Comparison of Corneal and Total Ocular Aberrations Before and After Myopic LASIK

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ABSTRACT

PURPOSE: To assess the compensation of total ocular and corneal wavefront aberrations after conventional myopic LASIK.

METHODS: This study comprised 57 eyes of 57 patients. Total and corneal aberrations were measured preoperatively and 3 months postoperatively using the OPD-Scan (NIDEK Co Ltd) aberrometer. Total and corneal aberrations root-mean-square (RMS) was calculated out to the 6th Zernike order for a 6.0-mm pupil diameter. The percentage increase postoperatively was defined by the ratio of RMS pre- and postoperatively for each corneal and total eye group. The compensation between corneal and internal aberrations for a given aberration group was defined as: (corneal aberration group RMS − total eye aberration group RMS)/corneal aberration group RMS.

RESULTS: Postoperatively, higher order aberrations increased by a factor of 1.77±1.26 (total) and 2.47±2.25 (corneal) ($P<.05$). Coma aberration increased by a factor of 2.43±2.61 (total) and 2.56±2.66 (corneal). Spherical aberration increased by a factor of 1.46±1.83 (total) and 2.64±2.24 (corneal). The values of the ratio of compensation did not change significantly before and after LASIK for individual aberrations ($P>.05$).

CONCLUSIONS: Although myopic LASIK induced significant corneal aberrations, the level of partial compensation of corneal aberrations by internal structures remained unchanged. These results suggest that the previously described emmetropization that is effective during development may also be effective with acquired variations in corneal shape. [*J Refract Surg*. 2010;26:333-340.]
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The human eye is affected by aberrations that can degrade retinal image quality. Recent studies have found that in pre-presbyopic patients, the magnitude of higher order aberrations for the cornea or the lens individually are larger than for the whole eye.[1-4] Additionally, despite variation in size and shape, the average magnitude of higher order aberrations of emmetropic eyes is similar to that found in mild to moderate myopes and hyperopes.[5] Guirao and Artal[2] propose a passive, simple geometric model for the ocular compensation of aberrations. They suggest that the components of the eye are similar to an auto-compensating design, producing similar overall average optical quality for different refractive errors, despite large structural variations.[2]

The progressive lack of compensation over time may be explained by changes in the lens shape and size throughout life.[6,7] Whether a compensatory mechanism exists that operates over a period of months to account for the optical decoupling of corneal and lenticular higher order aberrations after corneal refractive surgery remains unaddressed. The variations of the total ocular and corneal higher order aberrations and visual performance before and after LASIK have been investigated previously.[8-11] One study that measured corneal and internal higher order aberrations on separate instruments reports partial compensation of higher order aberrations before and after corneal refractive surgery.[12] In the current study, we used a combined ocular aberrometer and corneal topographer to compare pre- and postoperative corneal (corneal aberrations)

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and total ocular aberrations (total aberrations) of eyes that underwent myopic LASIK. These measurements were used to determine whether the sudden decoupling of higher order aberrations due to LASIK unlocked a compensatory process that minimized the amount of induced aberrations after surgery.

PATIENTS AND METHODS

Patient Population

Consecutive patients undergoing conventional myopic LASIK by the same surgeon (D.G.) were included in this study. Inclusion criteria were preoperative manifest refraction spherical equivalent (MRSE) <-10.00 diopters (D) and preoperative refractive astigmatism <0.75 D. Soft contact lens wearers had to remove their lenses 1 week prior to the first examination. Patients wearing hard contact lenses prior to surgery were not included. Eyes with topographic abnormalities such as forme fruste keratoconus, keratoconus, pellucid marginal degeneration, contact lens warpage, marked corneal irregularity, and <490 µm of central corneal thickness preoperatively were not included in this study. Patients with a physiologic pupil diameter <6 mm under mesopic conditions were excluded from participating.

Patients with intra- or postoperative complications were not included in this study. Postoperative corneal topographies were evaluated by the surgeon (D.G.) to ensure a well-centered ablation and the lack of irregular corneal astigmatism. The criteria for evaluating ablation centration using corneal topography have been described previously.[13]

This study adhered to the tenets of the Declaration of Helsinki. Informed consent was obtained from all patients after an explanation of the risks and benefits of the study.

All eyes underwent a baseline ophthalmic examination that included measurement of uncorrected visual acuity (UCVA), best spectacle-corrected visual acuity (BSCVA) (decimal notation), manifest refraction, cycloplegic refraction, slit-lamp microscopy, dilated funduscopy, ultrasound corneal pachymetry (Reichert Ophthalmic Instruments, Depew, NY) and simultaneous corneal topography, wavefront aberrometry and pupillometry (infrared light) using the OPD-Scan (NIDEK Co Ltd, Gamagori, Japan). Postoperatively, all patients underwent the same measurements as preoperatively with the exception of dilated funduscopy (unless clinically warranted).

Combined Aberrometry and Corneal Measurements

Mean central keratometry, corneal, and total optical aberrations were measured using the OPD-Scan, which measures corneal topography and wavefront aberrations nearly simultaneously (within 0.20 seconds of each other) on the same optical axis without moving the patient. The corneal topography is measured using Placido-disk technology and aberrometry is measured using the principle of skiascopic phase difference.[14] Wavefront measurements are performed by scanning with an infrared slit beam, and the reflected light is captured by an array of rotating photodetectors covering 360° within the eye in 1° increments. With this technique, 1440 wavefront data points within a 6-mm pupil diameter are measured. A built-in eye tracker accounts for eye movements that may occur during measurements. A quality check of the difference in the pupil centers between corneal and wavefront measurements is included to ensure there is no shift in pupil center between measurements. This quality check alerts the operator to shifts in the pupil center with a color-coded message. Alignment in the x-y-z axes and automated tracking ensures all measurements were centered without pupillary shift between corneal and wavefront measurements. Internal wavefront and corneal wavefront can be computed using OPD-Station software (NIDEK Co Ltd). The patient remained seated in the same position for all measurements, hence the wavefront and corneal topography data can be directly correlated.

All measurements were acquired in a dark examination room after 2 minutes of dark adaptation and were repeated at least three times (with dark adaptation between each measurement). Both the total and corneal wavefronts were reconstructed using 6th order Zernike polynomial decomposition for a 6-mm pupil, centered on the corneal vertex.

The internal aberration calculations are proprietary. To simplify the description for the purposes of this paper, the wavefront of the internal eye was calculated using the corneal wavefront derived from corneal topography and whole eye wavefront measured with the OPD-Scan. The wavefront was converted to Zernike polynomials to calculate internal aberration coefficients by determining the difference between corneal aberrations and whole eye aberrations. All aberrations were transposed to vertex=0 (corneal vertex) prior to calculation. The computation of corneal aberration used in the current study has been described previously.[15]

Surgery

All patients underwent bilateral conventional (not wavefront) myopic LASIK using the NIDEK EC-5000 (NIDEK Co Ltd) excimer laser. All surgeries were performed by the same surgeon (D.G.) and outcomes were targeted for emmetropia using a personalized nomogram. The eye undergoing surgery was prepared using a povidone-iodine solution. Topical anesthetic was instilled on the cornea and a lid speculum was inserted. The Hansatome microkeratome (Bausch & Lomb Inc, Rochester, NY) was used to create the corneal flap with a superior hinge. The corneal flap was reflected back and the laser ablation was delivered to the stroma using an optical zone of 6.0 mm and a 7.0-mm transition zone. The NIDEK EC-5000 laser ablation algorithm uses an expanding diaphragm and rotating scanning slit delivery system to remove the appropriate volume of corneal tissue. Patients fixated on a red fixation light, coaxial with the surgeons' line of sight, and the excimer laser beam. A 60-Hz active infrared eye tracker was used for all surgeries. The flap was repositioned and the interface was irrigated using balanced salt solution. One drop each of topical fluoroquinolone, corticosteroid, and artificial tears was instilled prior to discharging the patient. Patients received topical fluoroquinolone antibiotic to use four times per day for 5 days and corticosteroid drops twice a day for 21 days.

Data Analysis

Although all surgeries were bilateral, only one eye per patient was selected for this study based on a randomization schedule developed by a biostatistician. The following data were compared preoperatively and 3 months postoperatively: MRSE, BSCVA, 3-mm central mean keratometry, and RMS values of the total higher order wavefront and corneal higher order wavefront.

The following normalized Zernike terms out to the 6th Zernike order were examined (excluding the 0th=Z_0^0 piston term):

- total higher order aberrations group (all terms included in the 3rd, 4th, 5th, and 6th order),
- total coma group (7th=Z_3^{-1}, 8th=Z_3^1, 17th=Z_5^{-1}, 18th=Z_5^1 terms),
- total trefoil group (6th=Z_3^{-3}, 9th=Z_3^3, 16th=Z_5^{-3}, 19th=Z_5^3 terms),
- total spherical aberration group (12th=Z_4^0 and 24th=Z_6^0 terms),
- total tetrafoil group (10th=Z_4^{-4}, 14th=Z_4^4, 22nd=Z_6^{-4}, 26th=Z_6^4 terms), and
- total higher order astigmatism (11th=Z_4^{-2}, 13th=Z_4^2, 23rd=Z_6^{-2}, 25th=Z_6^2, 39th=Z_8^{-2}, 41st=Z_8^2 terms).

These aberration groups were used to describe both the corneal aberration and the total eye aberrations. All wavefront measurements were reported for a 6-mm pupil diameter. The percentage increase (PI) postoperatively was defined as the ratio between the RMS values before and after LASIK for each of the corneal and total eye aberration groups described above.

The ratio of compensation (RC) between corneal and internal aberrations was quantified using the following equation:

$$RC = \frac{\text{(corneal aberration group RMS value} - \text{total eye aberration group RMS)}}{\text{corneal aberration group RMS}}$$

When the total eye aberration group is equal to the corneal aberration group, the RC value is 0 (no internal compensation). When the total eye aberration group value is null (eg, full compensation), the RC value is 1.

Statistical comparisons between the pre- and postoperative measurements were performed using the Student *t* test (independent samples). A *P* value <.05 was considered statistically significant.

RESULTS

Fifty-seven eyes from 57 patients were included in this study. Mean patient age was 33.24±9.09 years (range: 20 to 56 years). Measurements and clinical examinations were performed 27±39 days before and 73±17 days after LASIK surgery.

Mean central (3 mm) keratometry changed from 7.63±0.252 mm (range: 7.05 to 8.14 mm) preoperatively to 8.41±0.46 mm (range: 7.65 to 9.40 mm) postoperatively (*P*<.001). Mean preoperative spherical equivalent refraction was −4.19±2.19 D (range: −0.75 to −9.75 D), and mean postoperative spherical equivalent refraction was −0.39±0.65 D (range: −2.25 to +1.00 D) (*P*<.00). Thirty-seven (64.9%) eyes had a postoperative MRSE between −0.50 and +0.50 D. Fifty-one (89.5%) eyes had a postoperative MRSE within ±1.00 D of the intended correction. Preoperatively, mean astigmatism was −0.32±0.33 D (range: 0 to 0.75 D). Mean postoperative astigmatism was −0.31±0.27 D (range: 0 to 1.00 D) (*P*=.75).

Pre- and postoperative corneal higher order aberrations and total higher order aberrations are shown in Table 1. The RMS of each corneal aberration group increased significantly after LASIK (*P*<.05) (Table 1). The RMS of total trefoil and total higher order astigmatism did not increase significantly (*P*>.05); however, all other groups showed a statistically significant increase in RMS postoperatively (*P*<.05) (non-paired Student *t* test) (Table 1). The ratio of compensation for various aberrations is shown in Table 2.

DISCUSSION

In our investigation of eyes that had undergone conventional myopic LASIK, partial compensation of induced corneal higher order aberrations by the internal aberrations of the eye was found. However, the differences in the methods of measurement used in this study compared to previous studies requires explanation.

TABLE 1

Change in Root-mean-square Aberrations of 57 Eyes That Underwent Conventional Myopic LASIK

	Mean±Standard Deviation			
Aberration Group	**Preoperative (μm)**	**Postoperative (μm)**	**PI**	***P* Value**
Total higher order aberration				
Total eye	0.33±0.11	0.53±0.31	1.77±1.26	<.00002
Corneal	0.85±0.51	1.71±1.64	2.47±2.25	<.0003
Total coma				
Total eye	0.151±0.07	0.277±-0.217	2.43±2.61	<.000061
Corneal	0.385±0.276	0.715±0.777	2.56±2.66	.0030
Total trefoil				
Total eye	0.214±0.103	0.249±0.167	1.42±1.22	.18
Corneal	0.478±0.403	0.85±0.91	2.92±3.67	.0075
Total spherical aberration				
Total eye	0.108±0.066	0.231 ±0.178	1.46±1.83	<.0000035
Corneal	0.307±0.12	0.688±0.467	2.64±2.24	.00000003
Total tetrafoil				
Total eye	0.075±0.062	0.10±0.10	2.13±2.66	.0536
Corneal	0.284±0.241	0.671±0.79	4.38±6.69	.00054
Total higher order astigmatism				
Total eye	0.068±0.11	0.078±0.042	1.84±1.40	.51
Corneal	0.23±0.19	0.52±0.57	4.66±13.38	.0005

PI = increase factor, defined as the ratio between the root-mean-square values before and after LASIK for each of the corneal and total eye aberration groups, total eye = total ocular aberrations, corneal = total corneal aberrations
All wavefront measurements are reported for a 6-mm pupil diameter.
Note. P<.05 *denotes a statistically significant difference.*
Total higher order aberration group, all terms included in the 3rd, 4th, 5th, and 6th Zernike order; total coma group comprises the 7th=Z_3^{-1}, 8th=Z_3^1, 17th=Z_5^{-1}, and 18th=Z_5^1 Zernike terms; total trefoil group comprises the 6th=Z_3^{-3}, 9th=Z_3^3, 16th=Z_5^{-3}, and 19th=Z_5^3 Zernike terms; total spherical aberration group comprises the 12th=Z_4^0 and 24th=Z_6^0 Zernike terms; total tetrafoil group comprises the 10th=Z_4^{-4}, 14th=Z_4^4, 22nd=Z_6^{-4}, and 26th=Z_6^4 Zernike terms; and total higher order astigmatism comprises the 11th=Z_4^{-2}, 13th=Z_4^2, 23rd=Z_6^{-2}, 25th=Z_6^2, 39th=Z_8^{-2}, and 41st=Z_8^2 Zernike terms.

Corneal Vertex Versus Line of Sight Representation of Wavefront Aberrations

Historically, internal aberrations have been measured using two separate instruments, a corneal topographer and laboratory wavefront sensors or commercially available aberrometers. Using two instruments where the patient or instrument has to be shifted into position between these successive measurements introduces error due to the two different measurement axes. This limitation remains unaddressed without a cyclotorsion error detection module built into one of the measuring instruments that could verify the iris position remains unchanged. To date, no combined apparatus is available that addresses ocular cyclotorsion in this manner when reporting internal aberrations. The OPD-Scan circumvents this limitation by using one instrument for both corneal and whole eye measurements.

The American National Standards Institute (ANSI) recommends the representation of wavefront aberrations relative to the line of sight (axis joining the fovea with the natural pupil center).[16,17] The OPD-Scan reports all wavefront data using the vertex normal rather than the line of sight, which does not conform to the recommended "standard" proposed by ANSI. The vertex normal has been in use for well over two decades in instruments such as autorefractors, autokeratometers, and corneal topographers, yet the ANSI recommendation is relatively recent. It seems the manufacturer elected to use the convention incorporated in the majority of ophthalmic instruments. The ANSI recommended line of sight has one limitation that remains unaddressed—the change in pupil center that can occur due to different pupil sizes. Using the vertex normal obviates this limitation, as this axis is independent of pupil diameter.

TABLE 2

Pre- and Postoperative Values of the Ratio of Compensation Between Corneal and Total Eye Aberrations

Aberration Group	Preoperative Ratio	Postoperative Ratio	*P* Value*
Total higher order aberration	0.51±0.25	0.59±0.28	.09
Total coma	0.44±0.40	0.40±0.50	.31
Total trefoil	0.29±0.59	0.36±0.77	.27
Total spherical aberration	0.62±0.20	0.64±0.19	.39
Total tetrafoil	0.55±0.60	0.65±0.55	.17
Total higher order astigmatism	0.61±0.38	0.69±0.28	.15

All wavefront measurements are reported for a 6-mm pupil diameter.
Note. P<.05 denotes a statistically significant difference.
Total higher order aberration group, all terms included in the 3rd, 4th, 5th, and 6th Zernike order; total coma group comprises the 7th=Z_3^{-1}, 8th=Z_3^1, 17th=Z_5^{-1}, and 18th=Z_5^1 Zernike terms; total trefoil group comprises the 6th=Z_3^{-3}, 9th=Z_3^3, 16th=Z_5^{-3}, and 19th=Z_5^3 Zernike terms; total spherical aberration group comprises the 12th=Z_4^0 and 24th=Z_6^0 Zernike terms; total tetrafoil group comprises the 10th=Z_4^{-4}, 14th=Z_4^4, 22nd=Z_6^{-4}, and 26th=Z_6^4 Zernike terms; and total higher order astigmatism comprises the 11th=Z_4^{-2}, 13th=Z_4^2, 23rd=Z_6^{-2}, 25th=Z_6^2, 39th=Z_8^{-2}, and 41st=Z_8^2 Zernike terms.

To allow direct calculation of the internal aberration, corneal and total aberrations must be plotted on a common axis to avoid calculation errors. In the current study, both the total and corneal aberrations were acquired while the eye was focused at infinity and calculated with regard to the vertex normal; no realignment procedure was required before comparing corneal and total aberrations. However, systematic parallax between the overlying cornea and the aberrations at the pupil plane may occur due to this measuring principle. The anticipated effect of this misregistration would be elevated coma values, which warrants further investigation. Therefore, the coma values generated in this study must be interpreted with caution.

Unlike OPD-Scan measurements, most aberrometers that evaluate wavefront measure the wavefront slope from which the pupil center or line of sight is determined. However, this is ambiguous, as locating the pupil center depends on the pupil diameter and the center can deviate with differing pupil diameters.[17,18] Furthermore, coma aberration that is common in most ocular structures displaces the chief ray, which considerably changes the wavefront plot depending on the definition of the line of sight (axis joining the fovea to the pupil center vs average of a bundle of rays recommended by the Optical Society of America) used.[18,19] The ambiguity of plotting wavefront on the line of sight is obviated in the current study by using a single instrument measuring corneal and total aberrations on the same optical axis. Although the vertex normal may change after refractive surgery, it remains independent of pupil diameter.

In 2002, Salmon and Thibos[20] investigated the lack of compensation of reporting corneal wavefront data at the vertex normal and whole eye wavefront on the line of sight. They found the overall magnitude of corneal and internal aberrations was slightly lower when there was no compensation.[20] For example, the maximum mean difference between compensation and lack of compensation of higher order aberrations was 0.08 µm RMS for corneal aberrations and 0.05 µm RMS for internal aberrations.[20] To determine the magnitude of difference from reporting wavefront aberrations at the vertex normal and not the line of sight, we calculated the internal wavefront aberration at both locations to determine the difference for high, moderate, and low refractive errors representative of our patient population (Fig). The differences in the Figure are clinically negligible.

Aberration Compensation, Previous Studies, and Clinical Implications

Laser in situ keratomileusis is a corneal procedure that does not induce changes in the crystalline lens yet produces significant changes in optical aberrations and corneal power. If we hypothesize that no changes other than those incurred on the anterior corneal surface occur after LASIK (eg, no change in the internal aberrations postoperatively), the net increase in total aberrations should be equal to the increase in corneal aberrations. Thus, the balance between corneal and internal aberrations would be disrupted. Disruption of the balance between corneal and internal aberrations occurs with age in unoperated eyes.[1,7] For example, the internal optical aberrations increase three-fold

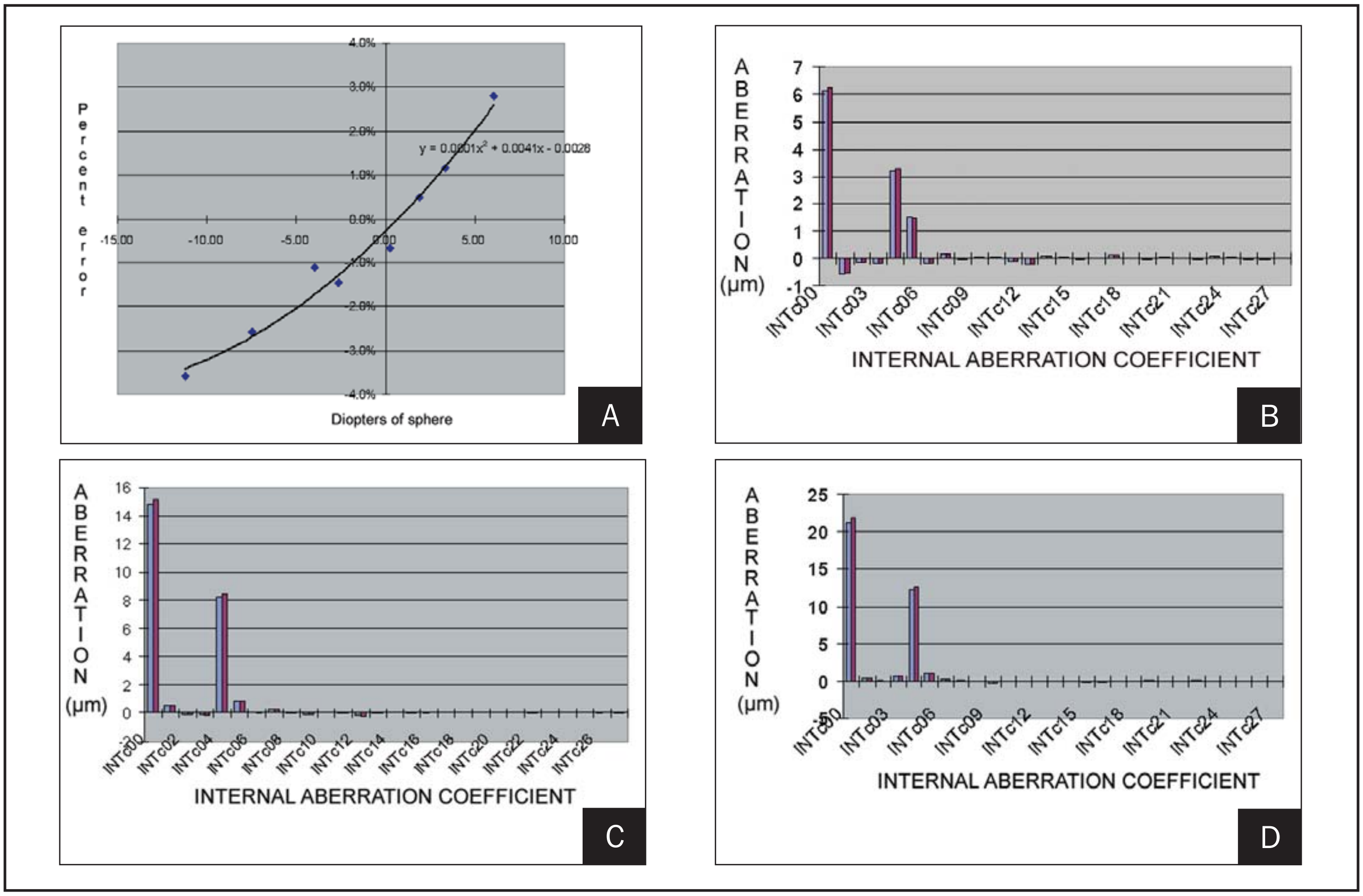

Figure. A) Percent difference in the internal wavefront aberrations reported using the vertex normal or line of sight as the reference axis. **B)** Internal wavefront aberration reported on the vertex normal (blue bar) or line of sight (red bar) for a low myope (−3.95 D). **C)** Internal wavefront aberration reported on the vertex normal (blue bar) or line of sight (red bar) for a moderate myope (−7.48 D). **D)** Internal wavefront aberration reported on the vertex normal (blue bar) or line of sight (red bar) for a high myope (−11.23 D).

between ages 20 and 70 years, whereas corneal aberrations increase only mildly.[7]

We found that corneal aberrations were higher than the total aberrations both pre- and postoperatively. A decrease in the magnitude of the total eye aberrations indicates some degree of compensation by the internal optics, as corneal and internal aberrations combine to give total eye coefficients. The results of our study indicate that internal aberrations continue to reduce the impact of the induced corneal wavefront changes after LASIK. Our results concur with those of Marcos et al[12] who measured total ocular and corneal aberrations before and after LASIK surgery. Total aberrations were measured using a laser ray-tracing technique; whereas corneal aberrations were obtained from corneal elevation data measured using a corneal topographer with custom software.[12] Marcos et al found that the total spherical aberration increased less than the spherical aberration induced on the anterior corneal surface.[12] In contrast to our findings, the same analysis for postoperative LASIK 3rd order aberrations showed no statistically significant difference between corneal and total aberrations.[12] This discrepancy may be due to the limited sample size in the Marcos et al study[12] (14 eyes in the Marcos study vs 57 eyes in the current study) and to the difference in the wavefront acquisition method (eg, one instrument in the current study vs two separate instruments in the Marcos study). Additionally, there was an approximate 38-fold difference in the number of points used in our study (1440 points) compared to Marcos et al (37 points) to plot the total higher order aberrations of the eye; mathematical data smoothing between points may account for the differences. Alternately, the differences can be due to reporting aberrations based on ANSI standards (Marcos et al) versus non-ANSI standards discussed above.

The posterior corneal spherical aberration is negative in young eyes.[21] Marcos et al[12] attributed the increase in the internal compensation of spherical aberration observed after myopic LASIK to changes in the posterior curvature of the cornea due to biomechanical remodeling. However, the accuracy of the posterior corneal changes reported with slit-scanning topography after corneal surgery have been refuted by rotating Scheimpflug imaging, demonstrating instrument artifact.[22-24] The refractive power of the whole cornea is due to the variation in the refractive indices of air (1.0), cornea (1.376), and the aqueous (1.336).[25] Due to the difference in the indices of refraction and curvature, the anterior interface is 10 times greater than the posterior interface; hence the contribution of the posterior surface to the corneal aberration would be minimal. Dubbelman et al[26] concluded that the posterior corneal surface coma compensates approximately 6% of the anterior corneal surface coma.

Artal et al[27] reported a higher compensation of internal optics, particularly coma in hyperopic eyes, which usually have a larger angle kappa. They found that a displacement of the cornea with positive spherical aberration induces positive coma, whereas this same displacement for the lens, with a similar but negative spherical aberration, induces negative coma, which nearly cancels that of the cornea.[27] These results support a simple passive mechanism for the compensation. Such an auto-compensating design may explain the similar overall optical quality of hyperopes and myopes, despite the large scale of structural variations.

Our data show a consistent match in the magnitude of aberrations pre- and postoperatively, which suggests that a process exists to proportionally increase internal aberration compensation for the eye. This dual optimization strategy likely allows maintenance of retinal image quality (and visual quality) despite the induced corneal aberrations. Some studies have reported a recovery of contrast sensitivity at 3 months after LASIK.[28,29] Due to the surgically induced profile change of the anterior corneal surface, the angle of incidence of the light rays emerging from the posterior corneal surface and striking the crystalline lens is modified compared to preoperatively. During the course of writing this manuscript, one of the authors (D.G.) performed sample ray tracing calculations using myopic eyes and found that as the cornea flattened and became more oblate (akin to the changes induced after myopic LASIK), the calculated internal aberrations tended to increase in the same fashion as the current study (unreported data, June 2008), supporting a passive mechanism. However, this modeling was performed on a small sample size after conclusion of the study and was not submitted for publication. The change in position of the light rays striking the lens may passively change the optical properties of the internal optics and partially explain our results. Perhaps an active mechanism for this auto-compensation could also be at play (eg, a subtle shift, tilt, or curvature change of the physiologic lens), which would thus also make the eye robust to structural variations such as LASIK-induced corneal aberrations. An alternate explanation may be a mild change in the gradient refractive index of the lens that allows active compensation of the induced corneal aberrations.[6,30] However, a change in refractive index generally does not occur so quickly. The observation that the ratio of internal compensation was not statistically different before and after LASIK supports both an active or passive mechanism or a combination. In both cases, the mechanisms behind such changes have yet to be determined.

Sufficient plasticity seems to exist in the optical design of the eye that allows for this “emmetropization” to occur across the range of refractive error treated in the current study. However, the range of induced corneal change over which this compensation occurs remains unanswered in our study. One requirement of an auto-compensation mechanism is the presence of an active feedback loop that enables changes over a relatively short temporal scale. There are examples of such rapid ocular auto-compensating mechanisms. For example, retinal photoreceptors used the direction of incident light to realign themselves from the pupil periphery to the pupil center within 10 days after intraocular lens implantation in a patient with bilateral congenital cataracts for four decades.[31,32]

Some drawbacks of this study include the short follow-up period, which does not account for complete corneal wound healing, and the lack of normative data over the same time period. Ideally, a randomized, contralateral study design treating one eye with LASIK and not treating the fellow eye would have been provided conclusive data. In our experience, few refractive surgery candidates would accept or tolerate anisometropia over 3 or 4 months, and we would have been faced with repeated requests for treatment of the untreated eyes and a significant dropout rate. Physiologic “emmetropization” generally occurs before age 40. In the current study, patients were presbyopic and pre-presbyopic; however, we did not dichotomize the compensation of aberrations between these groups. This observation warrants further study. Furthermore, the effect of the natural decoupling of corneal and lenticular spherical aberrations from the presbyopic years onwards requires further investigation

This is the first publication to measure corneal and ocular optical aberrations on one instrument using the same optical axis to show that the compensation for corneal aberrations by the internal aberrations of the eye increases after myopic LASIK surgery. In our study, this effect was observed in all higher order aberration groups that were tested. This systematic compensation suggests an automated mechanism and supports the concept of an optically robust design to developmental variation in ocular shape and geometry and to acquired variation in corneal shape.

AUTHOR CONTRIBUTIONS

Study concept and design (D.G.); data collection (D.G., P.A., S.C., J.M., M.T.); analysis and interpretation of data (D.G., P.A., S.C., J.M., T.H.X., S.P., M.F., H.S.B.); drafting of the manuscript (D.G., P.A., H.S.B.); critical revision of the manuscript (D.G., P.A., S.C., J.M., M.T., T.H.X., S.P., M.F., H.S.B.); statistical expertise (D.G.); supervision (D.G., J.M.)

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