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Optical coherence tomography in measurement of the optical power of the cornea after laser correction of myopia

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ABSTRACT

Aim: To compare total corneal power (TCP) values obtained from optical coherence tomography with conventional keratometry in intraocular lens (IOL) power calculation methods in corneas after laser correction of myopia.

Material and methods: The retrospective analysis included 64 eyes of patients after laser vision correction (LVC) of myopia. The results of optical coherence tomography of the anterior segment of the eye (Avanti RTVue XR) – central corneal thickness (CCT) and TCP – parameters from the optical biometry of IOLMaster 500 and the corneal tomography of Sirius were analyzed. Based on the obtained measurements, the IOL power was calculated using Haigis-L, Barrett True K No History and OCT formulas as well as the average from the ASCRS IOL Calculator for Eyes with Prior Myopic LASIK/PRK.

Results: The average spherical equivalent value before LVC was –3.99 ±2.13 D. The average decrease in mean keratometry after keratorefractive surgery measured with IOLMaster 500 and Sirius was 3.34 ±1.89 D and 3.14 ±1.83 D, respectively. Mean difference between TCP after LVC and keratometry measured by two conventional keratometers was 1.344 ±0.5 D for IOLMaster 500 and 1.267 ±0.82 D for Sirius. We did not observe a statistically significant difference in the IOL power using different calculation formulas for post-myopic eyes, but we found the highest agreement between the OCT formula and ASCRS average.

Conclusions: Optical coherence tomography of the anterior segment of the eye (Avanti RTVue XR) allows measurement of the TCP in patients after LVC, which makes the calculation of the IOL power in these patients more accurate.

KEY WORDS: refractive surgery, optical coherence tomography of the anterior segment of the eye, total corneal power, calculation of the intraocular lens power

INTRODUCTION

Nowadays, we can observe a significant increase in the incidence of myopia among the population, especially among children and adolescents [1, 2]. Due to the increasing incidence of myopia, as well as the increase in its mean value, interest in keratorefractive surgery is growing [3]. Laser correction of refractive error is becoming more popular due to its high accuracy and very good postoperative results, ensuring a permanent effect [2, 4]. As a result of laser correction of myopia, the optical power of the cornea (and its steepness) decreases, which leads to focusing of light rays directly on the retina [2, 3].

An important parameter of the cornea in relation to keratorefractive surgery is keratometry, which provides information about the curvature and the power of the cornea [2-4]. It can be measured using manual or automatic keratometers and in a simulated way using topography based on Placido discs [5, 6]. These techniques use the keratometric index of the cornea (1.3375), which allows the total corneal power of the cornea to be calculated by measuring its anterior surface, extrapolating the posterior [3, 5-8]. As a result of laser correction of myopia, the anterior curvature of the cornea changes, as well as the keratometric index expressing the ratio of anterior to posterior curvature [3, 5, 7, 8]. However, traditional methods for measuring keratometry do not take into consideration the changes that have occurred in the keratometric index as a result of keratorefractive surgery and use its standard

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value; therefore, these devices yield incorrect values of the optical power of the cornea [3, 5, 6, 8]. After laser correction of myopia, traditional keratometry devices overestimate the optical power of the cornea. The amount of this overestimate depends on the degree of nearsightedness [3, 5, 6, 9].

Corneal tomography allows one to measure both anterior and posterior surfaces and calculate the optical power of the cornea. This method is independent from the keratometric index of the cornea; therefore, the optical power of the cornea is more accurate compared to traditional keratometry devices [3, 5, 6, 8].

The correct estimation of the optical power of the cornea is particularly important for patients who, after a certain period of time after laser correction of myopia, will have to undergo phacoemulsification of the cataract. To estimate the intraocular lens (IOL) power for implantation, devices for measuring keratometry as well as estimating the optical power of the cornea are used [3, 5, 6, 9]. When using standard keratometers and calculating formulas to estimate the intraocular lens power in post-refractive surgery patients, its underestimation should be expected [3, 5, 6, 9]. As a result, this leads to a shift of postoperative refraction towards hyperopia, which negatively affects the uncorrected visual acuity and comfort of the patient.

The aim of the study is to compare total corneal power (TCP) values obtained from optical coherence tomography with conventional keratometry in IOL power calculation methods in corneas after laser correction of myopia.

MATERIAL AND METHODS

Study design

This is a retrospective study conducted at the Division of Ophthalmology and Optometry, Department of Ophthalmology, Collegium Medicum Nicolaus Copernicus University in Bydgoszcz (Poland) and Oftalmika Eye Hospital in Bydgoszcz. We analyzed the medical data of patients from the clinic. The study was approved by Ethics Committee on Clinical Investigation of Nicolaus Copernicus University.

Patients

The study group consists of 64 myopic eyes, including 36 female eyes and 28 male eyes. Before laser correction of myopia, the mean spherical equivalent was −3.99 ±2.13 D. Eyes with the post-operative spherical equivalent greater than or equal to ±0.25 D were excluded. Baseline characteristics of enrolled eyes before laser correction of myopia are presented in Table I.

Study protocol

Before and 3 months after keratorefractive surgery each patient underwent a general ophthalmic examination, the results of which we analyzed. In this study, we used the following parameters:

- subjective refractive error,
- keratometry from Sirius topography/tomography (CSO, Italy) and optical biometer IOLMaster 500 (Zeiss, Germany),
- total corneal power from Avanti RTVue XR (Optovue, USA),
- central corneal thickness and central corneal epithelial thickness from Avanti RTVue XR – Optovue (USA),
- axial length of the eye from optical biometer IOLMaster 500 (Zeiss, Germany).

We estimated intraocular lens power using the IOL Calculator for Eyes with Prior Myopic LASIK/PRK (Figure 1) from the American Society of Cataract and Refractive Surgery (ASCRS).

The results of keratometry were entered into the calculator from ASCRS with the keratometric index of 1.3375 for Sirius and 1.3375 for IOLMaster 500.

Based on the entered data, the IOL calculator estimates the power of IOL for the following formulas[10]:

1) Masket Formula,
2) Modified-Masket,
3) Barrett True K,
4) Shammas,
5) Haigis-L,
6) OCT using TCP,
7) Barrett True K No History.

The power of IOLs obtained using different formulas from the IOL Calculator for Eyes with Prior Myopic LASIK/PRK was also compared.

Optical coherence tomography of the anterior segment of the eye

In our study, we used optical coherence tomography in the spectral domain with a corneal adaptor module of Avanti RTVue XR (USA). The scanning speed of this device is 70,000 A-scans per second, which ensures a high quality of measurements [11]. The optical axial resolution and optical transverse resolution are 5 μm and 15 μm, respectively. The A-scan depth is 2-3 mm (depending on the scan protocol) and the transverse of its depth is in the range of 2 to 12 mm. An 840 nm wavelength beam is used for scanning [11].

Table I. Baseline characteristics of enrolled eyes; mean values (SD)

	Mean (SD), $n = 64$
Age [years]	32.31 (6.6)
Spherical defect [D]	–3.35 (2.46)
Cylindrical defect [D]	–1.28 (1.34)
Spherical equivalent [D]	–3.99 (2.13)
UCVA	0.2 (0.24)
BCVA	1.12 (0.24)
Average keratometry [D]	43.89 (1.53)
Central corneal thickness [μm]	539.34 (34.34)
Central corneal epithelial thickness [μm]	54.47 (3.06)
Axial length [mm]	24.68 (0.92)

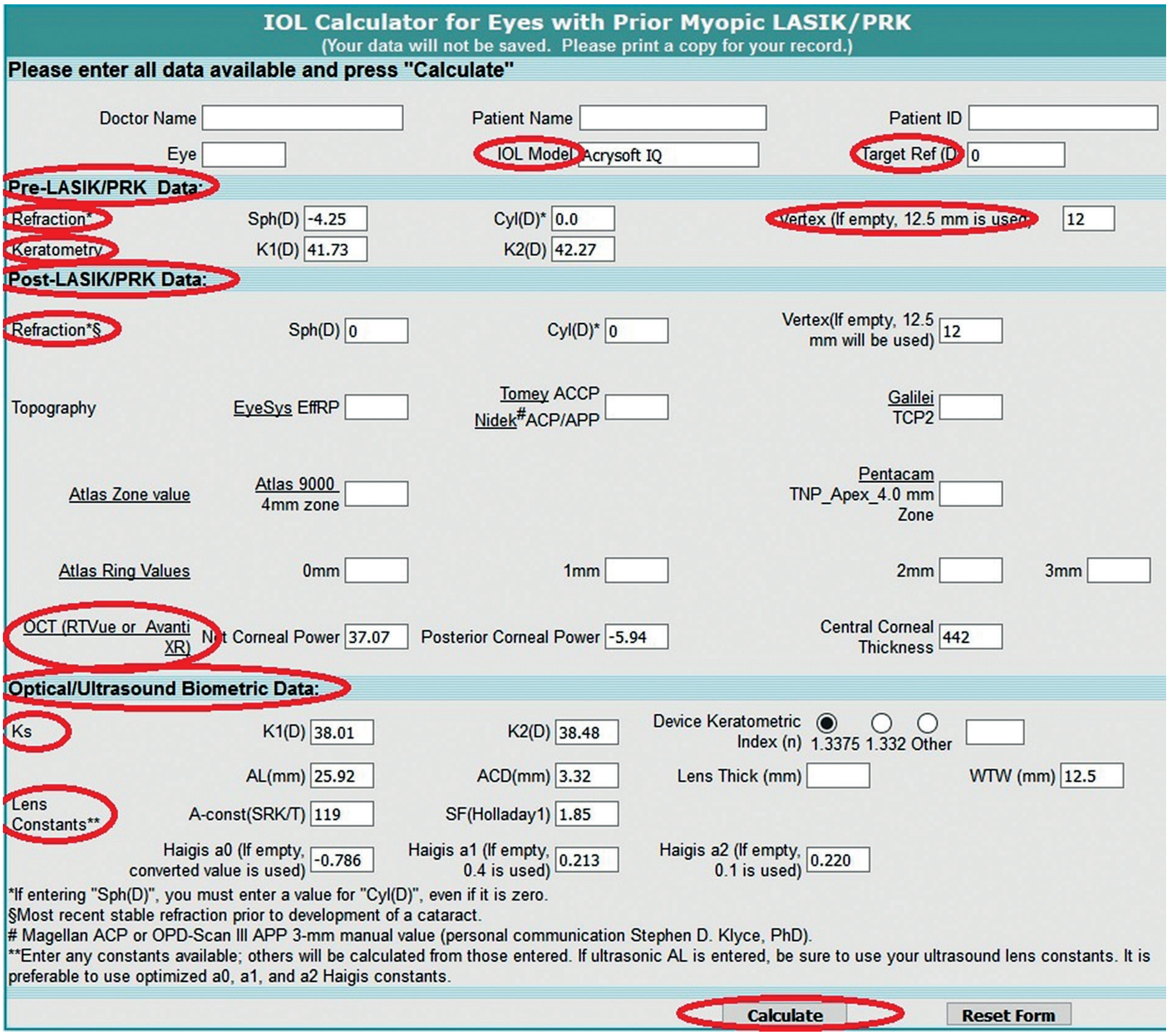

Figure 1. Data entry scheme for the calculator from ASCRS estimating the power of the intraocular lens in patients after laser correction of myopia. [Based on: American Society of Cataract and Refractive Surgery, http://iolcalc.ascrs.org/wbfrmCalculator.aspx]

It enabled us to assess the central corneal thickness and the central corneal epithelial thickness before and after laser correction of myopia. First of all, it was used to accurately evaluate the optical power of the cornea (TCP) after keratorefractive surgery based on measurements of both anterior and posterior curvatures of the cornea [11, 12].

Statistical analysis

For the statistical analysis, R software version 3.0.3 and Statistica 13 were used. The summary statistics for normally distributed continuous variables are presented as mean and standard deviation (SD). For dependent samples, repeated measurements ANOVA was used. In the case of data not normally distributed, differences were tested by the Wilcoxon test when the samples were independent or by the Friedman test if they were dependent. Pearson's correlation coefficient was used to investigate the dependencies between selected continuous variables. The results were considered as statistically significant when the p-value was less than 0.001 [13].

RESULTS

As a result of laser correction of myopia, we observed changes in mean measured keratometry using Sirius of −3.14 ±0.95 D ($p < 0.001$). For the optical biometer IOLMaster 500, the changes in keratometry were −3.27 ± 1.86 D ($p < 0.001$). The difference between these devices is 0.13 ± 0.95 D ($p = 0.27$). The results before and after laser correction of myopia are presented in Table II.

We observed a correlation between the changes in mean keratometry as a result of laser correction of myopia and the quantity of the spherical equivalent before surgery (Figure 2) at the level of 0.837 ($p < 0.001$).

After laser correction of myopia, we analyzed the TCP parameter measured by Avanti RTVue XR with keratometry from Sirius and IOLMaster 500 after laser correction of myopia. We observed a significant difference between TCP and keratometry measured by IOLMaster 500 and Sirius, 1.34 ±0.5 D ($p < 0.001$) and 1.267 ±0.82 D ($p < 0.001$), respectively. The results are presented in Table III.

Table II. Changes in mean keratometry after laser correction of myopia; mean values (SD).

	Keratometry [D]			
	Before	After	*Δ*	*p*
Sirius	43.89 (1.52)	40.75 (2.13)	–3.14 (1.83)	< 0.001
IOLMaster 500	44.03 (1.26)	40.79 (2.18)	–3.27 (1.86)	< 0.001
Δ	–0.22 (0.83)	–0.07 (0.53)	0.13 (0.95)	
p	0.054	0.29	0.27	

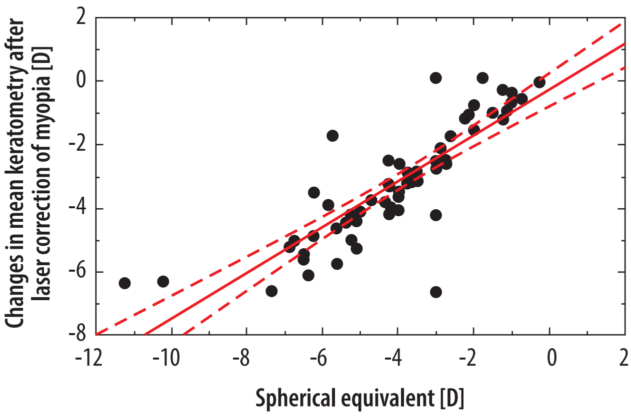

Figure 2. Pearson's correlation plots between the spherical equivalent of the refractive error and changes in mean keratometry after laser correction of myopia

Table III. Mean keratometry and Total Corneal Power after laser correction of myopia and the difference between them; mean values (SD)

	Mean (SD)						
	IOLMaster 500	Sirius	Avanti	ΔIOLMaster 500/Avanti		ΔSirius/Avanti	
					p		p
Keratometry/TCP [D]	40.79 (2.18)	40.75 (2.13)	39.49 (2.44)	1.344 (0.5)	< 0.001	1.267 (0.82)	< 0.001

Moreover, we evaluated changes in the central corneal thickness and central corneal epithelial thickness after laser correction of myopia. The corneal thickness decreased by 83.41 ±34.17 µm ($p < 0.001$), i.e. 26.56 µm per 1 D. The central corneal epithelial thickness increased by 1.11 ± 3.86 µm ($p < 0.001$), i.e. 0.35 µm per 1 D. We also assessed the change in axial length after myopia correction. We observed a decrease by 0.093 µm. This change is associated with a decrease in the central corneal thickness; the correlation between these changes is 0.577 ($p < 0.001$). These results are presented in Table IV.

Table IV. Changes in the central corneal thickness, central corneal epithelial thickness, and axial length after laser correction of myopia; mean values (SD)

	Mean (SD)			*p*
	Before	After	Δ	
Central corneal thickness [µm]	539.34 (34.34)	456.56 (45.59)	–83.41 (34.17)	< 0.001
Central corneal epithelial thickness [µm]	54.47 (4.67)	55.58 (4.67)	1.11 (3.86)	<0.001
Axial length [mm]	24.68 (0.92)	24.59 (0.9)	–0.093 (0.067)	< 0.001

We compared IOL power obtained with the OCT formula using TCP and different formulas from the IOL Calculator for Eyes with Prior Myopic LASIK/PRK (Table V). We did not observe a significant differences between IOL power from the OCT formula and from the Haigis-L and Barrett True K No History formulas. We observed the highest agreement between the average of ASCRS IOL Calculator and the OCT formula.

We evaluated the correlation between TCP and average intraocular lens power using ASCRS (Figure 3). We observed a moderate correlation; the Pearson's correlation coefficient was –0.478 ($p < 0.001$). With the increase in TCP, IOL power decreased.

Table V. Comparison of IOL power obtained with different formulas from the IOL Calculator for Eyes with Prior Myopic LASIK/PRK and the difference between them; mean values (SD).

	Mean (SD)													
	Average of ASCRS formulas	Haigis-L	Barrett True K No History	OCT formula	ΔASCRS/OCT		ΔASCRS/ Haigis-L		ΔASCRS/ Barrett True K No History		ΔOCT/Haigis-L		ΔOCT/Barrett True K No History	
						p		p		p		p		p
Intraocular lens power [D]	22.76 (1.5)	23.22 (1.49)	22.56 (1.5)	22.76 (1.65)	0.0077 (0.55)	0.98	–0.45 (0.51)	0.09	0.2 (0.54)	0.45	–0.46 (0.73)	0.1	0.19 (0.92)	0.49

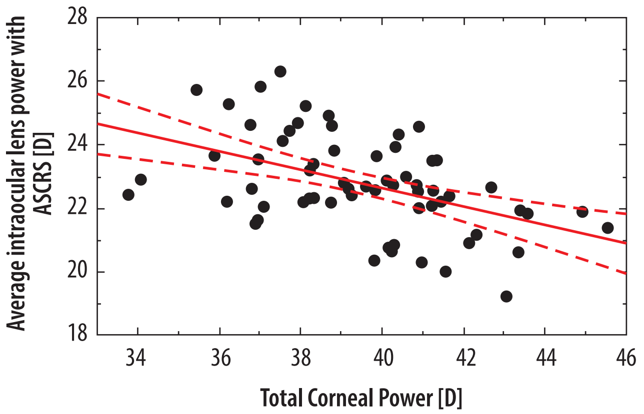

Figure 3. Pearson's correlation plots between Total Corneal Power (TCP) and average intraocular lens power with ASCRS

DISCUSSION

An important parameter used in calculating IOL power in post-refractive surgery patients, namely the TCP, was measured by the Avanti RTVue XR device. The average TCP after laser correction of myopia is 39.49 ±2.44 D. Analyzing the TCP parameter from Avanti with average keratometry from IOLMaster 500 and Sirius, it can be seen that TCP is significantly lower for the Avanti measurement by −1.344 ±0.5 D and −1.267 ±0.82 D, respectively. This is due to the fact that standard keratometers measure only the anterior curvature, extrapolating the posterior curvature. In addition, these devices use the keratometric index to measure the optical power of the cornea, which changes as a result of keratorefractive surgery. In turn, the Avanti device measures both curvatures, so that the result is not falsified.

In 2006, the Tang *et al.* study was published in which the optical power of the cornea was analyzed before and after LASIK in 32 eyes of 17 patients. The mean spherical equivalent and cylindrical defect were −4.45 ±1.87 D and 0.62 ±0.54 D, respectively. In this study, the mean simulated keratometry (SimK) measured with corneal topography using Placido discs after the LASIK procedure was 40.95 D. The postoperative value of the corneal optical power measured by corneal and anterior segment optical coherence tomography (CAS-OCT) prototype was 39.36 D. The difference in the measurement of the optical power of the cornea by traditional methods and optical coherence tomography is significant. Topography overestimated the optical power of the cornea by 1.6 D [5]. In our study, a similar difference between measurements of the corneal optical power using a standard keratometer in IOLMaster 500 and Sirius corneal tomography, and Avanti was achieved: 1.344 D and 1.267 D, respectively. Lower values result from a lower average spherical equivalent value than in Tang's study [5].

In 2010, Tang *et al.* published another study on the optical power of the cornea after laser correction of myopia in 13 eyes of 11 patients. The mean spherical equivalent was −6.86 ±2.97 D. The mean post-LASIK keratometry measured by a standard keratometer was 38.13 ±3.23 D. The postoperative value of the keratometry measured by Fourier-domain OCT was 35.24 ±4.15 D. Standard keratometry overestimated the net corneal power by 2.89 D [14]. We achieved a smaller difference between standard methods and Avanti RTVue XR, which is due to the much lower spherical equivalent of refractive error before the laser correction of myopia.

Error in corneal radius measurement, keratometric (K) index error, and error in the IOL power calculation are the three main reasons for IOL power calculation inaccuracy [15]. In the case of post-refractive surgery patients, to calculate the IOL power, formulas should be used that take into account changes in the anterior and posterior surface of the cornea and, consequently, in the keratometric index. The IOL power calculation using a standard formula, for example as a result of an incorrectly conducted medical history during the qualifying examination, will lead to a significant error in target refraction. In our cohort, the average IOL power estimated by the SRK/T formula using standard keratometry from IOLMaster 500 was 20.9 ±1.3 D. The difference of IOL power between the average for formulas from the IOL Calculator for eyes with Prior Myopic LASIK/PRK and SRK/T was 1.88 ±0.77 D. In post-myopic eyes, the measurement of the optical power of the cornea with standard keratometers is overestimated, which in turn leads to underestimation of IOL power and unsatisfactory postoperative refractive results. Taking the correct index into consideration when calculating IOL power increases the chance of avoiding postoperative hyperopia [16-18].

In our study, we analyzed the IOL power of post-myopic patients assessed using the IOL Calculator for Eyes with Prior Myopic LASIK/PRK from ASCRS, with particular emphasis on the following formulas: OCT, Haigis-L and Barret True K No History. We chose the Haigis-L formula as it is the most commonly used and Barrett True K No History and ASCRS average as the ones providing the most accurate results [19]. For the OCT formula, we observed the smallest difference between the IOL power and the average power of all the ASCRS formulas. This proves the high accuracy in estimating the IOL power with the OCT formula using the TCP parameter from the Avanti device, which takes into account changes in the keratometric index after keratorefractive surgery.

The mean axial length of the eye in patients before keratorefractive surgery was 24.68 ±0.92 mm, while as a result of the laser correction of myopia, it decreased by 0.093 ±0.067 mm. Comparing the change in the central thickness of the cornea with the change in the axial length of the eye, a similar magnitude of this change can be observed. For the central thickness of the cornea, the change was 0.083 mm. A moderate correlation between the difference in the central corneal thickness and the difference in the axial length of the eye was observed. In addition, the axial length of the eye strongly depends on the magnitude of the spherical equivalent.

CONCLUSIONS

Optical coherence tomography of the anterior segment of the eye (Avanti RTVue XR) enables TCP measurement, which makes IOL power calculation in post-refractive surgery patients more accurate. There is a significant difference in the total power of the cornea measured by the Avanti RT-Vue XR, IOLMaster 500 and the Sirius corneal tomography after LVC. In eyes after laser refractive correction of myopia, the IOL calculation formula using TCP does not provide statistically different results from the average value from the ASCRS Calculator. Moreover, taking into account the two most commonly used formulas in post-myopic patients, the OCT formula shows the highest agreement with the average IOL power from the ASCRS Calculator.

DISCLOSURE

The authors declare no conflict of interest.

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