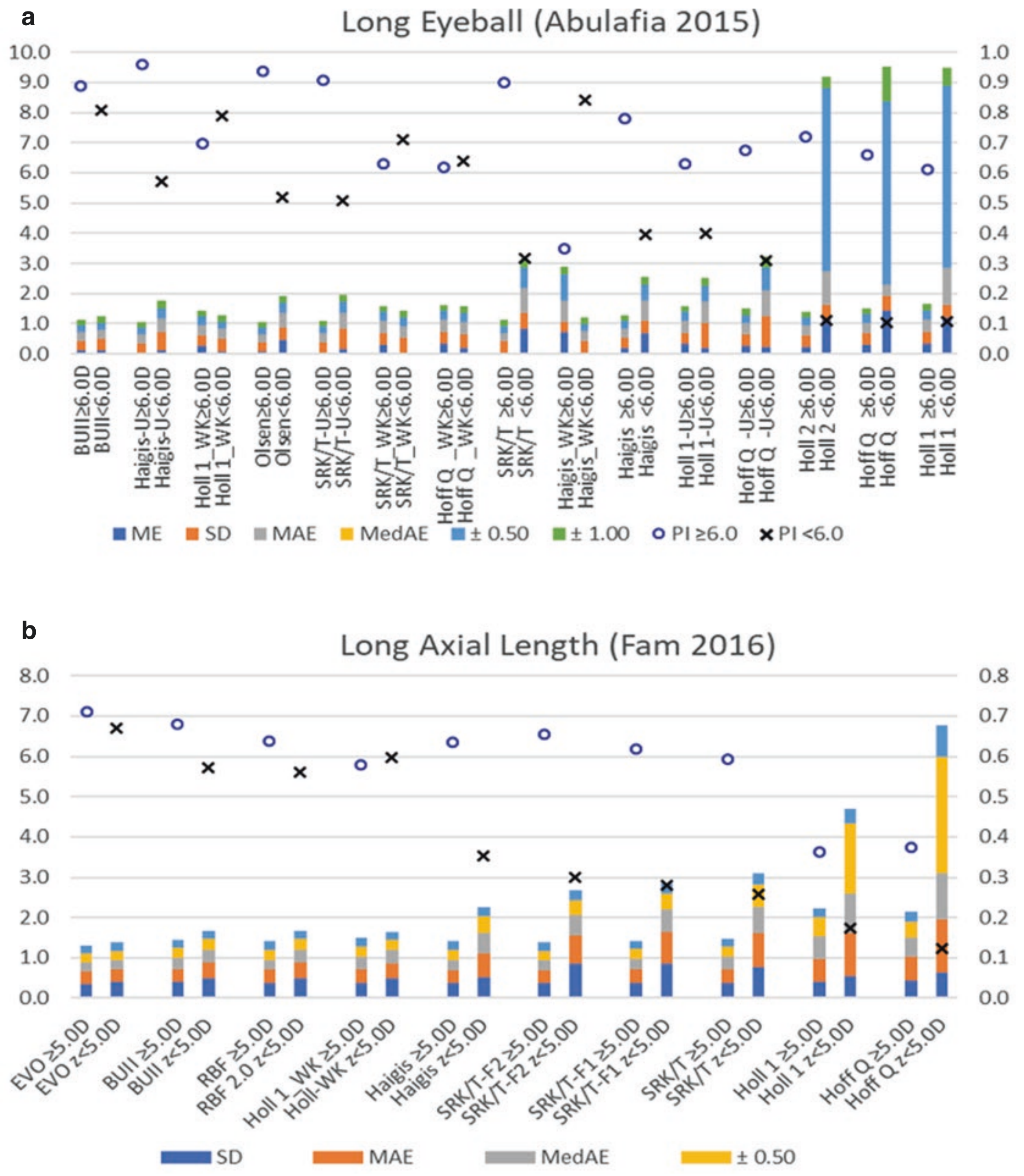

Fig. 33.10 Stacked histograms depicting the components of quality metrics and the line charts showing the subgroup Performance Indices, PI of the formulas for very long axial lengths. (**a**) is from the study by Abulafia [44] (**b**) is from Fam [32]. The circles are for higher diopter PIs, while the crosses are for lower diopter PIs. The scales for the stacked histograms *f* are on the left while the scales for PIs are on the right. BUII is Barrett. Holl and Hoff are short for Holladay and Hoffer Q respectively. SRK/T-F1 and SRK/T-F2 are Fam adjusted ALs [13]. -WK is with the Wang-Koch adjustments to the AL

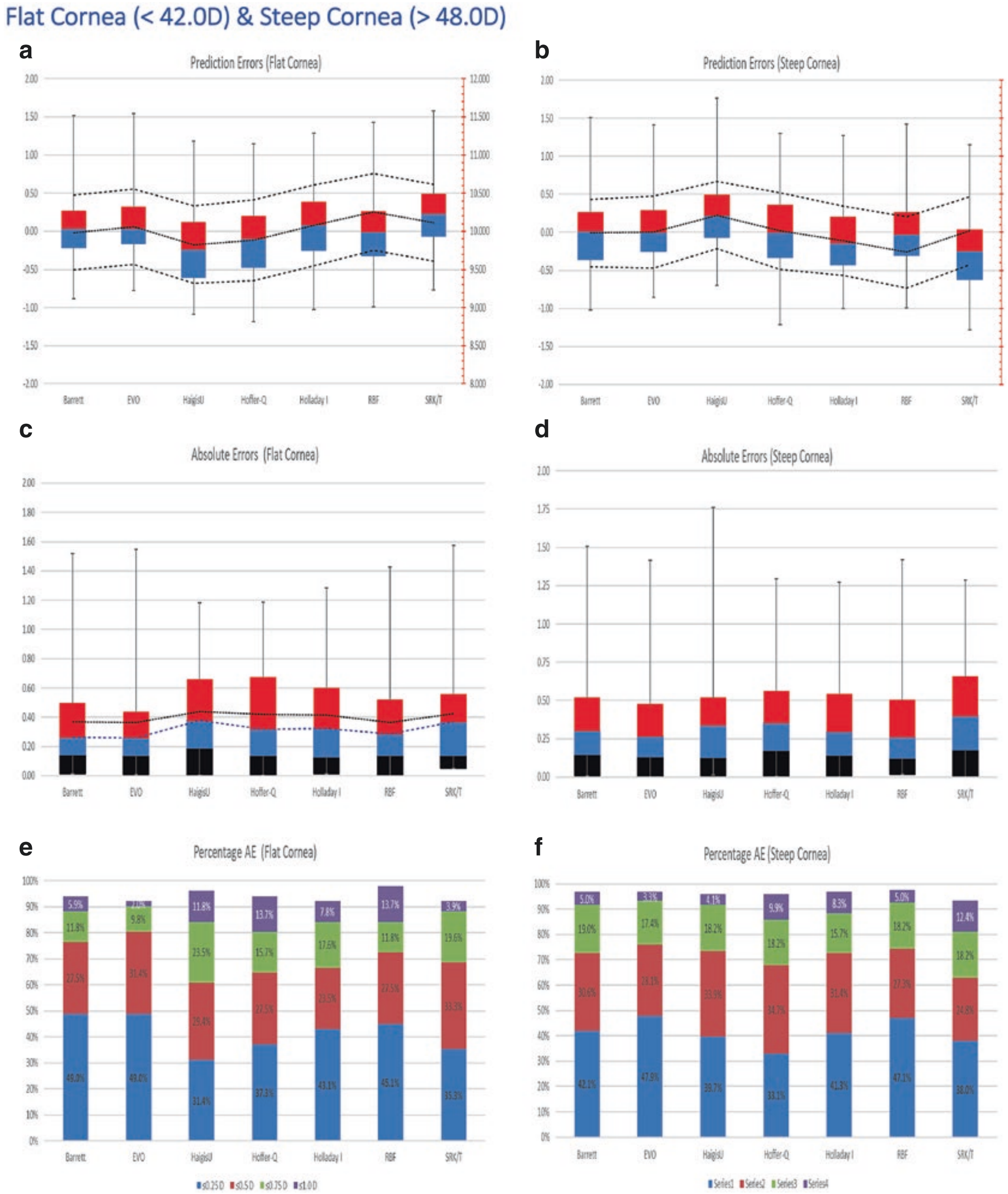

Fig. 33.11 The charts and Table 33.7 depict the outcomes for flat (<42.0D) and steep corneas (>48.0D). Charts on the left column were for flatter corneas and the right for steeper corneas. (**a**, **b**) Display the numerical prediction errors of the formulas. The colored boxes are for the 2nd and 3rd quartiles, while the error plots are for the 1st and 4th quartiles. The 2 dashed lines are the upper and lower SD. (**c**, **d**) depict the absolute errors. The tri-colored boxes are the 1st, 2nd, and 3rd quartiles, and the black and blue dashed lines are the MAEs and MedAEs. (**e**, **f**) The percentage of absolute errors

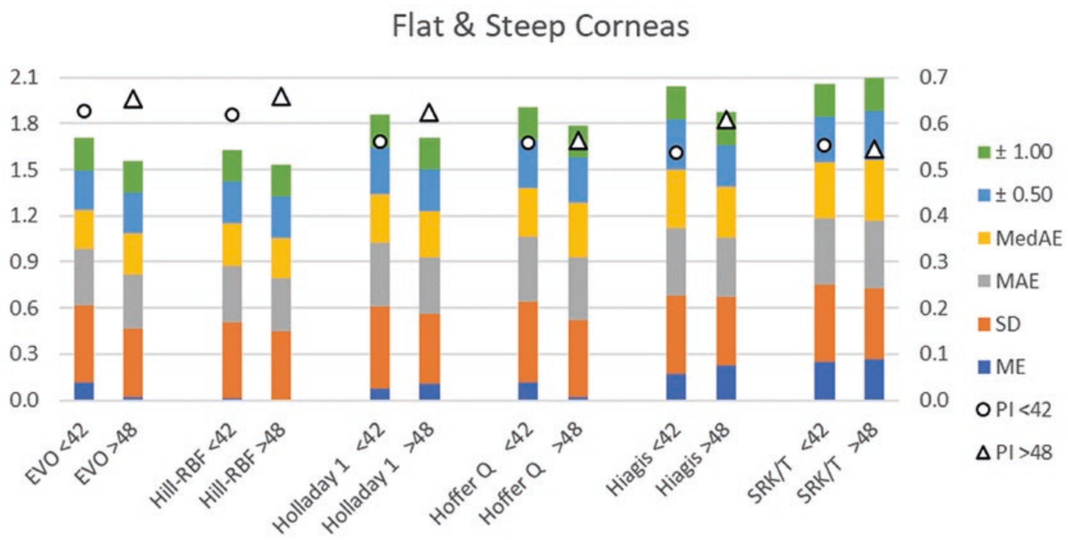

Fig. 33.12 The stacked histogram shows the quality metrics of the formulas with different corneal powers. <42 is for a corneal power of less than 42 D and >48 is for a corneal power of greater than 48 D. The scale for the stacked histogram is on the left. The lower the stacked histogram, the better is the formula. The circles and triangles are for the performance indices (PI). The scale for PI is on the right. The higher the PI score, the better. The formulas in Table 33.9 are arranged in order of their subgroup PI ranking. n is for the number of eyes. ME and SD are the means and standard deviations of numerical prediction errors, respectively. MAE and MedAE are the mean and median absolute errors. ±0.50 and ±1.00 are the percentage of eyes within ±0.50 D and ±1.00 D target refractions, respectively

Table 33.9 This table shows the modified Haigis performance indices of the various formulas (EVO is EVO 1.0; RBF is RBF 1.0) [32]

<42.0D	*n*	ME	SDE	MAE	MedAE	±0.50	±1.00	PI	Rank
RBF	51	−0.015	0.487	0.366	0.280	72.5	98.0	***0.615***	**1**
BUII	51	0.057	0.495	0.368	0.270	76.5	94.1	***0.601***	**2**
EVO	51	0.114	0.502	0.364	0.260	80.4	92.2	***0.586***	**3**
Holladay 1	51	0.078	0.530	0.413	0.320	66.7	92.2	***0.538***	**4**
Hoffer Q	51	−0.115	0.527	0.419	0.320	64.7	94.1	***0.526***	**5**
Haigis	51	−0.174	0.509	0.436	0.380	60.8	96.1	***0.491***	**6**
SRK/T	51	0.252	0.502	0.425	0.370	68.6	92.2	***0.486***	**7**
>48.0D	***n***	**ME**	**SD E**	**MAE**	**MedAE**	**±0.50**	**±1.00**	**PI**	**Rank**
RBF	121	−0.008	0.443	0.343	0.260	74.4	97.5	***0.654***	**1**
EVO	121	0.023	0.446	0.343	0.270	76.0	96.7	***0.644***	**2**
BUII	121	0.002	0.472	0.367	0.300	72.7	96.7	***0.616***	**3**
Holladay 1	121	−0.106	0.455	0.366	0.300	72.7	96.7	***0.585***	**4**
Hoffer Q	121	0.018	0.503	0.405	0.360	67.8	95.9	***0.559***	**5**
Haigis	121	0.225	0.443	0.382	0.340	73.6	95.9	***0.534***	**6**
SRK/T	121	−0.263	0.468	0.433	0.400	62.8	93.4	***0.477***	**7**

c, d show the absolute errors. Figure 33.11e, f are the percentage of absolute errors. Furthers details on the outcomes are in the following tables. Formulas had different accuracy in flat (<42.0D) and steep (>48.0D) eyes. Using the Haigis Quality Metrics, EVO 2.0 and BUII performed the best for flat corneas while RBF 2.0 and EVO 2.0 for steep corneas. In these extremes of curvatures, Haigis and SRK/T were biased and were oppositely affected. Haigis overestimated while SRK/T underestimated for the flat cornea. The converse was true for the steep cornea. From graph G, most formulas were slightly better with a steep cornea than with a flat, except for SRK/T. However, this may not be conclusive, as the comparison was not with the same number of eyes. The above paper was presented in APACRS 2016 in Bali [32].

The bias or neutrality of formulas with AL and K was reflected with the many charts above and below. This trend was also noted by Melles et al. [20, 21].

Ametropia

At the APACRS annual conference in Hangzhou, Fam presented his finding on ametropia outcomes [7]. The study included 111 eyes with 3 different IOLs. The IOL constants were optimized for the third-generation formulas from a larger pool. The BUIIt was calculated using the optimized A-constant. The targeted refraction ranged from −1.00 D to −5.00 D with the average at −2.00 D.

The charts (Fig. 33.13) and Table 33.10 detailed the outcomes for the ametropia study. IOL constants for the third-generation formulas were optimized from the larger pool of patients. HaigisT was Haigis with triple optimization. BUII and EVO were calculated with the optimized A-constant. Figure 33.13a, b show the prediction (numerical) errors and the absolute errors of the formulas, respectively, while Fig. 33.13c is a stacked histogram depicting the percentage of

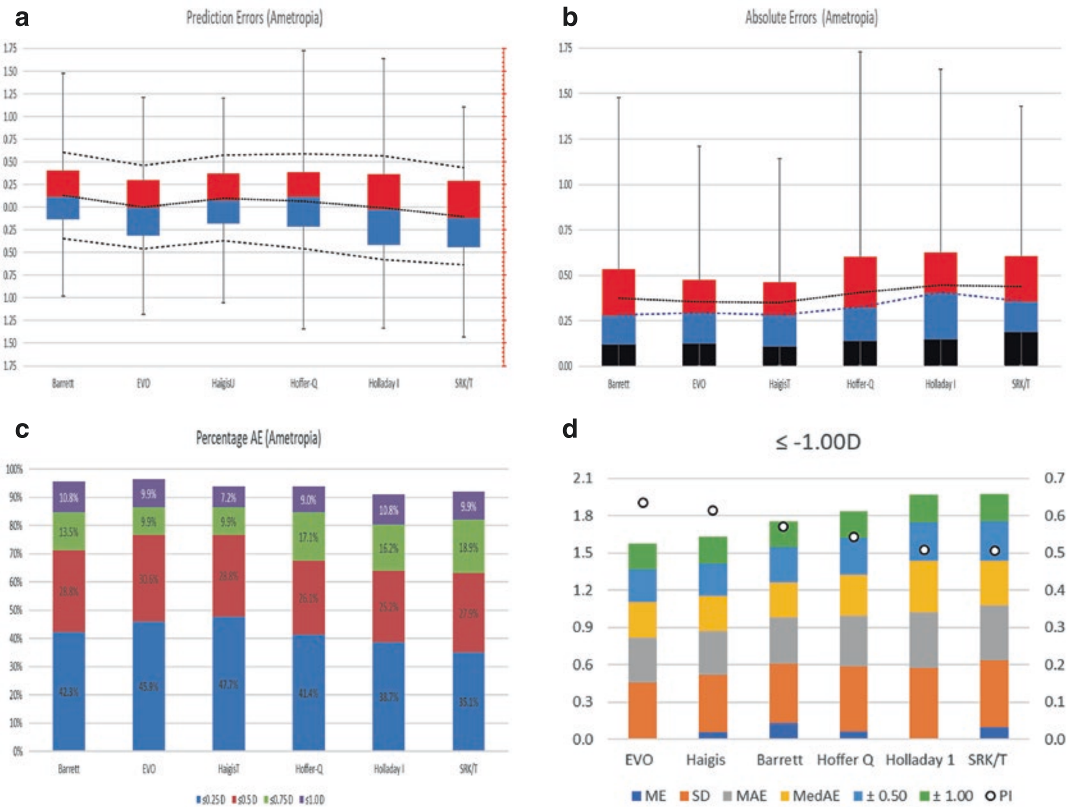

Fig. 33.13 The charts present the numerical prediction error (**a**), absolute error (**b**), the percentage of eyes within the specified prediction errors (**c**), and the quality metrics (**d**). The colored boxes in (**a**) are for the second and third quartiles while the error plot are for the first and fourth quartiles. The 2 dashed lines are the upper and lower standard deviations. The 3 colored boxes in (**b**) are the first, second, and third quartiles and the black and blue dashed lines are the mean and median absolute errors. The stacked histograms in (**d**) are the components of quality metrics. The lower the total column the better. The circles represent the subgroup PI. The higher the better. The details of the charts are tabulated in Table 33.10. The formulas in Table 33.10 are arranged in order of their subgroup PI ranking. *n* is for the number of eyes. ME and SD E are the means and standard deviations of numerical prediction errors, respectively. MAE and MedAE are the mean and median absolute errors. ± 0.50 and ± 1.00 are the percentage of eyes within 0.5 and 1.0D target refractions, respectively

Table 33.10 This table shows the modified Haigis performance indices of the various formulas [7]

≤-1.00D	*n*	ME	SD E	MAE	MedAE	±0.50	±1.00	PI	Rank
EVO	111	0.000	0.460	0.355	0.290	76.6	96.4	***0.635***	**1**
Haigis	111	0.061	0.459	0.353	0.280	76.6	93.7	***0.615***	**2**
BUII	111	0.131	0.477	0.376	0.280	71.2	95.5	***0.570***	**3**
Hoffer Q	111	0.067	0.524	0.408	0.330	67.6	93.7	***0.544***	**4**
Holladay 1	111	−0.008	0.570	0.446	0.410	64.0	91.0	***0.508***	**5**
SRK/T	111	−0.102	0.536	0.440	0.360	63.1	91.9	***0.507***	**6**

Table 33.11 ME, SD, MAE, and MedAE refer to mean numerical prediction error, the standard deviation of prediction error, mean absolute error, and median absolute error, respectively

Article	*Formula*	*ME*	*SD*	*MAE*	*MedAE*	*±0.50*	*±1.00*	*PI*	*Rank*
Turnbull et al. [26] *176/88* *SN6ATT* *Distance*	*BUII*	*−0.02*	*0.195*	*0.241*	*0.197*	*87.5*	*100*	***0.925***	***1***
	Haigis	*−0.03*	*0.211*	*0.284*	*0.218*	*85.2*	*100*	***0.849***	***2***
	RBF 2.0	*−0.1*	*0.202*	*0.271*	*0.225*	*86.4*	*100*	***0.813***	***3***
	SRK/T	*0.01*	*0.221*	*0.307*	*0.277*	*83*	*100*	***0.796***	***4***
	Holladay 1	*0.01*	*0.267*	*0.334*	*0.268*	*78.4*	*98.9*	***0.748***	***5***
	Hoffer Q	*0.01*	*0.265*	*0.344*	*0.289*	*75*	*98.9*	***0.726***	***6***
Near (−1.00D)	*BUII*	*0.01*	*0.26*	*0.298*	*0.235*	*86.4*	*97.3*	***0.806***	***1***
	RBF 2.0	*−0.06*	*0.258*	*0.3*	*0.233*	*81.8*	*97.7*	***0.769***	***2***
	SRK/T	*−0.02*	*0.294*	*0.356*	*0.261*	*70.5*	*97.7*	***0.705***	***3***
	Haigis	*0*	*0.311*	*0.351*	*0.26*	*69.3*	*95.5*	***0.704***	***4***
	Holladay 1	*−0.01*	*0.329*	*0.392*	*0.32*	*71.6*	*95.5*	***0.649***	***5***
	Hoffer Q	*−0.03*	*0.341*	*0.415*	*0.319*	*64.8*	*93.2*	***0.614***	***6***

eyes within a specified Diopter range of predicted spherical equivalent. Figure 33.13d is the stacked histogram of the quality metrics for each of the formulas. The circle represents the subgroup performance index, PI. The table shows the details of Haigis' Quality Metrics. EVO was the highest-ranking followed by Haigis and Barrett. All three formulas have performance indices that were better than 0.6.

Monovision is a fairly common practice to reduce spectacles dependency. Turnbull et al. looked at the accuracy of various formulas when targeting ametropia [26]. They used a single IOL (SN6ATx) with the constants optimized for the entire dataset. 88 patients planning for monovision were recruited for the study with one eye targeting distance and the other for −1.25 D for near (Table 33.11, Fig. 33.14). Postoperative refractions were done 4 weeks postoperatively.

The formulas perform better when targeting emmetropia than they do for ametropia. BUII and RBF 2.0 were similar in their accuracy and had the least difference between targeting emmetropia and targeting for near. BUII had 87.5% and 86.4%, while RBF had 86.4% and 81.8% within ±0.50 D for distance and near respectively. While Haigis and SRK/T had more than 80% (Haigis, 85.2% and SRK/T, 83.0%) within ±0.50 D for distance, that figure dropped down to 69.3% and 70.5% for near respectively. The differences were statistically significant. Holladay 1 and Hoffer Q had less than 70% for both distance and near eyes. The paper highlighted the decrease in accuracy when targeting ametropia as opposed to emmetropia in IOL power calculation. BUII and RBF were the least affected by this phenomenon.

In the year following his earlier study on short eyes, Gökce et al. published another paper looking into the accuracy of 8 different formulas with different ACDs in patients with normal ALs [47]. Gökce et al. stratified the ACD into 3 groups: ≤3.0 mm, >3.0 to <3.5 mm, and finally ≥3.5 mm.

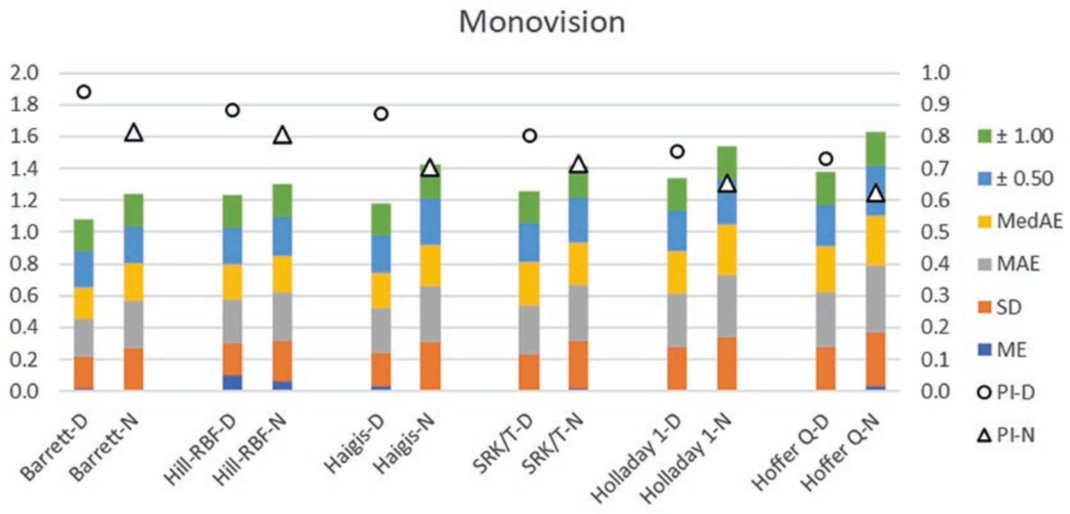

Fig. 33.14 The stacked histogram shows the quality metrics of the formulas with a different refractive target. -D is for distance target and -N for near (−1.00D). The scale for the stacked histogram is on the left. The lower the stacked histogram, the better is the formula. The circles and triangles are for the performance index (PI). The scale for PI is on the right. The higher the PI score, the better

Only patients with AL between 22.0 and 25.0 mm were recruited in this study. For the medium ACD group, all formulas had mean prediction error values that were close to zero. In the shallow ACD and deep ACD groups, BUII, Holladay 2, Haigis, and Olsen$_{4P}$ had mean prediction errors that were not significantly deviated from zero. BUII had the lowest MAE in all 3 ACD groups. It had the lowest MedAE (0.18 D) in the shallow ACD group and next to the lowest (0.21 D) in the deep ACD group. BUII, Haigis, and Holladay 2 (with and without refraction) were noted to have no bias against ACD. RBF 2.0 was good for medium and large ACD groups. Olsen$_{4P}$ was good for shallow and deep ACD groups. The study noted that when the mean numerical PE for each formula for the dataset was optimized to zero, the MedAE for BUII, Haigis, Holladay 1 and 2, Olsen, and RBF 2.0 were found to have no differences. The paper inferred that ACD was an important variable in the accuracy of IOL power calculation and that multiple-variable formulas were more accurate than 2-variable formulas (3rd generation).

Hipólito-Fernandez also looked at the impact of ACD and LT on the accuracy of the formulas [48]. Like Gökce, they divide the ACD into 3 similar groups. They included ALs between 22.0 and 26.0 mm. This is a single IOL (SN60WF) with LenStar LS900 (Haag-Streit AG, Köniz, Switzerland) as the preoperative biometer. 695 eyes of 695 patients were recruited. Postoperative refraction was done at 4 weeks. Their conclusion was the new generation formulas, particularly Kane, PEARL-DGS and EVO 2.0 were more reliable and robust across the various ACD and LT combinations.

From the 2 stacked histograms, the newer formulas such BUII, Kane, PEARL-DGS, and EVO 2.0 were more precise and robust than the third-generation theoretical formulas (Table 33.12, Fig. 33.15). For normal ACD (3.0 to 3.5 mm) most formulas perform well. It was in the shallow and deeper ACDs that we see the new formulas perform more consistently better. Without requiring ACD as a parameter, most of the third-generation formulas were unable to take ACD variation into account.

Table 33.12 ME, SD, MAE, and MedAE refer to mean numerical prediction error, the standard deviation of prediction error, mean absolute error, and median absolute error respectively. Holladay 2 PreSurgRef and Holladay 2 NoRef refer to Holladay 2 formula with and without preoperative refractions, respectively. Olsen2P and Olsen4P are Olsen using 2 parameters and 4 parameters to determine ELPs, respectively. Olsen2P is preinstalled in biometers, while Olsen4P is also known as Olsen standalone and is available in the program, PhacoOptics

Article	Formula	ME	SD E	MAE	MedAE	± 0.50	± 1.00	PI	Rank
Gokce et al. [47] LS-900 ZCB00, ZCT 270eyes/270 ACD $\le$ 3.0 mm	BUII	0.000	0.320	0.240	0.180	90.2	99.0	***0.859***	**1**
	Holladay 2 NoRef	0.010	0.360	0.290	0.250	86.3	100.0	***0.745***	**2**
	Olsen4P	0.060	0.350	0.280	0.240	87.3	100.0	***0.736***	**3**
	Holladay 2 PreSurgRef	−0.010	0.370	0.300	0.280	83.3	100.0	***0.714***	**4**
	RBF	−0.100	0.380	0.300	0.220	83.3	99.0	***0.693***	**5**
	Haigis	0.000	0.390	0.320	0.300	81.4	99.0	***0.686***	**6**
	Holladay 1	−0.140	0.360	0.300	0.230	80.4	99.0	***0.675***	**7**
	Olsen2P	0.100	0.380	0.320	0.280	79.4	100.0	***0.653***	**8**
	Hoffer Q	−0.200	0.410	0.360	0.300	74.5	98.0	***0.574***	**9**
	RBF	0.030	0.330	0.280	0.270	87.1	100.0	***0.746***	**1**
	BUII	−0.010	0.360	0.290	0.250	85.9	98.8	***0.743***	**2**
ACD > 3.0 mm ACD < 3.5 mm	Holladay 2 NoRef	−0.010	0.370	0.300	0.280	88.2	98.8	***0.720***	**3**
	Holladay 1	0.020	0.360	0.290	0.280	83.5	98.8	***0.718***	**4**
	Haigis	0.020	0.380	0.300	0.250	83.5	97.7	***0.717***	**5**
	Olsen4P	0.000	0.390	0.310	0.260	80.0	97.7	***0.707***	**6**
	Hoffer Q	0.020	0.370	0.320	0.290	85.9	97.7	***0.696***	**7**
	Holladay 2 PreSurgRef	−0.030	0.390	0.310	0.280	84.7	97.7	***0.689***	**8**
	Olsen2P	0.000	0.410	0.330	0.280	80.0	97.7	***0.678***	**9**
	BUII	0.010	0.300	0.240	0.210	88.0	100.0	***0.842***	**1**
	Olsen4P	−0.070	0.320	0.250	0.200	83.1	100.0	***0.781***	**2**
	Holladay 2 NoRef	0.020	0.320	0.270	0.270	88.0	100.0	***0.765***	**3**
ACD $\ge$ 3.5 mm	RBF	0.100	0.300	0.260	0.220	86.8	100.0	***0.763***	**4**
	Holladay 2 PreSurgRef	0.030	0.330	0.280	0.260	88.0	100.0	***0.753***	**5**
	Haigis	−0.020	0.350	0.280	0.260	86.8	100.0	***0.746***	**6**
	Holladay 1	0.150	0.300	0.270	0.260	89.2	100.0	***0.712***	**7**
	Olsen2P	−0.140	0.350	0.290	0.230	78.3	100.0	***0.682***	**8**
	Hoffer Q	0.210	0.330	0.320	0.320	81.9	98.8	***0.615***	**9**
Hipolito-Fernandes et al. [48] 695eyes/695 LS900 SN60WF	Kane	0.010	0.400	0.316	0.277	80.2	98.7	***0.687***	**1**
	PEARL-DGS	−0.020	0.400	0.322	0.270	81.1	99.1	***0.685***	**2**
	BUII	0.020	0.410	0.331	0.290	78.0	98.7	***0.662***	**3**
	EVO 2.0	0.030	0.410	0.327	0.297	78.0	97.8	***0.656***	**4**
	RBF 2.0	−0.010	0.430	0.337	0.280	74.9	98.7	***0.655***	**5**
	SRK/T	−0.090	0.440	0.348	0.292	76.7	97.4	***0.611***	**6**
	Haigis	−0.040	0.450	0.361	0.313	72.7	97.4	***0.608***	**7**
ACD $\le$ 3.00 mm	Holladay 1	−0.150	0.420	0.344	0.289	74.4	97.4	***0.596***	**8**
	Hoffer Q	−0.200	0.420	0.365	0.295	71.8	96.5	***0.566***	**9**
	Kane	0.000	0.400	0.315	0.276	81.6	97.3	***0.694***	**1**
	PEARL-DGS	−0.020	0.420	0.321	0.270	79.9	97.3	***0.673***	**2**
	Holladay 1	0.000	0.410	0.343	0.288	79.3	97.0	***0.667***	**3**
ACD > 3.00 ACD < 3.50	RBF 2.0	0.000	0.420	0.337	0.280	77.9	97.0	***0.667***	**4**
	EVO 2.0	−0.020	0.410	0.327	0.297	80.6	97.3	***0.663***	**5**
	BUII	−0.010	0.420	0.331	0.290	79.6	97.0	***0.663***	**6**
	SRK/T	0.000	0.430	0.348	0.292	77.9	97.3	***0.653***	**7**
	Hoffer Q	0.020	0.430	0.365	0.295	78.6	97.0	***0.637***	**8**
	Haigis	−0.010	0.450	0.360	0.313	76.6	94.6	***0.623***	**9**
	EVO 2.0	−0.050	0.440	0.345	0.285	75.7	97.9	***0.630***	**1**

(continued)

Table 33.12 (continued)

Article	Formula	ME	SD E	MAE	MedAE	± 0.50	± 1.00	PI	Rank
ACD ≥ 3.50	RBF 2.0	0.010	0.450	0.363	0.320	77.5	98.2	***0.623***	**2**
	Kane	−0.050	0.460	0.351	0.286	76.3	97.6	***0.620***	**3**
	BUII	−0.020	0.460	0.363	0.310	76.9	96.4	***0.617***	**4**
	PEARL-DGS	−0.040	0.460	0.359	0.310	74.0	95.3	***0.606***	**5**
	Haigis	−0.010	0.480	0.378	0.319	75.7	95.3	***0.602***	**6**
	Holladay 1	0.100	0.440	0.367	0.326	75.7	98.2	***0.588***	**7**
	SRK/T	0.080	0.470	0.386	0.370	71.6	97.6	***0.559***	**8**
	Hoffer Q	0.190	0.460	0.399	0.347	67.5	95.9	***0.526***	**9**

From Fig. 33.16, the newer formulas such as Kane, EVO 2.0, PEARL-DGS, and BUII show remarkable robustness between the 3 subgroups of LT (≤4.19 mm; 4.20–4.76 mm; ≥4.77 mm) and show good precision overall. The third-generation formulas were sensitive to thin and thick lens thickness.

Ray Tracing and Intraoperative Aberrometry

Hoffmann et al. looked at the benefits of raytracing IOL power calculation for 3 aspheric-correcting IOLs in 2013 [49]. The study compared the outcomes of 308 eyes of 185 patients using Okulix ray-tracing software (version 8.79) with Hoffer Q, Holladay 1, and SRK/T. All preoperative measurements were done with LenStar and the one-month postoperative refractions were used. The constants of the third-generation formulas were optimized. The ray-tracing calculation with offset correction (mean error adjust to zero) had the lowest SD/MAE/MedAE of 0.37D/0.30D/0.24D compared to the third-generation formulas. Raytracing with offset correction had the highest percentage (81.1%) of eyes within ±0.50 D of prediction error. The paper commented that raytracing reduced the number of outliers in calculating IOL powers.

Raufi et al. published a paper looking into the outcomes of intraoperative aberrometry and comparing it with BUII and RBF [50]. 949 virgin eyes of 949 patients with 4 different IOLs were included in this study. Preoperatively, all eyes were measured with Lenstar LS 900, and postoperatively, all eyes were refracted no earlier than one month. Overall, BUII had the lowest MAE/MedAE with 0.29 D and 0.23 D, respectively. BUII had the highest percentage of eyes within ±0.50 D, 84.0%. They concluded that there was no significant difference between ORA [51] and the 2 preoperative IOL formulas.

The accuracy of intraoperative aberrometry in short eyes was studied by Sudhakar et al. [52]. Using ULIB constants, the subjects in the retrospective study were implanted with 6 different IOLs. Preoperatively, measurements were done with IOLMaster 500 PCI, and refractions were done between 20 and 60 days postoperatively. Except for Haigis (+0.26 D), most of the formulas had mean prediction errors that were insignificantly different from zero. RBF and ORA had the lowest MAE with 0.49 D and 0.48 D and the highest percentage of eyes within ±0.50 D, 60.8%, and 58.8%, respectively. The conclusion was that ORA was equivalent to the best preoperative IOL formulas.

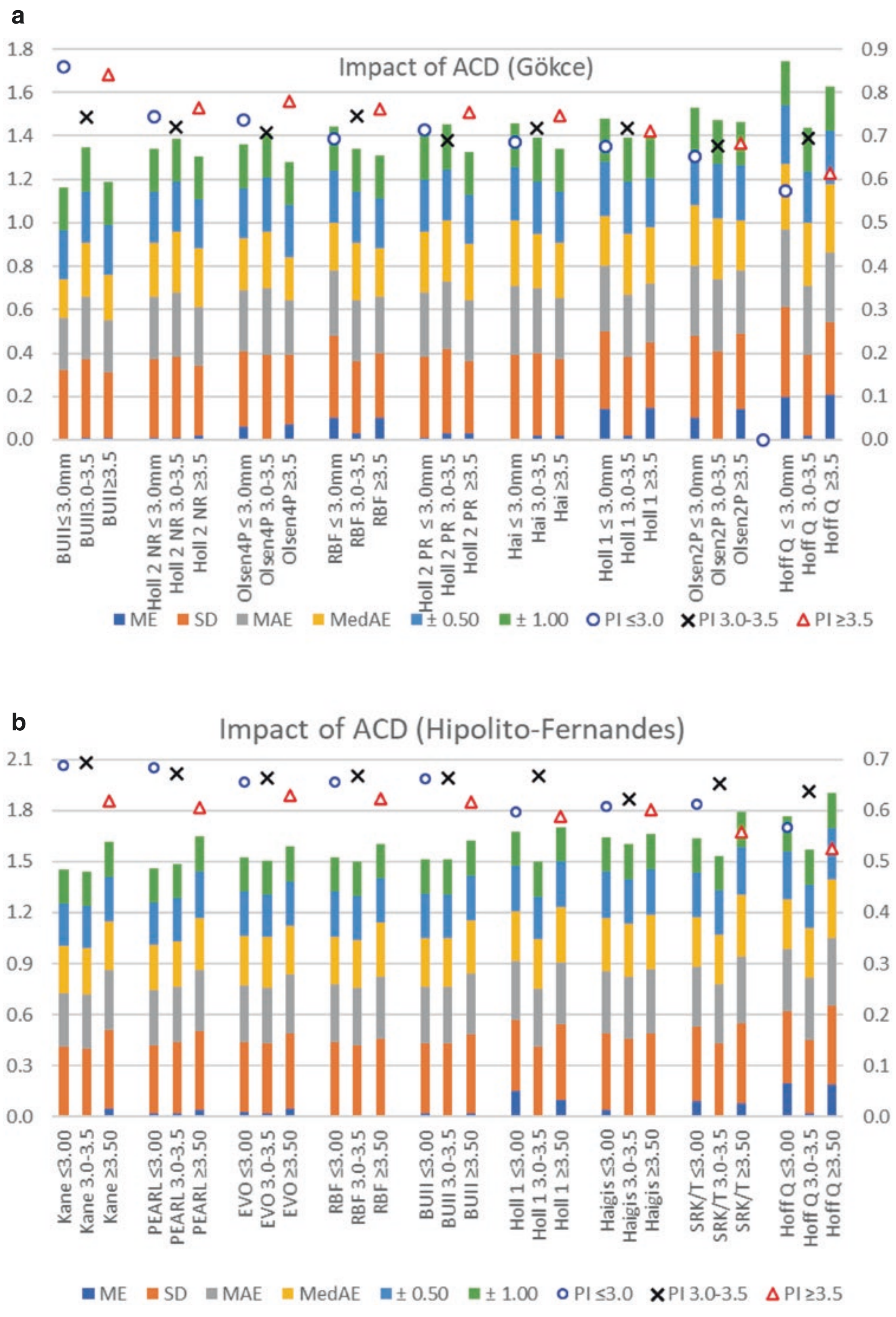

Fig. 33.15 The stacked histograms show the quality metrics of the formulas with different ACDs. Chart (**a**) and (**b**) are based on Gökce et al. [47] and Hipólito-Fernandez et al. [48] respectively. Each formula is divided into 3 ACD groups (≤3.00 mm; 3.00 to 3.50 mm; ≥3.50 mm). The scale for the stacked histogram is on the left. The lower the stacked histogram, the better is the formula performance. The circles and triangles represent the performance index (PI). The scale for PI is on the right. The higher the PI score, the better. BUII = Barrett Universal II, Hai = Haigis, Hoff = Hoffer Q, Holl = Holladay 1, PEARL = PEARL-DGS, RBF = RBF 2.0

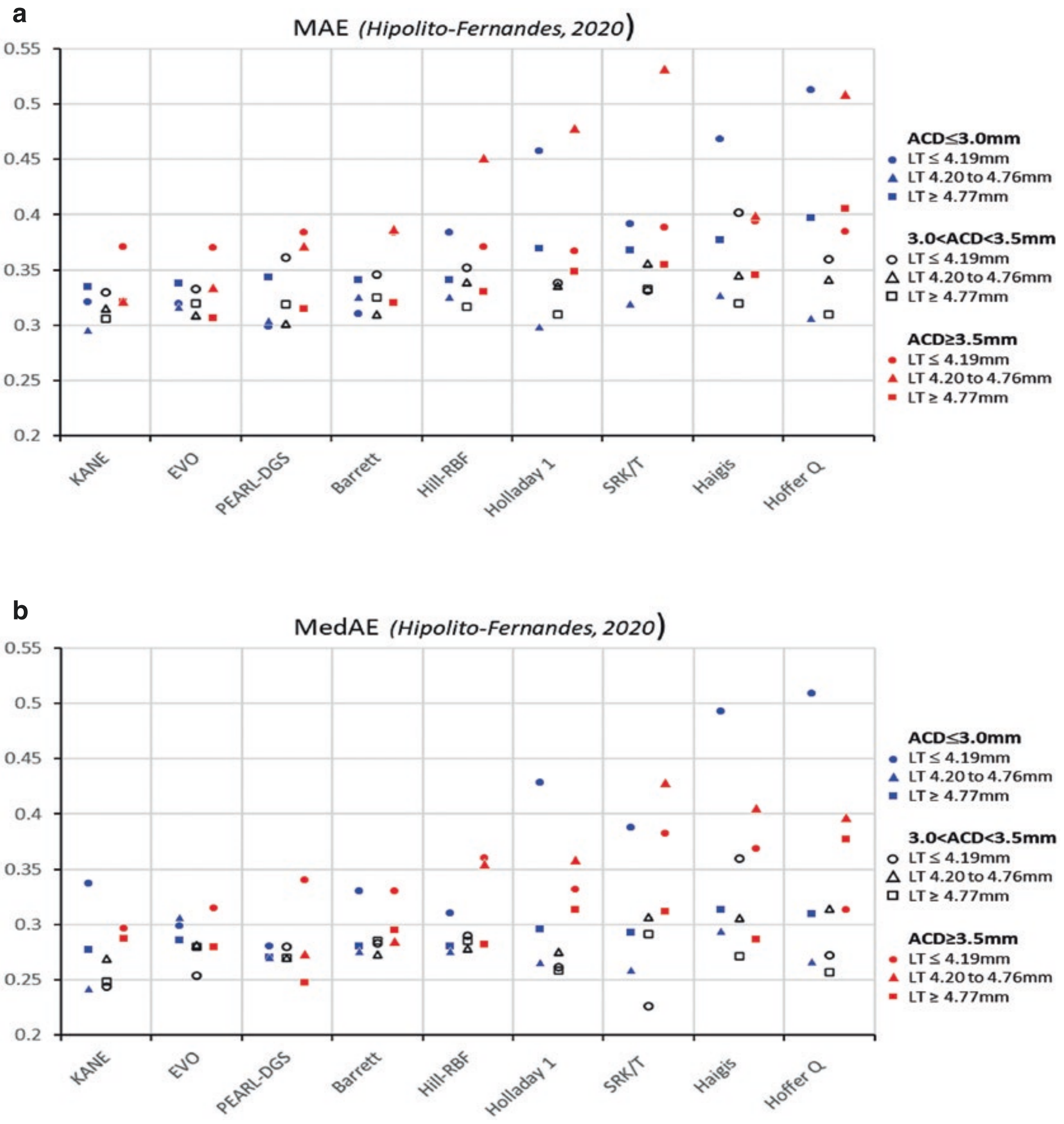

Fig. 33.16 The line graphs show the relationship of the mean (**a**) and median (**b**) absolute errors with varying ACDs and LTs. *BUII* = Barrett, *Hai* = Haigis, *Hoff* = Hoffer Q, *Holl* = Holladay 1, *PEARL* = PEARL-DGS, *RBF* = RBF 2.0

Even More Parameters

Table 33.13 is a summary of outcomes in the literature as well as papers presented at conferences on other parameters affecting IOL power calculation. As with the earlier table, the orders of the formula for each source are sorted in order based on a modification of Haigis "Quality metrics for comparing IOL calculation formulas."

The stacked histogram (Fig. 33.17) shows how the formulas fare in 4 articles, all of which are ranked. Each box indicates the number of times the formula is being ranked. Blue is for 1st; magenta for 2nd ranking; turquoise for 3rd, and yellow for 4th. The dotted line joins the number of ranked studies the formula was being compared tp. BUII was the most quoted and had dem-

Table 33.13 ME, SD, MAE, and MedAE refer to mean numerical prediction error, the standard deviation of prediction error, mean absolute error, and median absolute error respectively

Article	Formula	ME	SD E	MAE	MedAE	± 0.50	± 1.00	PI	Rank
Hoffmann & Lindemann, Intraocular lens calculation for aspheric intraocular lenses [49] 308eyes/185 iMics1, SN60WF, Tecnis	Okulix 8.79 (corrected)	0.000	0.370	0.300	0.240	81.1	99.7	***0.737***	**1**
	AL selected	0.000	0.410	0.310	0.260	79.8	97.7	***0.697***	**2**
	Holladay	0.000	0.410	0.310	0.260	79.2	97.4	***0.695***	**3**
	Hoffer Q	0.000	0.410	0.320	0.280	76.6	98.4	***0.678***	**4**
	SRK/T	0.000	0.430	0.340	0.280	78.8	98.1	***0.663***	**5**
	Okulix 8.79	0.040	0.410	0.340	0.300	76.2	99.4	***0.644***	**6**
Hirnschall et al. [53] 40Eyes/40 409 M/MP IOLMaster 700	Ray		0.320	0.320	0.270	80	95	***0.730***	**1**
	BUII		0.290	0.370	0.330	75	98	***0.685***	**2**
	RBF 2.0		0.310	0.390	0.300	73	93	***0.672***	**3**
	Haigis		0.360	0.420	0.330	55	93	***0.592***	**4**
	SRK/T		0.390	0.520	0.450	70	93	***0.537***	**5**
Raufi et al. [50] 949eyes/603 LS-900	BUII	−0.018		0.290	0.230	84	97	***1.018***	**1**
	RBF 2.0	0.047		0.310	0.240	83	97	***0.958***	**2**
	ORA	−0.041		0.310	0.250	82	97	***0.951***	**3**
Sudhakar [52] 51eyes/38 IOLMaster AO60, AF-1 FY60AD, SA60AT, ZCT, ZKB00, ZLB00	IA	0.000		0.480		58.8	88.2	***0.955***	**1**
	RBF 2.0	0.070		0.490		60.8	90.2	***0.900***	**2**
	BUII	0.110		0.510		52.9	86.3	***0.813***	**3**
	Hoffer Q	−0.080		0.540		49	86.3	***0.794***	**4**
	Holladay 2	−0.140		0.530		43.1	88.2	***0.735***	**5**
	Haigis	0.260		0.600		52.9	80.4	***0.673***	**6**

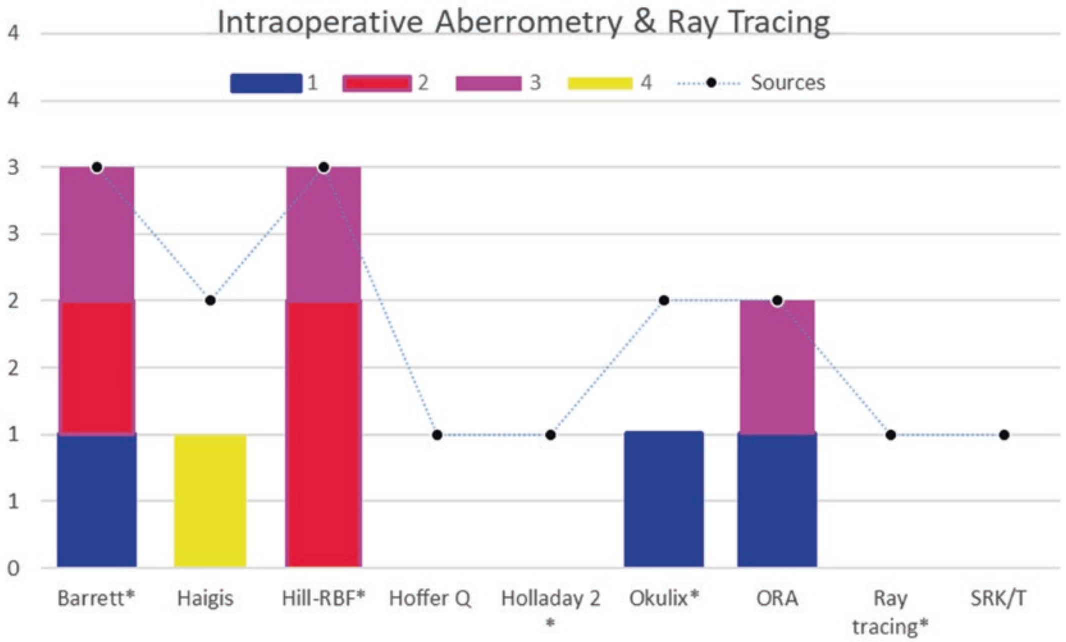

Fig. 33.17 Stacked histogram comparing the performance indices intraoperative aberrometry, ray tracing methods with the more more popular formulas of determining IOL power

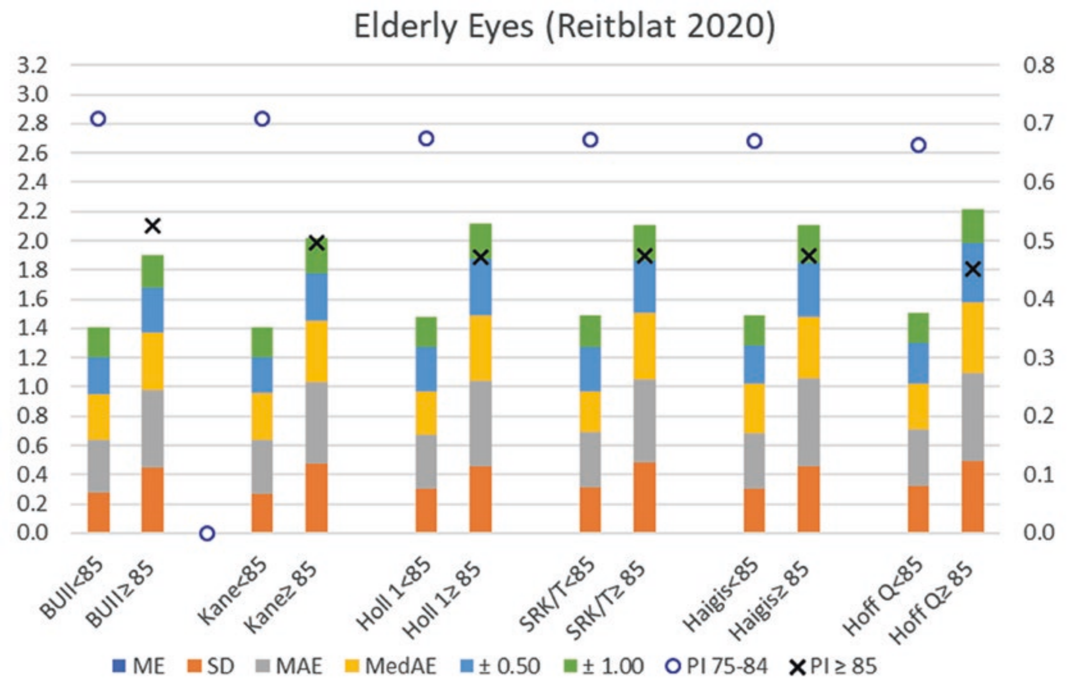

Fig. 33.18 The stacked histograms show the quality metrics of the formulas on different age groups (75–84 and ≥ 85) [30]. The scale for the stacked histogram is on the left. The lower the stacked histogram, the better is the formula. The circles and triangles represent the performance index (PI). The scale for PI is on the right. The higher the PI score, the better. BUII = Barrett Universal II, Hoff = Hoffer Q, Holl = Holladay 1, PEARL = PEARL-DGS, RBF=RBF 2.0.

onstrated good precision. Ray tracing (including Okulix) and intraoperative aberrometry (ORA) had shown results as good but not better than the newer formulas.

Elderly

The impact of the formulas on elderly patients was investigated by Reitblat et al. [30]. Her cohort of 90 eyes from 90 patients was measured with IOLMaster PCI. All patients were implanted with SN60WF and postoperative refractions were carried out at 1 to 3 months postoperatively. There were 2 arms to the study; one for the age group of 75–84 years old and the other was 85 years old or older. For both age groups, BUII, with MAE/MedAE of 0.36D/0.31D and 0.53D/0.39D and Kane, 0.37D/0.32D and 0.56D/0.42D, respectively, were found to be the most accurate. The percentage errors within ±0.5 D for Kane were 78.26% and 65.91%; and for BUII, 82.61% and 61.36% for the younger and older age group, respectively. The rest of the formulas were Haigis, Hoffer Q, Holladay 1 and SRK/T. All formulas showed lower accuracy in the more elderly group.

The graph (Fig. 33.18) and Table 33.14) shows quite clearly that all formulas performed worse in the more elderly age group. The drops in PIs were consistent throughout the formulas. BUII and Kane were the more accurate formulas in this study.

Table 33.14 ME, SD, MAE, and MedAE refer to mean numerical prediction error, the standard deviation of prediction error, mean absolute error, and median absolute error, respectively. This table is a summary of outcomes from Reitblat et paper [30]. As with the earlier tables, the orders of the formula for each source are sorted in order based on a modification of the Haigis "Quality metrics for comparing IOL calculation formulas"

Article	Formula	ME	SD E	MAE	MedAE	±0.50	±1.00	PI	Rank
Reitblat et al. [30] 90/90 IM 5.21 SN60WF 75–84	BUII		0.280	0.360	0.310	78.3	97.8	***0.709***	**1**
	Kane		0.270	0.370	0.320	82.6	95.7	***0.709***	**2**
	Holladay 1		0.300	0.370	0.300	65.2	97.8	***0.675***	**3**
	SRK/T		0.310	0.380	0.280	65.2	95.7	***0.673***	**4**
	Haigis		0.300	0.380	0.340	76.1	95.7	***0.670***	**5**
	Hoffer Q		0.320	0.390	0.310	71.7	95.7	***0.663***	**6**
≥85	BUII		0.450	0.530	0.390	65.9	86.4	***0.525***	**1**
	Kane		0.470	0.560	0.420	61.4	84.1	***0.497***	**2**
	Haigis		0.460	0.600	0.420	54.6	77.3	***0.475***	**3**
	SRK/T		0.480	0.570	0.460	56.8	81.8	***0.475***	**4**
	Holladay 1		0.460	0.580	0.450	52.3	81.8	***0.472***	**5**
	Hoffer Q		0.490	0.600	0.490	50.0	84.1	***0.451***	**6**

Conclusion

The third-generation theoretical formulas were popular in the past. Hoffer Q, Holladay 1 and 2, Haigis, and SRK/T were commonly used. These were good formulas. In the last decade, newer formulas began emerging. Barrett Universal II, Hoffer QST, Kane and then RBF 2.0 are the more prominent among these newer formulas. Subsequently, more and more formulas emerged and are still emerging. These formulas, unlike the third generation, are constantly being upgraded and enhanced. These are reflected by the changing version numbers.

Generally, the newer formulas are more accurate than the third-generation formulas. BUII, EVO, RBF 3.0, Hoffer QST and Kane are more frequently being quoted and have been shown to perform better, almost across all ALs, Ks, and ACDs. The other newer formulas also show promise. With these more accurate formulas, cataract surgery is becoming truly a refractive surgery. These will also allow for newer concepts of optical design to be developed.

The above reviews are by no means, exhaustive. The rankings method used here is a modification of the Haigis quality metrics. There are other ways of ranking but this, in my opinion, is an objective and quantitative way of ranking the formulas. The parameters used are limited to the data that were made available in the papers and presentations. Finally, these reviews were on virgin eyes. Post-corneal refractive surgery, keratoconus, etc. are beyond the scope of this chapter.

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