COMPARATIVE ANALYSIS OF METHODS FOR CALCULATION OF TORIC INTRAOCULAR LENSES IN PATIENTS AFTER PENETRATING KERATOPLASTY

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Calculation of toric intraocular lenses (tIOLs) in patients after penetrating keratoplasty (PK) is challenging. The study aimed to perform comparative retrospective analysis of various methods for calculation of tIOL during phacoemulsification in patients after PK. We analyzed case reports of 36 eyes (36 patients) after PK, which underwent phacoemulsification with tIOL implantation. All tIOLs were recalculated using four different methods. In group 1, tIOL calculation was performed using keratometry data of the anterior surface of the corneal graft measured using a corneal topographer, and the posterior surface of the corneal graft measured using optical coherence tomography of the cornea or the Scheimpflug keratotopographer. In group 2, keratometry of both corneal graft surfaces was measured using the Scheimpflug keratotopographer, in group 3 — using OCT of the cornea, in group 4 — using the keratotopographer. The online Barrett True — K Toric Calculator was used to calculate tIOLs in groups 1–3, and The Kane Formula was used in group 4. There were significant differences in the values of the spherical and cylindrical components of refraction between the studied groups ($p < 0.05$). The highest predictability of tIOL calculation was reported for group 1: the ensured postoperative refraction for the spherical component was within ±0.5 D in 58% of eyes, within ±1.0 D in 67% of eyes; postoperative refraction for the cylindrical component was within –0.5 D in 56% of eyes, within –1.0 D in 89% of eyes. Thus, the highest predictability of tIOL calculation is observed in patients of group 1.

Keywords: penetrating keratoplasty, postkeratoplastic ametropia, toric intraocular lens, calculation method

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СРАВНИТЕЛЬНЫЙ АНАЛИЗ СПОСОБОВ РАСЧЕТА ТОРИЧЕСКОЙ ИНТРАОКУЛЯРНОЙ ЛИНЗЫ У ПАЦИЕНТОВ ПОСЛЕ СКВОЗНОЙ КЕРАТОПЛАСТИКИ

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Расчет торической интраокулярной линзы (тИОЛ) у пациентов после сквозной кератопластики (СКП) вызывает ряд сложностей. Целью исследования было провести сравнительный ретроспективный анализ различных способов расчета тИОЛ при факоэмульсификации катаракты (ФЭК) у пациентов после СКП. Был проведен анализ историй болезни 36 глаз (36 пациентов) после СКП, на которых была выполнена ФЭК с имплантацией тИОЛ. Все тИОЛ были пересчитаны четырьмя способами. В группе 1 расчет тИОЛ проводили с применением данных кератометрии передней поверхности роговичного трансплантата, измеренных при помощи кератотопографа, и задней поверхности роговичного трансплантата — при помощи оптической когерентной томографии роговицы или шаймпфлюг-кератотопографа). В группе 2 измерение кератометрии обеих поверхностей роговичного трансплантата выполняли при помощи шаймпфлюг-кератотопографа, в группе 3 — на ОКТ роговицы, в группе 4 — при помощи кератотопографа. Для расчета тИОЛ в группах 1–3 применяли онлайн-калькулятор Barrett True — K Toric Calculator, в группе 4 — The Kane Formula. Была отмечена статистически значимая разница по значениям сферического и цилиндрического компонентов рефракции между исследуемыми группами ($p < 0,05$). Наибольшая предсказуемость расчета тИОЛ обнаружена в группе 1: попадание в послеоперационную рефракцию по сферическому компоненту в пределах ±0,5 дптр — в 58% глаз и в пределах ±1,0 дптр — в 67% глаз, по цилиндрическому компоненту — в пределах –0,5 дптр — в 56% глаз и в пределах –1,0 дптр — в 89% глаз. Таким образом, наибольшая предсказуемость расчета тИОЛ была отмечена у пациентов группы 1.

Ключевые слова: сквозная кератопластика, посткератопластическая аметропия, торическая интраокулярная линза, способ расчета

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Penetrating keratoplasty (PK) leads to the development of post-keratoplastic corneal astigmatism (CA) in almost all patients [1–3]. In cases of cataract development in patients after PK and the need for its extraction, the accuracy of the selected intraocular lens (IOL) calculation method is of great importance [4–6]. The best functional results are reported in patients with regular CA, who are through cataract extraction with the toric IOL (tIOL) implantation [7–9]. However, the method to calculate tIOL is still a matter of debate. Not all authors consider the posterior corneal graft curvature when calculating tIOL, since they believe that its refraction is similar to refraction of light by the anterior chamber fluid, like in the healthy cornea. That is why keratometry values of the anterior corneal graft surface only are often used [10, 11]. Currently, various online calculators and calculators by tIOL manufacturers are used, which consider curvature of both corneal graft surfaces. However, postoperative results vary considerably even when using keratometry data of both corneal graft surfaces due

to the use of different diagnostic equipment [12, 13]. In view of the above, selection of the most predictable method to calculate tIOL during cataract extraction in patients after PK has determined the relevance of the study.

The study aimed to perform comparative retrospective analysis of various methods for calculation of tIOL during cataract extraction in patients after PK.

METHODS

We performed retrospective analysis of case reports of 36 eyes (36 patients) after PK, which underwent phacoemulsification with tIOL implantation. All the patients were implanted the RayOne Toric RAO610T tIOL (Rayner; UK). The age of patients enrolled in clinical trial (12 males and 24 females) was 31–76 years (average age 57 ± 13 years). Past PK was performed due to congenital corneal dystrophy in six eyes, pellucid corneal degeneration in eight eyes, central corneal scar in six eyes, corneal opacity after the corneal ulcer in six eyes, stage IV keratoconus in six eyes, secondary keratectasia in four eyes. The interval between phacoemulsification and PK in patients was 4–15 years. All corneal grafts were transparent. The corneal graft diameter reached 7.5–8.5 mm (on average 8.14 ± 0.36 mm).

When calculating tIOL, the eye length, anterior chamber depth, lens thickness, white-to-white distance were measured by optical biometry using the IOL Master 500 system (Carl Zeiss AG; Germany). The values of keratometry data and orientation of the major meridians of the anterior corneal graft surface were determined using the TMS-5 corneal topographer (Tomey; Japan), Pentacam Scheimpflug keratotopographer (Oculus Optikgerate GmbH; Germany), by optical coherence tomography (OCT) of the cornea using the CASIA 2 system (Tomey; Japan). The values of keratometry data and orientation of the major meridians of the posterior corneal graft surface were determined using the Pentacam Scheimpflug keratotopographer and the CASIA 2 optical coherence tomography (OCT) system for the cornea. Regular CA was reported in all patients based on the keratotopography data before phacoemulsification.

When calculating tIOL, the following was entered in the calculator: values of the RayOne Toric RAO610T tIOL A-constant of 118.6, Lens Factor, induced astigmatism, orientation of the main surgical incision, target refraction, central corneal graft thickness. IOL was calculated using the online Barrett True-K Toric Calculator and The Kane Formula.

According to case reports, discrepancies in the values of the tIOL optical power and toric component were reported in some patients when calculating tIOL due to differences in the keratometry data of the anterior corneal graft surface measured using the keratotopographer, by corneal OCT, or using the Scheimpflug keratotopographer. In such cases, either mean values of keratometry parameters measured using the above diagnostic equipment, or mean values of similar keratometry parameters based on the results were taken.

We also took the values of the spherical (Sph) and cylindrical (Cyl) refraction components obtained three months and later after phacoemulsification, when stabilization of these parameters was reported, from medical records.

To determine the most predictable tIOL calculation method, we divided the methods into four groups depending on the diagnostic equipment used to measure keratometry parameters (Table 1).

In group 1, keratometry parameters of the anterior corneal graft surface were measured using the keratotopographer (TMS-5), while that of the posterior surface were measured using the Scheimpflug keratotopographer (Pentacam) or corneal OCT (CASIA 2), considering comparable keratometry values reported for the posterior corneal graft surface when using these devices. In group 2, keratometry parameters of both corneal graft surfaces were measured with the Scheimpflug keratotopographer (Pentacam), and in group 3 these were measured by the corneal OCT (CASIA 2). In group 4, the anterior corneal graft surface curvature only was measured using the keratotopographer (TMS-5).

In groups 1–4, tIOLs were calculated using the online Barrett True-K Toric Calculator, since it allows one to consider keratometry data of both corneal graft surfaces. In group 4, tIOL calculation was performed using the online The Kane Formula calculator allowing one to analyze the anterior corneal graft surface keratometry data only.

The tIOL optical power was calculated for emmetropic target refraction in all groups, toric component for full correction of total CA in groups 1–3, and for correction of CA of the anterior corneal graft surface in group 4.

Comparative analysis of predictability of tIOL calculation by various methods was performed in groups 1–4 based on the data on the implanted tIOL optic power, toric component, as well as the postoperative refraction results.

Statistical data analysis was performed using IBM SPSS Statistics 20. The Shapiro–Wilk test was used to test the data distributions for normality. The values of the studied parameters were normally distributed in all groups, so significance of differences in the studied parameters between two groups were assessed using the parametric Student's *t*-test for independent variables, and the differences between three groups were assessed by one-way analysis of variance. The differences in the studied parameters between two groups were considered significant at $p < 0.05$, and the differences between three groups were considered significant at $p < 0.017$. The values of the studied parameters were presented as $M \pm \sigma$, where M was the mean, σ was the standard deviation.

RESULTS

According to medical records, none of the patients had intra- or postoperative complications of phacoemulsification. The slit lamp examination performed on the next day after surgery showed that the eye media were transparent, and tIOLs were centered in all patients (Fig. 1).

Preoperative data on the average CA value and keratomery data (Km) of the anterior corneal graft surface showed significant differences based on the data obtained using the

Table 1. Methods for toric intraocular calculation during cataract extraction in patients after penetrating keratoplasty

Groups	Keratometry data measurement	
	Anterior corneal graft surface	Posterior corneal graft surface
1	Keratotopographer (TMS-5)	OCT (CASIA 2) or Scheimpflug keratotopographer (Pentacam)
2	Scheimpflug keratotopographer (Pentacam)	Scheimpflug keratotopographer (Pentacam)
3	Corneal OCT (CASIA 2)	Corneal OCT (CASIA 2)
4	Keratotopographer (TMS-5)	Keratometry was not taken into account

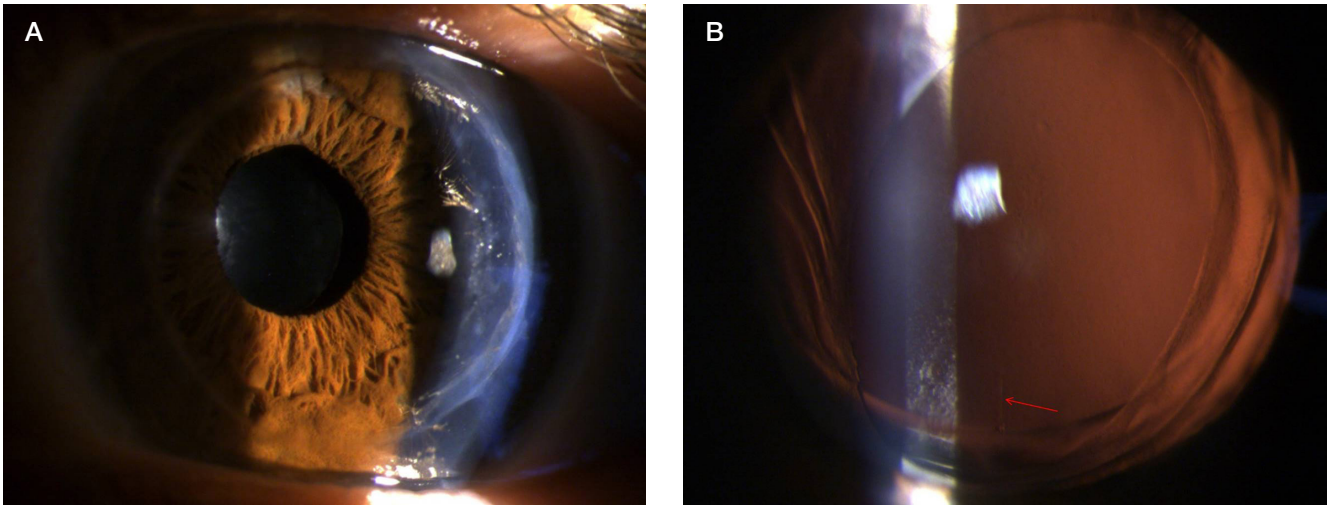

Fig. 1. View of the eye of patient N., 56 years, during slit lamp examination on day 1 after phacoemulsification with the toric intraocular lens implantation. **A**. A transparent corneal graft can be seen, along with the optic part of the toric intraocular lens in the projection of the pupil. **B**. View of the eye against the background of drug-induced mydriasis, a vertical mark of the intraocular lens toric axis (marked with a *red arrow*) located along the corneal graft keratometry strong meridian can be seen

corneal topographer (TMS-5), Scheimpflug keratotopographer (Pentacam), and OCT of the cornea (CASIA 2), while both CA and Km of the posterior corneal graft surface were comparable based on the data obtained using the Scheimpflug keratotopographer and OCT of the cornea (Tables 1, 2).

The difference in orientation of the axes of the major meridians of the corneal graft anterior and posterior surfaces exceeding 5° based on the data obtained using the Scheimpflug keratotopographer was reported for 12 eyes (33,3%), while that based on the data obtained using OCT of the cornea was reported for 15 eyes (41.7%).

The results of preoperative analysis of CA on the posterior corneal graft surface based on the Scheimpflug keratotopography and corneal OCT data are presented as a chart (Fig. 2).

The rate of CA on the posterior corneal graft surface based on the corneal OCT within ≤ –0.3 D was 11%, within ≤ –1.0 D — 56% (Fig. 1). The rate of CA on the posterior surface based on the Scheimpflug keratotopography data within ≤ –0.3 D was 11%, within ≤ –1.0 D — 44%. Thus, the average rate of CA on the posterior surface based on the data obtained using both devices within ≤ –0.3 D was 11%.

When calculating the tIOL optic power, getting into the planned target refraction for Sph in group 1 within ±0.5 D was reported for 58% of eyes, ±1.0 D for 66% of eyes, in group 2 that within ±0.5 D was reported for 33% of eyes, ±1.0 D for 49% of eyes, in group 3 that within ±0.5 D was reported for 17% of eyes, ±1.0 D for 25% of eyes, in group 4 that within ±0.5 D was not reported at all, ±1.0 D was reported for 17% of eyes (Fig. 3).

The highest predictability of getting into target refraction for Sph was reported when calculating the tIOL optic power in group 1, while the lowest predictability was reported for group 4 (Fig. 2).

When calculating the tIOL toric component, getting into target refraction for Cyl in group 1 within –0.5 D was reported for 56% of eyes, –1.0 D for 89% of eyes, in group 2 that within –0.5 D was reported for 22% of eyes, –1.0 D for 44% of eyes, in group 3 that within –0.5 D was reported for 22% of eyes, –1.0 D for 33% of eyes, in group 4 that within –0.5 was reported for 6% of eyes, –1.0 D for 17% of eyes (Fig. 4).

The highest predictability of getting into target refraction for Cyl was reported when calculating the tIOL toric component in group 1, while the lowest predictability was reported for group 4 (Fig. 3).

Table 2. Preoperative values of corneal astigmatism on both corneal graft surfaces measured using different equipment (M ± σ)

Astigmatism on the corneal graft	Equipment			
	Keratotopographer (TMS-5), D	Scheimpflug keratotopographer (Pentacam), D	Corneal OCT (CASIA 2), D	*p*
Anterior surface	–6.15 ± 3.28	–5.81 ± 2.89	–6.72 ± 3.23	0.0105
	(from –2.5 to –10.5)	(from –2.1 to –10.8)	(from –1.8 to –11.7)	
Posterior surface	no data	–1.05 ± 0.63	–1.04 ± 0.60	0.4115
		(from –0.1 to –1.8)	(from –0.3 to –1.9)	

Table 3. Preoperative average keratometry values of both corneal graft surfaces measured using different equipment (M ± σ)

Km of the corneal graft	Equipment			*p*
	Keratotopographer (TMS-5), D	Scheimpflug keratotopographer (Pentacam), D	Corneal OCT (CASIA 2), D	
Anterior surface	44.07 ± 4.20 (from 39.16 to 49.72)	44.69 ± 4.14 (from 39.5 to 49.1)	45.89 ± 4.34 (from 39.2 to 49.9)	0.0122
Posterior surface	no data	5.77 ± 0.75 (from 4.4 to 6.8)	7.24 ± 1.08 (from 5.9 to 8.6)	0.1225

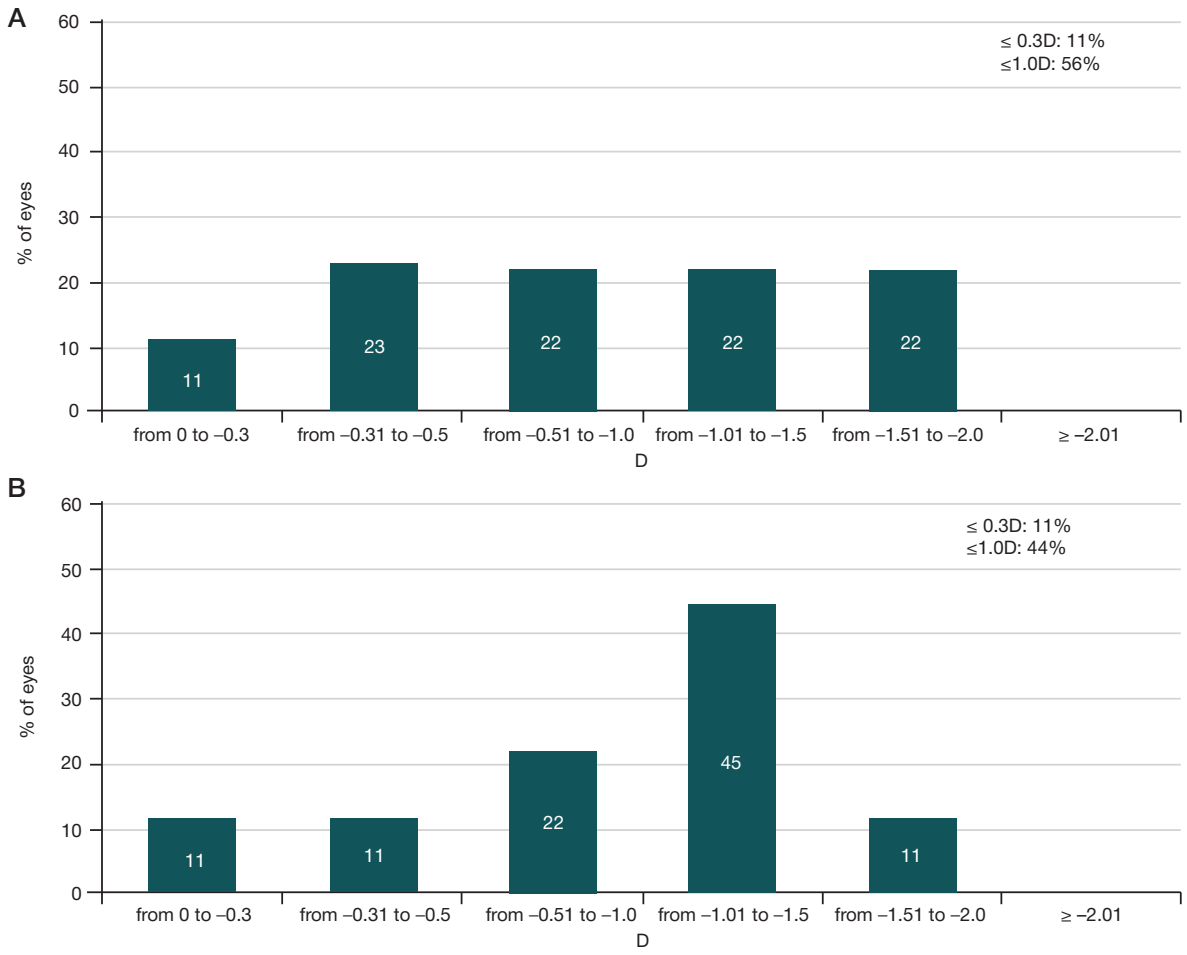

Fig. 2. Diagrams of the distribution of pre-operative values of corneal astigmatism on the posterior corneal graft surface based on the corneal OCT data (CASIA 2) **(A)**, Scheimpflug keratotopography data (Pentacam) **(B)**

DISCUSSION

Considering the fact that almost all patients develop CA after PK, performing cataract extraction with tIOL implantation allows one to solve a problem of cataract through one surgical procedure and at the same time correct CA. However, the accuracy of tIOL calculation in patients after PK has a lot of features. First, the tIOL calculation complexity results from trouble selecting the most accurate calculator. Currently, there are two types of tIOL calculators: those considering curvature of the anterior corneal surface only and those considering curvature of both corneal surfaces. As is well known, refraction of the posterior corneal surface is normally similar to light refraction of the anterior chamber fluid, due to which many authors neglect keratometry of the posterior corneal surface. However, keratometry parameters of the posterior surface of the cornea can change when performing corneal surgery. According to certain data, CA on the posterior corneal surface is normally on average –0.3 D, and only 9% of eyes have CA on the posterior corneal surface exceeding –0.5 D [14]. In our study, patients after PK have shown the opposite. Only 11% of eyes have CA on the posterior corneal graft surface within ≤ –0.3 D; CA exceeds –1.0 D in 44% of eyes based on the OCT data and in 56% of eyes based on the Scheimpflug keratotopography data. That is why it should be considered to accurately select the tIOL toric component.

The next thing that can lead to the tIOL calculation errors is orientation of the major meridians of the corneal graft anterior and posterior surfaces. As is well known, in case of matching axes of the major meridians of both corneal graft surfaces, CA on the posterior surface compensates for the value of CA on the anterior surface by its own value, which results in reduction of total CA. This, along with the induced astigmatism value, must be considered when calculating the tIOL toric component in order not to overcorrect and not to flip the CA axis to the opposite. Orientation of the major meridians of both corneal graft surfaces is also very important. If these differ by no more than 5°, tIOL can immediately correct the entire total CA, otherwise CA on the posterior corneal surface will persist and will be capable of affecting vision after surgery, depending on its value (in our study the value reached 1.8–1.9 D). In this study, the difference in orientation of the major meridians of both corneal graft surfaces exceeded 5° based on the Scheimpflug keratotopography data in 33.3% of eyes, based on the corneal OCT in 41.7% of eyes. In such cases, CA on the posterior surface persists after the tIOL implantation.

The next thing is selection of the device, the results of using which will be most accurate when calculating tIOL. According to the results of this study, keratometry parameters of the posterior corneal graft surface are comparably measured by corneal OCT and by using the Scheimpflug keratotopographer. The difference is in measuring keratometry of the anterior corneal graft surface. According to the findings, the highest predictability for the spherical and cylindrical refraction components was demonstrated by the tIOL calculation method used in group 1, where keratometry parameters of the anterior corneal graft surface were measured using the keratotopographer operating based on the Placido ring principle, and that of the posterior corneal graft surface were measured by corneal OCT or using

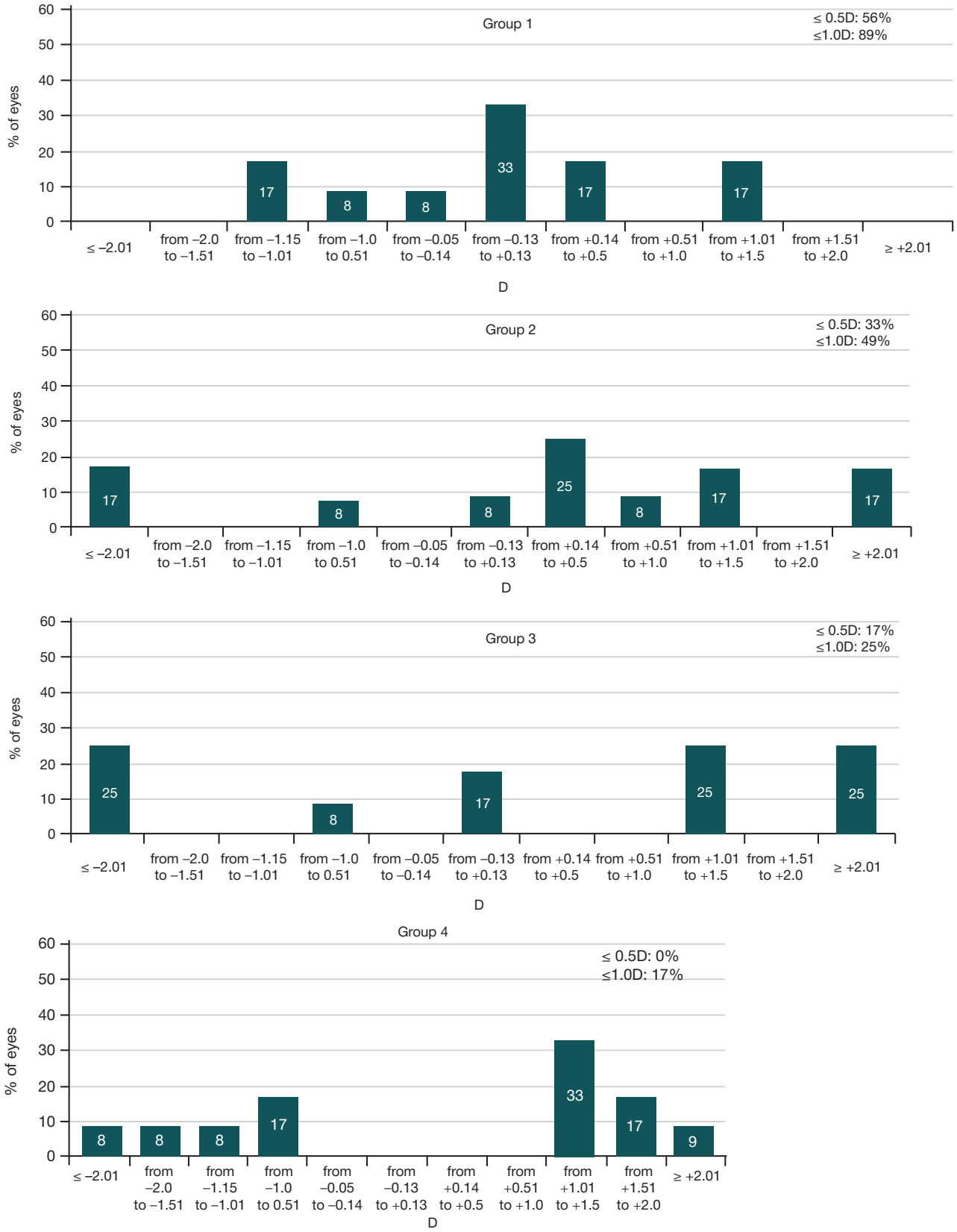

Fig. 3. Predictability of the spherical refraction component when calculating the tIOL optic power in groups 1–4

the Scheimpflug keratotopographer. The lowest tIOL calculation predictability was reported for group 4, which can be explained by the fact that tIOL calculation did not take into account the posterior corneal graft surface curvature.

Today, there are several tIOL calculators taking into account keratometry of both corneal graft surfaces. In our study, the value of one of the major meridians of the posterior corneal graft surface exceeded 7.5 D in 12 eyes (34.3%), which made it possible to enter these in the online Barrett True-K Toric Calculator only.

According to the literature data, the refraction results of the cataract extraction with tIOL implantation differ due to the facts that the authors used different tIOL calculators and keratometry

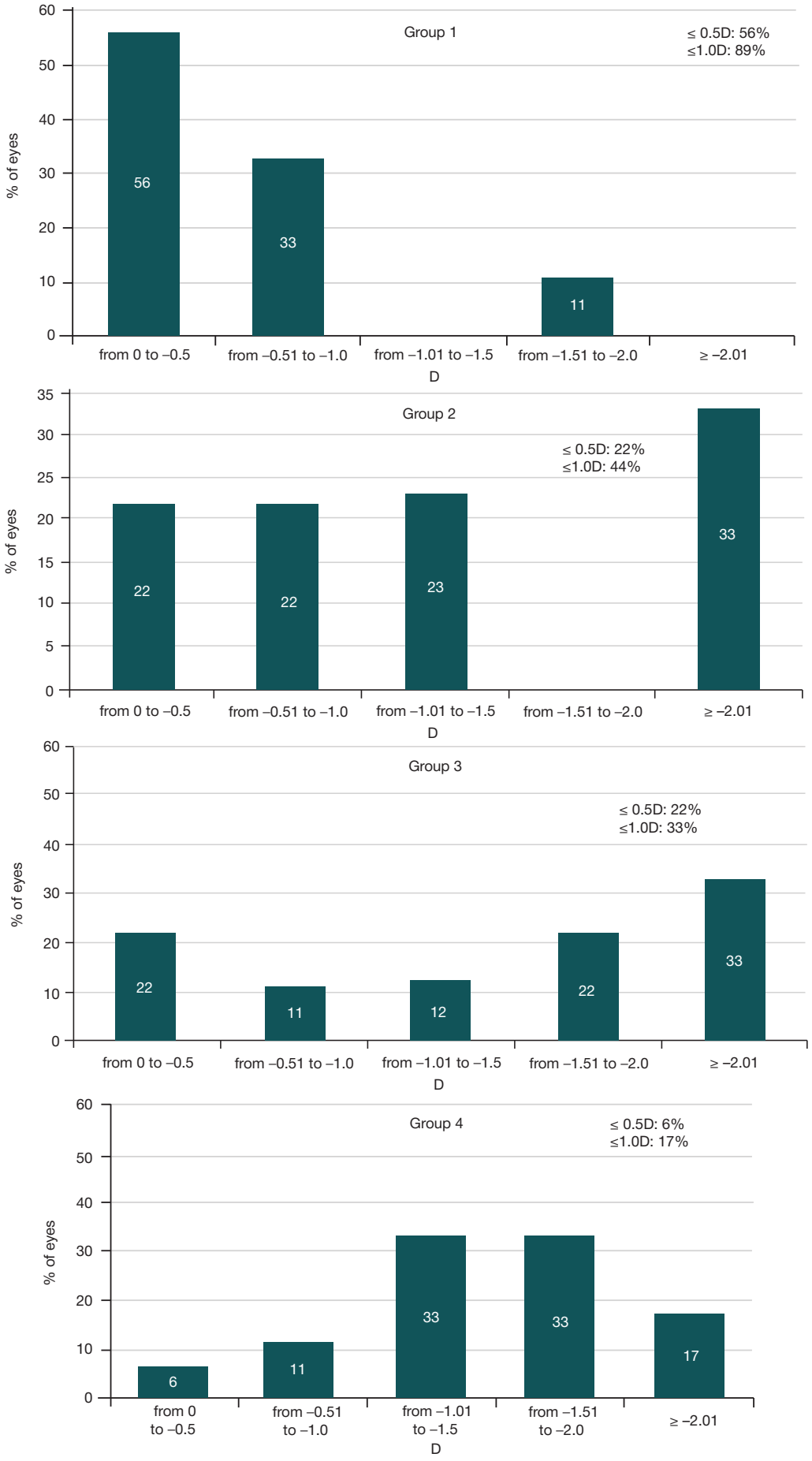

Fig. 4. Predictability of the cylindrical refraction component when calculating the tIOL optic power in groups 1–4

data obtained using different diagnostic devices. Thus, a clinical trial was conducted focused on correction of post-PK CA exceeding 2.25 D in 67 eyes (45 patients) with cataract by phacoemulsification with the Acrysof Toric SN60T6- SN60T9 tIOL implantation [15]. After surgery, UDVA was 0.61 ± 0.26, CDVA was 0.81 ± 0.21. Postoperative cylindrical refraction component (CRC) was below 0.75 D in 62% of eyes and below 1.00 D in 81% of eyes [15]. In 2021, the results of the clinical trial focused on correction of high corneal astigmatism (6–10 D) after PK in patients with cataract by phacoemulsification with tIOL implantation were published. After surgery, the average UDVA increased from 0.04 ± 0.02 to 0.6 ± 0.14, CRC reduced from –9.0 ± 1.80 to –1.1 ± 0.45 D, and postoperative average spherical equivalent was 0.75 ± 0.5 D [7]. In 2022, the results of phacoemulsification with tIOL implantation in patients after PK with the regular form of corneal astigmatism exceeding 1.5 D were provided. After surgery, UDVA increased from 0.1 ± 0.02 to 0.38 ± 0.11, CDVA increased from 0.23 ± 0.07 to 0.78 ± 0.12, and postoperative CRC was 0.93 ± 0.87 D [5].

Thus, the tIOL calculation method, in which the data of the anterior corneal graft surface measured using the keratotopographer operating based on the Placido ring principle and that of the posterior corneal graft surface measured by corneal OCT or the Scheimpflug keratotopographer are entered in the calculator taking into account keratometry data of both corneal graft surfaces, will be the most predictable.

CONCLUSIONS

Comparative retrospective analysis of various tIOL calculation methods used during cataract extraction in patients after PK showed the highest predictability of getting into planned target refraction in group 1. When calculating the intraocular lens optic power and toric component, it is reasonable to use the calculators taking into account keratometry data of both corneal graft surfaces, specifically keratometry data of the anterior corneal graft surface measured using the keratotopographer operating based on the Placido ring principle and keratometry data of the posterior corneal graft surface measured using the corneal optical coherence tomography scanner or the Scheimpflug keratotopographer.

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