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Selecting a formula for calculating the optical power of an intraocular lens for short eyes using artificial intelligence

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Abstract:
Objective: to conduct a comparative analysis of the accuracy of intraocular lens (IOL) selection in patients with an eye length of less than 22.0 mm using the Barrett Universal II, Kane, and Hoffer Q formulas, as well as via artificial intelligence (AI).
Materials and Methods. We analyzed the outcomes of 88 phacoemulsification cataract surgeries with monofocal IOL implantation. Preoperative biometry and IOL calculations were performed on an IOL Master 700 (Zeiss, Germany). The accuracy of IOL selection was also determined via the LensCalc software based on AI (DecisionTreeClassifier).
Results. The axial length of the eyes in patients ranged from 19.8 to 22.0 mm. The prediction of achieving the target refraction was most accurate when using the Barrett Universal II formula rather than Hoffer Q (Z=2.12; p=0.034). The mean error in achieving the target refraction when using the Barrett Universal II formula did not differ from the Kane formula (p>0.05). Using AI, we established that higher accuracy in the IOL power calculation was achieved when using the Barrett Universal II formula.
Conclusion. Based on a comparative analysis of the study results and an assessment of the accuracy of IOL selection using AI, we established that the Barrett Universal II formula (4th generation) was more accurate in determining the optical power of the IOL in short eyes than the Hoffer Q formula (3rd generation). Our calculation results based on using the Barrett Universal II formula, unlike the Hoffer Q formula, were similar (p>0.05) to those calculated using the Kane formula (5th generation), which, according to the results of the majority of published studies, is currently the most accurate formula for IOL selection.

Keywords: IOL power calculation, short eyes, artificial intelligence

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Introduction

At the current stage of developing cataract diagnostic and surgical technologies, the accuracy of achieving the target refraction of ±0.5 D has increased up to 71% [1], but difficulties remain in calculating the intraocular lens (IOL) optical power for eyes with atypical anatomy [2-5]. In particular, this applies to short eyes, i.e., eyeballs with an axial length of less than 22.0 mm [3, 6, 7]. Due to proximity of intraocular anatomical structures in such patients, even a small deviation in predicting the effective lens position (ELP) and calculating the IOL power can lead to a more substantial refractive error than in eyes with emmetropia and myopia [2].

According to published sources, the best formulas for IOL calculation for eyes with a length of less than 22.0 mm are Hoffer Q (3rd generation), Barrett Universal II (4th generation) and Kane (5th generation), as compared with SRK/T (3rd generation), Haigis, Holladay II, and Olsen formulas (4th generation) [6, 7].

In 2017, the Kane formula was proposed, which brought the methodology of using neural networks in IOL calculation to a new level. The formula belongs to the theoretical category, but its algorithm uses artificial intelligence (AI) trained on 30 thousand clinical cases [8].

Deep learning has become increasingly used in medicine, including ophthalmology (diagnosing keratoconus, glaucoma, diabetic neuropathy, etc.) [9-12]. AI is also employed in predicting the optical power of IOL [13]. The use of AI in IOL calculation dates back to 1997, when P. Gerald et al. suggested that the use of neural networks vs. the Holladay formula allows reducing the mean error of predicted refraction [14].

Objective – To conduct a comparative analysis of the accuracy of intraocular lens (IOL) selection in patients with an eye length of less than 22.0 mm using the Barrett Universal II, Kane, and Hoffer Q formulas, as well as artificial via intelligence (AI).

Materials and Methods

We carried out a retrospective analysis of the outcomes of 88 phacoemulsification cataract surgeries with monofocal IOL implantation at the Volgograd Branch of the S. Fedorov Eye Microsurgery National Medical Research Center of the Russian Federation Ministry of Healthcare. The implanted IOLs were SN60WF (Alcon), SA60AT (Alcon) and RAO100C (Rayner).

All patients underwent a standard ophthalmological examination prior to the surgery, including optical biometry, visual acuity test, keratometry, measurement of refractive error with autorefractor keratometer, tonometry, biomicroscopy, and B-scan ultrasonography. Preoperative biometry and IOL calculation were performed on the IOL Master 700 diagnostic system (Carl Zeiss, Germany). The target refraction was emmetropia. The following formulas were used for IOL calculation: Barrett Universal II, Kane, and Hoffer Q.

The accuracy of the IOL calculation was also assessed using the LensCalc software, which uses AI to identify the relevant formula and IOL value taking into account the individual characteristics of the patient. The software was developed at the clinic of the Volgograd Branch of the S. Fedorov Eye Microsurgery National Medical Research Center. Currently, the LensCalc database contains 1,080 clinical cases (1,080 eyes) of IOL selection with achieved target refraction (with an accuracy of ±0.5 D). The process of the database compilation is fully automated. To implement the AI, we developed four Decision Tree Classifier models.

Working with the AI models consisted of the following stages:

1) Collecting data in one relational database;

2) Data processing via converting them into a form suitable for further use;

3) Data partitioning into training and test parts, feature selection;

4) Building machine learning models and making predictions based on the test part;

5) Evaluation of the training results.

The assessment of the outcome in terms of achieving the target refraction based on retrospective data was performed according to the following criteria: by spherical equivalent (SE), measured with an autorefractor keratometer, as well as with uncorrected and best corrected visual acuity (UCVA and BCVA, respectively). The criterion for the accuracy of IOL prediction was the range of SE values ±0.5 D in the postoperative period.

All phacoemulsification cataract surgeries were performed using conventional technique, a 2.2 mm tunnel incision using the Infiniti Vision System or Centurion Vision System (Alcon, USA).

We observed no intraoperative or postoperative complications in any clinical case. In the postoperative period, all patients received standard therapy. The assessment of the implantation outcome was carried out no earlier than 1 month after the surgery based on the data of autorefractometry and subjective refraction.

The assessment was performed 1 day and 1 month after the intervention.

The statistical processing of the collected data was performed by the Statistica for Windows 10.0 software. The type of distribution was assessed using the Shapiro-Wilk test. In the presence of a normal distribution, the following parameters were calculated: arithmetic mean (M), standard deviation (σ), and standard errors of arithmetic means (m). In the absence of a normal distribution, in addition to M and σ, the median (Me), lower and upper quartiles [Q1; Q3], and minimum and maximum values (Xmin – Xmax) were determined. For comparing independent samples, we used the Mann-Whitney U test. Differences were considered statistically significant if the significance level (p) exceeded 95.0% ($p \leq 0.05$).

Results

The length of the anterior-posterior dimension of the eyes in patients ranged from 19.8 to 22.0 mm. Clinical and functional results and the outcomes of achieving the target refraction are presented in *Table 1*.

It is clear that the prediction of achieving the target refraction was most accurate when using the Barrett Universal II formula. At the same time, we observed a statistically significant difference between the results obtained by the Barrett Universal II and Hoffer Q formulas (Z=2.12; p=0.034), as well as between Hoffer Q and Kane formulas (Z=2.5; p=0.010). Outcomes were similar when using the Kane (5th generation) and Barrett Universal II formulas (Z=0.86; p=0.412) (*Table 1*).

Table 2 illustrates the errors in achieving the predicted refraction for each formula, assessed in two ways: based on the measurements by the autorefractometer and via the determination of subjective refraction.

The use of the Barrett Universal II and Hoffer Q formulas demonstrated their equivalence in assessing the SE error both based on the autorefractometry and the value of subjective refraction. The difference between the methods was not statistically significant ($p>0.05$).

However, a statistically significant difference was noted between the results obtained using the Hoffer Q and Kane formulas ($p<0.05$).

It should also be emphasized that the difference between the outcomes when using the Barrett Universal II and Kane formulas was not statistically significant ($p>0.05$), which favors the choice of the Barrett Universal II formula.

A sample of patients consisting of 88 clinical cases was also subjected to AI models. This analysis does not take into account calculations by the Kane formula, since it is already AI-based, which could lead to unreliable result. Based on the obtained data, reports on the effectiveness of models were created for the major accuracy metrics: Macro AVG, F1, and Accuracy (*Figure*).

Table 3 presents the accuracy values of AI models taking into account the choice of formulas.

Table 3 suggests that higher accuracy in determining the optical power of the IOL was achieved when using the Barrett Universal II formula.

Discussion

In Russia, some studies were based on the construction of artificial neural network models without using theoretical formulas [15]. Unlike well-known formulas (SRK II, SRK/T, Hoffer Q, Holladay II, Haigis, Barrett), such models of artificial neural networks take into account many recorded input values, which allows reducing the mean relative error in calculating the IOL optical power from 10-12% to 3.5%.

However, there are studies proving the high efficacy of a combination of present-day theoretical formulas, while each of them has different advantages depending on the biometric features of the eye [6, 7, 9]. For example, it is believed that with an axial length of the eye less than 22 mm, the Hoffer Q formula is preferable; with an atypical depth of the anterior chamber, the Haigis formula should be used; whereas in most cases, the Barrett Universal II formula has an advantage (albeit with some empirical corrections) [16]. A similar system has been developed abroad known as Ladas Super Formula [17], but the authors of this project employed a combination of five formulas (Hoffer Q, Holladay I, Holladay I with Wang-Koch adjustment, Haigis, SRK/T). According to some studies, compared with widely used theoretical formulas, Ladas Super Formula yields a similar level of accuracy in calculating the IOL optical power and a slight tendency to hyperopic postoperative refractive errors [18].

The results of our study demonstrated that the prediction of achieving the target refraction exhibited the highest accuracy in case of using the Barrett Universal II formulas, as opposed to the Hoffer Q formula (Z=2.12; p=0.034).

Considering that the Kane formula represents the 5th-generation formulas that operate on the basis of AI, we suggest that the Barrett Universal II formula has an advantage over the Hoffer Q formula in analyzing the SE error according to autorefractometry and subjective refraction data. Unlike the Hoffer Q formula, our results for using the Barrett Universal II formula are similar to those calculated with the Kane formula (p>0.05).

Table 1. Clinical and functional results after surgery with a prognosis of achieving the target refraction in patients: 88 eyes, M±σ (min, max); Me [Q_1; Q_3]

Parameter	*M*±σ (min, max); *Me* [Q_1; Q_3]
UCVA	0.76±0.17 (0.3; 1.0)
BCVA	0.84±0.11 (0.7; 1.0)
Expected SE (Barrett Universal II), D (1)	-0.027±0.19 (-0.56; 0.5) -0.020 [-0.17; 0.08]
Expected SE (Hoffer Q), D (2)	0.036±0.22 (-0.53; 0.46) 0.055 [-0.1; 0.195]
Expected SE (Kane), D (3)	-0.08±0.32 (-1.33; 0.73) -0.065 [-0.2; 0.095]
Z; *p*	$Z_{1,2}$=2.12; $p_{1,2}$=0.034 $Z_{1,3}$=0.86; $p_{1,3}$=0.460 $Z_{2,3}$=2.5; $p_{2,3}$=0.010

UCVA, uncorrected visual acuity; BCVA, best corrected visual acuity; SE, spherical equivalent.

Table 2. Mean error of achieving the target refraction in patients: 88 eyes, *M*±σ (min, max); *Me* [Q_1; Q_3]

SE error, D	Barrett Universal II (1)	Hoffer Q (2)	Kane (3)	*p*
Autorefractometry data	0.033±0.26 (-0.57; 1.2) 0.01 [-0.105; 0.175]	-0.030±0.27 (-0.7; 0.86) -0.055 [-0.22; 0.11]	0.086±0.37 (-0.73; 1.3) 0.04 [-0.15; 0.23]	$p_{1,2}$=0.110 $p_{1,3}$=0.460 $p_{2,3}$=0.040
Subjective refraction data	- 0.066±0.47 (-1.56; 1.67) -0.065 [-0.27; 0.16]	-0.130±0.44 (-1.63; 1.42) -0.115 [-0.31; 0.05]	-0.0134±0.49 (-1.43; 1.97) 0.03 [-0.265; 0.19]	$p_{1,2}$=0.250 $p_{1,3}$=0.350 $p_{2,3}$=0.040

SE, spherical equivalent

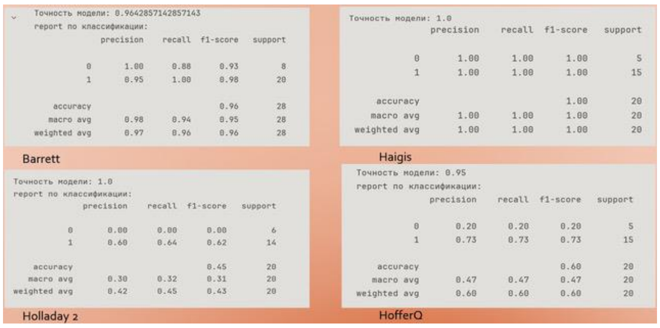

Figure. Reports on model performance by key accuracy metrics (Macro AVG, F1, Accuracy)

Table 3. Accuracy of the Barrett Universal II and Hoffer Q formulas for calculating the optical power of an intraocular lens in short eyes using artificial intelligence (AI), 88 eyes

AI Model	Model accuracy, %	Macro AVG	F1	Accuracy	Number of eyes
Barrett Universal II	96	0.98	0.98	0.96	28
Hoffer Q	95	0.47	0.73	0.6	20

Based on the neural network data, we conclude that the Barrett Universal II formula (4th generation) is more accurate in determining the IOL optical power in short eyes than the Hoffer Q formula (3rd generation). This finding matches the opinions of authors authors [6, 7].

Conclusion

Based on the comparative analysis of the study results and the assessment of the accuracy of IOL selection using AI, we established that the Barrett Universal II formula (4th generation) was more accurate in determining the optical power of the IOL in short eyes than the Hoffer Q formula (3rd generation). The results of using the Barrett Universal II formula, compared with the Hoffer Q formula, were similar to those calculated by the Kane formula (5th generation). The latter is currently considered by the majority of authors as the most accurate formula for IOL selection (p>0.05). Hence, we conclude that, despite the difficulties in selecting the optical power of the IOL in short eyes, the 4th and 5th generation formulas tested by us yielded similar results and can therefore be used to calculate IOL in eyes with an axial length of under 22 mm.

Author contributions: A.R.V.: data collection, analysis and processing, manuscript preparation; S.V.B. and E.G.S.: noteworthy contribution to the study concept and design and article editing.

Conflict of interest: None declared.

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