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A new method to accurately assess post-laser-surgery refractive changes with the intrinsic corneal power changes

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Abstract. To evaluate the ability of assessing the refractive change induced by myopic laser surgery using the intrinsic data, obtained from a reference intrinsic to the cornea. Twenty-nine eyes with laser in situ keratomileusis for myopia were included in the study. Statistical analyses were performed to determine the relationship between refractive changes and two kinds of corneal power: KIP_value (obtained by keratometric index of 1.3375 and radius of curvature) and RIP_value (obtained by real corneal refraction index of 1.376 and radius of curvature). The comparisons were made between results given by intrinsic data and Pentacam HR. Preoperatively, the intrinsic radii of curvature are significantly less ($p \ll 0.001$) than those from Pentacam HR, while the intrinsic radii of curvature are significantly larger ($p \ll 0.001$) after surgery. The corneal power changes given by Pentacam HR always underestimate the refractive changes. However, the intrinsic data generally reduce the discrepancies between the corneal power and the refractive changes. The intrinsic KIP_value correlated best with the refractive changes at the corneal plane ($p \ll 0.001$) with a prediction error as low as 1.51%. The use of intrinsic data of the cornea can possibly provide an accurate estimation of surgically induced refractive changes.

Keywords: Corneal power changes, refractive changes, intrinsic data

1. Introduction

One of the unresolved problems of the refractive surgery is the objective assessment of the amount of the refractive changes induced by the refractive surgery using corneal topography. Corneal changes given by corneal topographies are generally believed to underestimate the actual surgically induced refractive changes [1]. Several explanations, such as the invalid keratometric refraction index of 1.3375 [1, 2], the change in posterior surface [3, 4] and corneal index change after refractive surgery [5] were proposed to explain this phenomenon. Subsequently, different methods [6-8] to accurately assess the refractive changes have been proposed. However, no conclusive explanations have been achieved. When using the topography to estimate the surgically induced refractive change, it should be

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noted that the corneal power (given by most of the topographers) is the vertex normal power. All the given maps using the topographies are centered on a specific point, which is the origin of the two-dimensional map. Furthermore, this specific point is the vertex normal, which is the conreal intercept of the keratometric axis. However, the corneal anterior surface has its own optical axis and its own apex (point of maximum curvature and intercept of the optical axis). Mandell [9] observed a difference of 0.5 D in corneal power between the apex and the vertex normal for normal eyes. Therefore, we hypothesize that the difference in corneal power between the apex and vertex normal may play a role in the estimation of the surgically induced refractive changes. To our knowledge, this factor has not been considered for the estimation of the surgically induced refractive changes.

The vertex normal power could be easily obtained from the topography; however, the apical power could not be directly obtained by the topography. Fortunately, Navarro [10] proposed a mathematical method to determine the apical power. In addition, this method is capable of eliminating the errors such as the misalignment, tilt and slant of the real cornea with respect to the measuring device and the misalignment between corneal optical axis and axis of the topographer. In this method, an ellipsoid oriented and located arbitrarily in the space was used to represent the anterior corneal surface. The corneal parameters (radius and Q-value), which depend solely on the intrinsic axes of the cornea, instead of the coordinate of the topographer, were obtained. Navarro [10] also demonstrated that the ellipsoid model referring to the intrinsic axes of the cornea gave a root-mean-square (rms) fitting error as low as 5.5±1.7 μm for 123 normal corneas (without refractive surgery), indicating that the ellipsoid model closely traced the actual corneal surface. In a study by Anera [11], this mathematical method was also proven to be capable of characterizing the corneas of subjects with refractive surgery. Moreover, they demonstrated that the radii of curvature obtained from the ellipsoid model referring to the intrinsic system were different from those obtained directly from the topographer. According to these results, it is expected that there is a power difference between intrinsic data and those obtained directly from the topography.

In this paper, we use the intrinsic radius of curvature obtained by the surface fitting with the ellipsoid model to evaluate whether using the intrinsic radius improves the prediction of the surgically induced refractive changes. Our results show that by using the intrinsic data of the cornea, the prediction of the refractive change shows a significantly better fit to the surgically induced refractive change.

2. Methods

A total of 29 eyes of 15 patients operated on using laser in situ keratomileusis (LASIK) to correct myopia and astigmatism were studied. Those patients who had corneal or retinal disease, or previously had ocular surgery were excluded. Subjects who had worn contact lens at any time 2 weeks before the examination were also excluded. All subjects had a full ophthalmic examination. All LASIK procedures were performed in eyes under topical anesthesia. The Moria M2 (Moria SA, Antony, France) microkeratome was used to create a superior hinged 110 μm flap measuring 9.0 mm in diameter. The flap was superiorly reflected, and the stromal bed was ablated using the VISX STAR S4 Excimer laser system (VISX, Inc., Santa Clara, CA, USA).

Corneal topography was performed with the Pentacam HR (Oculus, GmbH, Wetzlar, Germany) system preoperatively and 3-6 months after refractive surgery. Additionally, all eyes underwent manifest refraction examinations preoperatively and 3-6 months after surgery.

The study followed the tenets of the Declaration of Helsinki. The study protocol was approved by the Tianjin Eye Hospital Institutional Review Board. All participants provided their written informed consent.

2.1. Surface fitting

The mathematical method to obtain the parameters of the corneal anterior surface in a reference coordinate intrinsic to the cornea was discussed in details by Navarro [10]. The raw elevation data is fitted by an ellipsoid surface oriented and located arbitrarily in the space. Here, a fitting diameter of 8 mm was chosen for eyes before surgery; however, after surgery, a fitting diameter of 6 mm was chosen to ensure that the postsurgical corneal data do not include the transition zone. The Levenberg-Marquardt algorithm was used to perform the surface fitting procedures. The fitting procedures and the coordinate translation and rotation were implemented in MATLAB software (The Mathworks, Inc. Natick, Mass). The R- value obtained from this surface fitting is called 'intrinsic R' in the following section.

2.2. Assessment of the manifest refractive changes

The subjective refraction was measured in diopters. The directly obtained manifest refraction spherical equivalent (MRSE) is measured at the spectacle plane, therefore MRSE at the corneal plane was also calculated using the following equation:

$$\text{MRSEcorneal} = \text{MRSEspectacle}/(1-0.012\times\text{MRSEspectacle}) \tag{1}$$

The MRSE changes are defined as the subtraction of the pre-surgical MRSE value from the corresponding post-surgical value.

2.3. Assessment of the corneal power changes

In the present study, the corneal powers were classified as the KIP-value (Keratometric index power value) and RIP-value (real index power value). Here, we define KIP-value as the corneal power in terms of the keratometric index and the radius of curvature R with KIP value=337.5/R. Similarly, the RIP-value refers to the corneal power in terms of the real corneal index and is equal to 376/R. The changes of the corneal power (KIP-value and RIP-value) were calculated by subtracting pre-surgical values from the corresponding post-surgical values.

2.4. Assessment of the predicting error

In order to identify which corneal power changes provide the best fit with the real surgically induced refractive changes, the following equation was used to quantify this fit:

$$\varepsilon(\%) = \left| \frac{refractive\_change - |corneal\_power\_change|}{refractive\_change} \times 100 \right| \tag{2}$$

where the corneal power change is the corneal power change. The refractive change is the MRSE change, and the corneal power can be the KIP value or the RIP value.

The Kolmogorov-Smirnov test was used to confirm a normal distribution for all data collected. The

2-tailed paired t-test was performed using SPSS11.5 software (SPSS Inc. Chicago, Ill). The correlation between refractive changes and corneal power changes was assessed by linear regression analysis using Origin 8.0 software (OriginLab Corp. Northampton, MA)

3. Results

This study comprised of 29 eyes. The average age of the subjects was 25.3±5.8 years (18 to 38 years). The MRSE at the spectacle plane was -6.28±1.95 D (-12 D to -3.13 D) before surgery and 0.00±0.52 D (-1.5 D to 1.38 D) after surgery. The MRSE at the corneal plane was -5.80±1.65 D (-10.49 D to -3.01 D) before surgery and 0.01±0.52 D (-1.47 D to 1.40 D) after refractive surgery.

Table 1 shows the mean values of the radii of curvature obtained from and from the Pentacam HR. The radii of curvature were calculated by averaging the radii in x and y meridians. The first notable result is the observed statistical significant differences between these two methods in all cases. The intrinsic radii of curvature are significantly lower than those from the Pentacam HR before surgery, whereas after surgery, the intrinsic radii of curvature are significantly higher than those obtained from the Pentacam HR. Therefore, the RIP_value from the surface fitting is significantly greater than that from the Pentacam HR before surgery, but it is significantly less than that from the Pentacam HR after surgery. Consequently, the change of the RIP_value after surgery for data given by surface fitting (-6.44 D) is significantly greater than that provided by the Pentacam HR (-5.23 D).

The linear regression formulas for the refractive changes and the corneal power changes are shown in Table 2. All the changes in corneal power predicted the refractive changes very well with an R^2 very close to 1 (0.99 for data from Pentacam HR and 0.98 for data from surface fitting, $p<<0.001$). For Pentacam HR data, the regression coefficient of all cases had an absolute value higher than 1, suggesting that all the changes in corneal power from the Pentacam HR underestimated the surgically-induced refractive change. For Intrinsic data, one result to highlight is that the changes of the

Table 1

The mean values of the radii of curvature obtained by surface fitting of the 29 eyes before and after surgery, as well as those taken directly from the Pentacam HR

	Pre-radii (mm)	Pre RIP-value (D)	Post Radii (mm)	Post RIP-value (D)	Δcorneal power (D)
Pentacam	7.75±0.24	48.55±1.46	8.70±0.43	43.32±2.10	-5.23±1.51
Intrinsic	7.61±0.23	49.17±1.45	8.82±0.50	42.73±2.34	-6.43±1.81
p-value	<<0.001	<<0.001	<<0.001	<<0.001	<<0.001

Table 2

Regression formulas of refractive and cornel power changes after laser surgery

	Regression formula	R^2	p-value
Pentacam	ΔMRSEspectacle= -1.34*ΔKIP-value	0.99	<<0.001
	ΔMRSEcorneal= -1.24*ΔKIP-value	0.99	<<0.001
	ΔMRSEspectacle= -1.21*ΔRIP-value	0.99	<<0.001
	ΔMRSEcorneal= -1.11*ΔRIP-value	0.99	<<0.001
Intrinsic data	ΔMRSEspectacle = -1.09*ΔKIP-value	0.98	<<0.001
	ΔMRSEcorneal = -1.00*ΔKIP-value	0.98	<<0.001
	ΔMRSEspectacle = -0.98*ΔRIP-value	0.98	<<0.001
	ΔMRSEcorneal = -0.90*ΔRIP-value	0.98	<<0.001

Note: ΔMRSE spectacle: MRSE changes at the spectacle plane, ΔMRSEcorneal: MRSE changes at the corneal plane.
ΔKIP-value: KIP-value changes after surgery, ΔRIP-value: KIP-value changes after surgery.

KIP-value accurately predict the surgically induced refractive changes in the corneal power change with an absolute regression coefficient of 1.

Though the RIP-value changes provided by Pentacam HR gives a more closely correlation with the refractive changes in comparison with the KIP-value changes, they continue to underestimate the actual surgically induced refractive changes. The intrinsic RIP-value changes overestimate both the refractive change at the spectacle plane and the corneal plane because the linear fit of the absolute slopes are less than 1, 0.98 for refractive change at the spectacle plane, and 0.90 for refractive change in the corneal plane. Notably, the intrinsic KIP-value changes provide an improved estimation of the surgically induced refractive change both at the corneal plane and the spectacle plane.

In order to give a more direct picture, the differences between surgically induced refractive and corneal power changes are shown in Table 3. As expected, the corneal power changes given by the Pentacam HR underestimate the refractive changes. In contrast, the intrinsic data gives a better estimation of the surgically induced refractive changes. The intrinsic KIP-value changes produce the best estimation of the surgically induced refractive change with a mean difference as low as -0.03 D.

Table 4 shows the prediction errors of the surgically induced refractive change with intrinsic data as well as with Pentacam HR. With the exception of the RIP-value changes used to predict the refractive changes at the corneal plane, the prediction capacity significantly improves when intrinsic data are used, giving a significantly lower prediction error (p<<0.001). For Pentacam HR data, the use of the real corneal index improves the prediction capacity as the RIP-value changes produce a significantly less prediction error (p<<0.001) than KIP-values. In addition, the surgically refractive changes are better estimated at the corneal plane than at the spectacle plane with the Pentacam HR data. For intrinsic data, it is noteworthy that the intrinsic KIP-value changes provides the best estimation of the refractive changes at the corneal plane with a prediction error as low as 1.51%.

4. Discussion

An accurate assessment of the corneal power after laser refractive surgery is essential for several applications. This data can be used for the intraocular lens (IOL) power calculation in eyes with

Table 3

Mean difference between surgically induced refractive and corneal power changes

	Mean difference at spectacle plane		Mean difference at corneal plane	
	KIP-value	RIP-value	KIP-value	RIP-value
Pentacam	-1.58±0.85	-1.05±0.75	-1.11±0.61	-0.58±0.55
Intrinsic	-0.50±0.90	+0.16±0.88	-0.03±0.76	+0.63±0.80
P-value	0.001	<<0.001	<<0.001	<<0.001

Note: '+' represents overestimation, '-'represents underestimation.

Table 4

The prediction errors of the surgically induced refractive change with Pentacam HR data and with intrinsic data

	Refractive change at spectacle plane		Refractive change at corneal plane	
	KIP-value (%)	RIP-value (%)	KIP-value (%)	RIP-value (%)
Pentacam	23.65	14.94	18.04	8.69
Intrinsic	5.42	5.33	1.51	13.05
p-value	<<0.001	<<0.001	<<0.001	<<0.001

previous refractive surgery to avoid refractive surprises after surgery. Furthermore, it might help surgeons to assess the reliability of their laser treatments and help to improve the design of ablation profiles. In the present paper, we attempted to find a method to accurately assess the surgically induced refractive change. Thereby the ability of the intrinsic corneal power to assess the refractive changes was examined by comparing with the data taken from the Pentacam HR.

The radius of curvature reference to the intrinsic coordinate (7.61 mm) is lower than that provided by Pentacam HR (7.75 mm) for eyes before refractive surgery whereas a higher radius of curvature (8.82 mm) is observed in comparison with data from Pentacam HR (8.70 mm) after refractive surgery. The explanation for these results is straightforward. Before refractive surgery, the corneal anterior surface is prolate [12], which means the lowest of the radius of curvature is at the apex of the cornea. However, after refractive surgery, the corneal anterior surface is oblate [13, 14], meaning that the highest radius of curvature is at the apex of the cornea. The difference in the radius of curvature between intrinsic data and Pentacam HR data is vital as it leads to a difference in the corneal power changes. The intrinsic RIP-value is 0.62 D higher than that from Pentacam HR before refractive surgery and 0.59 D lower than that from the Pentacam HR after refractive surgery. The differences before surgery and after surgery are additive, resulting in an intrinsic RIP-value change of 1.21 D higher than those obtained from Pentacam HR. Considering that the corneal power changes given by Pentacam HR underestimate the surgically induced refractive changes, the present results show that the intrinsic RIP-value has the possibility to provide a better estimation of the refractive changes. Therefore, this possibility was testified by comparing with the results from the Pentacam HR.

Though many researchers have previously tried to find more accurate methods to assess the refractive chanes, no conclusive results have been achieved. In a preliminary study, Savini, et al [6] reported that the Total Refractive Power (the power determined by corneal ray tracing, in which Snell's law and specific indices of air, the cornea and the aqueous are used) on the Pentacam HR seems to be an accurate method to evaluate surgically induced refractive changes. Using high-speed optical coherence tomography (OCT), Tang [1] found that the difference between total power for 3.0 mm and 4.0 mm zones (calculated by the radius of the corneal anterior surface and posterior surface with the real corneal index of 1.376) changes, and LASIK-induced refraction changes is 0.16 D with a correlation coefficient of 0.94, while simulated keratometry underestimated refraction the change by 0.60 D, 18.9% by linear regression. Therefore, these investigators concluded that measuring both anterior and posterior corneal surfaces with a combination of OCT and Placido ring topography provided a better measure of total corneal power that closely tracked the surgically induced refractive changes. Srivannaboon [7] studied the accuracy of Orbscan total optical power maps (TOP), which was based on the measurement of both surfaces, in detecting refractive changes after myopic laser in situ keratomileusis. They found that the central 4.0 mm zone TOP map gave the best correlation between manifest refractive changes and Orbscan measured corneal power changes, with a correlation coefficient of 0.853. Additionally, using Orbscan, Sógo-Krone [8] found that refractive changes after myopic LASIK was best estimated by 2-mm total mean power (0.07±0.62 D) with a correlation coefficient of 0.76 and 4-mm total optical power (-0.08±0.53 D) with a correlation coefficient of 0.87. The above studies obtained different conclusions about which are the best value to track surgically induced refractive changes. However one common aspect of all the above studies is that both the anterior and posterior corneal surfaces are recommended to be used to estimate the surgically refractive error change.

Increasing numbers of recent studies [15-18] have shown that the posterior corneal surface was barely changed by refractive surgery; therefore, we speculate that the anterior corneal surface alone is sufficient to reflect the surgically induced refractive changes. Therefore, only the radius change in the curvature of the anterior corneal surface was considered in the present study.

The intrinsic KIP-value was demonstrated to give the best estimation of the surgically induced refractive error at the corneal plane with an underestimation of only 0.03 D (R^2=0.98). The intrinsic RIP-value changes track the refractive changes at the spectacle plane closely with an overestimation of only 0.16 D (R^2=0.98).

In this study, we studied the effects of the keratometric index of 1.3375 on the prediction of the refractive changes by classifying the corneal power into KIP-values and RIP-values. For the Pentacam HR data, using the real corneal refraction index improves the prediction accuracy of the refractive changes. When the real corneal index of 1.376 is used to assess the corneal power changes, a better track to the real surgically induced refractive changes is obtained, with the prediction error of the refractive changes in the corneal plane decreasing from 14.94% to 8.69%. Therefore, the keratomertic index of 1.3375 does play a role in the underestimation of the surgically refractive changes for data provided by the Pentacam HR. However, in the case of the intrinsic data, the role of the keratometric index of 1.3375 is complicated. If the refractive changes were evaluated at the spectacle plane, the prediction error with an index of 1.3375 is slightly higher than that with the real corneal index of 1.376. Surprisingly, when the refractive changes are evaluated at the corneal plane, the prediction error increased when the real corneal index is used. Therefore, when the intrinsic data are used to assess the surgically refractive changes, the keratometric index of refraction of 1.3375 is a better choice.

Because we speculate that the position where the MRSE was calculated may influence the accuracy of the prediction of the refractive changes, the MRSE at the corneal plane and the spectacle plane were studied respectively. Generally, the corneal power changes could provide a better assessment of the refractive changes at the corneal plane than at the spectacle plane (with an exception of intrinsic RIP-value changes).

One of the several limitations of our study is the duration following surgery where the refractive error and the corneal topography measurements were made is close to the surgery, when the refractive changes had not stabilized. Ivarsen [19] found that corneal power after LASIK continues to increase from 1 to 7 years. Therefore, the keratometric changes over time after laser surgery may change the reliability of our findings. Another limitation of the study is that different fitting diameters were chosen for eyes before (8 mm) and after (6 mm) refractive surgery. However, the obtained radius of curvature is minimally influenced [20] by the fitting diameter, therefore we believe different fitting diameter barely effects the results of this study. A third limitation of the study is the relatively small patient sample size. However, considering that the apical intrinsic power is higher than that from the Pentacam HR before surgery and lower than that from the Pentacam HR after surgery, the apical corneal power changes are higher than those from the Pentacam HR, suggesting the apical corneal power changes have the tendency to give a better estimation of the surgically induced refractive changes, no matter how many samples are included. Certainly, a larger sample size can provide a more accurate quantification of the estimations.

In conclusion, we used the ellipsoid model to fit the elevation maps given by the Pentacam HR to obtain the radius of the cornea reference to its own reference system. This is independent of the position of the cornea with respect to the Pentacam HR. The radii of corneal anterior curvature, corneal power and the corneal power changes (KIP-value and RIP-value) from the intrinsic data and those provided by the Pentacam HR were compared. The intrinsic corneal power gives larger changes than those obtained by the Pentacam HR. Furthermore, the changes in corneal power were compared with the refractive changes both at the corneal plane and the spectacle plane for the intrinsic data and the Pentacam HR data. By using the intrinsic data of the cornea, the prediction of the refractive changes shows a significantly better fit to the surgically induced refractive changes.

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References

[1] M. Tang, Y. Li and D. Huang, Measuring total corneal power before and after laser in situ keratomileusis with high-speed optical coherence tomography, Journal of Cataract & Refractive Surgery **32** (2006), 1843–1850.

[2] E. Jarade, N.F. Abi and K. Tabbara, Intraoculare lens power calculation following LASIK: Determination of the new effective index of refraction, Journal of Refractive Surgery **22** (2006), 75–80.

[3] B. Seitz, F. Torres, A. Langenbucher, et al., Posterior corneal curvature changes after myopic laser in situ keratomileusis, Ophthalmology **108** (2001), 666–672.

[4] D.M. Grzybowski, C.J. Roberts, A.M. Mahmoud, et al., Model for nonectatic increase in posterior corneal elevation after ablative procedures, Journal of Cataract & Refractive Surgery **31** (2005), 72–81.

[5] L. Spadea, R. Fasciani, S. Necozione, et al., Role of the corneal epithelium in refractive changes following laser in situ keratomileusis for high myopia, Journal of Refractive Surgery **16** (2000), 133–139.

[6] G. Savini, K.J. Hoffer, M. Carbonelli, et al., Assessing refractive change after excimer laser surgery, Cataract & Refractive Surgery Today (2001), 29–31.

[7] S. Srivannaboon, D.Z. Reinstein and H.F. Sutton, et al., Accuracy of orbscan total optical power maps in detecting refractive change after myopic laser in situ keratomileusis, Journal of Cataract & Refractive Surgery **25** (1999), 1596–1599.

[8] S. Sónego-Krone, G. López-Moreno, O.V. Beaujon-Balbi, et al., A direct method to measure the power of the central cornea after myopic laser in situ keratomileusis, Arch Ophthalmol **122** (2004), 159–166.

[9] R.B. Mandel, C.S. Chiang and S.A. Klein., Location of the major corneal reference points, Optometry & Vision Science **72** (1995), 776–786.

[10] R. Navarro, L. González and J.L. Hernandez, Optics of the average normal cornea from general and canonical representations of its surface topography, Journal of the Optical Society of America A-Optics Image Science and Vision **23** (2006), 219–232.

[11] R.G. Anera, A. Alarcon, J.R. Jimenez, et al., Characterizing corneal shape after LASIK using a reference system intrinsic to the cornea, Journal of the Optical Society of America A-Optics Image Science and Vision **27** (2010), 1549–1554.

[12] J.M. González-Méijome, C. Villa-Collar, R. Montés-Micó, et al., Asphericity of the anterior human cornea with different corneal diameters, Journal of Cataract & Refractive Surgery **33** (2007), 465–473.

[13] R. Anera, J. Jime´nez, L.G. Barco, et al., Changes in corneal asphericity after laser in situ keratomileusis, Journal of Cataract & Refractive Surgery **29** (2003), 762–768.

[14] H.S. Hersh, K. Fry and J.W. Blaker, Spherical aberration after laser in situ keratomileusis and photorefractive keratectomy, clinical results and theoretical models of etiology, Journal of Cataract & Refractive Surgery **29** (2003), 2096–2104.

[15] J.B. Ciolino and M.W. Belin, Changes in the posterior cornea after laser in situ keratomileusis and photorefractive keratectomy, Journal of Cataract and Refractive Surgery **32** (2006), 1426–1431.

[16] J.B. Ciolino, S.S. Khachikian, M.J. Cortese, et al., Long-term stability of the posterior cornea after laser in situ keratomileusis, Journal of Cataract & Refractive Surgery **33** (2007), 1366–1370.

[17] A. Pérez-Esudero, C. Dorronsoro, L. Sawides, et al., Minor influenced of myopic laser in situ keratomileusis on the posterior corneal surface, Investigative Ophthalmology & Visual Science **51** (2010), 3468–3474.

[18] L. Zhang and Y. Wang, The shape of posterior corneal surface in normal, post-LASIK and post-epi-LASIk eyes, Investigative Ophthalmology & Visual Science **50** (2009), 4146–4154.

[19] A. Ivarsen and J. Hjortdal, Seven-year changes in corneal power and aberrations after PRK and LASIK, Investigative Ophthalmology & Visual Science **53** (2012), 6011–6016.

[20] T. Kawamorita, H. Uozato, K. Kamiya, et al., Repeatability,reproducibility, and agreement characteristics of rotating Scheimpflug photography and scanning-slit corneal topography for corneal power measurement, Journal of Cataract &Refractive Surgery **35** (2009), 127–133.